BC Clean Air Research Fund

Final Report

April 1, 2013 to March 14, 2014

March 28, 2014

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PROJECT OVERVIEW

Abstract

Background: The town of Quesnel (population 10,000) has high annual average fine particulate matter ($PM_{2.5}$) concentrations compared with most other communities in BC. We believe that these concentrations are driven by a mix of industry, commercial transportation, and residential woodsmoke. The town of Smithers (population 5,400) has high wintertime $PM_{2.5}$ concentrations driven primarily by residential woodsmoke. We conducted two weeks of summertime mobile monitoring of aerosols in both towns to identify air pollution hotspots, and to provide a baseline for comparisons with wintertime air quality, which is affected by woodsmoke.

Methods: A driving route for Quesnel was identified via partnership between the Quesnel Air Quality Roundtable and the BC Ministry of Environment. The driving route for Smithers was a modified version of that used for previous mobile monitoring in the community. We conducted two 14-day field campaign in both towns, one in summer and one in winter. Routes or partial routes were driven two times per day, on average. The driving schedule was designed to capture differences between peak driving hours and quieter times of the day, as well as differences between weekdays and weekends. Ambient aerosol was measured using a mobile nephelometer sampling every 10 seconds, and concentrations were compared with those from a fixed site nephelometer in both locations.

Results: The within-drive and between-drive variability in fixed-site aerosols was much higher for Quesnel than for Smithers in both season. This speaks to the sensitivity of Quesnel to conditions across the airshed. Once the influence of this regional variability had been removed, there was minimal evidence of specific pollution hot spots attributable to industry or commercial transportation, and clear evidence that road dust is an important contributor to summertime air quality in specific locations while woodsmoke is an important contributor in winter. There was little within-drive and between-drive variability in fixed-site aerosols for Smithers, but similar evidence of road dust and woodsmoke as an important sources of short-term pollution.

Next steps: All campaigns went smoothly. There were minor problems with equipment in all cases, but we now have an excellent data basis for further analyses. Given that the winter campaign ended in mid-February we have not yet had time to thoroughly compare summer and winter results, not to compare winter results from Smithers with those from previous years. This work will be done by a practicum student over the summer of 2014, and we are holding a small amount of cash from QAQR in reserve for publication of the results in the peer-reviewed literature.

FINANCIAL OVERVIEW

Revenue Description

Table 1 Projected Total Project Revenue (cash and in-kind)

Organization	2012/13		2013/14		Total
	Cash	In-kind	Cash	In-kind	
BC CLEAR - Fraser Basin Council			20,000		20,000
University of British Columba				10,000	10,000
Quesnel Air Quality Roundtable			5,000	2,000	7,000
Ministry of Environment				4,000	4,000
TOTAL			25,000	16,000	41,000

Table 2 Actual Revenue for Reporting Period (cash and in-kind)

Organization	2012/13		2013/14		Total
	Cash	In-kind	Cash	In-kind	
BC CLEAR - Fraser Basin Council			20,000		20,000
University of British Columba				10,000	10,000
Quesnel Air Quality Roundtable			5,000	2,000	7,000
Ministry of Environment				4,000	4,000
CREATE-AAP				3,216	3,216
TOTAL			25,000	19,216	44,216

Note: Please attach copies of letters or agreements confirming additional funds.

Please explain revenue discrepancies (if any)

The first round of sampling was conducted by a 4^{th} year undergraduate student, 2/3 funded through the CREATE-AAP program at UBC, which is reflected in the in-kind revenue. All other support was received as planned.

Expenses Description

Table 3 Projected Expenses for Reporting Period (cash and in-kind)

Project Costs	**Expenses**		
	All Sources		
	Cash	*In-kind*	*Total*
Salaries and fees	16,000	4,000	20,000
Travel and accommodation	9,000		9,000
Equipment and supplies		10,000	10,000
Communications and outreach		2,000	2,000
TOTAL PROJECT COSTS	25,000	16,000	41,000

Table 4 Actual Expenses for Reporting Period (cash and in-kind)

Project Costs	**Expenses**		
	All Sources		
	Cash	*In-kind*	*Total*
Salaries and fees	11,110	7,216	8,024
Travel and accommodation	8,660		4,931
Equipment and supplies	1,630	10,000	6,329
Communications and outreach	102	2,000	1,102
TOTAL PROJECT COSTS	22,500	19,216	40,716

Please explain expense discrepancies (if any)

The entire winter sampling campaign was conducted by a contractor for $9,000 plus tax and the associated costs of delivering equipment to and from the study areas. We received an unexpected in-kind contribution of $3216 for the summer campaign, and are thus holding $2,600 from QAQR in reserve to pay for publication of the results in an open-access, peer-reviewed journal.

RESULTS OVERVIEW

Activity Description

Table 5 Summary of Activities for the Reporting Period

Activity*	Completion Date	Description of Results
Complete summer sampling	August 28, 2013	26 drives in Quesnel and 25 in Smithers. Clear differences between communities, and clear evidence of road dust as an important factor in summertime local air quality.
Summer sampling report	October 18, 2013	Wrote generalized code for data cleaning. Drive-by-drive maps of aerosol adjusted for regional trends. Mean overall, rush hour, and weekday/weekend maps showing influence of traffic and industry in Quesnel.
Complete winter sampling	February 20, 2014	30 drives in Quesnel and 29 in Smithers. Clear differences between communities, and clear evidence of localized impacts from residential woodsmoke.
Winter sampling report	March 28, 2014	Updated generalized code for data cleaning. Drive-by-drive maps of aerosol adjusted for regional trends. Mean overall, rush hour, and weekday/weekend maps showing influence of smoke in both locations.

*As outlined in the project contribution agreement or contract.

Please explain activity discrepancies (if any)

Deliverable Description

Please include copies of all deliverables with the final report (e.g. publications, presentations, research reports, etc.). The final report will be considered incomplete without copies of the project deliverables.

Table 6 Summary of Key Deliverable Accomplishments for the Reporting period

Deliverable*	Description	Description of Results
Summer report	20-page report summarizing results of the summer sampling campaign in maps.	Drive-by-drive maps of aerosol adjusted for regional trends. Mean overall, rush hour, and weekday/weekend maps showing influence of traffic and industry in Quesnel.
Winter report	20-page report summarizing results of the winter sampling campaign in maps.	Drive-by-drive maps of aerosol adjusted for regional trends. Mean overall, rush hour, and weekday/weekend maps showing influence of traffic and woodsmoke in both study locations.

*As outlined in the project contribution agreement or contract.

Please explain deliverables discrepancies (if any)

DELIVERABLES

Appendix 1: Report on Summer Mobile Sampling in Smithers and Quesnel

Appendix 2: Report on Winter Mobile Sampling in Smithers and Quesnel

Short report on summer sampling for the study on mobile monitoring to characterize the spatial variability of winter and summer particulate matter concentrations in Quesnel and Smithers

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7 November 2013

Table of Contents

Abstract

Background: The town of Quesnel (population 10,000) has high annual average fine particulate matter ($PM_{2.5}$) concentrations compared with most other communities in BC. We believe that these concentrations are driven by a mix of industry, commercial transportation, and residential woodsmoke. The town of Smithers (population 5,400) has high wintertime $PM_{2.5}$ concentrations driven primarily by residential woodsmoke. We conducted two weeks of summertime mobile monitoring of aerosols in both towns to identify air pollution hotspots, and to provide a baseline for comparisons with wintertime air quality, which is affected by woodsmoke.

Methods: A driving route for Quesnel was identified via partnership between the Quesnel Air Quality Roundtable and the BC Ministry of Environment. The driving route for Smithers was a modified version of that used for previous mobile monitoring in the community. We conducted one 14-day field campaign in both towns, driving the route two times per day, on average. The driving schedule was designed to capture differences between peak driving hours and quieter times of the day, as well as differences between weekdays and weekends. Ambient aerosol was measured using a mobile nephelometer sampling every 10 seconds, and concentrations were compared with those from a fixed site nephelometer in both locations.

Results: The within-drive and between-drive variability in fixed-site aerosols was much higher for Quesnel than for Smithers. This speaks to the sensitivity of Quesnel to conditions across the airshed. Once the influence of this regional variability had been removed, there was minimal evidence of specific pollution hot spots attributable to industry or commercial transportation, and clear evidence that road dust is an important contributor to summertime air quality in specific locations. There was little within-drive and between-drive variability in fixed-site aerosols for Smithers, but similar evidence of road dust as an important source of short-term pollution.

Next steps: Both summertime campaigns went very smoothly. The temperatures were high in Quesnel (daytime highs above 30°C), and there was some challenge in keeping the fixed site monitor adequately cool for unbiased operation. The temperatures were considerably lower in Smithers (daytime highs of 25°C). There were a few challenges with the GPS in Quesnel, where the mountains may have interfered with the satellite signals. These resulted in the loss of two drives of data, leaving 24 available for analysis. The winter sampling campaign has been contracted to a research assistant who has been helping with Ryan Allen's work in the area, and we feel confident that it will be equally trouble-free.

Background

The town of Quesnel (population 10,000) has high annual average fine particulate matter ($PM_{2.5}$) concentrations compared with most other communities in BC. Furthermore, a recent report showed that the local planning target of 18 ug/m^3 (based on the annual 98th percentile) is persistently not achieved at some monitoring stations. The dominant sources of $PM_{2.5}$ in Quesnel include local industry, commercial transportation, and residential woodsmoke. However, the relative contributions from each source remain unclear and are challenging to evaluate with limited data from three stationary monitors. Mobile monitoring is an inexpensive and flexible method that has been used to supplement information from the fixed air quality monitoring network in many parts of BC. One example is the town of Smithers (population 5,400), which was previously identified as having high $PM_{2.5}$ concentrations attributable to residential woodsmoke, and which has been the focus of an aggressive woodstove exchange program over the past five years. Mobile monitoring was used to characterize spatial variation in $PM_{2.5}$ from residential woodsmoke in Smithers during the winter of 2007-2008, early in the implementation of the exchange program. Smithers and Quesnel are comparable with respect to population, climate, and geographic situation, but industry and commercial transportation are not dominant sources in Smithers. We proposed to map spatial variability of summer and winter $PM_{2.5}$ concentrations in Smithers and Quesnel using mobile monitoring methods previous developed and applied in BC. By comparing summer and winter results for both towns we expect to clarify the contribution of residential woodsmoke to the $PM_{2.5}$ mixture in Quesnel. By comparing 2007-2008 results with 2013-2014 results for Smithers we expect to clarify how changes to residential wood burning can affect short- and long-term $PM_{2.5}$ concentrations within a small community. The following is a short report on the results of the summer 2013 sampling campaigns in both communities.

Methods

Quesnel

Sampling route

There had been no prior mobile monitoring in Quesnel, so it was necessary to define a sampling route that would meet the needs of our stakeholders at the Quesnel Air Quality Roundtable (QAQR). This was done by QAQR in consultation with Arvind Saraswat, who was the regional Air Quality Meteorologist with the Ministry of Environment (MOE) at that time. Together they designed a route that covered their priority areas and that took approximately two hours to drive in either direction. This was provided on a local map (Figure 1) and then entered turn-by-turn into our global positioning system (GPS). Some refinements were made by the study team to capture within-neighbourhood variability, as seen in the Results section. It is likely that further refinements will be made for the winter sampling campaign, and that the route will be split into two driving sections, as has been done in Smithers.

Sampling period, schedule, and protocol

Sampling in Quesnel was conducted between July 15th and July 28th, 2013. One concern about the summer sampling campaign was the possibility of impacts from wildfires across the province. According to records from the Wildfire Management Branch at the Ministry of Forests, Lands, and Natural Resource Operations, there were 8 fires greater than 10 hectares in the province during this period, with none in the Cariboo Fire Centre itself and all fires less than 100 hectares in size (Table 1). Temperatures in Quesnel were quite warm during this period, with means ranging from 13.1 – 22.7 °C and highs ranging from 24.3 – 31.1 °C. There was no precipitation during the sampling period. The sampling schedule was designed to capture patterns in particulate matter over a wide range of times-of-day and day-of-week scenarios (Table 2). At the beginning of each drive a coin was tossed to determine the direction in which the route would be driven (heads = forwards; tails = backwards). All drives were conducted according to the study protocol, a final version of which will be included in our final report.

