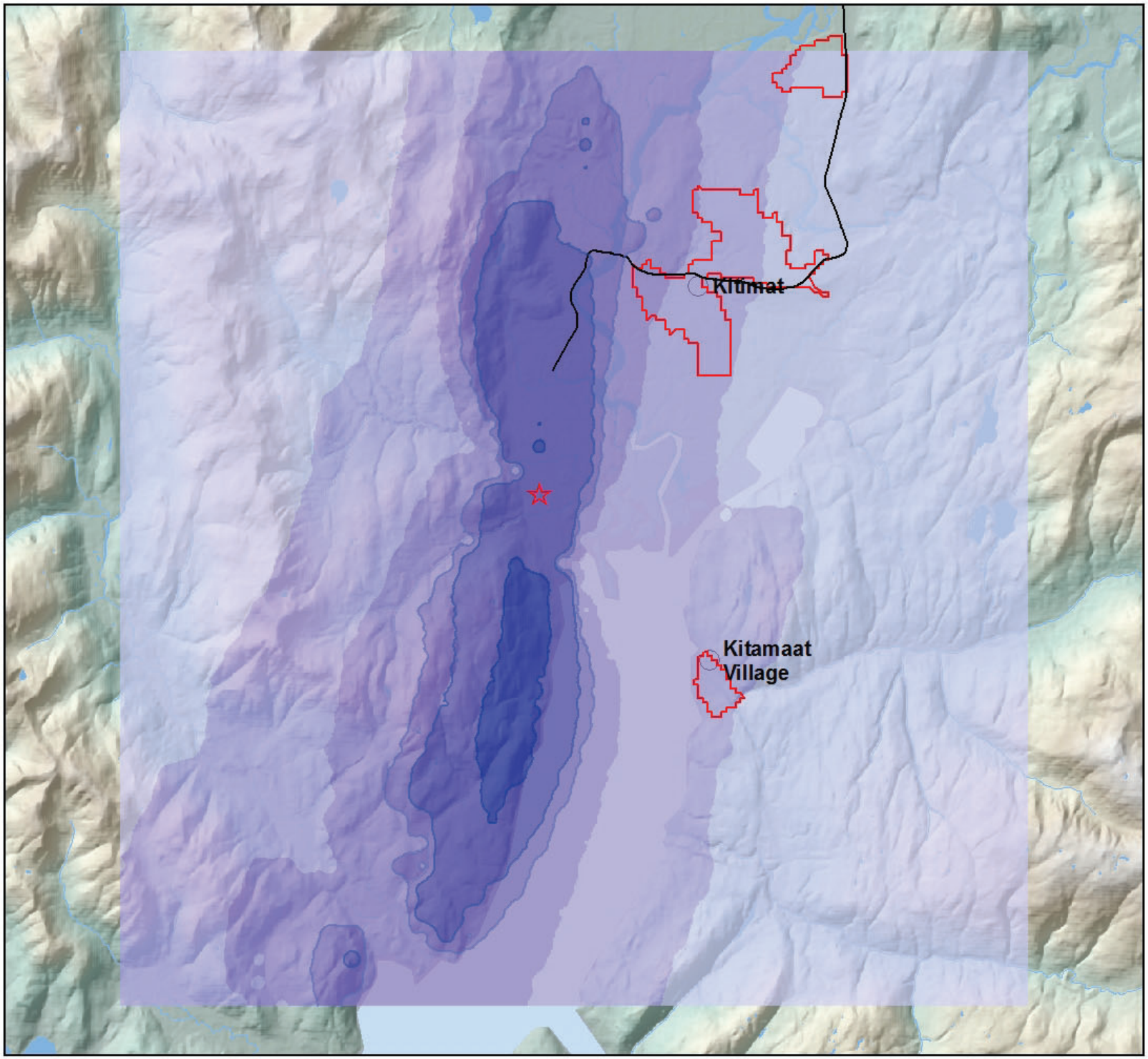
Attachment 1
Model Result Plots

Local Scale – 42 TPD Scenario
Regional Scale – Actual Scenario
Local Scale – Actual Scenario



SO_2 EEM Atmospheric Pathway

Rio Tinto Site

Primary Road

Residential Area

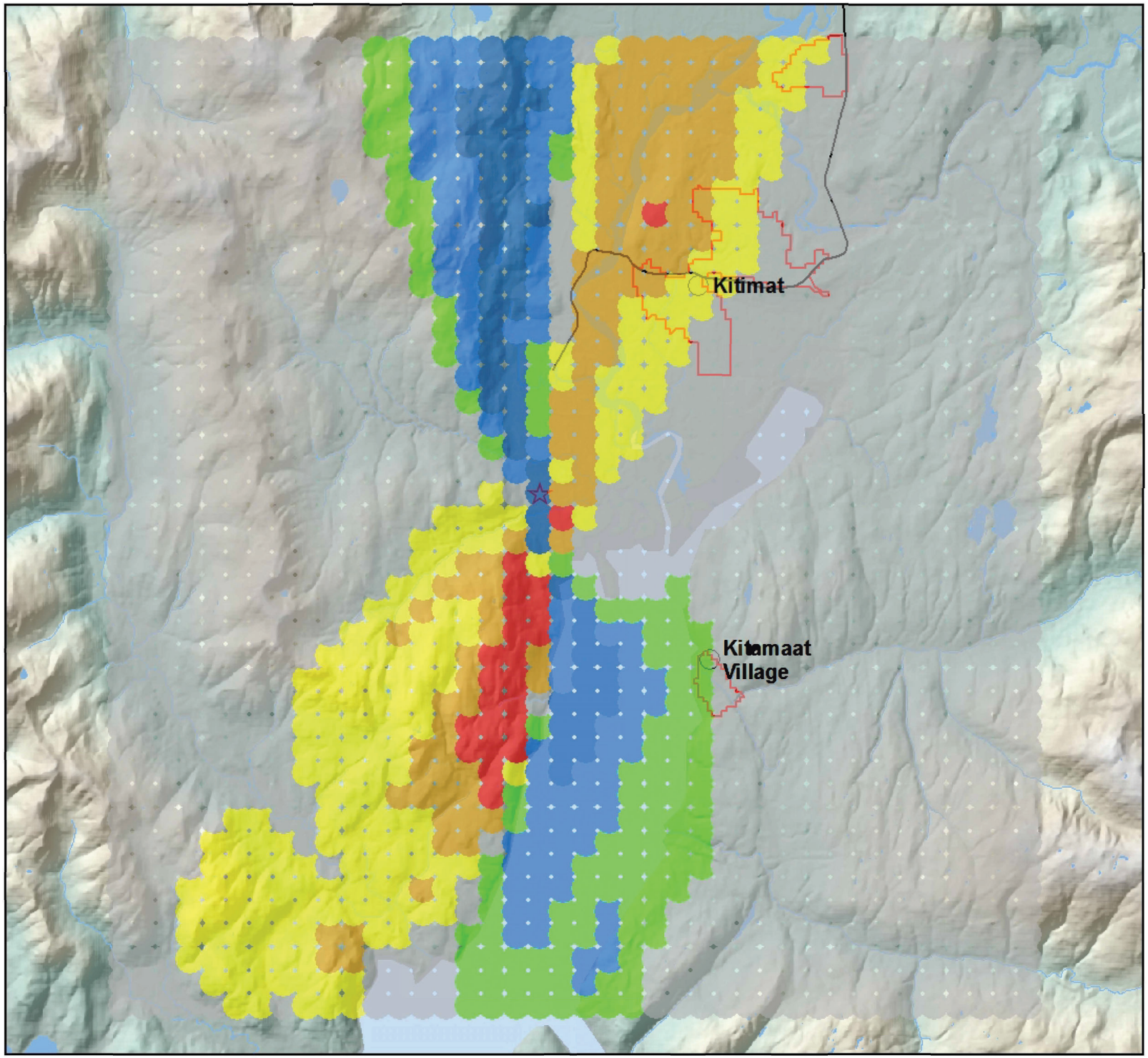
SO2 Annual Average Concentration (ppb) (Includes background of 0.47 ppb)

