BC Clean Air Research Report

AIR-QUEST

*An **AIR QU**ality **E**nhancement **S**imulation **T**ool*

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1. Scientific Background and Objectives

The development of air quality management plans is challenging and demanding as economic interests, health issues and many other concerns have to be taken into account (Brauer, Reynolds, & Hystad, 2012). Due to a combination of various emission sources, meteorological and topographic factors that efficiently trap emissions, ambient levels of particulate matter in Prince George, British Columbia are among the highest in western Canada. Consequently, there have been several scientific projects and publications to study Prince George's major sources of particulate matter as well as related health issues within the last few years (Ainslie & Jackson, 2009; Noullett, Jackson, & Michael, 2010; Allen, Bartlett, Graham, & Jackson, 2011; Owens, Caley, Campbell, Koiter, Droppo, & Taylor, 2011).

In Prince George, air quality is managed by the Prince George Air Improvement Roundtable (PGAIR), a multi-stakeholder non-profit society with representatives from various government agencies, industry, non-governmental organizations, academia and the public. PGAIR develops and monitors air quality management plans for the region. In the past five years great effort has been made to model source emissions from all kind of emission sources using the Calpuff dispersion model (Stantec, 2010). For the period 2003-2005 model results for approximately 1500 individual sources at approximately 2000 receptor locations are archived in a dataset of 300 GB of model outputs. This extensive dataset allows an assessment of the contribution of individual emitters to ambient air quality. Thus, the impact of source reduction scenarios on ambient particulate matter concentrations can be assessed by manipulating source emissions.

Prior to this project accessing and visualizing this tremendous volume of data had been time-consuming and not feasible for non-modelers, especially since the Calpuff model output is in a binary format. Nevertheless PGAIR members, many of whom are non-technical, need to make use of these data to draw science-based air quality management decisions. In order to see whether proposed reduction scenarios will result in achieving PGAIR air quality objectives, e.g. an annual $PM_{2.5}$ average of 6 $\mu g\, m^{-3}$ for 2013, PGAIR members need to be able to perform various reduction scenario simulations quickly and without assistance. Since the contribution of a source to ambient levels is a linear function of the emission rate, emission reduction scenarios can be performed by simply manipulating the contribution of individual sources and displaying the resulting ambient levels of particulate matter. This can be done using the database of already created Calpuff model outputs, without the need to re-run the Calpuff model. Therefore the main objective of this project was to create a prototype web-based tool to query the model output database, and visualize spatial and temporal ambient air quality variations in response to changes in source contributions. Thus, fast client response as well as a simple and intuitive design has been defined as basic requirements by PGAIR.

In order to stress the overall aim of this project – the 'quest' for a better air quality- we decided to call our web application '***AIR-QUEST***' – an ***AIR QU****ality* ***E****nhancement* ***S****imulation* ***T****ool'*. Even though AIR-QUEST was developed as a prototype of a web tool limited to the Prince George airshed, there may be interest in the transfer of this tool to other airsheds.

In addition to the designated development of AIR-QUEST, it turned out to be important for both the tool as well as for other PGAIR purposes to investigate reliable background concentration values for $PM_{2.5}$ and PM_{10}. Background concentrations had not been taken into account as an independent 'source' in the 2009-2010 modeling study, but firm estimated annual backgrounds had been added to overall concentrations afterwards. After consulting the PGAIR Research Working Group, we decided to include seasonal, precipitation related background concentrations in AIR-QUEST. In this report we will only briefly describe the basic results of our study as there is a separate report attached to the BC CLEAR final report discussing the approaches of that investigation in more detail.

2. Methods

In this section we will briefly describe the models and methods we used to develop AIR-QUEST. Besides a description of the Calpuff model set-up and some technical details on the web interface, basic statistical features and plotting routines will be illustrated. Additionally a short abstract about the implementation of the R based air quality data analysis package ‘openair’ will be given.

2.1 Calpuff Model

General Model Set-Up

All PM concentrations simulated with AIR-QUEST are based on the Calpuff dispersion modeling system. Calpuff is an advanced, integrated Gaussian puff modeling system that simulates the transport and dispersal of all PM emissions in the airshed that are included in the emission inventory (primary sources). While it is not an atmospheric chemistry model, it has a basic calculation for the conversion of SO_2 and NO_x in the presence of ammonium, to secondary particulate matter. For more information about the Calpuff model, see (Scire, Strimaitis, & Yamartione, 2000). Most of the AIR-QUEST inventory has been created by the preceding modeling described in Stantec (2010). Because of a hard disk crash during the former project, the Calpuff model had to be rerun for about 100 particular emission sources. Nevertheless the emission inventory, the meteorology used for model dynamics and all other input parameters such as land use and topography have not been changed at all. Therefore the Calpuff data base used in the current version of AIR-QUEST and information about the evaluation of the Calpuff model results can be found in Stantec (2010). In a separate project, the Stantec (2010) model results and emission inventory are be re-assessed and remodeled. The new results, when they are available, will be available in AIR-QUEST.

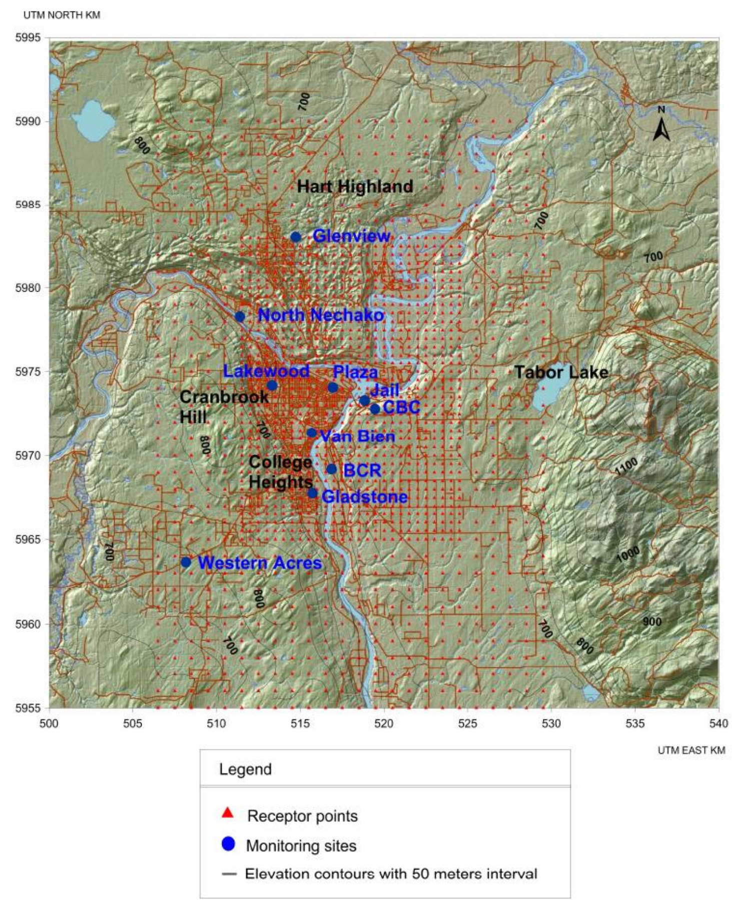

Figure 2-1: Map of the PG airshed showing receptor points and monitoring sites (Stantec, 2010).

Grid Resolution

The Prince George airshed used for AIR-QUEST consists of 1873 discrete receptors defining the nested receptor grid. The inner receptor grid is centered over the urban area and has a resolution of 500 m, whereas the outer receptor grid resolution is 1000 m. Contaminant concentrations were calculated each hour for the three year period (2003-2005) at a flagpole height of 1.5 m above ground level. For purposes of model evaluation, ten discrete receptors were identified and coincide with the location of ten monitoring stations of which six measured PM_{10} or $PM_{2.5}$ at least for some time within the 2003-2005 period (see Figure 2-1). AIR-QUEST uses the low resolution grid for fast chart creation on a monthly to yearly basis. Due to the required fast server response, statistical data and visualization other than airshed maps are limited to the ten monitoring stations. These ten locations represent most of the densely populated areas of the airshed and are much more feasible for detailed analysis than a data set for all 1873 grid points. Model evaluation calculations are available for the downtown Plaza receptor location only, because this is the station with the most extensive observation data. For more details on the AIR-QUEST data base and user output charts see sections 3 and 4.