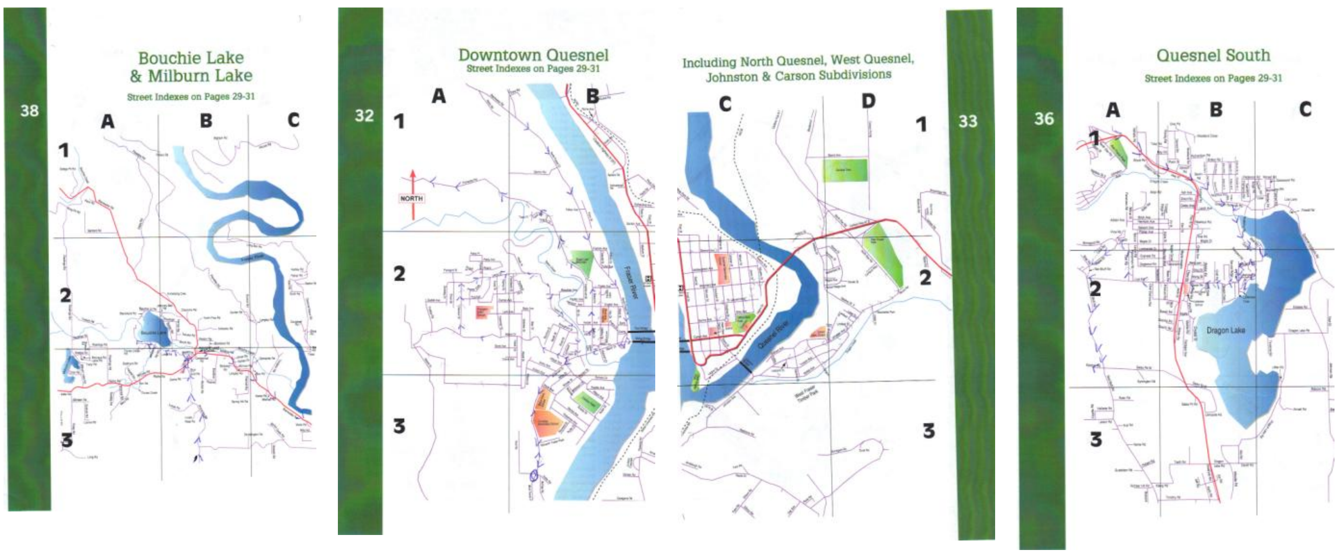

Figure 1. Driving route provided to the study team but the Quesnel Air Quality Roundtable following consultation with the Ministry of Environment.

Table 1. Provincial fires greater than 10 hectares that burned during the July 15th through July 28th sampling campaign in Quesnel.

Fire Centre	Fire Name	Discovery Date	Area Burned (hectares)
Coastal	Lizzie	July 15	31
Kamloops	Bose Lake	July 23	16
Kamloops	Ashcroft	July 24	16
Southwest	Perry Creek	July 24	64
Kamloops	Fredricks	July 27	64
Southwest	French Creek	July 27	16
Coastal	Pitt Lake	July 28	64
Kamloops	White Lake Road	July 28	69

Fixed monitor

A fixed nephelometer was co-located with the fine particulate matter ($PM_{2.5}$) tapered element oscillating microbalance (TEOM) at Quesnel Senior Secondary school in the central business district. The nephelometer was located on the roof of the utility trailer where the MOE instruments are housed (Figure 2). It was protected by a large, black waterproof casing (Figure 3) that caused risk of overheating in the hot, sunny weather experienced during the sampling period. The field technicians ran daily checks on the instrument between July 15th and 19th, and shut it down on some nights to ensure that it had the opportunity to cool. On July 20th they installed several vents and a fan to keep air circulating through the casing, and the instrument was run continuously for the duration of the campaign.

Table 2. Sampling schedule for mobile monitoring in Quesnel

Date	Drive 1 Time	Drive 1 Direction	Drive 2 Time	Drive 2 Direction
July 15	12:30-14:30	Forward	17:00-19:00	Forward
July 16	10:30-12:30	Forward	14:30-17:00	Backward
July 17	11:45-13:45	Backward	22:45-00:45	Forward
July 18*	15:45-17:45	Forward		
July 19*	11:30-13:30	Backward	20:00-22:00	Backward
July 20*	15:45-17:45	Backward		
July 21	09:30-11:30	Forward	22:45-00:45	Backward
July 22	08:45-10:45	Backward	13:45-15:45	Forward
July 23	13:30-15:30	Forward	22:45-00:45	Backward
July 24	10:45-12:45	Forward	19:30-21:00	Backward
July 25	08:15-10:15	Backward	16:30-18:30	Forward
July 26	08:15-10:15	Forward	21:00-23:00	Forward
July 27	17:00-19:00	Forward	22:30-00:30	Backward
July 28	09:45-11:45	Backward	15:45-17:45	Forward

*These dates correspond the annual Billy Barker Days festival, and sampling was reduced because traffic during this period was unusual (and so that the field technicians could enjoy the festivities!).

Figure 2. The mobile monitoring vehicle parked at the MOE air quality monitoring station at Quesnel Secondary School, where the fixed nephelometer was located.

Figure 3. The fixed nephelometer in its black case, on top of the air quality monitoring station at Quesnel Secondary School.

Smithers

Sampling route

Between 2007 and 2009 Gail Millar conducted thesis research that required mobile monitoring in five communities affected by residential woodsmoke, including both Smithers and the nearby community Telkwa. At the request of in-kind contributors Michael Brauer and the MOEe decided to include both communities in this study. Given that one objective of this study is to evaluate changes in particulate pollution in the Smithers/Telkwa region following a woodstove changeout program, we used the same sampling route that Gail used in her study. This route took considerably longer to drive than the route in Quesnel, and it was broken into two sections to reduce work load for the field technicians. On most days the complete route was driven once, and the Smithers section or the Telkwa section was driven once. Some minor changes to the turn-by-turn route recorded by Gail to improve efficiency.

Sampling period, schedule, and protocol

Sampling in Smithers/Telkwa was conducted between July 30th and August 12th, 2013. According to records from the Wildfire Management Branch there were 20 fires greater than 10 hectares in the province during this period, two of which were in the Northwest Fire Centre (bile measurements.). These fires were generally larger than those that burned in the previous two weeks. Temperatures in Smithers were similar to those in Quesnel, with means ranging from 16.8 – 22.0 °C and highs ranging from 22.7 – 31.8 °C. Conditions were dry throughout. Again, the sampling schedule was designed to capture patterns in particulate matter over a wide range of times-of-day and day-of-week scenarios (Table 4). At the beginning of each drive a coin was tossed to determine the direction in which the route would be driven (heads = forwards; tails = backwards). All drives were conducted according to the study protocol.

Table 3. Provincial fires greater than 10 hectares that burned during the July 30st through August 12th sampling campaign in Smithers/Telkwa.

Fire Centre	Fire Name	Discovery Date	Area Burned (hectares)
Coastal	South Bentick Arm	August 1	178
Coastal	Lemolo Creek	August 1	89
Kamloops	Pyramid Falls	August 2	13
Prince George	Stony Lake	August 3	410
Northwest	Kitlope Heritage	August 4	170
Prince George	Peta Mountain	August 5	260
Northwest	Skeena River	August 6	103
Prince George	Walker Creek	August 7	100
Cariboo	Saddle Itcha	August 7	1200
Southeast	Jumping Creek	August 10	3
Kamloops	Lyons Lake	August 10	69
Kamloops	Joss Mountain	August 10	18
Cariboo	Isaac Lake	August 10	50
Cariboo	Till Lake	August 10	11
Cariboo	Niagra River	August 10	43
Cariboo	70 Mile House	August 10	12
Prince George	Morkill River	August 11	17
Prince George	Quanstrom Creek	August 11	405
Southeast	Woodarm River	August 11	13
Southeast	Dunn Creek Train	August 11	204

Table 4. Sampling schedule for mobile monitoring in Smithers/Telkwa

Date	Drive 1 Time	Drive 1 Area/Direction	Drive 2 Time	Drive 2 Direction
July 30	17:00-21:00	Total/Forward		
July 31	13:00-16:00	Smithers/Backward	22:30-01:30	Telkwa/Forward
August 1	11:00-13:00	Telkwa/Forward	16:45-17:45*	Smithers/Forward
August 2	10:15-13:45	Smithers/Backward	14:30-16:30	Telkwa/Backward
August 3	18:00-21:30	Telkwa/Backward	23:45-02:30	Smithers/Backward
August 4	10:00-13:15	Smithers/Forward	16:00-18:30	Telkwa/Forward
August 6	12:45-15:45	Telkwa/Forward	22:45-01:30	Smithers/Backward
August 7	11:45-14:00	Smithers/Forward	18:45-22:30	Total/Backward
August 8	08:30-11:30	Total/Backward	16:00-17:00*	Telkwa/Forward
August 9	08:00-11:00	Total/Forward	22:45-01:00	Smithers/Forward
August 10	17:00-23:00	Total/Forward	23:30-01:45	Telkwa/Backward
August 11	09:40-12:40	Total/Backward	14:30-16:30*	Smithers/Backward
August 12	10:45-14:00	Total/Backward	16:45-19:45	Telkwa/Forward

*The GPS unit failed on these trip, so data were either not available or partially available. Reason for failure was unclear in all cases, but given the similar time of day it may have been related to reception through the surrounding mountains.

Fixed monitor

The fixed nephelometer was co-located with the $PM_{2.5}$ TEOM at the air quality monitoring station in central Smithers. Once again, it was located on the roof of the trailer that houses the MOE equipment, but that the area was more protected than that in Quesnel. There were no problems with the instrument overheating in this location. Note that the Smithers TEOM is scheduled to be decommissioned, but that the MOE will leave it running through spring 2014 to ensure that we have adequate data for this study. However, the TEOM will not be fixed or replaced if it fails over the coming months.

Data Analysis

Data combination

Data from three devices are required to adjust and map measurements from the mobile nephelometer. These are: (1) latitude and longitude from the GPS unit, logging at 1-second intervals; (2) scatter coefficients from the mobile nephelometer, logging at 10-second intervals; and (3) scatter coefficients from the fixed nephelometer, logging at 1-minute intervals. To combine these three streams of data we made a few important assumptions. First, that air sampled by the mobile nehpelometer took 1.0 seconds to read the instrument, such that the scatter coefficient recorded at 10:10:10 reflected aerosol from the 10:10:09 location. Second, that mobile scatter coefficient between 10-second recordings was constant, and third that the fixed scatter coefficient between 1-minute recordings was constant. Raw data from all instruments were cleaned and combined in this way using the R statistical computing environment (Figure 4).

Date.time	Latitude	Longitude	Mobile	Fixed
2013-07-28 15:49:40	52.98234	-122.4958	53.642	50.3
2013-07-28 15:49:41	52.98233	-122.4959	53.642	50.3
2013-07-28 15:49:42	52.98233	-122.4960	53.642	50.3
2013-07-28 15:49:43	52.98232	-122.4961	53.642	50.3
2013-07-28 15:49:44	52.98231	-122.4962	53.642	50.3
2013-07-28 15:49:45	52.98231	-122.4964	53.642	50.3
2013-07-28 15:49:46	52.98230	-122.4966	51.763	50.3
2013-07-28 15:49:47	52.98229	-122.4967	51.763	50.3
2013-07-28 15:49:48	52.98228	-122.4969	51.763	50.3
2013-07-28 15:49:49	52.98227	-122.4970	51.763	50.3
2013-07-28 15:49:50	52.98227	-122.4971	51.763	50.3
2013-07-28 15:49:51	52.98226	-122.4972	51.763	50.3
2013-07-28 15:49:52	52.98226	-122.4972	51.763	50.3
2013-07-28 15:49:53	52.98226	-122.4973	51.763	50.3
2013-07-28 15:49:54	52.98226	-122.4973	51.763	50.3
2013-07-28 15:49:55	52.98225	-122.4974	51.763	50.3
2013-07-28 15:49:56	52.98225	-122.4975	47.741	50.3
2013-07-28 15:49:57	52.98224	-122.4976	47.741	50.3
2013-07-28 15:49:58	52.98223	-122.4977	47.741	50.3
2013-07-28 15:49:59	52.98222	-122.4979	47.741	50.3
2013-07-28 15:50:00	52.98222	-122.4980	47.741	50.3

Figure 4. Screenshot of cleaned and combined data from the first mobile sampling run in Quesnel on July 28th, 2013.

Adjustment for within-drive temporal trend

Background aerosol concentrations are variable in the short-term and long-term. In some cases we observed steady increases or decreases the in the fixed site scattering coefficient over the period of a single sampling drive (Figure 5). To adjust the mobile measurements for these short-term changes we first calculated the 30-minute running average of the fixed measurements to smooth the data. Next, we calculated the drive-specific mean of the fixed measurements, and divided all of the mobile measures from the drive by the ratio of the time-specific running average to the fixed mean value (Equation 1). This is different from the approach used by Gail Millar, who adjusted mobile nephelometer measurements with the 24-hour running average of fixed-site $PM_{2.5}$ TEOM measurements. This modified approach was designed in consultation with Michael Brauer after initial data cleaning and analysis.

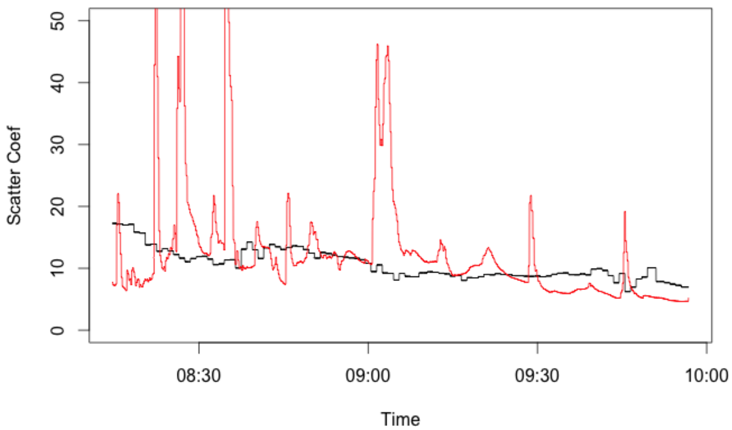

Figure 5. Fixed (black line) and mobile (red line) nephelometric scattering coefficients from the 08:00-10:00 drive in Quesnel on July 26th, 2013. Image clearly shows a drive-specific downward trend in fixed measurements that is also reflected in the mobile measurements.

$$MobileShortAdjusted_t = \frac{MobileRaw_t}{FixedRunning_t / FixedRaw_{drive}}$$

Equation 1. Equation for calculating mobile measurements adjusted for short-term trends, where *t* is the second-specific value of the measured mobile (MobileRaw) or smoothed fixed (FixedRunning) data, and *drive* is the mean of the measured fixed (FixedRaw) data for that particular sampling run.