42 tpd, 2016

- 0 - 1.25: Below 2025 CAAQS
- 1.25 - 2.5: Below 2025 CAAQS
- 2.5 - 4: Below 2025 CAAQS
- 4 - 5: Above 2025 CAAQS and Below 2020
- 5 - 10: Above 2020 CAAQS
- 10+: Above 2020 CAAQS

0 0.9 1.8 Miles

0 1 2 Kilometers



SO_2 EEM Atmospheric Pathway

Rio Tinto Site

Primary Road

Residential Area

Difference between Post-CALMET Data and Pre-CALMET Data Annual, 2016, 42 tpd

Difference

-12.6 - -5

-5 - -2.5

-2.5 - -1

-1 - 1

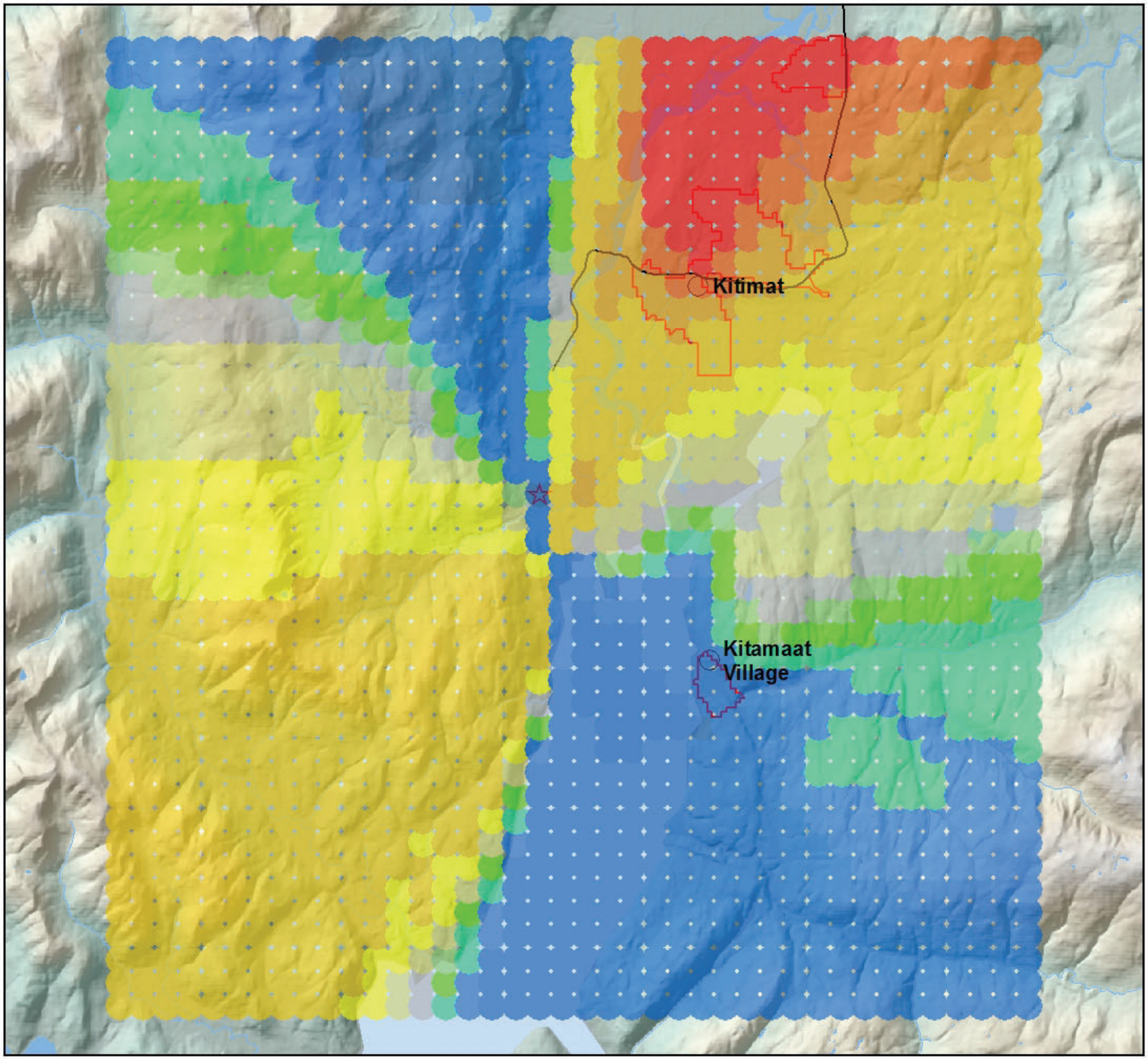
1 - 2.5

2.5 - 5

5 - 13.9

0 0.9 1.8 Miles

0 1 2 Kilometers



SO_2 EEM Atmospheric Pathway

Rio Tinto Site

Primary Road

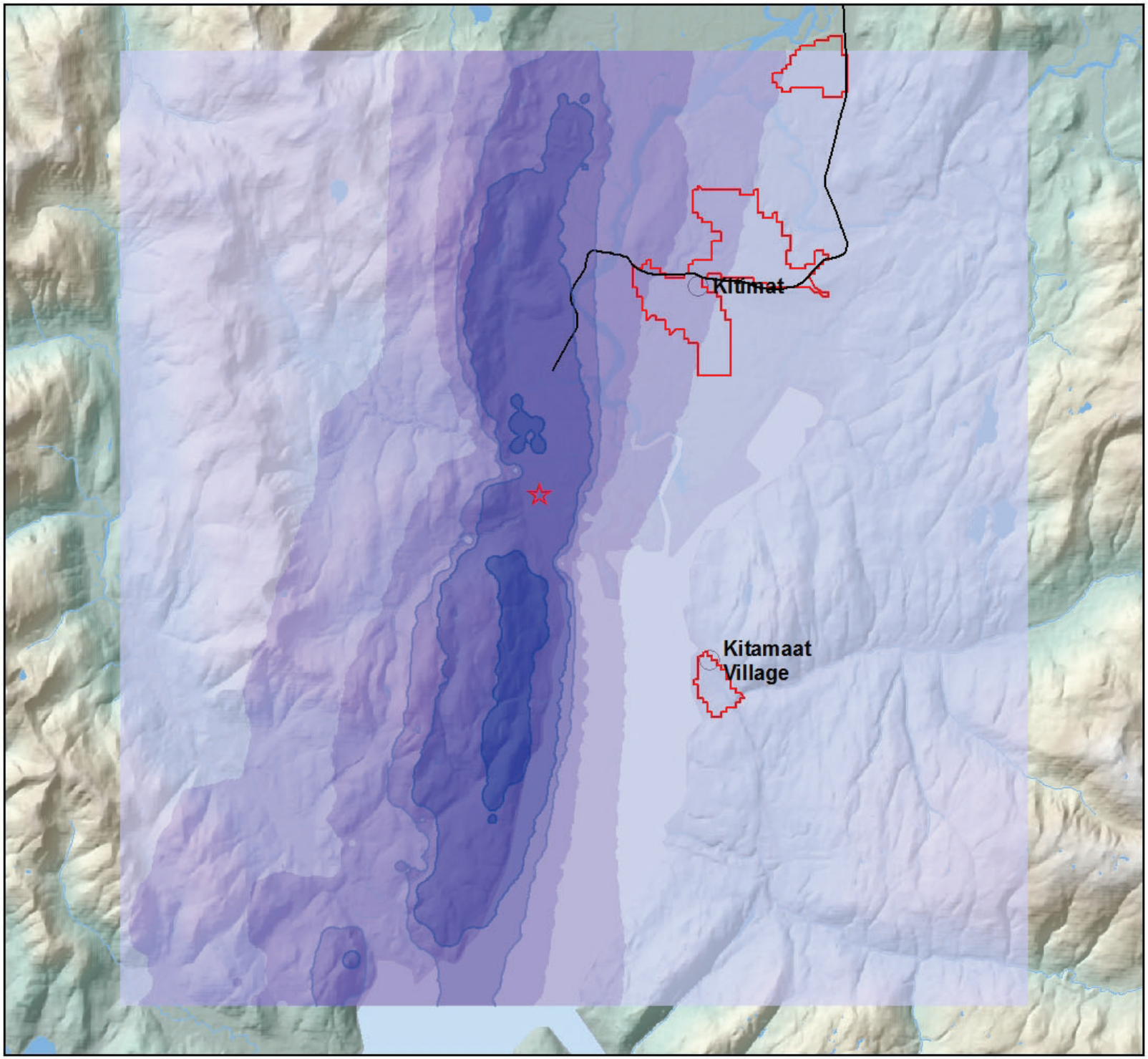
Residential Area