Emission Inventory

The Prince George emission inventory used in AIR-QUEST corresponds to the 2005 inventory described in (Stantec, 2010). It includes all known sources of PM_{10}, $PM_{2.5}$, NO_x, and SO_2 emissions within the Prince George airshed. For each emission source, one full-receptor dispersion simulation predicted the source contribution to the hourly airshed concentrations. All sources are implemented as one of point, line or area source shapes. In order to accomplish a clear and fast web interface, source emission ‘tuning’ (i.e. adjustment of the emission rate) in AIR-QUEST is restricted to 11 source categories by merging all individual sources of the same emission class into one category. In addition, the 33 industrial permits of the industrial category are tunable separately. Table 2-1 describes the 11 source categories and the number of sources included in each category. Each of those single sources in turn consists of one to several individual sources, e.g. one line-like road source may consist of 5-10 individual point sources. Thus the overall sum of emission sources merged in all source categories shown in Table 2-1 is significantly smaller than the number of individual point sources mentioned in section 1 (approximately 1500).

Source category	Number of sources merged	Contribution to overall annual $PM_{2.5}$ concentration at Plaza in 2005
(Background)	-	(24.26%)
Permitted users (2per)	33	18.42%
On-road dust (3Rdu)	30	13.96%
Commercial restaurants (10ComR)	39	11.78%
Locomotive (4Rai)	13	10.71%
Residential heating (6Hea)	42	9.15%
On-road mobile (5Rmo)	26	3.79%
Open/MF burning (7Bur)	37	3.17%
Commercial miscellaneous (10Com)	39	1.66%
Commercial dust	42	1.30%

(10ComD)		
Residential others (9Res)	**39**	**0.91%**
Commercial heating (8Chea)	**39**	**0.89%**

Table 2-1: AIR-QUEST Source categories and their contribution to overall $PM_{2.5}$ concentrations. Background concentrations were applied post modeling (Stantec, 2010).

A companion study currently underway by Corbel, Ainslie, Jackson and Fudge, is revising the model database by improving the estimation of some sources and rerunning Calpuff. As these new data fields become available, they will be integrated into the AIR-QUEST database.

Background Concentrations

Background concentrations for the Prince George airshed had not been investigated in detail in the Stantec modeling study. The constant concentrations for PM_{10} and $PM_{2.5}$ mentioned in the final report are 5.1 µg m^{-3} and 1.3 µg m^{-3}, respectively. In order to meet the requirements of seasonal emission reduction scenarios performed with AIR-QUEST, there was a need for more reliable seasonal background concentrations. The lack of background concentration data for similar geographical locations and vegetation conditions forced us to perform an extensive background concentration study. Due to the small number of measurement stations in Northern BC, no actual background data are available for Prince George, because all measurements are related to semi-urban or urban locations close to emission sources. Therefore we developed a 'low pollution sectors and conditions' background calculation method, which is applicable for peripheral stations and cities with at least some low emission surroundings. Low pollution sectors are identified for meteorological low pollution conditions considering both observational PM data as well as source emissions in certain direction sectors. More detailed information about the approach and the accuracy of the method as well as comparisons to scientific literature are provided by the 'background concentration report' attached to the final report of this project.

2.2 Technical Details on the Web Interface

While the technical set-up of the AIR-QUEST web interface is a very important and an indispensable part of the project, this research report focuses on the scientific content of the project. Therefore only a short listing of programs used for the web interface is given in the following sections. Exclusively open source software was chosen to be applied in this web interface so that the system is as transferrable as possible to other airsheds and communities. All individual sets of data which will be described in more detail in section 3 are organized in a PostgreSQL 9.1 database. Interactive mapping applications are created by MapServer 6.0 using a WMS Server to enable the preparation of client customized maps. Furthermore several javascript tools were used to create the AIR-QUEST client interface, which is based on the cross-browser rich internet application network Ext Js 3.4 whereupon the javascript library OpenLayers is utilized for dynamic maps on the webpage. The Javascript toolkit GeoExt enables the integration of the rich web mapping applications. Calculations for source reduction scenarios for particular station locations are implemented by specific R scripts and make use of the R 'openair' package.

2.3 Basic Statistical and Plotting Features of AIR-QUEST

This section describes the analysis methods AIR-QUEST provides for air quality scenarios at ten monitoring locations in the airshed ("Station Statistical Scenarios"), as well as spatially across the airsed ("Basic Spatial Scenarios"). One way for air quality managers to assess the relative importance of ambient levels, is to compare them with standard or threshold levels. Depending on the pollutant as well as the region and organization, international air quality regulations and standards for yearly, daily and hourly PM concentrations show great differences. For instance neither the World Health Organization (WHO) nor Canada has standards for PM_{10} whereas official standards do exist for the European Union, the USA and Japan (Baldasano, Valera, & Jimenez, 2003). The numerical target for the Canada Wide Standard for $PM_{2.5}$ is 30 $\mu g\,m^{-3}$ for a 24 hour average, whereupon this achievement is to be based on the 98^{th} percentile ambient measurement annually, averaged over three consecutive years (CCME, 2000). In order to accommodate the mentioned Canadian standard in AIR-QUEST Station Statistical Scenarios, we decided to calculate mean and standard deviation as well as 2, 5, 10, 25, 50, 75, 90, 95 and 98 percentiles as basic statistical parameters for all source reduction scenarios. AIR-QUEST Station Statistical Scenarios provide extensive comparisons of these parameters before and after modifying, or "tuning" of source emissions to create various scenarios. Furthermore a ranking of the top 10-100 hourly / daily overall concentrations should help to detect those days and seasons with critical concentrations. In addition PGAIR members suggested including the calculation of the exceedance frequency of hourly / daily limits, e.g. 50 $\mu g\,m^{-3}$, for hourly $PM_{2.5}$ concentrations. AIR-QUEST users are able to choose these hourly and daily limits for $PM_{2.5}$ as well as for PM_{10} according to their specific problem. As users are not supposed to spend a lot of time working through the output data set for every single simulation, most of the statistical results are visualized in the form of several charts.

In addition to the detailed Station Statistical Scenarios that can be run at 10 specific locations in the airshed, AIR-QUEST also can calculate the result of emission scenarios spatially across the airshed (Basic or Advanced Spatial Scenarios) with time resolutions for one month or longer.

A more detailed description of the visualizations will be provided in section 2.4 and section 4.

2.4 The R Openair Package

In addition to the basic Station Statistical Scenario plots describing statistical features of source reduction scenarios, AIR-QUEST takes advantage of the R package 'openair' designed for air quality data analysis. A detailed specification of the current openair version was recently published by (Carslaw & Ropkins, 2012). The use of openair constitutes an efficient way of importing and manipulating data utilizing a broad range of analyses to enhance understanding of air pollution data. Bivariate polar plots describing the wind speed and direction dependency of modeled PM concentrations visualize and identify specific high pollution conditions. Calendar-type views of mean values and corresponding wind directions supplement the polar plot analyses in an intuitive and descriptive way. Thus PGAIR members can adjust the tuning of their source reduction scenarios according to their results leading to an interactive way of simulation assessment. For Plaza there are also model evaluation tools available comparing modeled to observed $PM_{2.5}$ and PM_{10} concentrations. Complimentary temporal pollution characteristics for seasonal periods of time as well as particular weekday and intraday analysis are provided. Use of the openair model evaluation is an optional tool in AIR-QUEST which can be turned off by users. Examples of openair plots will be provided in section 4.

3. Database Details

Considering that a basic requirement for AIR-QUEST is that it is supposed to be a fast, robust and handy tool, the data base design required certain constraints to the available 300 GB Calpuff data base. Thus the split of the overall data set into two separate data sets for different purposes turned out to be the most efficient way to meet the given requirements. The GeoTIFF file data set has the best available spatial resolution for the entire airshed providing detailed concentration charts on a yearly to monthly basis, whereas the set of comma-separated value (csv) files used for statistical calculations in R and the openair package is limited to 10 specific locations, but comprises the highest temporal resolution of one hour.