Adjustment for between-drive temporal trend

Long-term trends in background aerosols can affect our ability to compare the mobile monitoring results from different drives on different days. To adjust the data for these trends we divided the drive-adjusted mobile values by the ratio of the drive-specific mean of the fixed values to the campaign-specific mean of the fixed values (Equation 2, Figure 6).

$$MobileLongAdjusted_t = \frac{MobileShortAdjusted_t}{FixedRaw_{drive} / FixedRaw_{campaign}}$$

Equation 2. Equation for calculating mobile measurements adjusted for long-term trends, where *t* is the second-specific value of the short-term adjusted mobile measurements (MobileShortAdjusted), *drive* is the mean of the measured fixed (FixedRaw) data for that particular sampling run, and *campaign* is the mean of the measured fixed (FixedRaw) data for the entire field campaign.

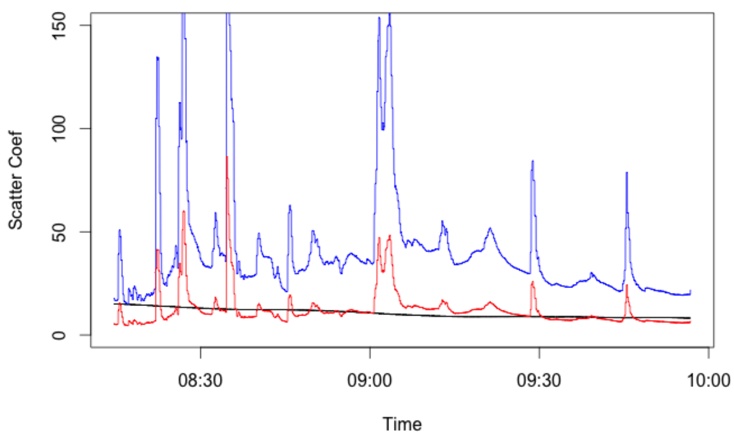

Figure 6. The fully adjusted data from Figure 5, showing the 30-minute running averaged of raw fixed measurements (black line), the short-term adjusted mobile measurements (red line), and the long-term adjusted mobile measurements (blue line).

Mapping

All analysis and mapping was conducted using R 3.0.1. For each trip, the Global Positioning System latitude and longitude readings for the nephelometer measurements were represented as a spatial points layer. The spatial points layers were then converted raster layers. The spatial extent of the raster layers was set to the spatial extent of points layers for all trips combined for each community. Raster layers for Quesnel had 51376 cells 71.58m by 50.70m in size, and raster layers for Smithers had 53650 cells 38.56m by 94.41m in size. When assigning values to the raster cells, if more than one point fell into a raster cell, the nephelometer measurements for those points were averaged. Next, the raster data were smoothed over a 200m moving radius filter using the focal function in the R raster package. Nephelometer measurements within each radius were averaged. Individual trip raster layers were merged to yield raster layers for all trips combined, weekday trips, weekend trips, morning rush hour trips, evening rush hour trips, and night-time trips, respectively. The values in overlapping cells were averaged during this merging process. Raster layers were mapped on top of Open Street Map tiles, imported into R using the OpenStreetMap package.

Results and Discussion

Quesnel

Background measurements

There was considerable variation in the fixed site scatter coefficients in Quesnel, both within-drive and between-drive. The mean scatter coefficient was 35, with a median of 24 and an interquartile range of 14 to 46. The maximum recorded value was 595. Daily increases from baseline to a maximum of 150 were repeatedly observed repeatedly over the 14-day sampling campaign. Aerosol would increase in the early hours of the morning, then decline rapidly starting between 09:00 and 11:00 (Figure 7). The most sustained increase occurred on July 25th (Figure 8). There were two small fires in the region discovered on July 24th that may have contributed to pattern (Table 1), but fires cannot explain all occurrences. Overall it appears to be related to time-of-day, and may be driven by both traffic and meteorology. We will consult with the MOE on this.

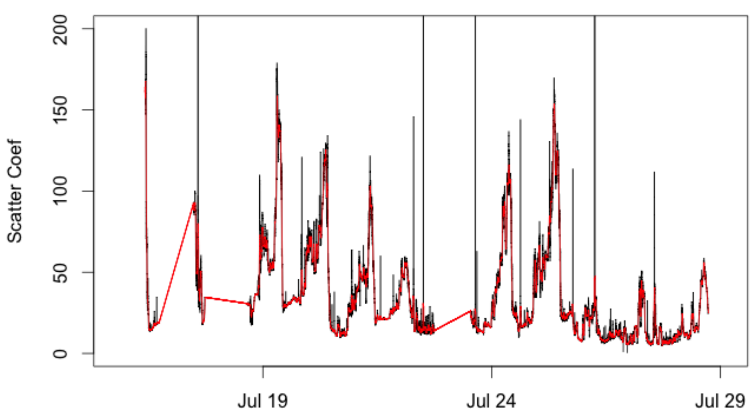

Figure 7. Raw (black line) and smoothed (red line) fixed nephelometer measurements at Quesnel Secondary School from July 15th through July 28th, 2013. Disconnections in the black line indicate periods when the instrument was shut down for cooling.

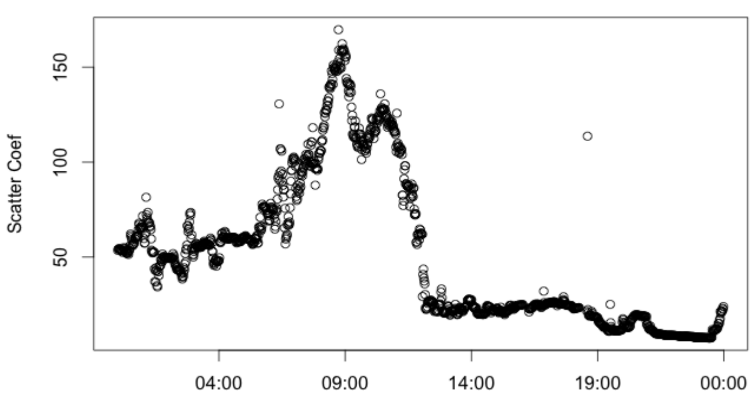

Figure 8. Scatter coefficient measured at Quesnel Secondary School on July 25th, 2013 in 1-minute averages.

Spatial hotspots

With data displayed on a linear scale there was only one clear aerosol hotspot during the summer campaign in Quesnel, to the south of the city on the east side of the river (Figure 11). This hotspot is attributable to our own vehicle stirring up dust on the gravel road that leads down to/up from (depending on the sampling direction) the plywood substation. There is little traffic along this street and no residential area around the hotspot, so the impacts on human exposure are low. However, samples taken during morning rush hour show clear evidence of aerosol impacts in the downtown core of the city, especially around the bridges, and on the major routes to the north. Given that these estimates have been adjusted for the short- and long-term temporal trends described for the fixed site data, this reflects the impacts of traffic moving through the region at this busy time of day. The interaction between morning traffic pollution and strong diurnal patterns with morning highs (Figure 7) will be further examined over the coming months. Data displayed on a log scale show more nuances (Figure 12).

Smithers

Background measurements

There was much less variation in the fixed site scatter coefficients in Smithers than in Quesnel, and the background aerosols were lower (Figure 9). The mean scatter coefficient was 22, with a median of 18 and an interquartile range of 12 to 26. The maximum recorded value was 1142. A similar diurnal trend was observed, but the increases above baseline were less extreme, reaching an average scatter coefficient of 50. The greatest increase occurred on August 7th, where the influence of morning rush hour is clearer than that observed in Quesnel (Figure 10). There was a small fire in the Prince George fire centre and a large fire in the Cariboo fire centre on August 7th, which may have contributed to the peak scatter coefficients observed on that date (Table 3).

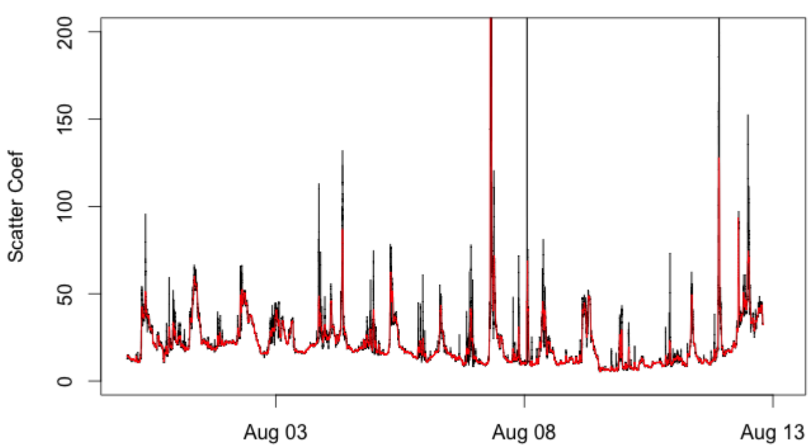

Figure 9. Raw (black line) and smoothed (red line) fixed nephelometer measurements in Smithers from July 28th through August 12th, 2013.

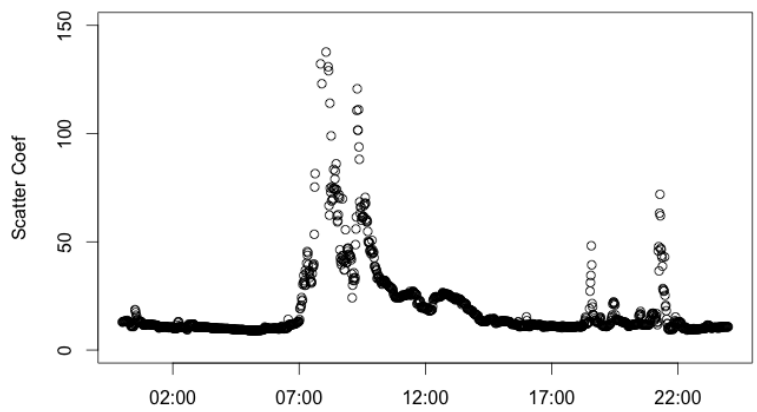

Figure 10. Scatter coefficient measured Smithers on August 7th, 2013 in 1-minute averages.

Spatial hotspots

For data displayed on linear and log scales there were two persistent aerosol hotspots during the summer campaign in Smithers/Telkwa, one just to the north of Smithers, and one just to the south (Figure 13, Figure 14). Both of these hotspots are attributable to road dust but, unlike the dust hotspot in Quesnel, they are on moderately trafficked roads surrounded by residential areas. Samples taken during morning rush show that the hotspots are more diffuse at this time, when more vehicles are disturbing the dust.

Next Steps

The summer campaign for this project went very smoothly. We did not have any of the instrumental frustrations experienced by other mobile monitoring projects in the province, with the exception of some overheating of the fixed nephelometer in Quesnel and some trouble with the logging GPS on a few days in Smithers. Such problems are only to be expected in the field. The data collected have provided a nice baseline for understanding the additional impacts of woodsmoke in both communities, and have demonstrated that road dust is an important source of summertime aerosol, especially in Smithers where it affects populated areas. The fixed data clearly show strong diurnal effects on aerosol in summer, likely driven by a combination of morning traffic pollution and meteorology. The impacts were much larger in Quesnel than in Smithers.

This report will be distributed to the QAQR and the MOE for comment, and to help plan for the winter sampling campaign. The BCCDC is in the process of developing a contract for the winter work with a field technician who has worked on Ryan Allen's woodsmoke study in the region. The technician is a local who is familiar with both communities, and she will conduct all of the sampling herself using her own vehicle, which is 4-wheel-drive. Much of the funds remaining in the budget will be used to cover this contract and another contract for more in-depth analyses of the entire dataset. Winter sampling is scheduled to begin in early January and to run through the first week of February, allowing five weeks to prepare our final reports for the project.