Percent Difference between Post-CALMET Data and Pre-CALMET Data Annual, 2017, 42 tpd

- -60 - -40
- -40 - -20
- -20 - -15
- -15 - -10
- -10 - -5
- -5 - -2.5
- -2.5 - 2.5
- 2.5 - 10
- 10 - 20
- 20 - 50
- 50 - 80
- 80 - 120
- 120 - 295

0 0.9 1.8 Miles

0 1 2 Kilometers



SO_2 EEM Atmospheric Pathway

Rio Tinto Site

Primary Road

Residential Area

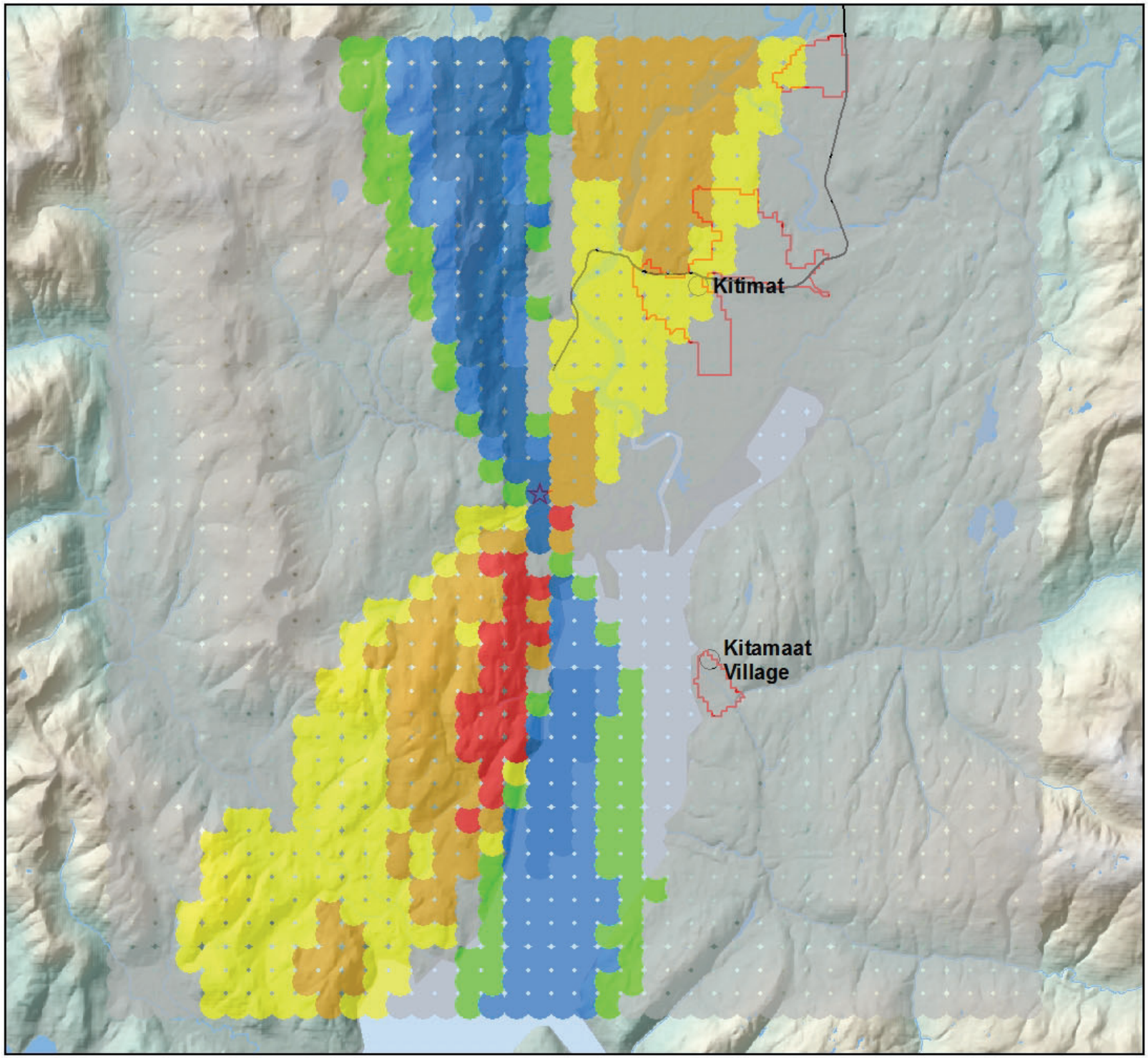
SO2 Annual Average Concentration (ppb) (Includes background of 0.47 ppb)

42 tpd, 2017

- 0 - 1.25: Below 2025 CAAQS
- 1.25 - 2.5: Below 2025 CAAQS
- 2.5 - 4: Below 2025 CAAQS
- 4 - 5: Above 2025 CAAQS and Below 2020
- 5 - 10: Above 2020 CAAQS
- 10+: Above 2020 CAAQS