3.1 Calpuff Data Set

The Calpuff Data set forms the general basis of this project, but the AIR-QUEST PostgreSQL data base does not provide direct access to this data set. As already mentioned above, this data set has the highest temporal and spatial resolution available, but it is not feasible to include every single one of the 1500 individual sources on the 1873 points grid for each hour of the entire period of time 2003-2005. Because of the binary format, the Calpuff data set had to be transformed into a project-adapted csv text file format to be used in the GeoTIFF and csv file R data set. The idea of including new Calpuff model runs directly into AIR-QUEST via a specific algorithm was considered, but due to the limited time of this project it is proposed to be included in a future version of AIR-QUEST. For the prototype version, the transformation of Calpuff binary data into csv and GeoTIFF files is performed by Calpuff post modeling applications, several python scripts and the Geospatial Data Abstraction Library 'GDAL' in several steps.

3.2 GeoTIFF File Data Set

As the GeoTIFF format provides a very efficient way of adding up GeoTIFF layers describing PM concentrations on the airshed grid, a GeoTIFF data set with monthly to yearly temporal and both 0.5 km x 0.5 km as well as 1km x 1km horizontal resolution was developed (Basic and Advanced Spatial Scenarios). The GeoTIFF files are created by converting csv files into GeoTIFF files using GDAL. In order to provide a clear data structure and a fast server response for users, the emission inventory tuning is restricted to monthly averages of the 11 source categories plus the additional 33 industrial permits. Overall approximately 6000 GeoTIFF files are available for $PM_{2.5}$, PM_{10}, SO_2 and NO_x Output maps show monthly to annual average concentrations for the untuned 2003-2005 emission inventory and the tuned emissions.

3.3 Csv File Data Set for R Scripts

Since they are a text file format, comma-separated value (csv) files are particularly suitable for use in R scripts (Station Statistical Scenarios). In agreement with the PGAIR Research Working Group members, we decided to limit the csv file data set used in AIR-QUEST to the ten measurement locations within the PG airshed marked in Figure 2-1. These ten locations cover most of the relevant parts of the airshed including several locations in the more highly polluted valley area as well as more rural locations like Western Acres. This data set is sufficient to discuss the source reduction effects for the entire airshed without reverting to the tremendous amount of the high resolution model grid data including 1873 grid points. Similar to the GeoTIFF data set, the R data set is also limited to tuning of the 11 source categories and the industrial permits. In contrast to the GeoTIFF data set, the R data set has full temporal resolution of one hour over the three-year period and the R scripts performing the tuning calculations provide a large set of statistics and charts.

Splitting the overall analysis into a GeoTIFF and an R data base illustrates the compromise about a fast web application and a data set of sufficient resolution to draw reliable conclusions based on the performed reduction simulations. Table 3-1 shows a summary of the data sets used in AIR-QUEST.

Parameter	Calpuff Data Base	GeoTIFF Data Set (Spatial Scenarios)	R Data Set (Station Statistical Scenarios)
File Format	Binary (.con)	GeoTIFF	CSV
Temporal Resolution	Hourly	Monthly	Hourly
Spatial Resolution	1km x 1km & 500m x 500m	1km x 1km & 500m x 500m	10 discrete Locations only

Tunable Emission Inventory	**1500 Individual Sources**	**11 Categories + 33 Industrial Permits**	**11 Categories + 33 Industrial Permits**
Statistics	**-**	**Mean**	**Means, Percentiles, Std dev, Top 10-100 values**
Output	**-**	**Plot of concentration across PG Airshed (after tuning)**	**Several Plots + 1 csv File (before & after tuning)**
Simulation Calculation Time	**Several Months**	**<10s**	**10-120s**

Table 3-1: Summary of data base details used for AIR-QUEST.

4. Results

In this section we will describe AIR-QUEST source reduction scenarios in detail. Screenshots illustrate the web application and how users can choose simulation parameters. Furthermore an example of a simple source reduction scenario will be given to visualize what the output looks like. AIR-QUEST is available at http://weather.unbc.ca/airquest/. For BC CLEAR, a guest account has been set up with a login of "guest-clear" – please contact Peter Jackson for the password.

4.1 General Design of the Web Interface

A screenshot of the web interface for AIR-QUEST is provided in Figure 4-1. Currently AIR-QUEST is secured and only accessible to those with accounts, but not to the general public.

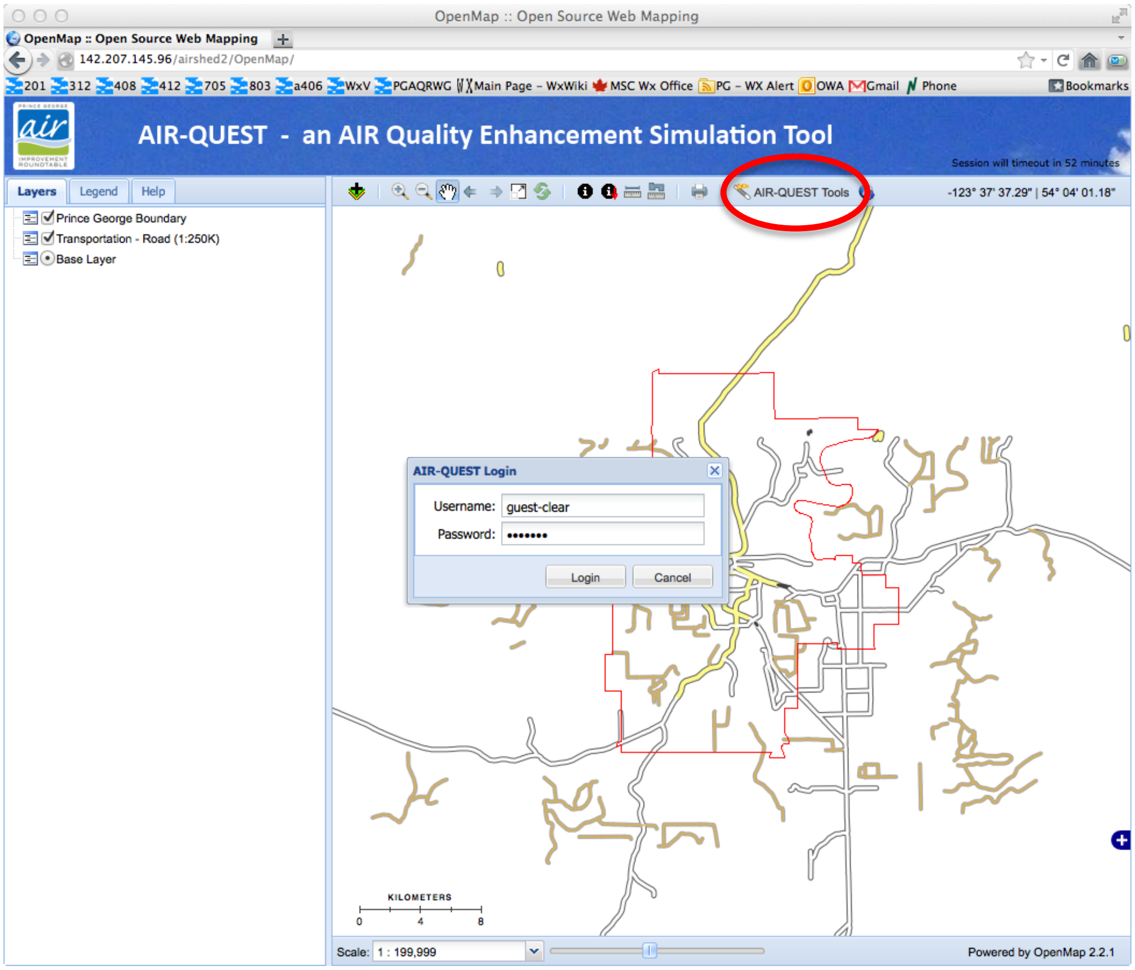

Figure 4-1: Home page screenshot of AIR-QUEST. Selecting "AIR-QUEST Tools" opens a login dialog and then the AIR-QUEST user interface.