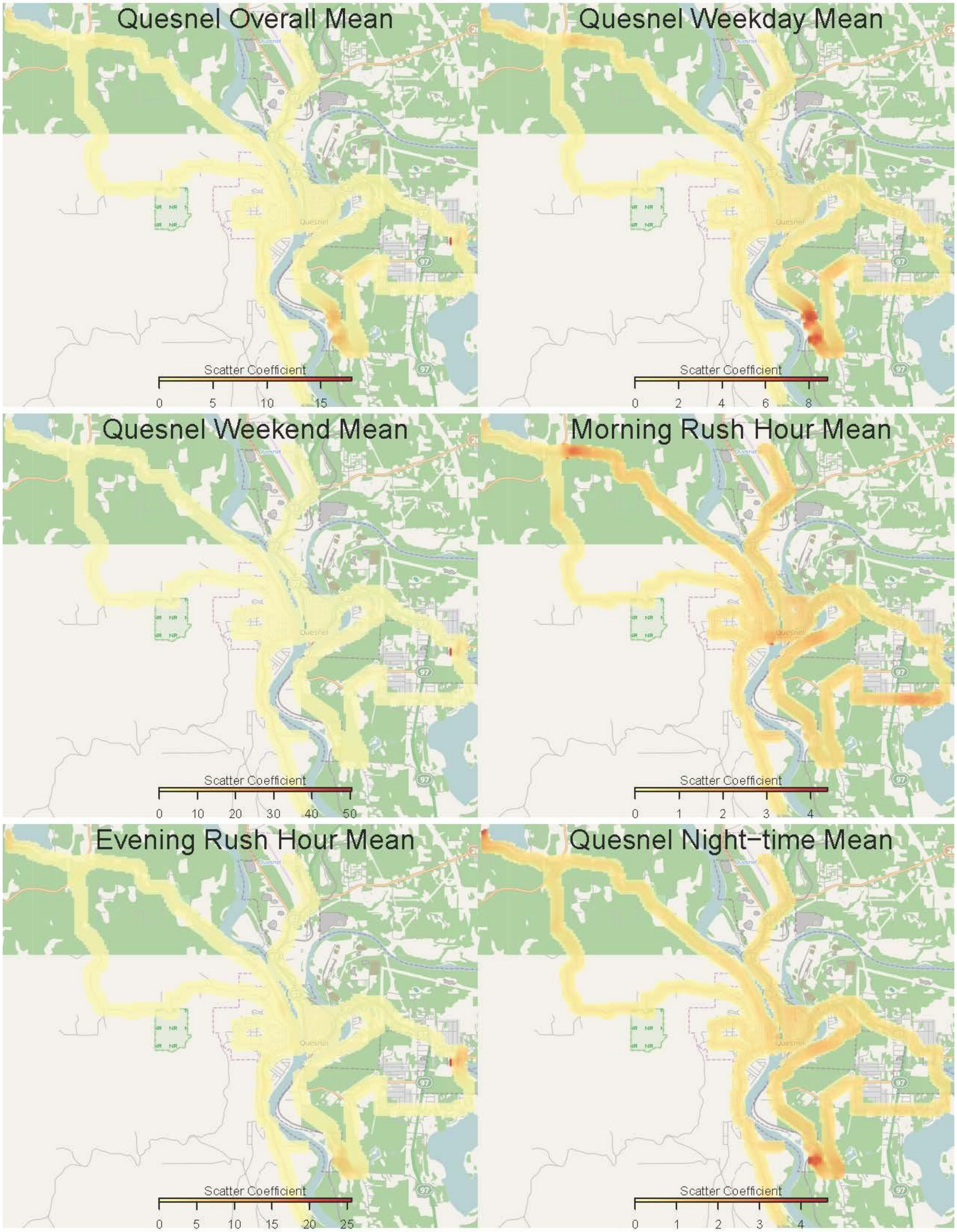

Figure 11. Spatial averages of the adjusted mobile monitoring measurements for Quesnel overall, and during specific periods, displayed on a linear scale.

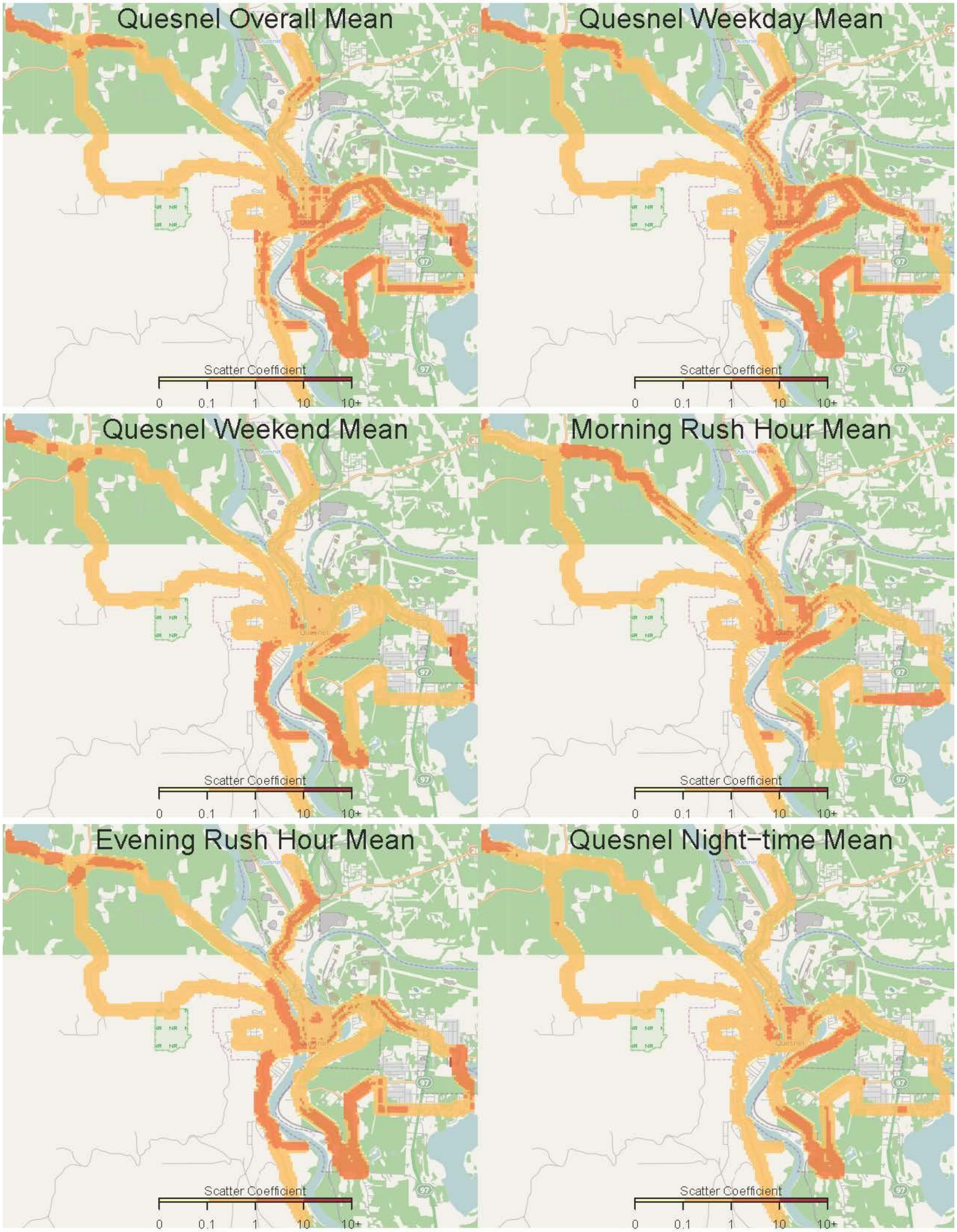

Figure 12. Spatial averages of the adjusted mobile monitoring measurements for Quesnel overall, and during specific periods, displayed on a log scale.

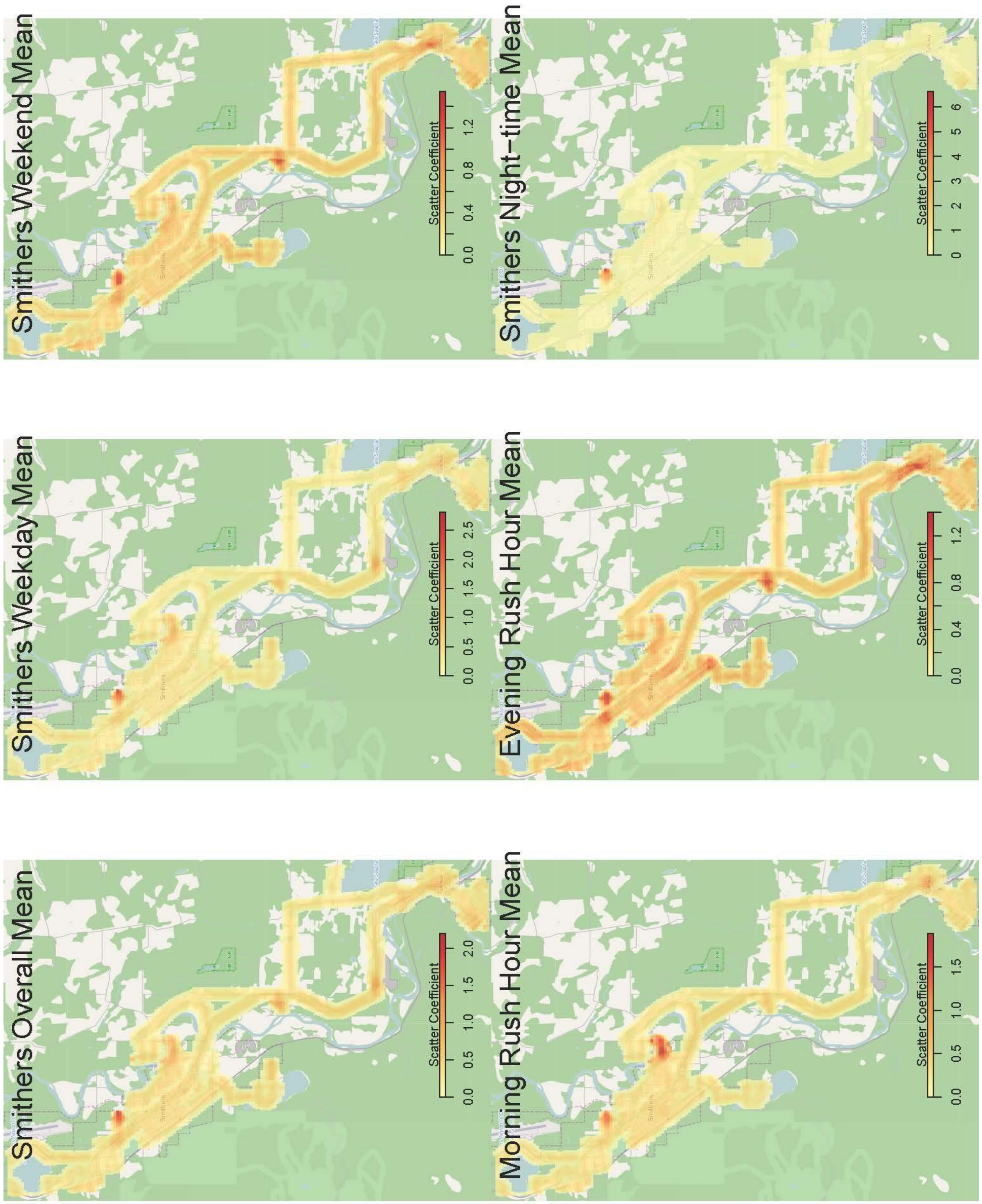

Figure 13. Spatial averages of the adjusted mobile monitoring measurements for Smithers overall, and during specific periods, displayed on a linear scale.

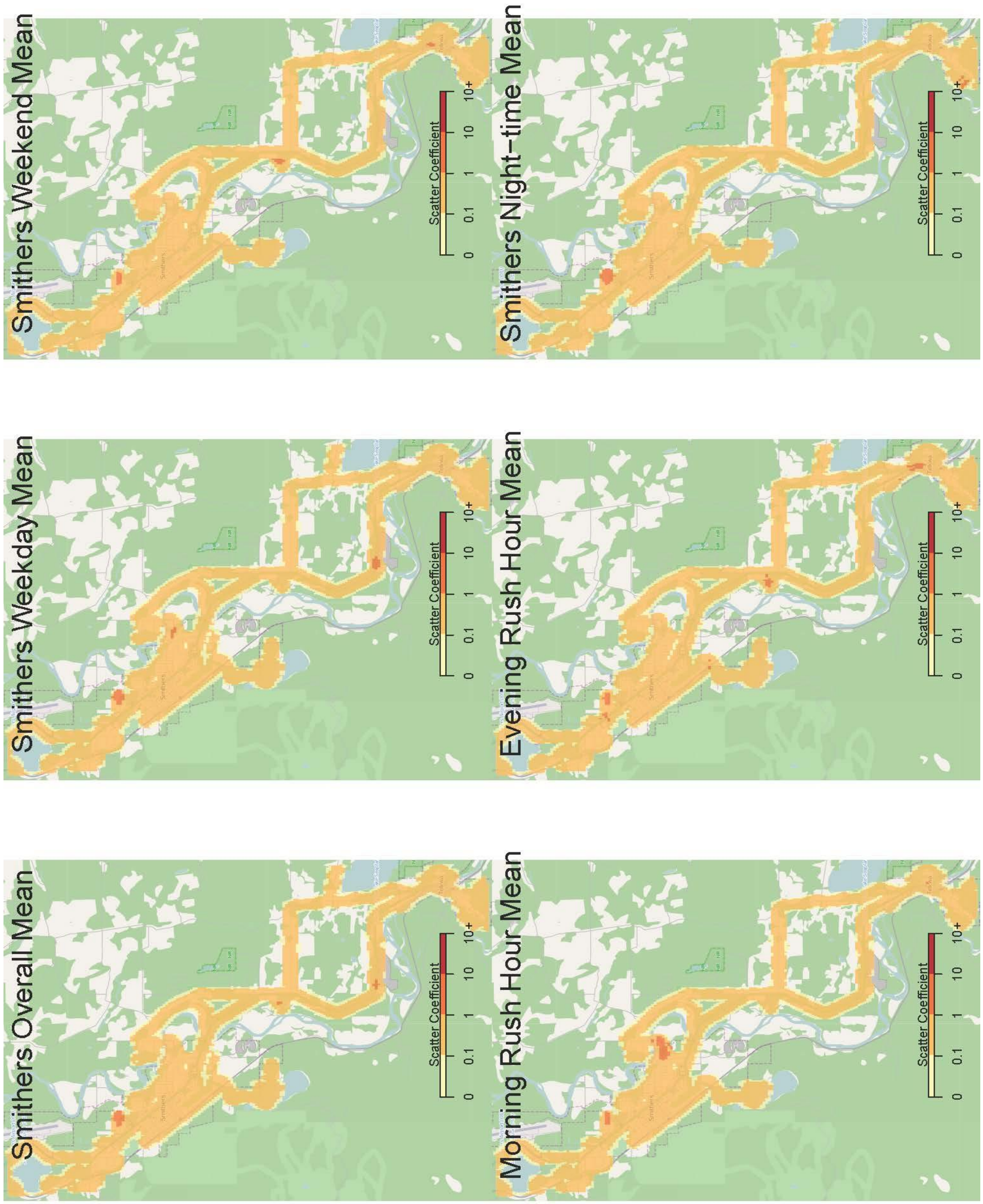

Figure 14. Spatial averages of the adjusted mobile monitoring measurements for Smithers overall, and during specific periods, displayed on a log scale.