0 0.9 1.8 Miles

0 1 2 Kilometers



SO_2 EEM Atmospheric Pathway

Rio Tinto Site

Primary Road

Residential Area

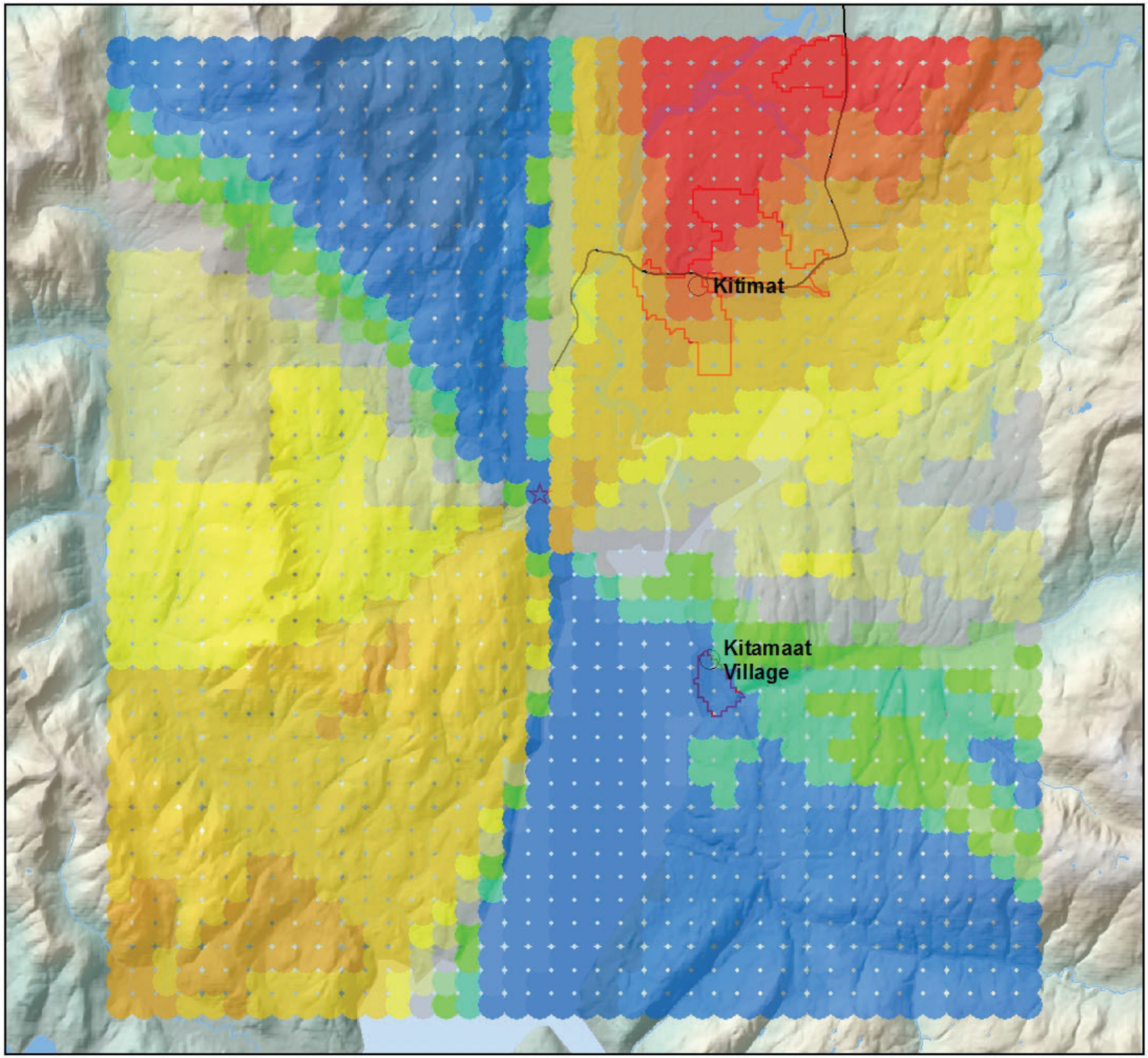
Percent Difference between Post-CALMET Data and Pre-CALMET Data Annual, 2017, 42 tpd

Difference

- -15.5 - -5
- -5 - -2.5
- -2.5 - -1
- -1 - 1
- 1 - 2.5
- 2.5 - 5
- 5 - 11.4

0 0.9 1.8 Miles

0 1 2 Kilometers



SO_2 EEM Atmospheric Pathway

Rio Tinto Site

Primary Road

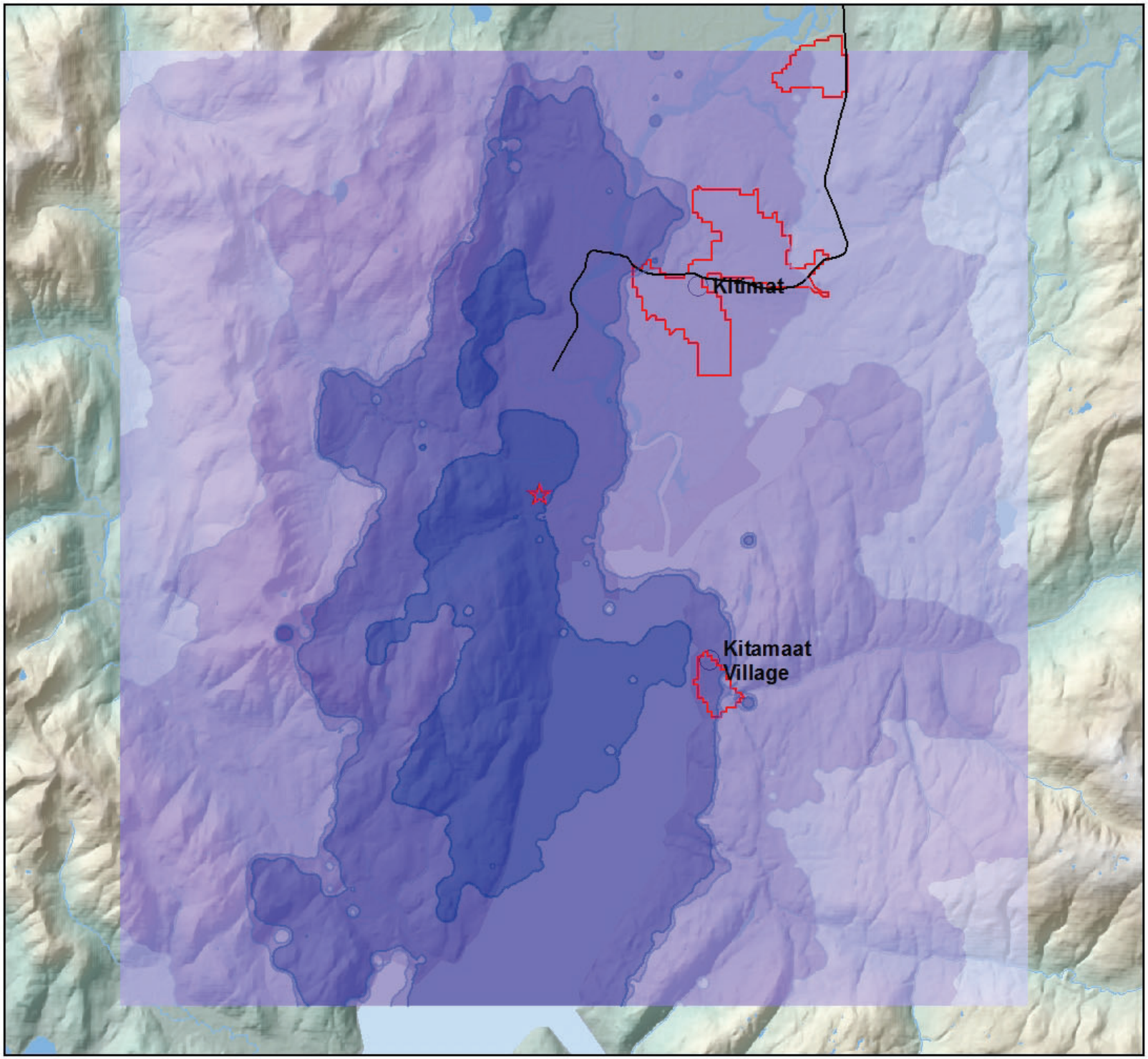
Residential Area

Percent Difference between Post-CALMET Data and Pre-CALMET Data Annual, 2017, 42 tpd