The OpenMap web page consists of a side frame on the left side, where users can choose map overlays (topographic/pollution maps) and a main frame on the right side. To perform a scenario, users select "AIR-QUEST Tools (red circled area in Figure 4-1) which brings up a login box and then activates the AIR-QUEST Tools screen seen in Figure 4-2. The AIR-QUEST tools screen has 4 tabs: "Basic Spatial Scenarios" (Figure 4-2 bottom panel), "Advanced Spatial Scenarios" (not described here), "Station Statistical Scenarios" (Figure 4-2 top panel), and "About". In future developments and on-line help system will be added.

The two main tabs are "Basic Spatial Scenarios" for spatial plots with monthly average data, and "Station Statistical Scenarios" for detailed analysis at one of ten locations in the airshed with hourly resolution data. Both tabs have dialogs in which the pollutant is selected (PM2.5, PM10, SO2 or NOx), the multipliers for each source category is chosen, the scenario time period is selected, and the output file name is chosen. Output files are stored in the users directory from one session to the next and can be displayed and output. Meta-data that document the scenario that created each output file are linked to each file.

Source categories can be tuned in 1% steps from 0-1000% regarding the 2003-2005 emission inventory. For the permitted users category of industrial emission, setting a value of "0" percent opens up a new dialog where amounts can be specified for each of the 33 industrial permits in the airshed. For the Spatial

Scenarios, either the 500m or 1000m grid has to be chosen, while for the Station Statistical Scenarios, one of the ten locations shown in Figure 2-1 has to be chosen. Sensible default values are provided. For the Station Statistical Scenarios at the Plaza station, users can choose whether they would like to receive model evaluation charts that compare observed data with default (unturned) and scenario (tuned) model output. Users may also choose “Basic Graphs Only” for quicker execution. Users can provide an output name. As soon as all necessary parameters are defined, users can start the calculations by clicking the appropriate button at the bottom of the dialog. After a few seconds of calculation, the Tiff maps or R charts become available in the Results section and can be added to the map for the Spatial Scenarios, or viewed for the Station Statistical Scenarios, by right-clicking on the name. A detailed illustration of the R output charts is provided in section 4.2.

The button enables users to export and download maps, charts and the csv file including the calculation statistics. Other openmap standard icons visible in the toolbar above the map frame enable zooming and area measurements. More information about the operation of the tool and the meaning of all icons and layers is provided by the ‘help’ toolbar in the left frame. An online information tab describing the tool will be developed in the future.

4.2 Example Station Statistical Scenario: Plots, Calculations, Statistics

Using a simple $PM_{2.5}$ emission reduction scenario as an example, this section describes and visualizes the design and structure of the AIR-QUEST output. In order to arrange this report clearly, all output plots of the mentioned source reduction simulation are placed in the appendix and restricted to the Plaza location. Those concentrations referred to the unchanged 2003-2005 PG emission inventory (as modeled by Calpuff) are named ‘untuned’ scenarios, whereas those output values related to source emissions that are adjusted to create a scenario, are called ‘tuned’ simulations. As observational data for $PM_{2.5}$ are available for Plaza, a descriptive model evaluation is provided.

In the example scenario, for reasons of simplicity, overall $PM_{2.5}$ emission sources except permitted industrial users and railway emission are reduced by 30%. Due to the closing of several industrial facilities within the last few years, industrial emissions are simulated to drop by 50% (assuming that great effort will be made to reduce emissions), whereas locomotive emissions are increased by 70%. According to the expansion of port Prince Rupert, railway emissions in Prince George will presumably increase within the next few years, thus this rough simulation could be a possible future scenario. Although only source categories are tuned in this scenario, tuning of individual industrial permits does not lead to any major changes in the output design.

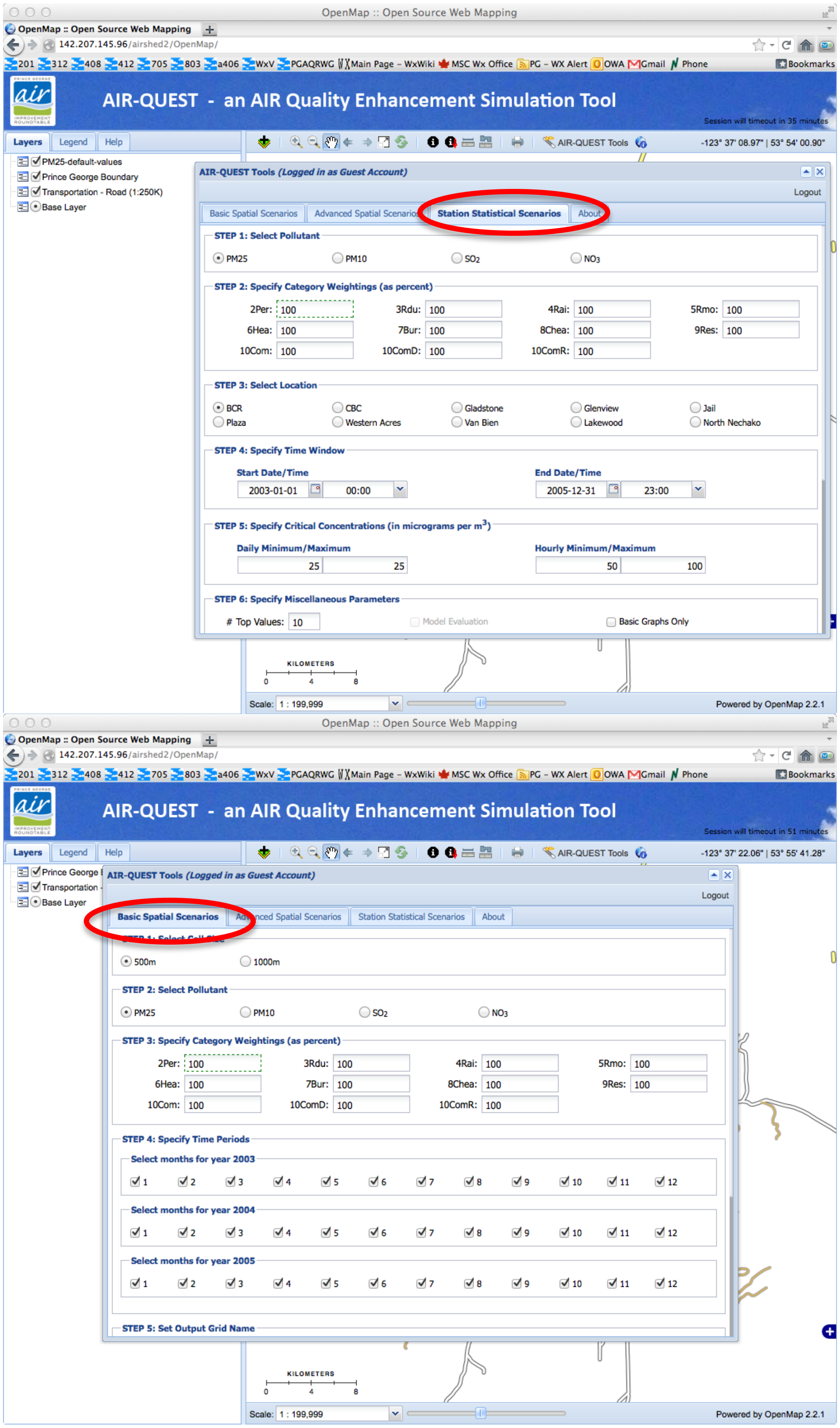

Figure 4-2: Screenshot of the scenario selection process on the AIR-QUEST web page. Top: for Station Statistical Scenarios. Bottom: for Basic Spatial Scenarios.

The simulated period is 2003-2005 and model evaluation is *on*. 'Critical' daily and hourly concentrations were set to 25 $\mu g\,m^{-3}$ and 100 $\mu g\,m^{-3}$ respectively. All statistical values like percentiles, means, deviations and maximum measured and modeled concentrations are explained in an output csv file, which will not be discussed in more detail, because most of the information is visualized by the simulation plots, which are described in the following paragraphs.