Report on winter sampling for the study on mobile monitoring to characterize the spatial variability of winter and summer particulate matter concentrations in Quesnel and Smithers

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14 October 2014

Table of Contents

Abstract

Background: The town of Quesnel (population 10,000) has high annual average fine particulate matter ($PM_{2.5}$) concentrations compared with most other communities in BC. We believe that these concentrations are driven by a mix of industry, commercial transportation, and residential woodsmoke. The town of Smithers (population 5,400) has high wintertime $PM_{2.5}$ concentrations driven primarily by residential woodsmoke. We previously conducted two weeks of summertime mobile monitoring of aerosols in both towns to identify air pollution hotspots and to provide a baseline for comparisons with wintertime air quality, which is more affected by residential woodsmoke. Now we have also conducted two weeks of wintertime mobile monitoring of aerosols in both towns to allow for this comparison to be effectively made.

Methods: A driving route for Quesnel was identified via partnership between the Quesnel Air Quality Roundtable and the BC Ministry of Environment. The driving route for Smithers was a modified version of that used for previous mobile monitoring in the community. We conducted one approximately 14-day field campaign in both towns, driving the route at least one time per day, on average. Routes were not driven as frequently in winter as in summer due to much slower driving conditions on icy roads and in heavy snow. The driving schedule was designed to capture differences between peak driving hours and quieter times of the day, as well as differences between weekdays and weekends. Ambient aerosol was measured using a mobile nephelometer sampling every 10 seconds, and concentrations were compared with those from a fixed site nephelometer in both locations.

Results: The within-drive and between-drive variability in fixed-site aerosols was again higher for Quesnel than for Smithers. This continues to speak to the sensitivity of Quesnel to conditions across the airshed. Once the influence of this regional variability had been removed, there was minimal evidence of specific pollution hot spots attributable to industry, but clear evidence that both traffic and woodsmoke are important sources of aerosol in winter. Morning rush hour continued to be a period of interest in Quesnel, though diurnal influences were less clear than in summer. In Smithers there was less within-drive and between-drive variability in fixed-site aerosols, but strong evidence of woodsmoke aerosol on the night time runs. Qualitative evaluation indicated that woodsmoke hotspots spatially matched with those identified in previous studies, but further quantitative evaluation is pending.

Conclusions: We have not had adequate time to thoroughly analyze data from the winter campaign, to thoughtfully combine data from the summer and winter campaigns, and to compare the winter of 2014 with previous winters in Smithers. All of these activities are planned for September-October 2014, when we will prepare a manuscript for peer review. At this time we can say that (1) diurnal variability was much stronger in summer than in winter for both locations, (2) overall aerosols were higher in winter than in summer for both locations, (3) there was clear evidence of road dust hotspots in summer and woodsmoke hotspots in winter in both locations, and (4) morning rush hour is a period of particular concern in Quesnel but not Smithers during both summer and winter months.

Acknowledgements

This research was supported by a financial contribution from the BC Clean Air Research (BC CLEAR) Fund and the Quesnel Air Quality Roundtable. BC CLEAR is sponsored by the BC Ministry of Environment, jointly managed with Metro Vancouver and Environment Canada. The Fraser Basin Council administers the program in partnership with the BC Lung Association.

Background

The town of Quesnel (population 10,000) has high annual average fine particulate matter ($PM_{2.5}$) concentrations compared with most other communities in BC. Furthermore, a recent report showed that the local planning target of 18 $\mu g/m^3$ (based on the annual 98th percentile) is persistently not achieved at some monitoring stations. The dominant sources of $PM_{2.5}$ in Quesnel include local industry, commercial transportation, and residential woodsmoke. However, the relative contributions from each source remain unclear and are challenging to evaluate with limited data from three stationary monitors. Mobile monitoring is an inexpensive and flexible method that has been used to supplement information from the fixed air quality monitoring network in many parts of BC. One example is the town of Smithers (population 5,400), which was previously identified as having high $PM_{2.5}$ concentrations attributable to residential woodsmoke, and which has been the focus of an aggressive woodstove exchange program over the past five years. Mobile monitoring was used to characterize spatial variation in $PM_{2.5}$ from residential woodsmoke in Smithers during the winter of 2007-2008, early in the implementation of the exchange program. Smithers and Quesnel are comparable with respect to population, climate, and geographic situation, but industry and commercial transportation are not such dominant sources in Smithers. We proposed to map spatial variability of summer and winter $PM_{2.5}$ concentrations in Smithers and Quesnel using mobile monitoring methods previous developed and applied in BC. By comparing summer and winter results for both towns we expect to clarify the contribution of residential woodsmoke to the $PM_{2.5}$ mixture in Quesnel. By comparing 2007-2008 results with 2013-2014 results for Smithers we expect to clarify how changes to residential wood burning can affect short- and long-term $PM_{2.5}$ concentrations within a small community. The following is the subsequent short report on the results of the winter 2014 sampling campaigns in both communities.

Methods

Protocol

The attached sampling protocol provides information on all instrumentation and methods used during the field campaigns. Note that the summer campaign was conducted with a Ford Focus station wagon, while the winter campaign was conducted with the Jeep Cherokee sport utility vehicle due its four wheel drive capabilities. The small roads in Quesnel and Smithers were very icy during the January/February campaign, and we did not feel safe having our field staff in a the smaller vehicle.

In both cases the intake for the mobile nephelometer was attached to the roof rack of the vehicle on the side opposed to the exhaust. This is the same setup first used by Tim Larson in his ground-breaking study on application of mobile monitoring for mapping of woodsmoke hotspots in urban Vancouver (http://tinyurl.com/kv8ddwl), and that was used for Gail Millar's previous mobile woodsmoke monitoring in Northern BC (http://tinyurl.com/n5xdbmx). Here we have applied the same sampling and data cleaning methods used in those previous studies. This method does not account for particulate matter generated by the vehicle and then trapped by the vehicular envelope. Accounting for the vehicular envelope would require raising the intake approximately two metres above the top of the vehicle, which would remove it from the typical exposure zone and would introduce route limitations to avoid damage to the intake.

Quesnel

Sampling route

The winter sampling route was the same route used during the summer sampling campaign with some modifications to better characterize areas with potentially high woodsmoke. The summertime route was produced by the collaboration of Quesnel Air Quality Roundtable (QAQR) with Arvind Saraswat, the regional Air Quality Meteorologist from the Ministry of Environment at the time. The wintertime route was expanded in consultation with QAQR to include residential areas around Maple Drive (where annual $PM_{2.5}$ objectives are consistently exceeded), Johnston Avenue, and the downtown core. Route information was input turn-by-turn into the global positioning system (GPS). Expansions to the winter route added considerable driving time, especially in winter conditions, so only half of the route was driven at a time (Area 1 or Area 2), but the entire route was covered each day.

Sampling period and schedule

Winter sampling in Quesnel occurred between January 19th and February 2nd, and was conducted according to the attached protocol. Because this sampling transpired during the winter, impacts from wildfires were of no significant concern for this session. Temperatures in Quesnel were cold, with means ranging from (-19.0ºC) – (-1.7ºC) while the lows ranging from (-23.9ºC) – (-3.1ºC) (Figure 1). There was some mild precipitation (< 4mm) on a few of the sampling days, which were January 21st, 28th and 29th. A sampling schedule was devised in order to be able to capture patterns in particulate matter with respect to a variety of times-of-day and day-of-week scenarios (Table 1). A coin toss was used in order to determine which direction the given route would be driven, with a result of heads indicating forwards while tails indicated backwards.

Figure 1. Sample conditions during the winter sampling period in Quesnel.

Table 1. Sampling schedule for mobile monitoring in Quesnel

DATE	DRIVE 1 Time	DRIVE 1 Area, Direction	DRIVE 2 Time	DRIVE 2 Area, Direction
Jan. 19	13:15 - 16:45	Total Forward	-	-
Jan. 20	11:00 - 15:53*	Total Forward	22:15 - 00:15	Area 2, Forward
Jan. 21	12:00 - 16:30*	Total Backward	-	-
Jan. 22	10:50 - 13:10	Area 1, Forward	20:40 - 22:10	Area 2, Forward
Jan. 23	08:30 - 10:45	Area 2, Backward	13:15 - 15:30	Area 1, Backward
Jan. 23	17:15 - 21:20	Area 1, Forward	-	-
Jan. 24	09:30 - 11:30	Area 1, Backward	12:50 - 15:05	Area 2, Backward
Jan. 25	10:00 - 12:10	Area 2, Forward	17:00 - 19:15	Area 2, Forward
Jan. 25	22:30 - 00:30	Area 2, Forward	-	-
Jan. 26	10:00 - 12:00	Area 1, Forward	19:00 - 21:15	Area 2, Backward
Jan. 27	06:30 - 09:00	Area 2, Forward	15:00 - 17:00	Area 1, Backward
Jan. 28	07:00 - 09:00	Area 1, Backward	15:00 - 17:00	Area 2, Forward
Jan. 28	19:00 - 21:00	Area 1, Backward	-	-
Jan.29	07:00 - 09:00	Area 2, Backward	15:05 - 17:10	Area 1, Forward
Jan.29	19:30 – 21:30	Area 1, Backward	-	-
Jan.30	07:00 - 09:10	Area 2, Forward	15:30 – 18:20	Area 2, Backward
Jan.31	07:05 – 09:00	Area 1, Forward	14:50 – 16:40	Area 1, Forward
Jan.31	17:10 - 19:30	Area 2, Forward	21:20 – 23:50	Area 2, Backward
Feb.01	10:15 - 12:30	Area 1, Backward	15:20 – 17:30	Area 2, Backward
Feb.02	11:00 – 13:15	Area 2, Backward	-	-

*These trips were identified to be missing data. For trip 2, the GPS data were completely unreadable while trip 4 was missing data for the first 3 hours of the trip.

Fixed monitor:

The fixed nephelometer was co-located with the BC Ministry of Environment fine particulate matter ($PM_{2.5}$) tapered element oscillating microbalance (TEOM) at Quesnel Senior Secondary school within the central business district. This location is representative of air quality in the relatively flat area of downtown Quesnel, but might not be representative of the conditions experienced in the outlying and more topographically complex areas (Figure 2). The nephelometer itself was positioned on top of the roof of a utility trailer which contains the MOE instruments. To protect it from precipitation, the nephelometer is encased by a black waterproof casing. For this sampling campaign, there was no threat of over-heating. The fixed nephelomter was set to record a reading every minute.

Smithers

Sampling route

In Smithers we followed the same sampling route used for the summer campaign. This route was first defined by Gail Miller for her thesis research pertaining to mobile monitoring in five communities affected by residential woodsmoke (http://tinyurl.com/n5xdbmx). Both Smithers and Telkwa were a part of those original five, and at the request of in-kind contributors Michael Brauer and the MOE, both were incorporated within this study early on. Due to earlier fragmentation of the originally long route into two separate sections, work load was once again minimized for the field technicians. Minor alterations to the original route were also made in order to improve efficiency during the winter conditions, as was done in the earlier summer sampling campaign.

Figure 2. Red dot indicates the location of the fixed monitoring site in context of the greater area sampled.

Sampling period, schedule, and protocol

Winter sampling in Smithers/Telkwa occurred between February 5th and February 18th according to the attached protocol. To reiterate, since this sampling transpired during the winter, impacts from wildfires were of no significant concern for this session. Temperatures in Smithers this time around were notably colder as well, with means ranging from (-21.3ºC) – (-1.3ºC) while the lows ranging from (-27.6ºC) – (-4.1ºC) (Figure 3). Unlike during the summer sampling, there was some mild to moderate precipitation (~ 1-9mm) on a few of the sampling days, which were February 14th, 15th, 16th, and 18th. Once again, a sampling schedule was devised in order to be able to capture patterns in particulate matter with respect to a variety of times-of-day and day-of-week scenarios (Table 2). A coin toss was used in order to determine which direction the given route would be driven, with a result of heads indicating forwards while tails indicated backwards.