- -61.63 - -40
- -40 - -20
- -20 - -15
- -15 - -10
- -10 - -5
- -5 - -2.5
- -2.5 - 2.5
- 2.5 - 10
- 10 - 20
- 20 - 50
- 50 - 80
- 80 - 120
- 120 - 351

0 0.9 1.8 Miles

0 1 2 Kilometers



SO_2 EEM Atmospheric Pathway

Rio Tinto Site

Primary Road

Residential Area

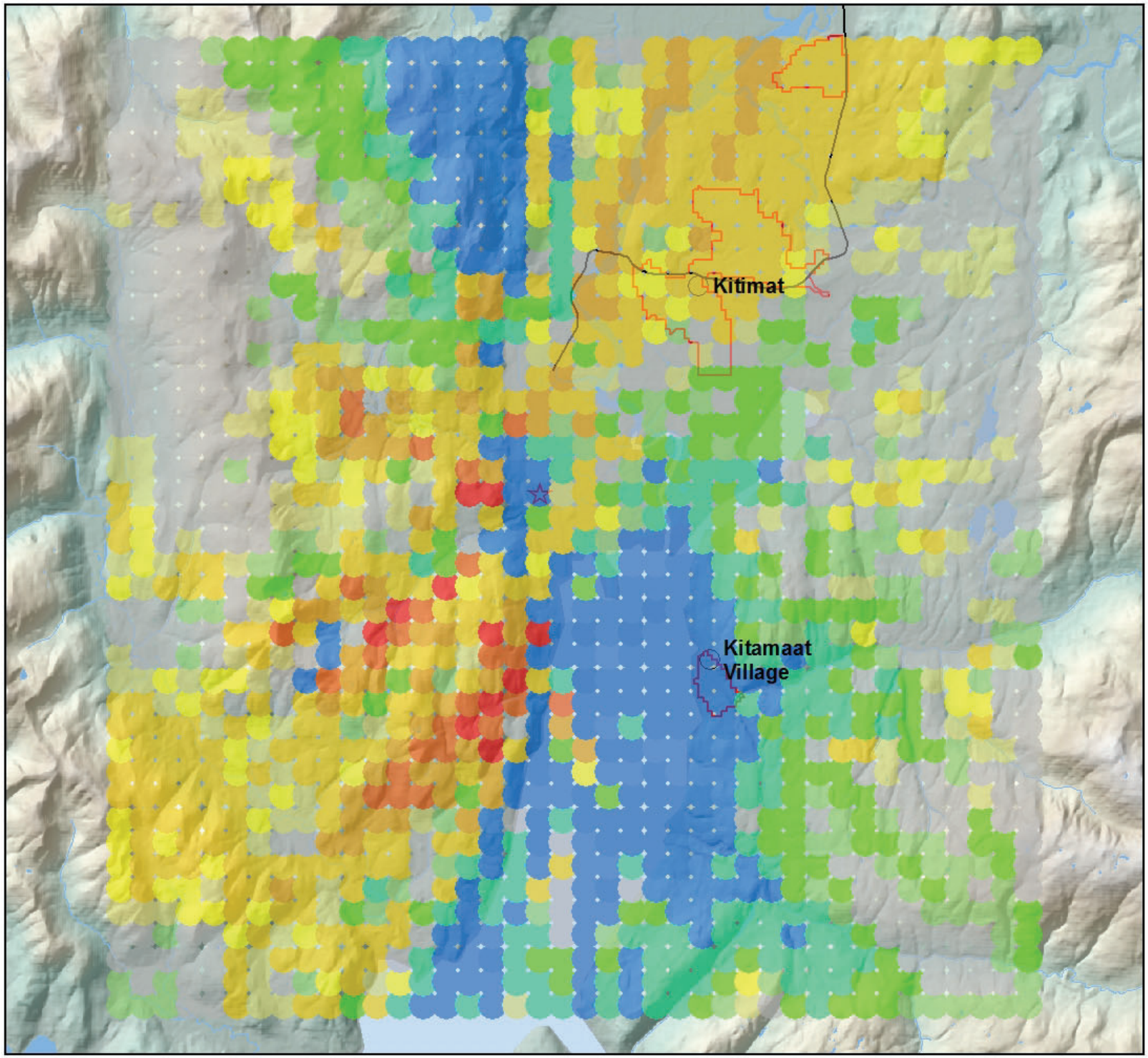
SO2 1 hr Average Concentration (ppb) (Includes background of 5.53 ppb)

42 tpd, 2016

- 0 - 17.5: Below 2025 CAAQS
- 17.5 - 30: Below 2025 CAAQS
- 30 - 65: Below 2025 CAAQS
- 65 - 70: Above 2025 CAAQS and Below 2020
- 70 - 140: Above 2020 CAAQS
- 140+: ABove 2020 CAAQS