Figure A-1 shows two pie plots breaking down the overall $PM_{2.5}$ concentrations to relative contributions by source category before and after 'tuning' of the emissions. All commercial as well as both residential and both road source categories are summarized in one pie piece each in order to avoid crowded charts. That means the pie charts visualize 7 instead of 11 source categories mentioned in Table 2-1. In this particular scenario the AIR-QUEST simulation shows, for example, that railway emissions contribute 8.04% to the overall $PM_{2.5}$ concentrations and are ranked 6th before tuning, i.e. for the unchanged 2003-2005 inventory, whereas railway emissions for the simulated 'tuned' conditions are ranked 3rd contributing 16.59% to the overall concentrations. As means are not necessarily good indicators for health effects, the AIR-QUEST output includes a percentile plot shown in Figure A-2. This chart describes the comparison of percentiles for untuned and tuned conditions. Although 5th, 25th and 50th percentiles don't decrease considerably in this scenario, the 95th percentile drops by more than 7.5 $\mu g\,m^{-3}$ to 24.70 $\mu g\,m^{-3}$ after tuning. Values for 98th percentiles which are of significance for the Canada Wide Standard are provided in the output csv file. In addition to the percentile plot, two charts which describe the exceedance frequency of critical daily and hourly $PM_{2.5}$ concentrations are calculated. Figure A-3 shows one bar plot example comparing observed and modeled concentrations for untuned and tuned conditions. On the one hand these charts provide a first model evaluation in terms of maximum daily and hourly concentrations, on the other hand air quality managers can easily estimate whether the achievement of certain aims like avoidance of the violation of particular limits can be realized by specific source reductions.

Figure A-4, Figure A-5 and Figure A-6 show openair polar plots describing the wind dependency of the measured and modeled (untuned & tuned) concentrations. These charts are helpful to identify meteorological conditions (wind speed and directions), where PM concentrations are particularly high. Considering the specific geographical location of the chosen simulation location, individual emission sources may be tagged and if observational data are available, wind speed and direction related model performance can be investigated. To visualize daily and seasonal variations at a glance, AIR-QUEST takes advantage of the calendar plot functions in the openair package. Figure A-7 and Figure A-8 characterize untuned modeled daily concentrations for 2004 with regards to seasons, weekdays and predominant wind directions. These plots are available for all years of the simulation for untuned as well as tuned conditions. A comparison of untuned and tuned conditions by calendar display (not shown in this report) enables a fast and easy estimation, whether seasonal pollution patterns change significantly for the chosen emission reduction scenario. More detailed information about the model performance in terms of seasonal, weekday and day-time variations are also provided by Figure A-9. The additional model evaluation plot shown by Figure A-10 compares modeled and observed quantiles expressing pollution related model performance features. The mentioned model evaluation chart types represented by Figure A-9 and Figure A-10 are limited to the Plaza location, whereas all other plots are also created for the other locations although observational data are not shown for these. In addition to those charts described so far, AIR-QUEST also provides so-called 'pollution rose' and 'percentile polar plots' which investigate the wind dependency of pollution. For simulation periods shorter than three months, time series plots, showing concentration variation with time, are available. For yearly periods like in our simulation example AIR-QUEST does not create those charts since they are hard to interpret due to random noise and related marginal significance.

Figure A-11 provides an example of output from the Basic Spatial Scenario on the 500 m grid for PM2.5.

4.3 Background Results

As mentioned in section 2.1, a detailed discussion about the results from the background study is provided in the 'background concentration study' that was submitted with the interim final report of this project. According to large general seasonal variations, road dust events in spring and forest fires during dry summer periods, background concentration values were investigated seasonally and related to precipitation effects. It turned out to be suitable to define a 48h precipitation $P_{48h} \geq 2mm$ as *'wet'* conditions and $P_{48h} < 2mm$ as *'dry'* conditions. The lack of suitable observational PM data for 2003-2005 and the need for statistically significant and scientifically reliable concentrations forced us to use a 2000-2009 data set for Plaza observations (located in eastern downtown) and a 2006-2009 data set for Gladstone observations (located at the western city boundary). The mean seasonal and precipitation related values shown in Table 4-1 describe averages of Plaza and Gladstone.

Season	PM_{10} dry [µg m^{-3}]	PM_{10} wet [µg m^{-3}]	$PM_{2.5}$ dry [µg m^{-3}]	$PM_{2.5}$ wet [µg m^{-3}]
Year round	9.70	6.53	2.74	2.20
Winter	6.33	5.96	1.95	2.10
Spring	10.30	6.34	2.78	1.75
Summer	10.94	6.35	3.54	2.06
Fall	10.21	7.41	2.63	2.96

Table 4-1: Seasonal background concentrations for the PG airshed. See text for explanations of 'dry' and 'wet' conditions. For confidence intervals see background study report attached to the final project report.

For the winter season differences between dry and wet conditions are marginal due to the regular snow cover suppressing dust mobilization. All other seasonal values show significantly higher concentrations for dry conditions. A forest fire related summer season peak can only be detected for $PM_{2.5}$, whereas wet and dry conditions for $PM_{2.5}$ do not differ significantly in fall within a 95% confidence interval. For wet conditions the highest seasonal concentrations can be identified in fall, potentially this seasonal feature could be related to long-range transport or the assumption of special meteorological conditions that do not match the low pollution requirements in this season.

The background study results were submitted as a peer-reviewed journal article, that at the time of this report is still under review at the Journal of the Air and Waste Management Association (Veira et al, 2013).

4.4 Limitations of AIR-QUEST

Most of the basic limitations have already been discussed in the context of the data base description in section 3. The most important restrictions of AIR-QUEST in comparison to the original Calpuff data base are computing time related, e.g. the use of 11 source categories plus 33 industrial permits instead of 1500 individual sources. That means AIR-QUEST is capable of performing source reduction simulations for instance for an overall reduction of residential heating emission by 23% for the entire airshed, but users can not perform these calculations for one particular residential area or by a single street. The limitation to ten locations for the R data set is still sufficient for air quality managers as well as the GeoTIFF file data set limitations to monthly data, because PGAIR members are interested in maps for monthly averages, but maps for particular single hours or days of the 2003-2005 period will be of limited relevance for their purposes. Due to the incomplete Calpuff data set prior to this project requiring unexpected remodeling within this project, it was impossible to design the location selection for simulations on an interactive map suggested by PGAIR members, but this feature could be added in a future version of AIR-QUEST. According to the current general set-up of the data base, the integration of new sources within the PG airshed requires additional work to manually update files – this process is not yet completely automated. For future versions of AIR-QUEST these features could be realized.

5. Conclusions and Future Work

In this section a discussion and evaluation of the benefits as well as the limitations of transferability to other airsheds are provided. In addition prospects and ideas for further improvement of AIR-QUEST are discussed.

5.1 Benefits for PGAIR

The use of AIR-QUEST enables all members of PGAIR to perform source reduction simulations themselves using a fast and intuitive web tool. This tool bridges the gap between scientists and laymen. Thus, the accessibility of the modeling results to an expanded group of people can broaden the discussion about different kinds of reduction scenarios and stimulate new ideas for future air quality improvement strategies. By involving the PGAIR members in the development process of this tool most of their suggestions could be realized although technical restrictions require limitations with regards to the resolution of the data set.

5.2 Transferability to Other Airsheds

The transferability of AIR-QUEST to other airsheds would be a great benefit to other communities. Basically the developed general concept, the data base structure and the R script for performing statistical calculations could serve as a model for other regions. In particular the R script can be used independently from the rest of the web interface without great effort. In contrast the transfer of the data bases using other airsheds, temporal resolutions and source categories is more difficult, because the web interface has to be modified significantly if these parameters are changed. Nevertheless, as long as the required data base format and structure for a different airshed is available, the necessary work is limited. All our scripts and programs developed for the web interface are available on request.

5.3 Future and Additional Work

In the coming weeks we plan to improve the online documentation of the tool, improve the ability to output images and data, and add colour and a legend to the spatial maps. The Calpuff emission inventory for 2003-2005 has been revised and updated within the last few months including the implementation of fugitive dust emissions which form a new source category. The calpuff modeling system which produces the model output has also been revised and streamlined and all sources are currently being rerun. Corresponding updates for all AIR-QUEST data sets are scheduled for the end of April 2013 and will be available to PGAIR members shortly thereafter. Even though the objectives of this project focused on PM, the basic Calpuff data base also includes modeled SO_2 and NO_x concentration at the same resolution as PM.