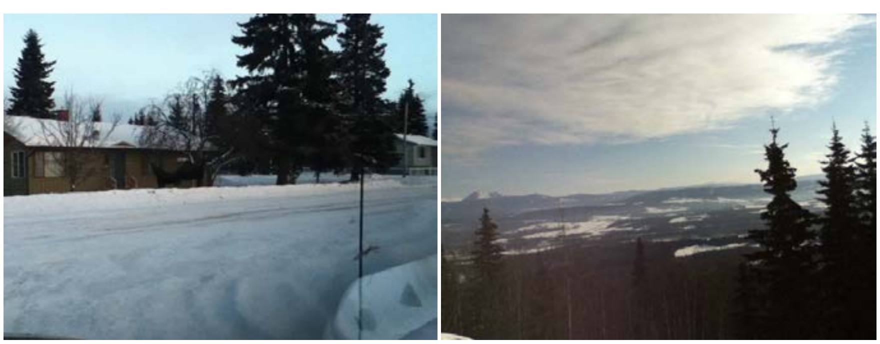

Figure 3. Sample conditions during the winter sampling period in Smithers.

Table 2. Sampling schedule for mobile monitoring in Smithers/Telkwa

DATE	DRIVE 1 Time	DRIVE 1 Area, Direction	DRIVE 2 Time	DRIVE 2 Area, Direction
Feb. 5	10:23 – 14:12	Total Forward	18:10 – 21:53	Total Backward
Feb. 6	09:47 – 12:01	Smithers, Backward	15:40 – 18:17	Telkwa, Backward
Feb. 7	08:15 – 10:50	Telkwa, Forward	19:30 – 22:00	Smithers, Forward
Feb. 8	11:40 – 14:09	Smithers, Forward	16:30 – 18:55	Telkwa, Forward
Feb. 9	09:07 – 11:28	Telkwa, Forward	14:00 – 16:55	Smithers, Forward
Feb. 10	07:35 – 11:19	Total Backward	16:20 – 18:41	Telkwa, Forward
Feb. 11	06:54 - 09:48	Smithers, Forward	17:21 – 20:36	Telkwa, Backward
Feb. 12	11:10 – 14:54	Total, Backwards	19:15 – 21:42	Telkwa, Forward
Feb. 13	10:20 – 12:32	Telkwa, Forward	19:44 – 23:22	Total Forward
Feb. 14	10:42 – 13:43	Smithers, Forward	18:48 – 22:42	Total Backward
Feb. 15	09:14 – 12:55	Total Backward	15:28 – 18:17	Telkwa, Backward
Feb. 16	08:48 – 12:37	Total Forward	19:14 – 21:56	Smithers,Backward
Feb. 17	08:37 – 12:18	Total, Forward	20:35 – 22:56	Telkwa, Forward
Feb. 18	07:40 – 11:30	Total Backward	20:00 – 23:04	Smithers, Forward

Fixed monitor

The fixed nephelometer was co-located with the BC Ministry of Environment $PM_{2.5}$ TEOM at the air quality monitoring station based in central Smithers. This station is located in the Bulkley River valley, which runs between Smithers and Telkwa (Figure 4). Again, the nephelometer itself was positioned on top of the roof of a utility trailer which holds the MOE instruments. Fortunately the TEOM did not fail prior to the winter sampling session, since plans for its eventual decommission in spring 2014 meant it would not have been repaired/replaced. This nephelometer is also even more protected than the one found in Quesnel (Figure 5).

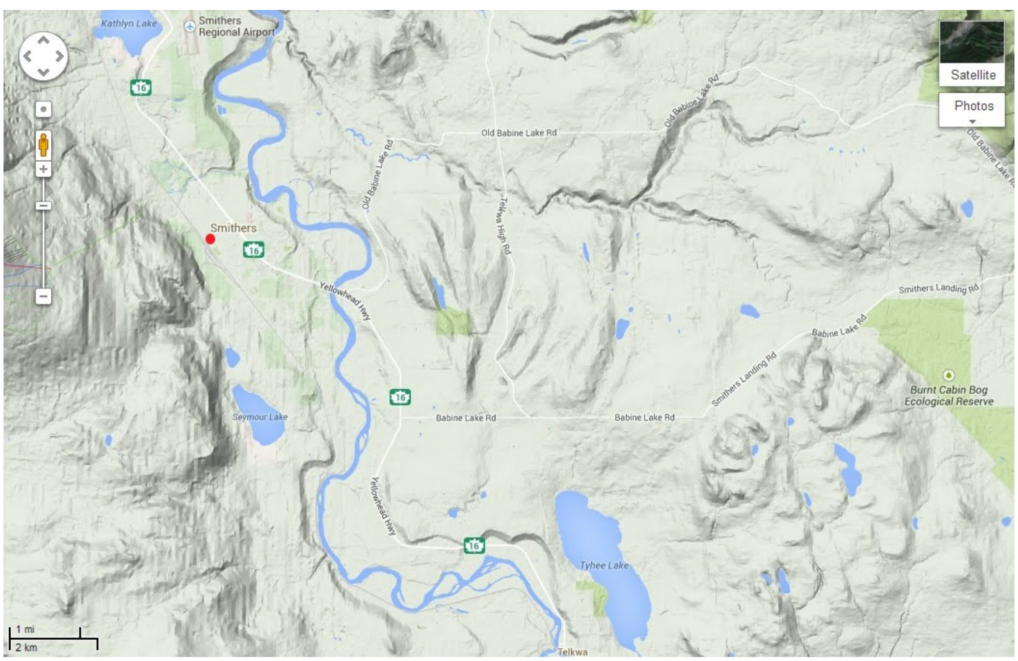

Figure 4. Red dot indicates the location of the fixed monitoring site in context of the greater area sampled.

Figure 5. The fixed nephelometer within its protective black case on top of the air quality monitoring station in Smithers.

Data Analysis

Data missing from fixed nephelometers

We lost data from the fixed nephelometers from January 19 – 23 in Quesnel and February 5 – 9 in Smithers due to an administrative error. These periods covered the first nine trips in both cases. Data from the device should have been downloaded halfway through the campaigns, but this information was missing from the study protocol, so the field technician was not aware of this requirement. As such, the instrument ran out of memory and earlier data was overwritten by later data.

To account for these missing records we requested 1-minute average concentrations from the $PM_{2.5}$ TEOM instruments collocated with the nephelometer at the Quesnel and Smithers MOE sites. The correlation between 1-minute $PM_{2.5}$ concentrations and 1-minute scatter coefficients for the coincident data was moderate in Smithers (r = 0.51) and stronger in Quesnel (r = 0.77). The correlations were weaker during peak periods ($PM_{2.5} > 10\ \mu g/m^3$), though scatter plots indicated that some data cleaning would improve the relationships under all conditions. As such, we took the 60-minute running averages of each to improve the correlations to 0.62 and 0.86, respectively. We then used the following linear regression equations to estimate the missing scatter coefficients from the available $PM_{2.5}$ concentrations:

$$\text{Quesnel:}\ \ 9.0 + 5.95*PM_{2.5}$$

$$\text{Smithers:}\ \ 5.2 + 0.56*PM_{2.5}$$

Note that scatter coefficients were considerably higher in Quesnel than in Smithers, with an interquartile range (IQR) of 20-60 compared with 4-12, respectively. This was not true for the $PM_{2.5}$ measurements, where the IQR values were 2.2-9.1 and 2.5-9.4 $\mu g/m^3$, respectively. These differences in scatter coefficient IQR are likely driven by larger particles not sampled by the $PM_{2.5}$ TEOM in Quesnel.

Regardless of this discrepancy between the two instruments, the correlations were higher in Quesnel because the TEOM and nehpelometer more consistently had coincident elevated readings.

Data combination

The procedure of data combination was similar to that done for the summer sampling campaign data. The data that were needed for adjustment and mapping of measurements from the mobile nephelometer originated from three different devices. These included geographic coordinates from the GPS (logging at 1-second intervals), scatter coefficients from the mobile nephelometer (logging at 10-second intervals), and scatter coefficients from the fixed nephelometer (logging at 1-minute intervals) or its estimated values. A few key assumptions were required to combine these three different streams of data. First, the mobile nephelometer takes approximately 1.0 seconds to read the instrument, and hence scatter coefficients reflected aerosol in the location passed a second earlier. The next assumption was that both mobile and fixed scatter coefficients were constant between recordings. All raw data were cleaned and combined via use of the R statistical computing environment.

Adjustment for within-drive temporal trend

The primary objective of this work is to examine spatial patterns to detect aerosol hotspots. We were not concerned with the absolute measurements, but rather spatial differences in the relative measurements compared across the drives. To do this, we must remove the short- and long-term temporal trends from the data such that each drive can be fairly compared with every other drive. This means that the baseline measurements for each drive must be standardized, so that the spatial elements of the relative changes from baseline can be clearly observed. To this end we use data from the fixed site to adjust the mobile data for the within- and between-drive variability observed at the fixed site.

The first step was to adjust for the within-drive temporal trend. If, for example, the aerosol in the entire region was increasing over the three-hour drive period, the trend must be removed from the mobile data (Figure 6). To do this, 30-minute running averages of the fixed measurements were computed so that the data could be smoothed. Following the smoothing, means of the fixed measurements for each drive were determined. By forming ratios of time-specific running average to drive-specific fixed mean value, the mobile measures were divided by their respective ratios, leading to mobile measurements that were adjusted for short-term temporal trends (Equation 1). This is a modified version of the approach used by Gail Millar (http://tinyurl.com/n5xdbmx) and was designed in consultation with Dr. Michael Brauer during the period of time between sampling campaigns. Changes were made to the Millar approach because Drs. Henderson and Brauer felt that the approach described here was more consistent and correct.

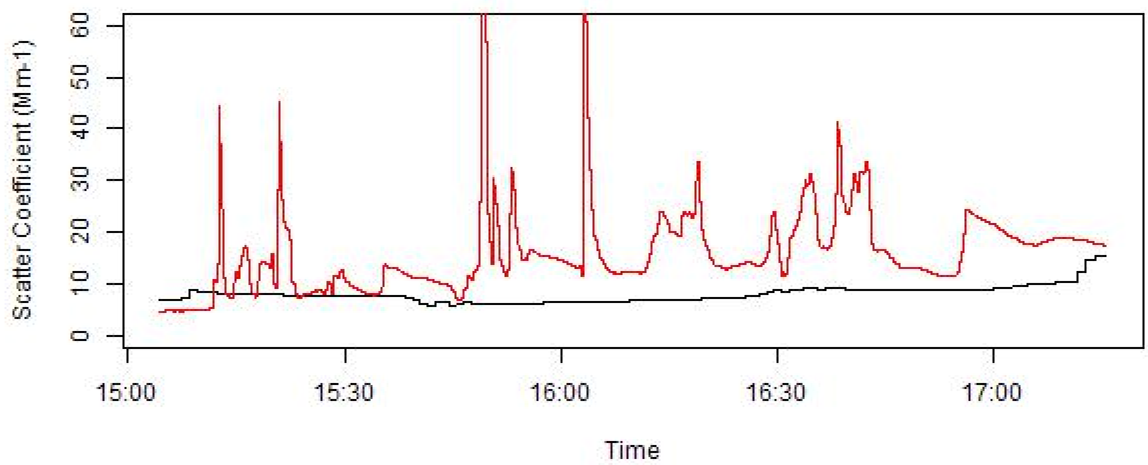

Figure 6. Fixed (black line) and mobile (red line) nephelometric scattering coefficients from the 15:00-17:00 drive in Quesnel on Jan 28th, 2014. The figure displays a general drive-specific upward trend in both the fixed measurements as well as in the mobile measurements. This trend must be removed to flatten the mobile measurements.

$$MobileShortAdjusted_t = \frac{MobileRaw_t}{FixedRunning_t / FixedRaw_{drive}}$$

Equation 1. This is the general equation applied to calculate short-term trend adjusted mobile measurements. "*t*" indicates a second-specific value while "*drive*" indicates a drive-specific value.

Adjustment for between-drive temporal trend

Having dealt with the short-term trend component, long-term trends were also of concern. These trends could affect comparisons between mobile measurements from different drives on different days. Therefore, the mobile measurements subsequently had to also be adjusted for the long-term changes. This was done by once again forming ratios, but this time they were ratios of drive-specific fixed mean value to campaign-specific fixed mean value. Hence, the short-term trend-adjusted mobile values were divided by their respective ratio, leading to mobile measurements which were adjusted for short-term as well as long-term temporal trends (Equation 2, Figure 7).