0 0.9 1.8 Miles

0 1 2 Kilometers



SO_2 EEM Atmospheric Pathway

Rio Tinto Site

Primary Road

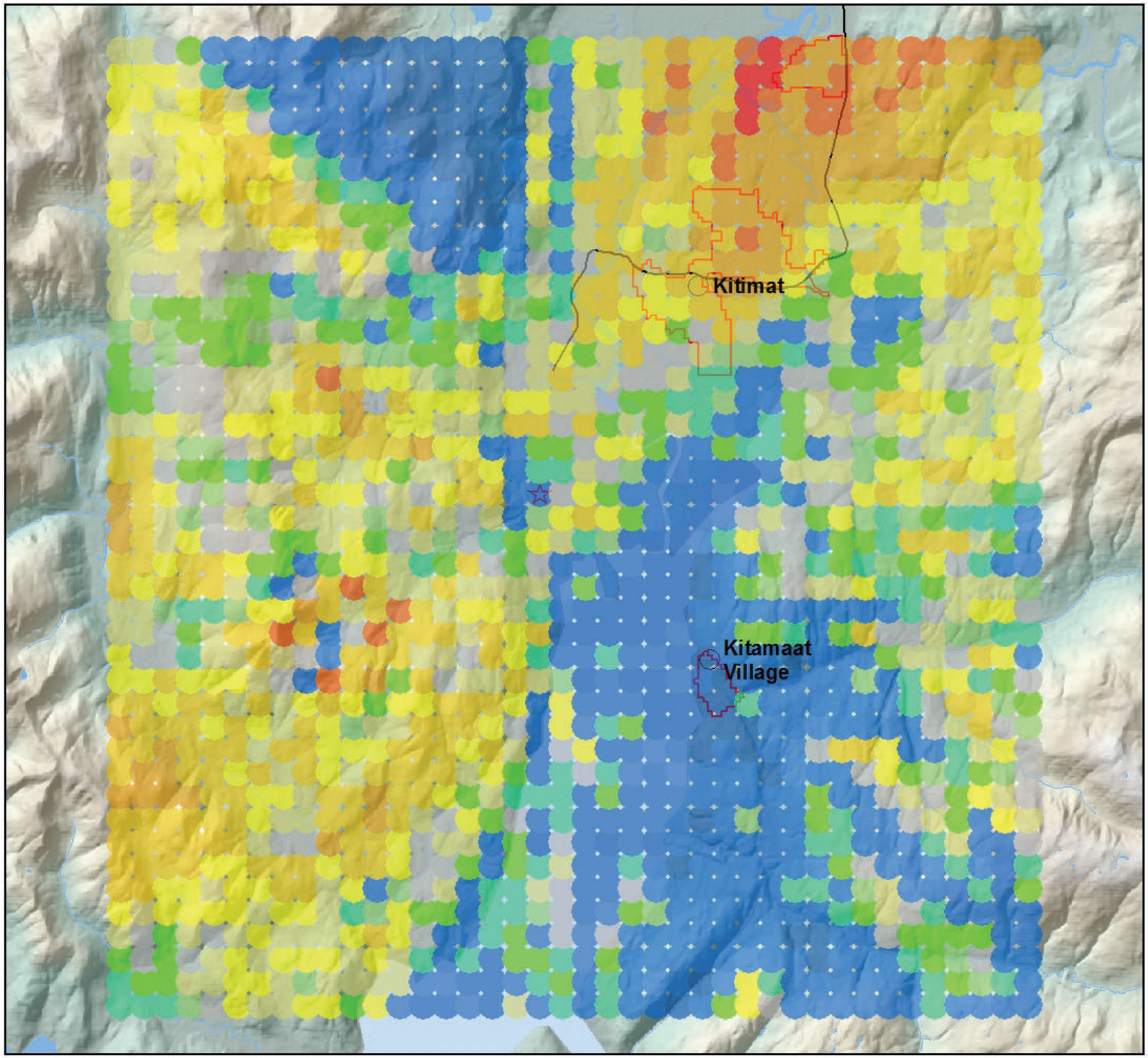
Residential Area

Difference between Post-CALMET Data and Pre-CALMET Data
1 hr, 2016, 42 tpd

- -701 - -400
- -400 - -100
- -100 - -50
- -50 - -25
- -25 - -10
- -10 - -5
- -5 - 5
- 5 - 10
- 10 - 15
- 15 - 50
- 50 - 100
- 100 - 150
- 150 - 203

0 0.9 1.8 Miles

0 1 2 Kilometers



SO_2 EEM Atmospheric Pathway

Rio Tinto Site

Primary Road

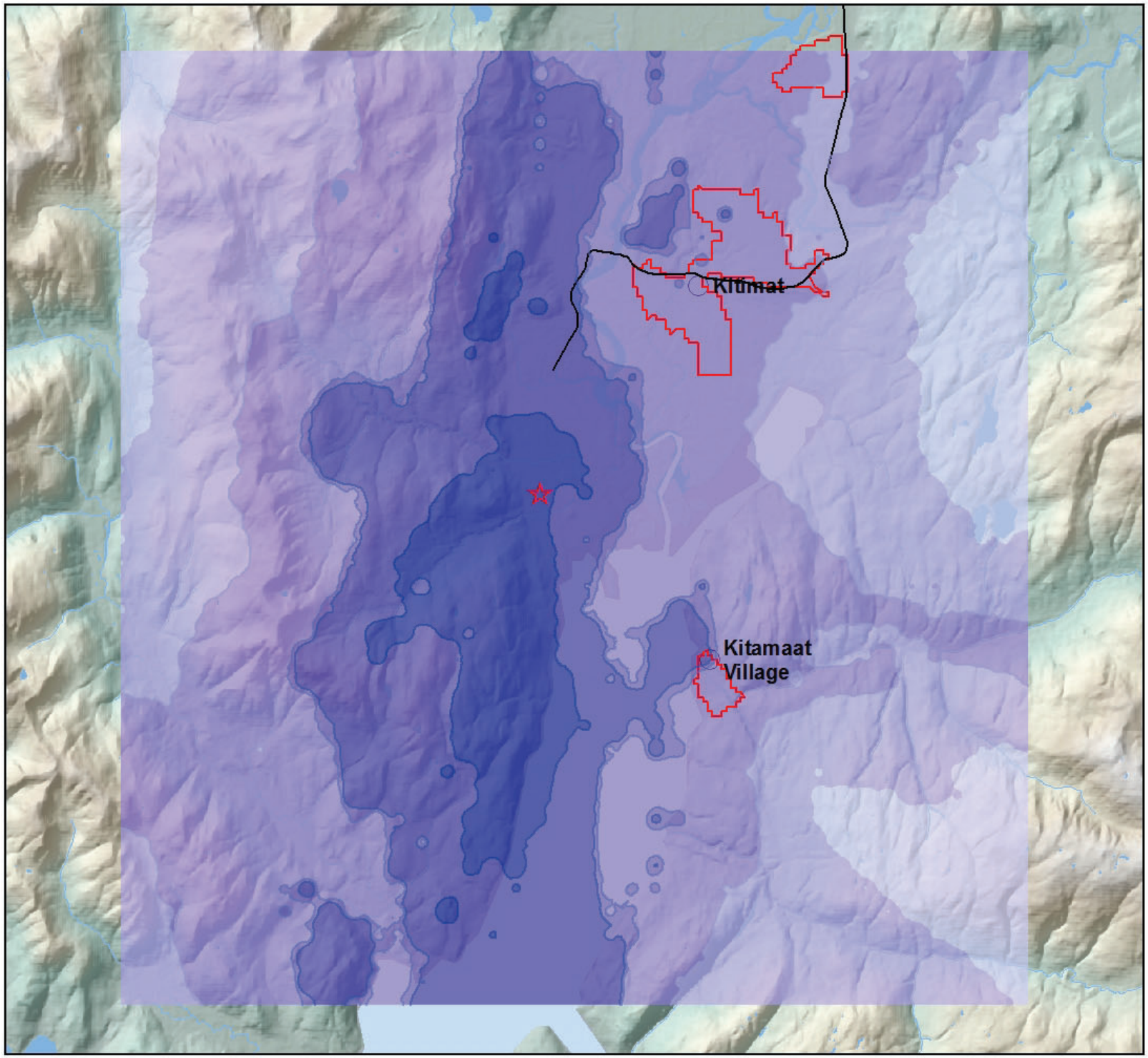
Residential Area

Percent Difference between Post-CALMET Data and Pre-CALMET Data 1 hr, 2016, 42 tpd

- -73.2 - -40
- -40 - -20
- -20 - -15
- -15 - -10
- -10 - -5
- -5 - -2.5
- -2.5 - 2.5
- 2.5 - 10
- 10 - 20
- 20 - 50
- 50 - 80
- 80 - 120
- 120 - 179.59