Another aim of future AIR-QUEST versions is the development of a completely automated data flow using Calpuff model outputs to update the GeoTIFF and R data sets and potential web page design changes without any ‘manual’ intervention.

Overall the current version of AIR-QUEST is a robust and fast prototype web application. The basic requirements for the development of this tool have been realized according to the feedback of PGAIR members. Although this web application presents a prototype and will have to be updated both technically and functionally, AIR-QUEST can contribute to the fast development of an ambitious and sustainable air quality management plan in Prince George. Thus, the entire community of Prince George is expected to benefit from this research project.

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References

Ainslie, B., & Jackson, P. L. (2009). The use of an atmospheric dispersion model to determine influence regions in the Prince George, B.C. airshed from the burning of open wood waste piles. *Journal of Environmental Management , 90* (8), 2393–2401.

Allen, J., Bartlett, K., Graham, M., & Jackson, P. (2011). Ambient concentrations of airborne endotoxin in two cities in the interior of British Columbia, Canada. *Journal of Environmental Monitoring , 13* (3), 631-640.

Baldasano, J. M., Valera, E., & Jimenez, P. (2003). Air quality data from large cities. *The Science of the Total Environment , 307* (1-3), 141–165.

Brauer, M., Reynolds, C., & Hystad, P. (2012). *Traffic-Related Air Pollution and Health:A Canadian Perspective on Scientific Evidence and Potential Exposure-Mitigation Strategies.* Vancouver: The Universtiy of British Columbia, School of Population and Public Health.

Carslaw, D. C., & Ropkins, K. (2012). openair - An R package for air quality data analysis. *Environmental Modelling & Software , 27-28*, 52-61.

CCME. (2000). *CANADA-WIDE STANDARDS forPARTICULATE MATTER (PM) and OZONE.* Quebec City: Canadian Council of Ministers of the Environment.

Noullett, M., Jackson, P. L., & Michael, B. (2010). Estimation and characterization of children's ambient generated exposure to PM2.5 using sulphate and elemental carbon as tracers. *Atmospheric Environment , 44* (36), 4629–4637.

Owens, P. N., Caley, K. A., Campbell, S., Koiter, A. J., Droppo, I. G., & Taylor, K. G. (2011). Total and size-fractionated mass of road-deposited sediment in the city of Prince George, British Columbia, Canada: implications for air and water quality in an urban environment. *Journal of Soil and Sediments , 11* (6), 1040-1051.

Scire, J. S., Strimaitis, D. G., & Yamartione, R. J. (2000). *A user's guide for the CALPUFF dispersion model.* Concord, MA, USA: Earth Tech Inc.

Stantec. (2010). *PRINCE GEORGE AIR QUALITY Dispersion Modeling Study - A Revision.* Burnaby: Stantec.

A. Appendix

In order to arrange this report clearly, all output plots of the source reduction simulation example described in section 4.2 are shown in full resolution and located in this appendix.

Figure A-1: Relative contribution by source category to the annual $PM_{2.5}$ at Plaza