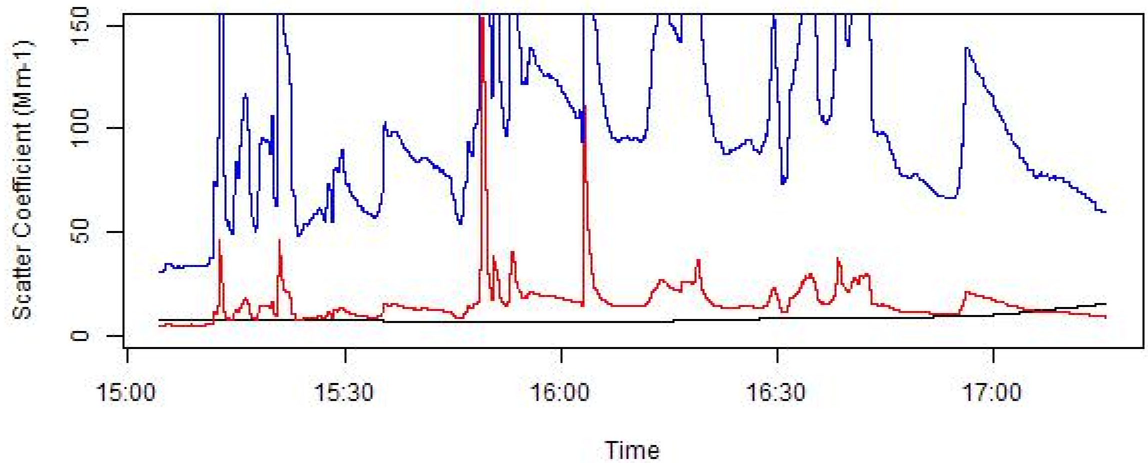

Figure 7. The fully adjusted data that was displayed in the previous figure, showing 30-minute running averages of raw fixed measurements (black line), the short-term adjusted mobile measurements (red line), and the both short-term and long-term adjusted mobile measurements (blue line).

$$MobileBothAdjusted_t = \frac{MobileShortAdjusted_t}{FixedRaw_{drive} / FixedRaw_{campaign}}$$

Equation 2. This is the general equation applied to calculate mobile measurements adjusted for both trend types, using measurements already adjusted for short-term. "*t*" indicates a second-specific value, "*drive*" indicates a drive-specific value, and "*campaign*" indicates a campaign-specific value.

Mapping

All maps were generated using R 3.0.1. In order to map these adjusted measurements mentioned earlier, the latitudes and longitudes readings from the GPS for each nephelometer measurement were used to form spatial points layer. These spatial points layers were then converted to raster layers with spatial extents set by the most extreme latitudes and longitudes of the collection of trips for each community. The difference between the maps for this winter campaign compared with the summer campaign is that the raster layers for both Quesnel and Smithers have 52900 cells, with cell sizes of 65.01m by 61.67m and 49.23m by 78.61m respectively. If more than one of the total collection of spatial points landed in the same raster cell, then the nephelometer measurements were ultimately averaged. Afterwards, smoothing of the raster data was executed by using a 200 m moving radius filter via the focal function found in the R raster package. Measurements that fell within each of the radii were thus averaged. Eventually, the trip raster layers were merged based on trip characteristics to form raster layers for "all trips combined", "weekday trips", "weekend trips", "morning rush hour trips", "evening rush hour trips", and "night-time trips". Once again, any overlapping values sharing the same cell for the raster layers were averaged. Finally, these raster layers were mapped on Open Street Map tiles, which were imported using the OpenStreetMap package for R.

Results and Discussion

Quesnel

Background measurements

This time in the winter sampling session, we see once again considerable variation among the fixed site scatter coefficients in Quesnel (both within-drive and between-drive), somewhat greater than what was observed during the summer sampling campaign (Figure 8). However, the same strong diurnal patterns are not evident. During summer we repeatedly (9 of 12 available days) observed increasing aerosol overnight, with decreasing concentrations in the morning as temperatures warmed (around 11:00). We do see some smaller diurnal variation during the winter campaign, but without the same variability and consistency. These patterns are likely strongly correlated with ambient temperature, which we will consider in the final analyses. The scatter coefficients were also generally higher than what was seen in the summer sampling campaign. The mean scatter coefficient was 53 Mm^{-1}, with a median of 39 Mm^{-1} and an interquartile range of 21 to 72 Mm^{-1}. The maximum recorded value was 563 Mm^{-1}. There was much oscillation in the values, where during the period of Jan 20th to Jan 24th we see coefficients taking on values between baseline and 100. Then during the period of Jan 26th to Jan 30th, we see that the coefficients are fairly low and mostly under 50 Mm^{-1} with few large peaks. This may possibly be related to the slight precipitation experienced during this time interval. There were also large peaks in scatter coefficient on the night of Jan 24th and Feb 1st. The most sustained increase though occurred on Jan 31st (Figure 9).

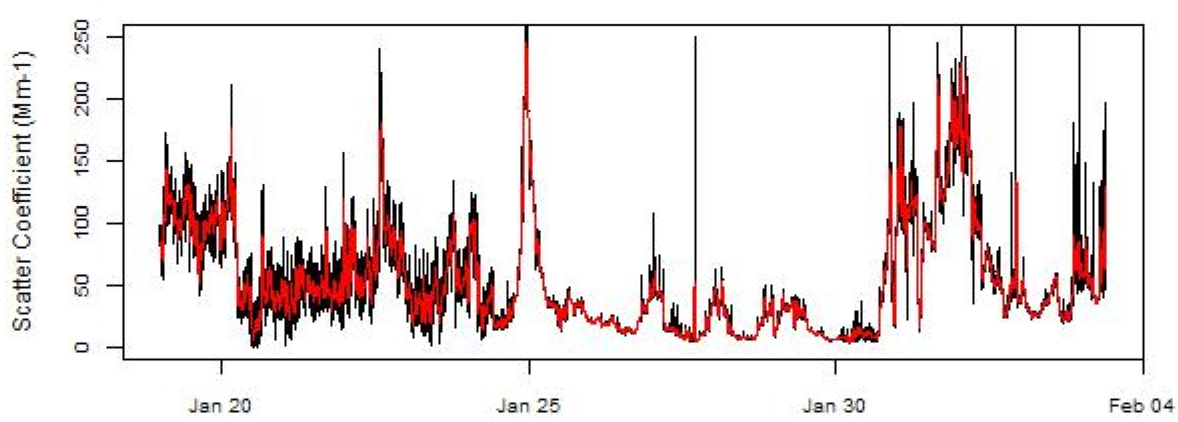

Figure 8. Raw (black line) and smoothed (red line) fixed nephelometer measurements in Quesnel Secondary School from Jan 19th through Feb 03th, 2014.

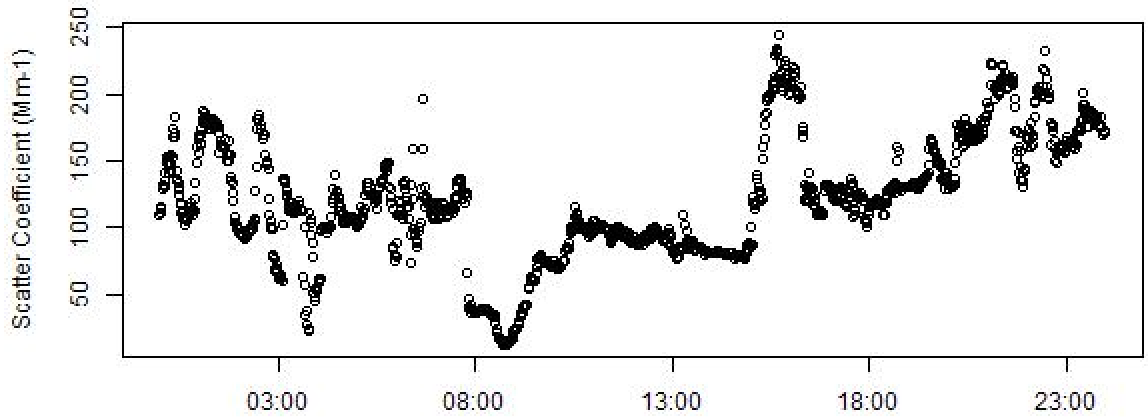

Figure 9. Scatter coefficient measured at Quesnel Secondary School on Jan 31st, 2014 in 1-minute averages.

Spatial hotspots

When examining the data on a linear scale, several clear aerosol hotspots were evident in Quesnel (Figure 12). Monitoring sessions conducted during the morning and evening rush hours show hotspots in the downtown core, in residential areas east of downtown, and on major routes to the north and south of Quesnel. Scatter coefficients were generally higher overall than what was seen during the summer sampling campaign, and hotspots were more numerous, particularly during the morning and evening rush hours. The main hotspot during the summer campaign in the south of the city to the east of the river was attributable to our own vehicle stirring up dust on the gravel road that leads down to/up from (depending on the sampling direction) the plywood substation. This particular hotspot is not seen as clearly in the winter maps, indicating as expected that road conditions are less dusty in winter. More hotspots during rush hours in the winter suggests that traffic has a higher impact on air pollution in Quesnel in the winter compared with the summer, perhaps due to higher traffic volumes or different meteorological conditions. Higher scatter coefficients overall suggests that activities like residential wood-burning are in fact impacting air pollution in Quesnel during winter months. When the data is displayed on a log scale, more information regarding the overall distribution of values is revealed (Figure 13).

Smithers

Background measurements

The within-drive and between-drive variability among the Smithers fixed site coefficients was markedly lower than for Quesnel, as was also seen among the coefficients measured in the summer sampling campaign (Figure 10). The mean scatter coefficient was 9.7 Mm^{-1}, with a median of 7.7 Mm^{-1} and an interquartile range of 4.5 to 13.1 Mm^{-1}. The maximum recorded value was 115 Mm^{-1}. The greatest sustained increase occurred on Feb 14th, 2014, where the coefficients increased to nearly 100 Mm^{-1}, with some oscillation. The strong diurnal cycle observed in summer was not present in the winter data. In summer we found regular increases staring around 07:00 and ending around 12:00, with smaller and less sustained increases in the evening and at night. In winter we observed less variability during the day, with increasing scatter coefficients at night (Figure 11). This is consistent with increased woodsmoke when the population is at home, possibly combined with dropping temperatures and resulting atmospheric stability.

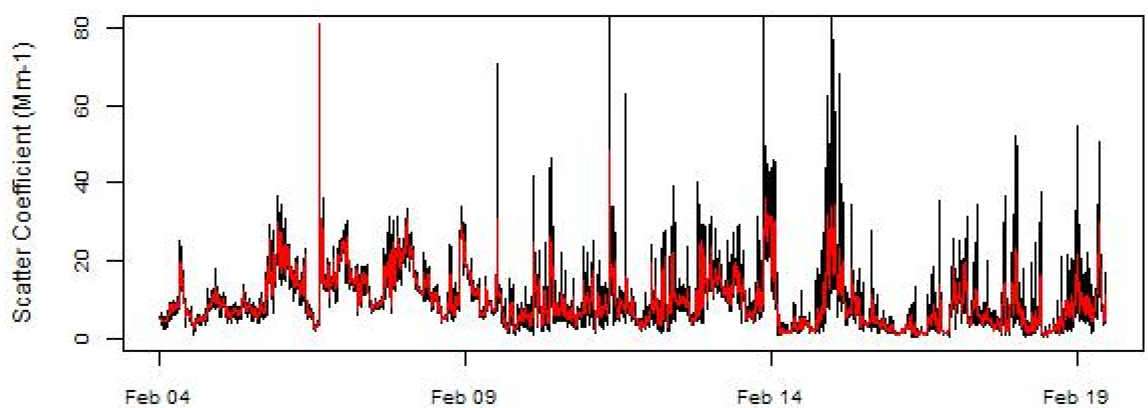

Figure 10. Raw (black line) and smoothed (red line) fixed nephelometer measurements in Smithers from Feb 04th through Feb 19th, 2014.

Spatial hotspots

In Smithers/Telkwa, data mapped on the linear scale showed four clear aerosol hotspots on the weekend and night time maps (Figure 14). These hotspots occur in central Telkwa, in east and south Smithers, and on a road between the two communities. The hotspot south of Smithers coincides with an aerosol hotspot found during the summer sampling campaign that was attributable to road dust. The hotspot north of Smithers from the summer campaign appears to be absent in the winter data. As in Quesnel, the winter scatter coefficients in Smithers are higher overall than those from the summer campaign, likely due to residential woodsmoke. Unlike Quesnel, there appears to be greater levels of particulate air pollution on weekdays, weekends, and during the night compared with the morning and evening rush hours, suggesting different traffic patterns or a different impact from traffic. Millar's thesis research also showed an aerosol hotspot in Telkwa, similar to the hotspot from this winter campaign. In addition, a couple of the winter campaign night time aerosol hotspots in Smithers were identified in Millar's research, as were a couple of the summer campaign hotspots. Data displayed on a log scale allows for greater perspective on the data distribution (Figure 15).

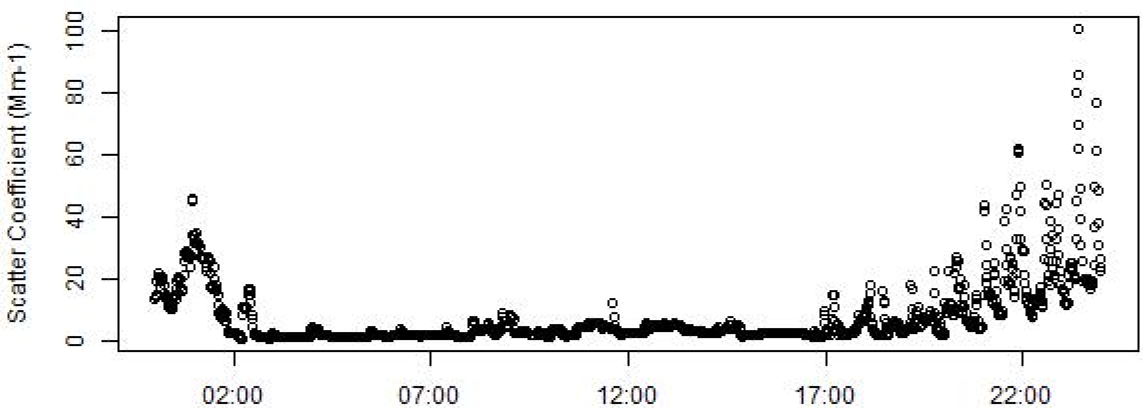

Figure 11. Scatter coefficient measured in central Smithers on Feb 14th, 2014 in 1-minute averages.