0 0.9 1.8 Miles

0 1 2 Kilometers



SO_2 EEM Atmospheric Pathway

Rio Tinto Site

Primary Road

Residential Area

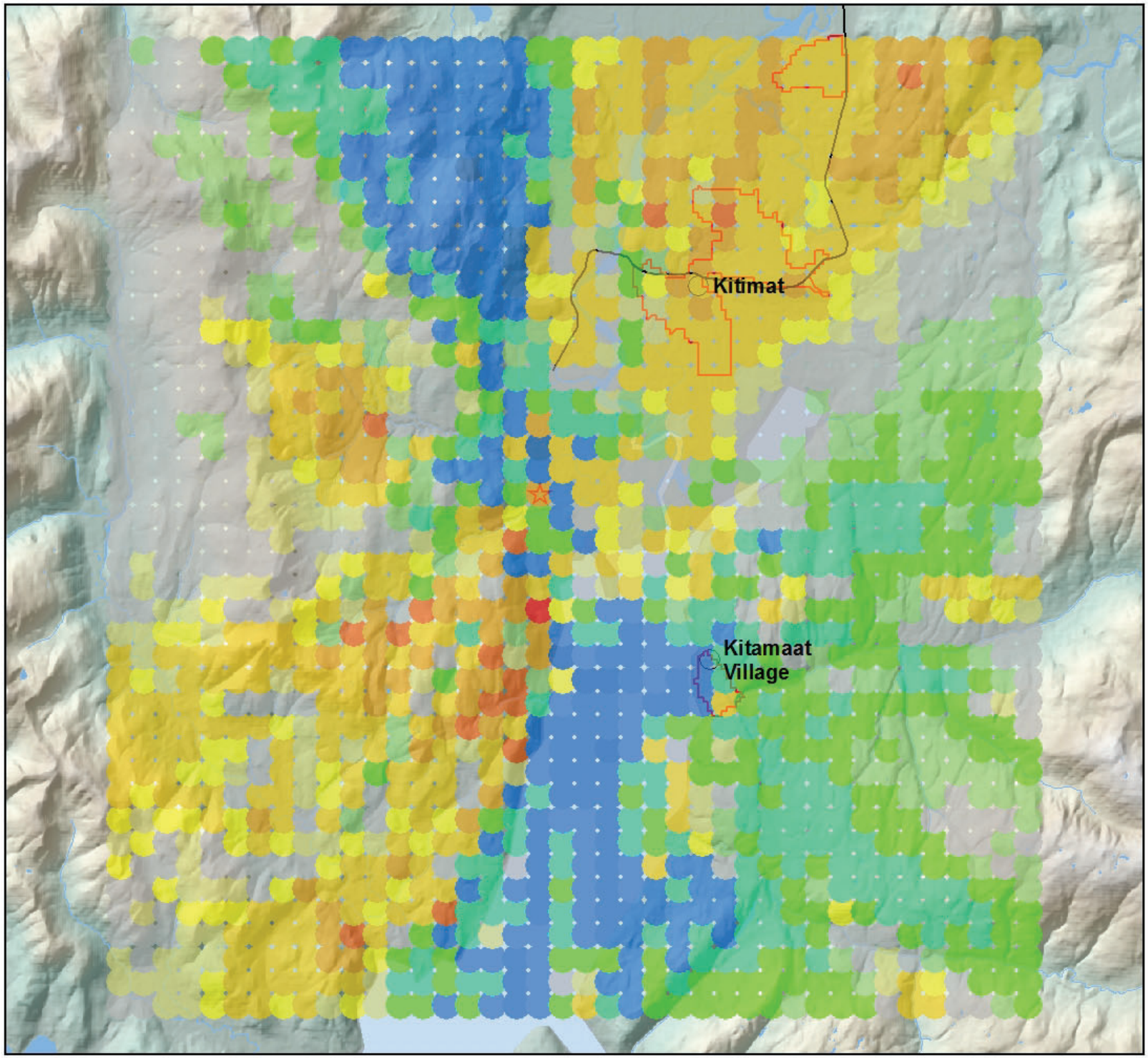
SO2 1 hr Average Concentration (ppb) (Includes background of 5.53 ppb)

42 tpd, 2017

- 0 - 17.5: Below 2025 CAAQS
- 17.5 - 30: Below 2025 CAAQS
- 30 - 65: Below 2025 CAAQS
- 65 - 70: Above 2025 CAAQS and Below 2020
- 70 - 140: Above 2020 CAAQS
- 140+: ABove 2020 CAAQS

0 0.9 1.8 Miles

0 1 2 Kilometers



SO_2 EEM Atmospheric Pathway

Rio Tinto Site

Primary Road

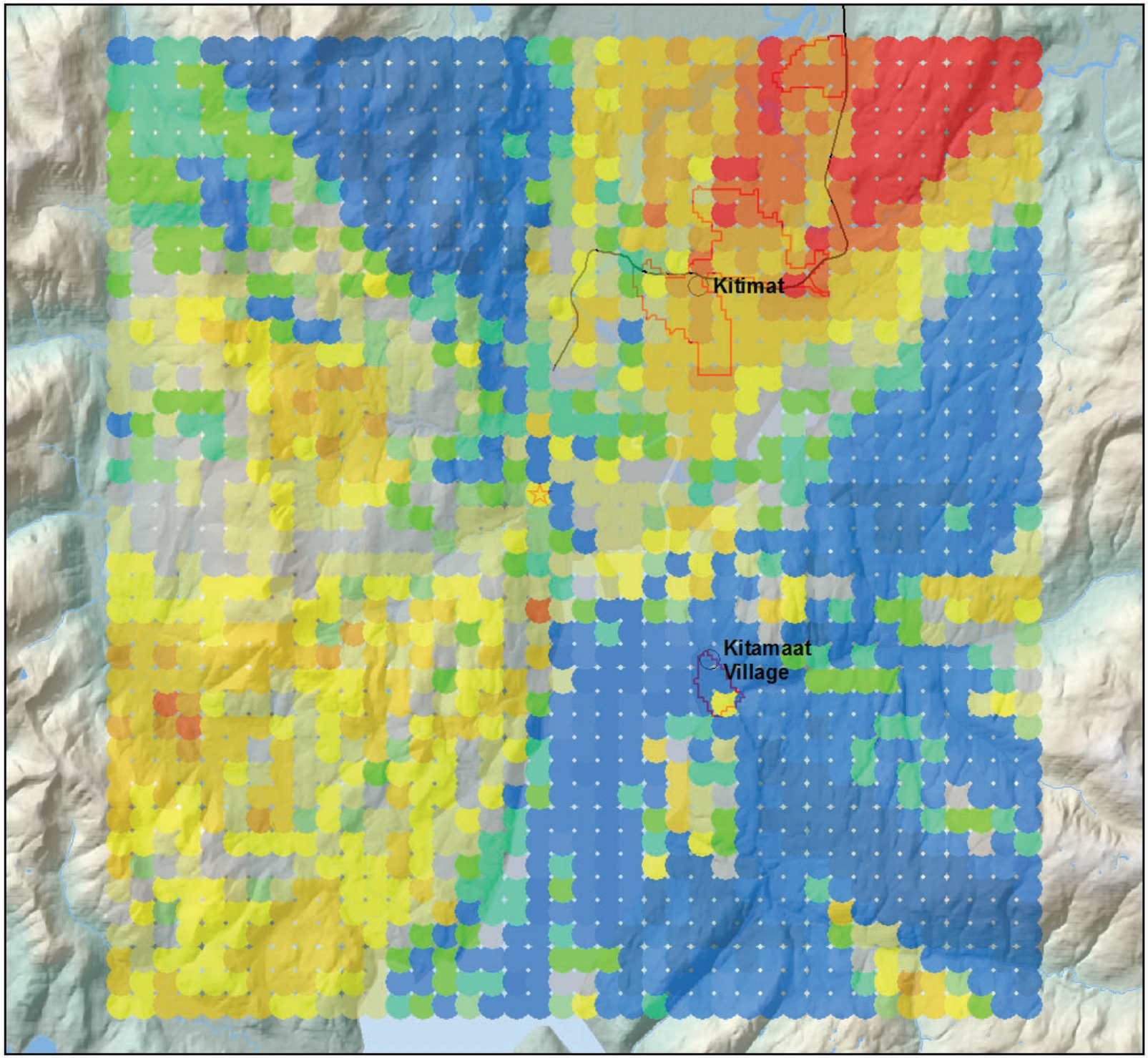
Residential Area

Difference between Post-CALMET Data and Pre-CALMET Data
1 hr, 2017, 42 tpd

- -701 - -200
- -200 - -100
- -100 - -50
- -50 - -25
- -25 - -10
- -10 - -5
- -5 - 5
- 5 - 10
- 10 - 15
- 15 - 50
- 50 - 100
- 100 - 150
- 150 - 334