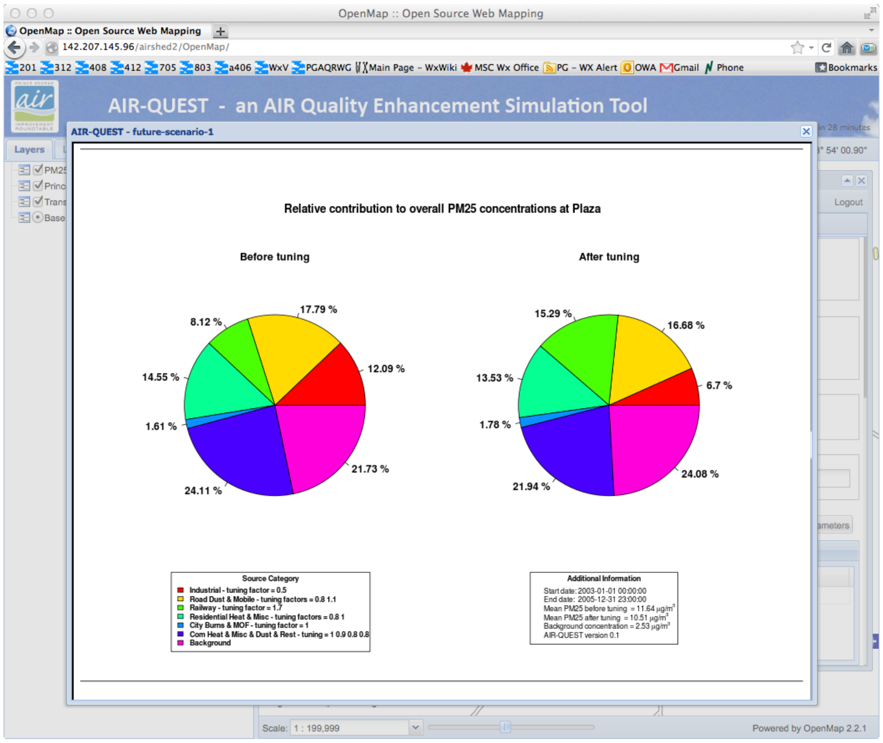

Figure A-2: $PM_{2.5}$ percentiles for tuned and untuned conditions at Plaza

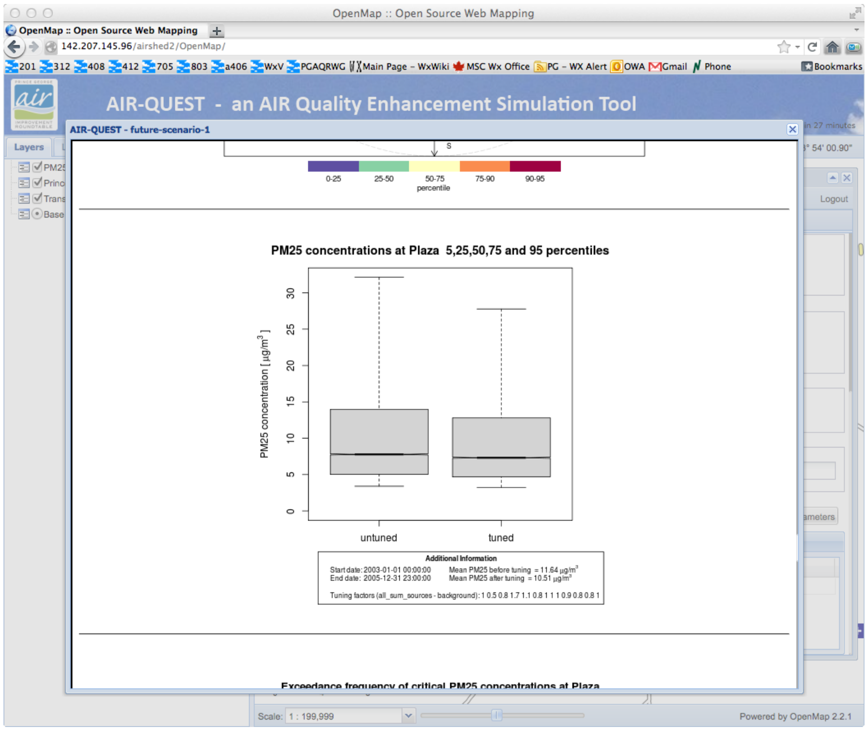

Figure A-3: Exceedance frequency of critical $PM_{2.5}$ concentrations at Plaza

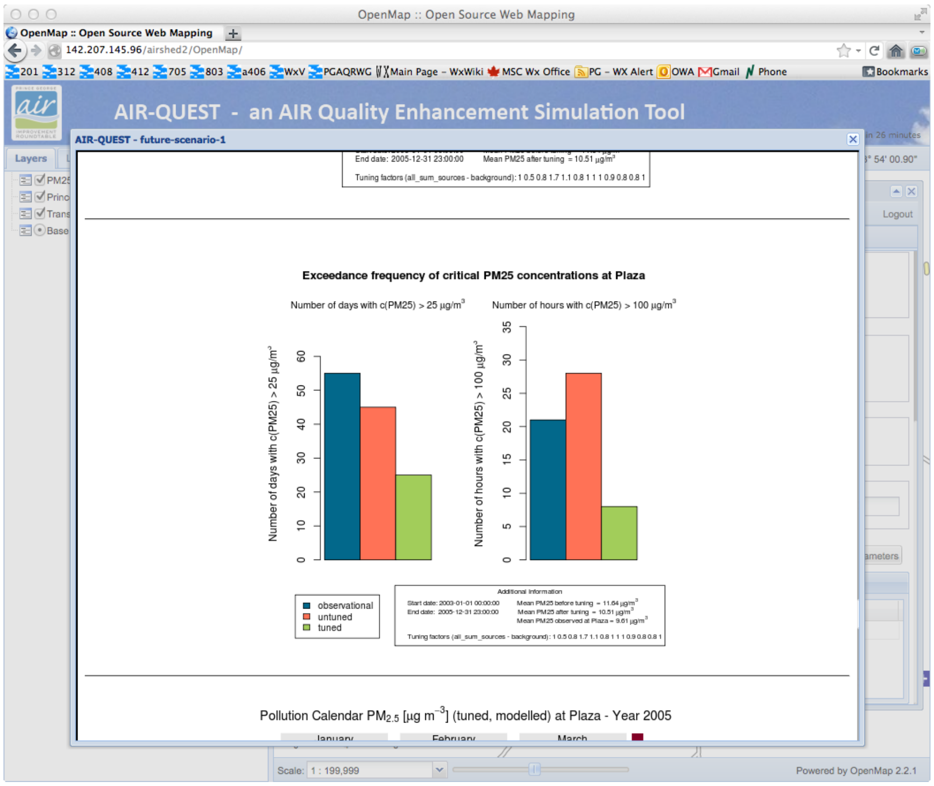

Figure A-4: Wind dependency of $PM_{2.5}$ concentrations [$\mu g\,m^{-3}$] at Plaza (observed)

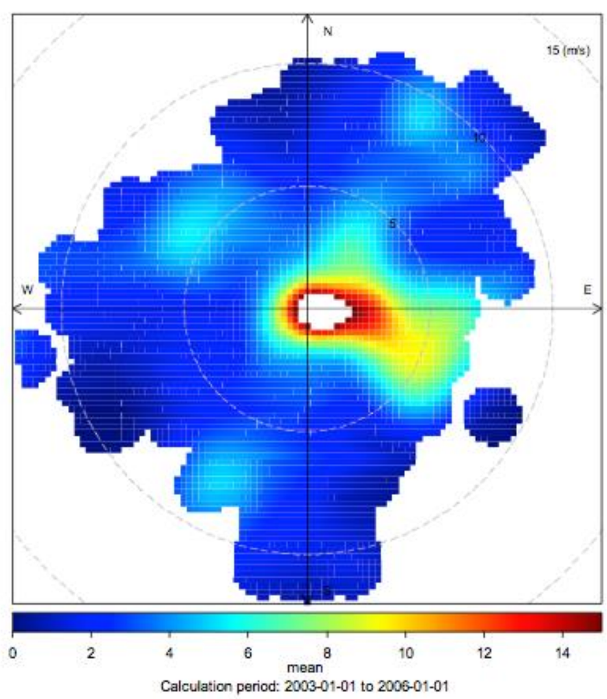

Figure A-5: Wind dependency of $PM_{2.5}$ [µg m^{-3}] at Plaza (modeled) for *untuned* conditions

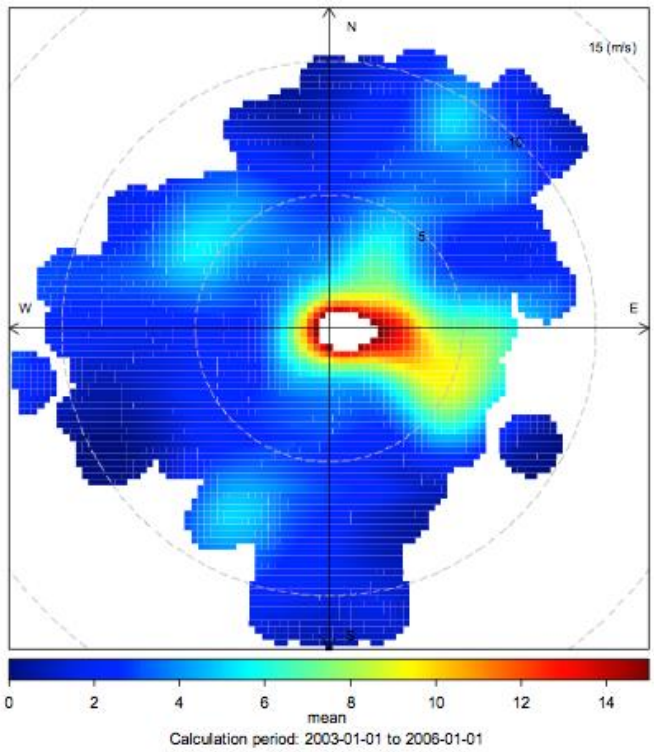

Figure A-6: Wind dependency of $PM_{2.5}$ [µg m^{-3}] at Plaza (modeled) for *tuned* conditions

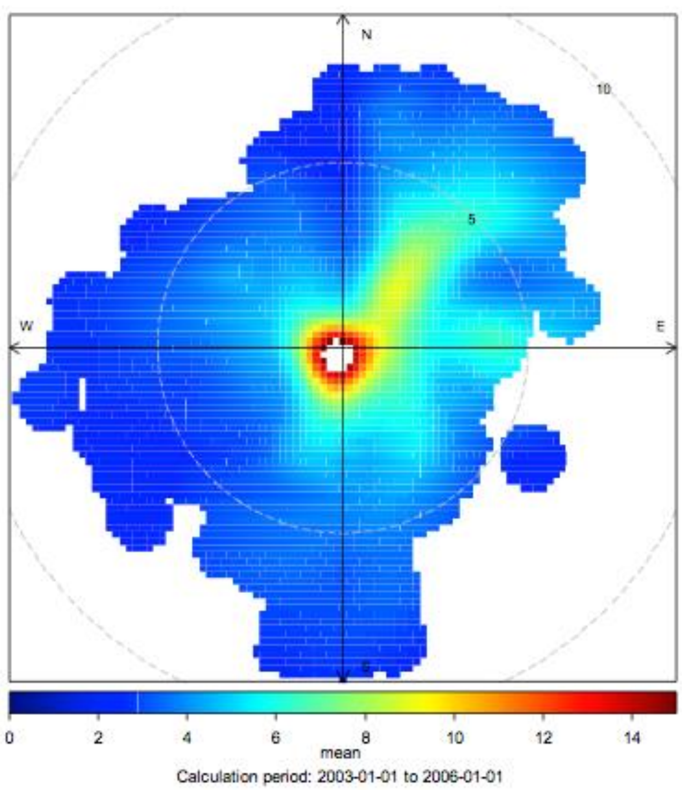

Figure A-7: Pollution calendar $PM_{2.5}$ [$\mu g\,m^{-3}$] at Plaza 2004 (modeled) for untuned conditions