Conclusions

We have not had adequate time to thoroughly analyze data from the winter campaign, to thoughtfully combine data from the summer and winter campaigns, and to compare the winter of 2014 with previous winters in Smithers. All of these activities are planned for the coming months, when we will prepare a manuscript for peer review. At this time we can say that (1) diurnal variability was much stronger in summer than in winter for both locations, (2) overall aerosols were higher in winter than in summer for both locations, (3) there was clear evidence of road dust hotspots in summer and woodsmoke hotspots in winter in both locations, and (4) morning rush hour is a period of particular concern in Quesnel but not Smithers during both summer and winter months.

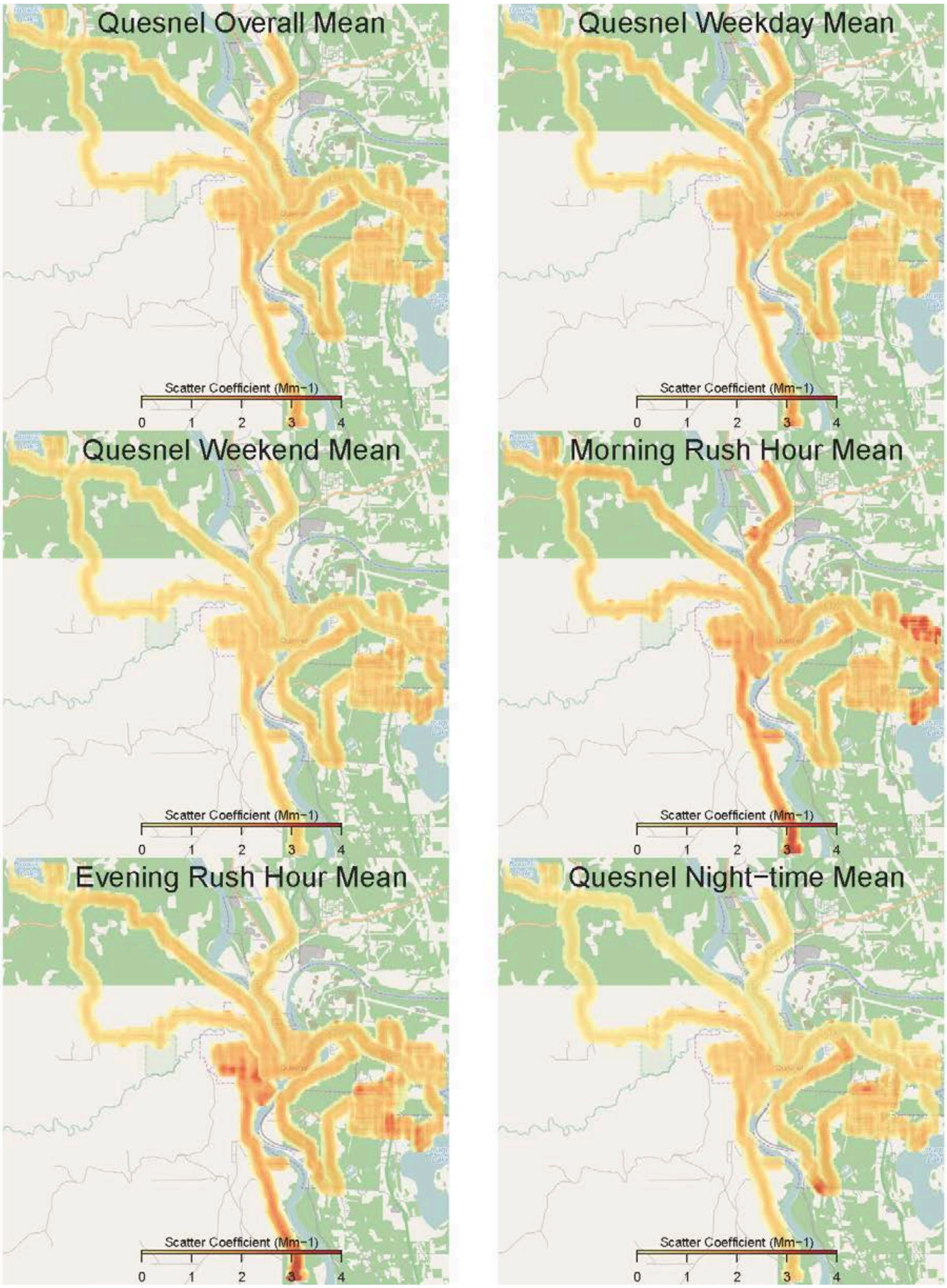

Figure 12. Spatial averages of the adjusted mobile monitoring measurements for Quesnel overall, involving particular periods of time, displayed on a linear scale. Any values exceeding 4 Mm^{-1} have the same colour as values equivalent to 4 Mm^{-1}.

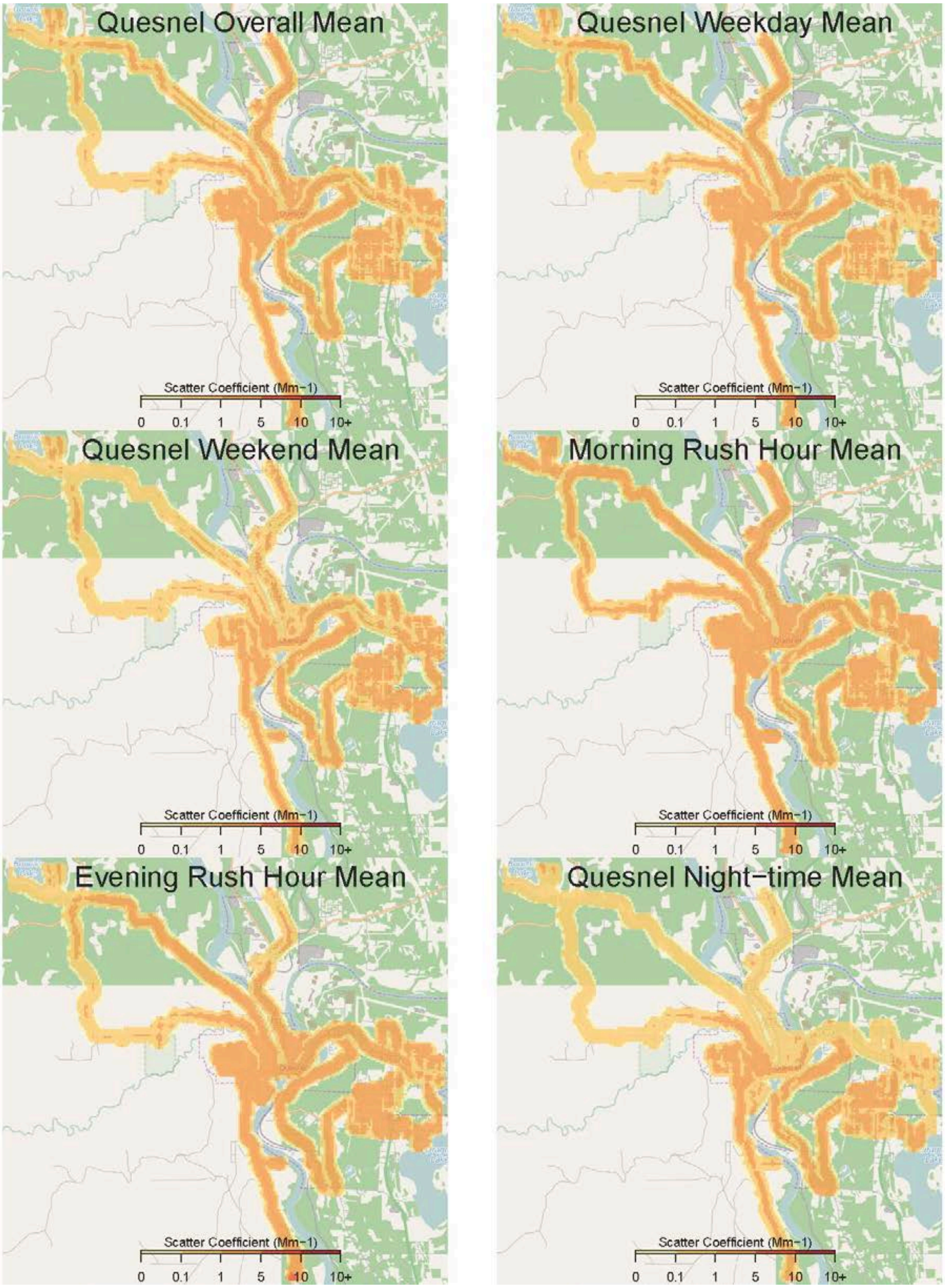

Figure 13. Spatial averages of the adjusted mobile monitoring measurements for Quesnel overall, involving particular periods of time, displayed on a log scale.

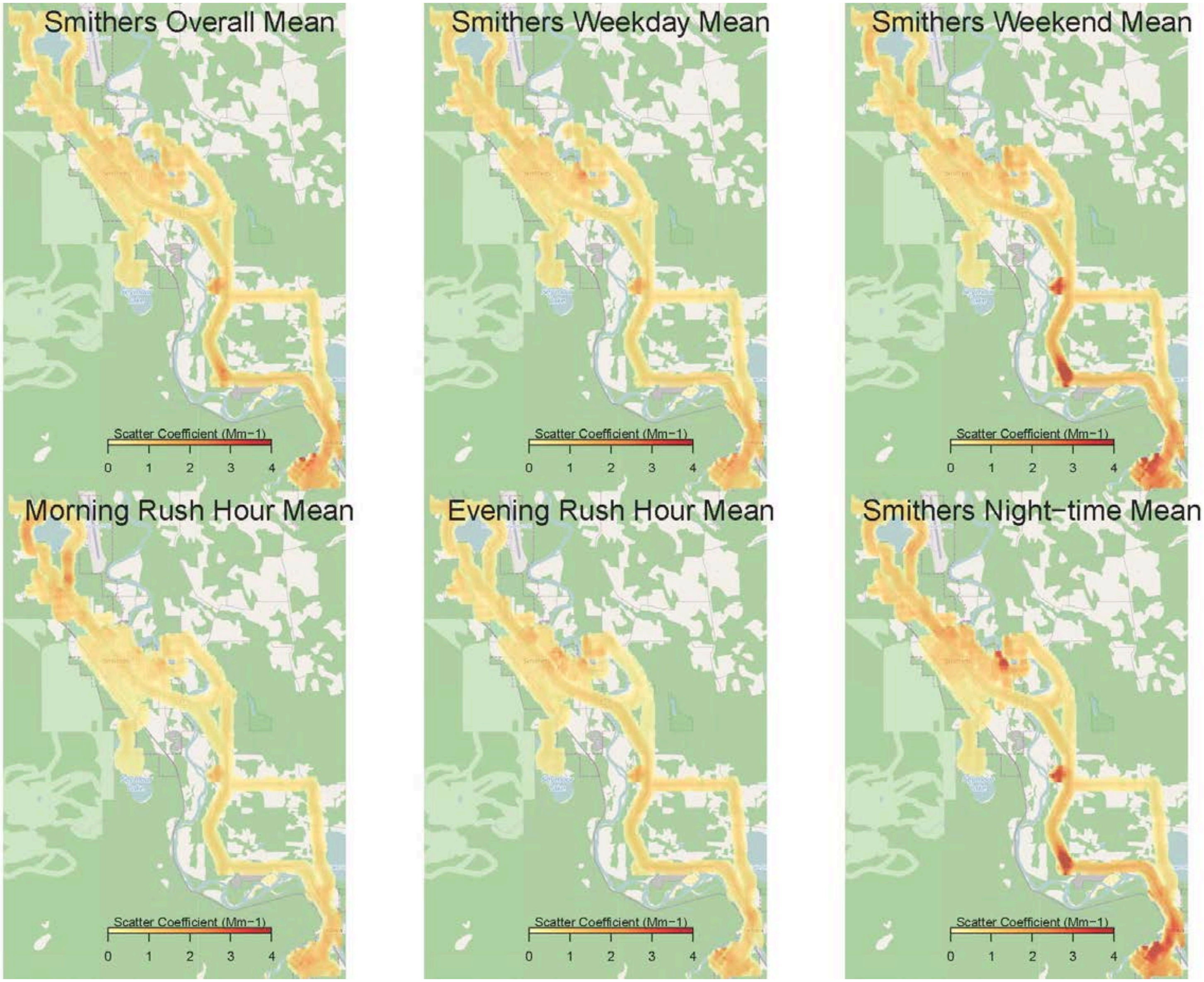

Figure 14. Spatial averages of the adjusted mobile monitoring measurements for Smithers overall, involving particular periods of time, displayed on a linear scale. Any values exceeding 4 Mm^{-1} have the same colour as values equivalent to 4 Mm^{-1}.

Figure 15. Spatial averages of the adjusted mobile monitoring measurements for Smithers overall, involving particular periods of time, displayed on a log scale.