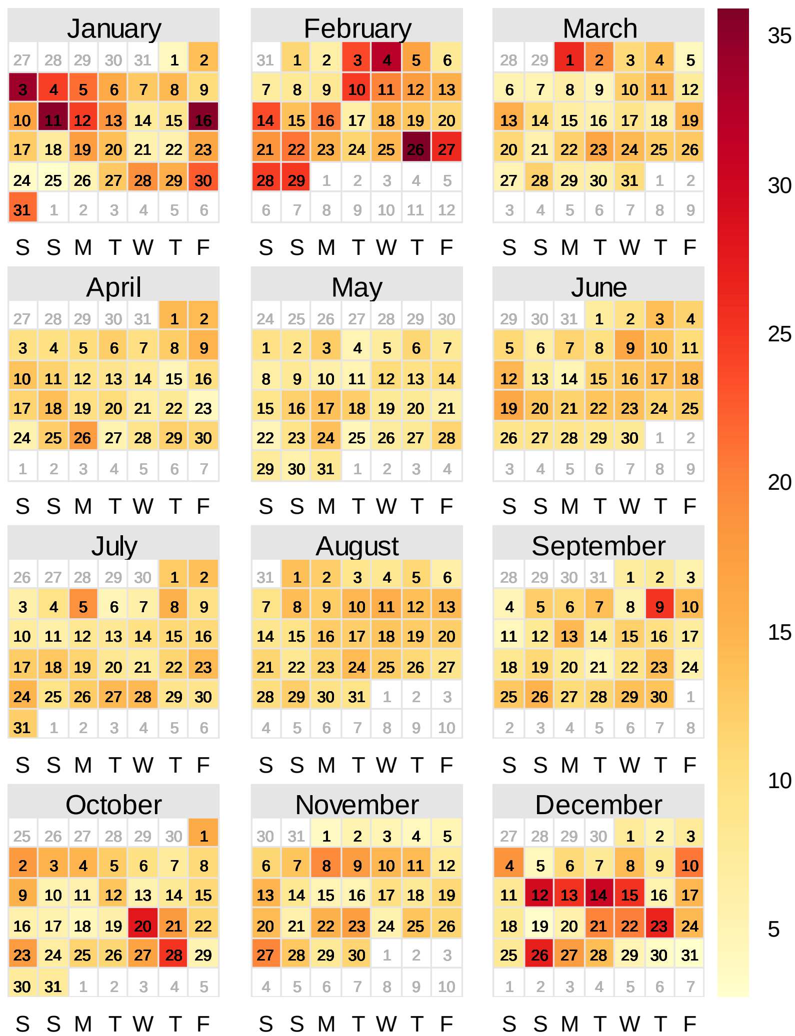

Figure A-8: Wind direction -pollution calendar $PM_{2.5}$ [$\mu g\, m^{-3}$] at Plaza 2004 for untuned conditions

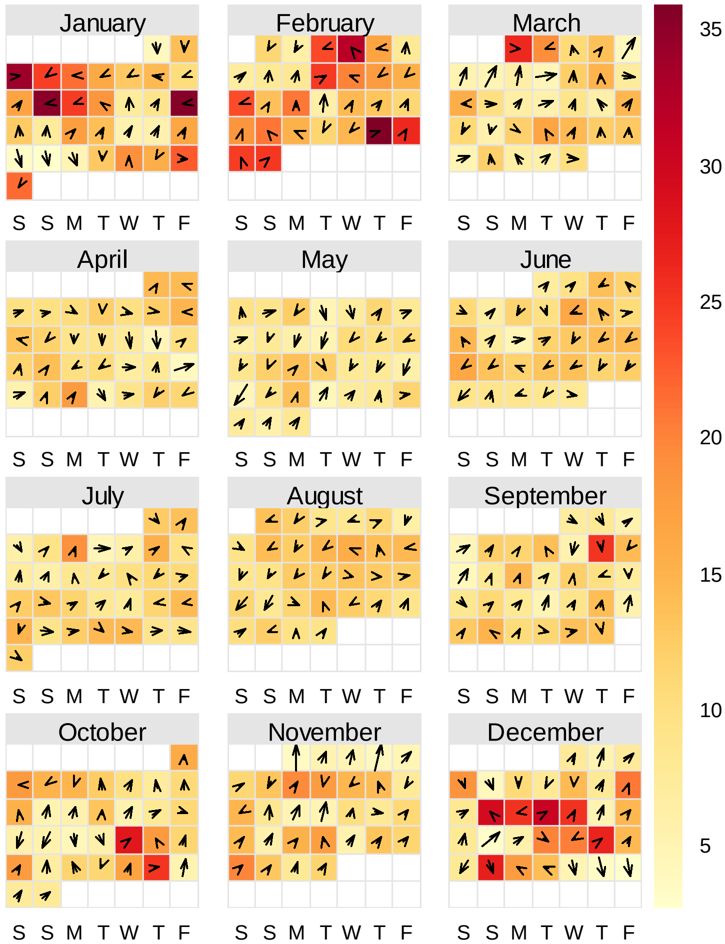

Figure A-9: Detailed model evaluation for $PM_{2.5}$ concentrations at Plaza 2003-2005

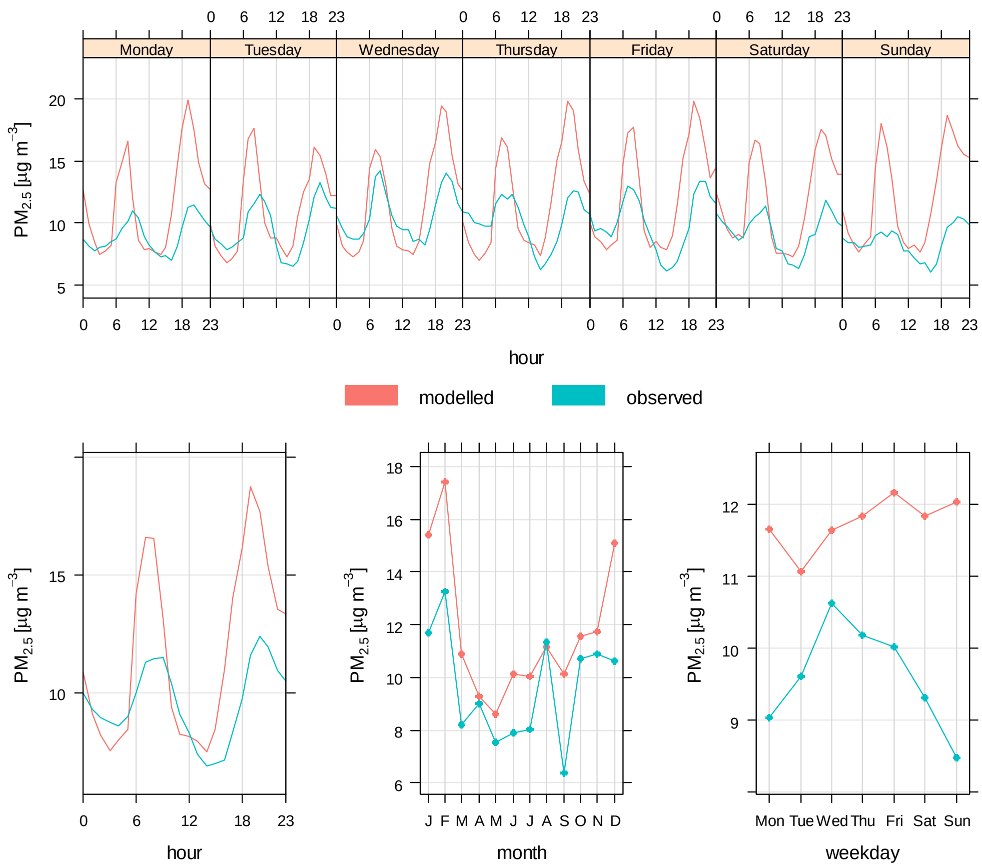

Figure A-10: Conditional quantiles for modeled and observed $PM_{2.5}$ [$\mu g\,m^{-3}$] at Plaza 2003-2005

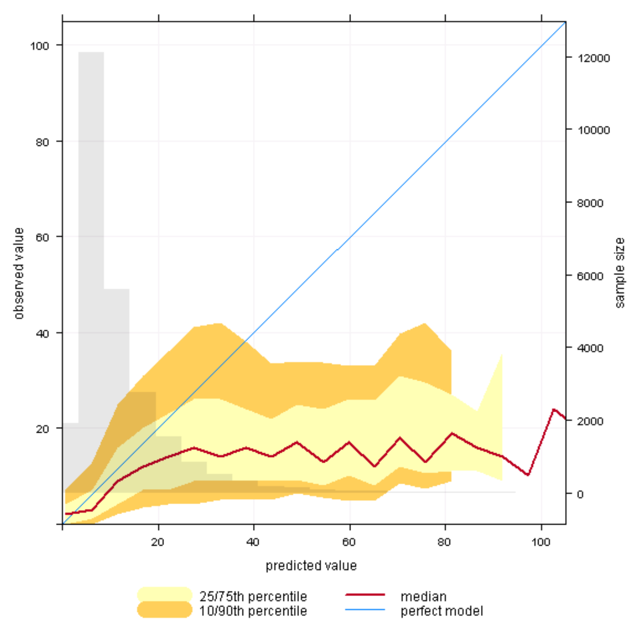

Figure A-11: Example Spatial Scenario plot – this is for the default PM2.5 values.