0 0.9 1.8 Miles

0 1 2 Kilometers



SO_2 EEM Atmospheric Pathway

Rio Tinto Site

Primary Road

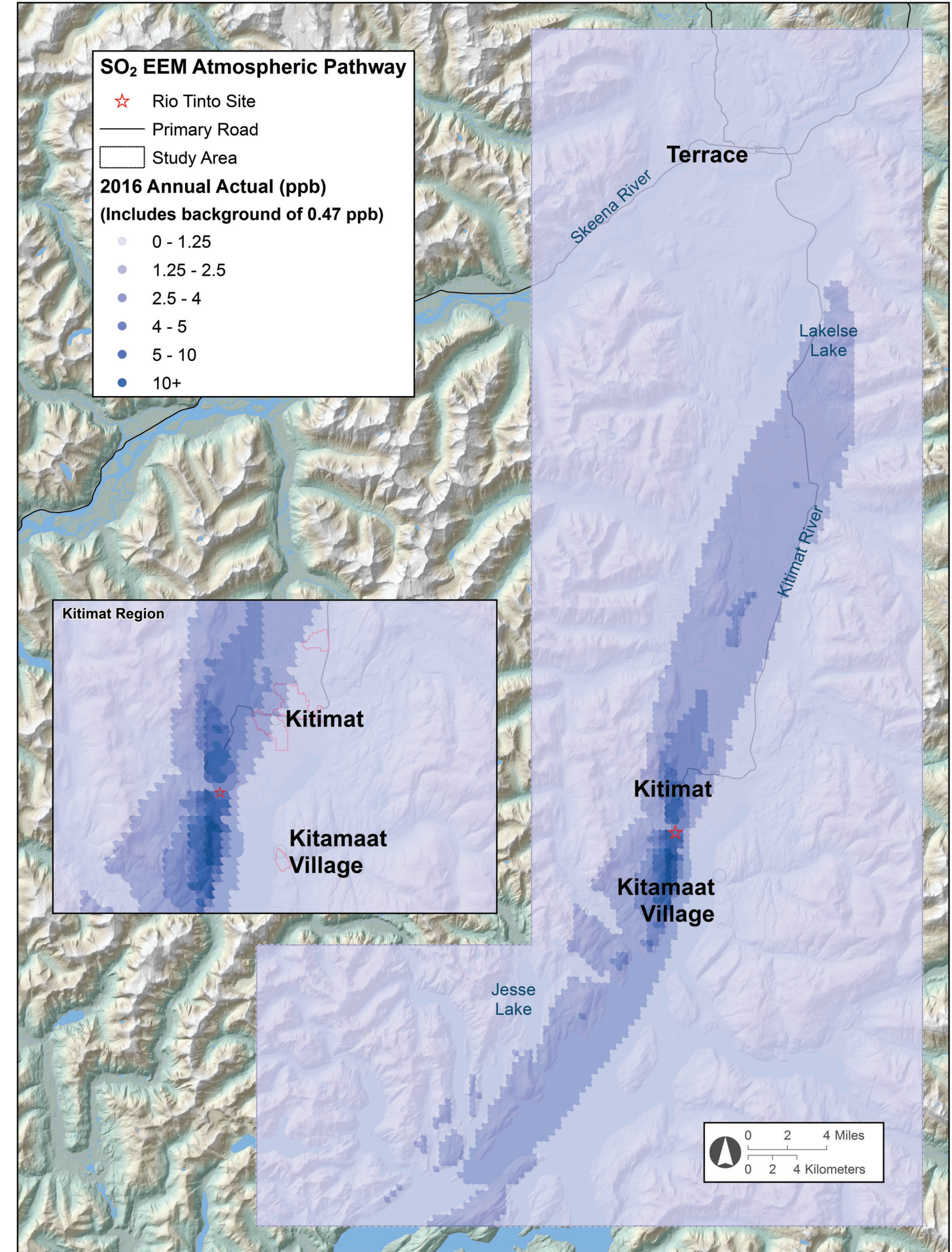
Residential Area

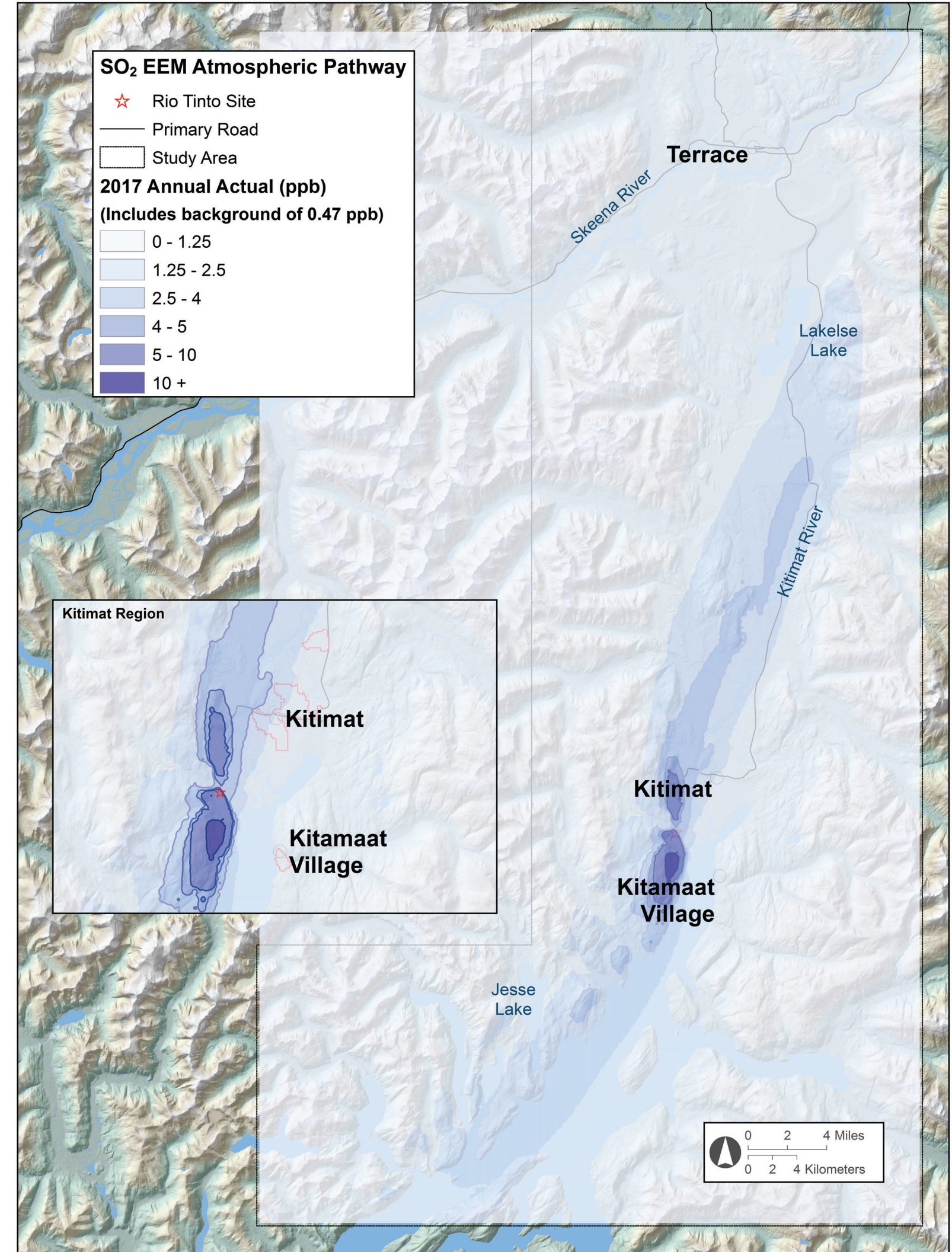
Percent Difference between Post-CALMET Data and Pre-CALMET Data
1 hr, 2017, 42 tpd

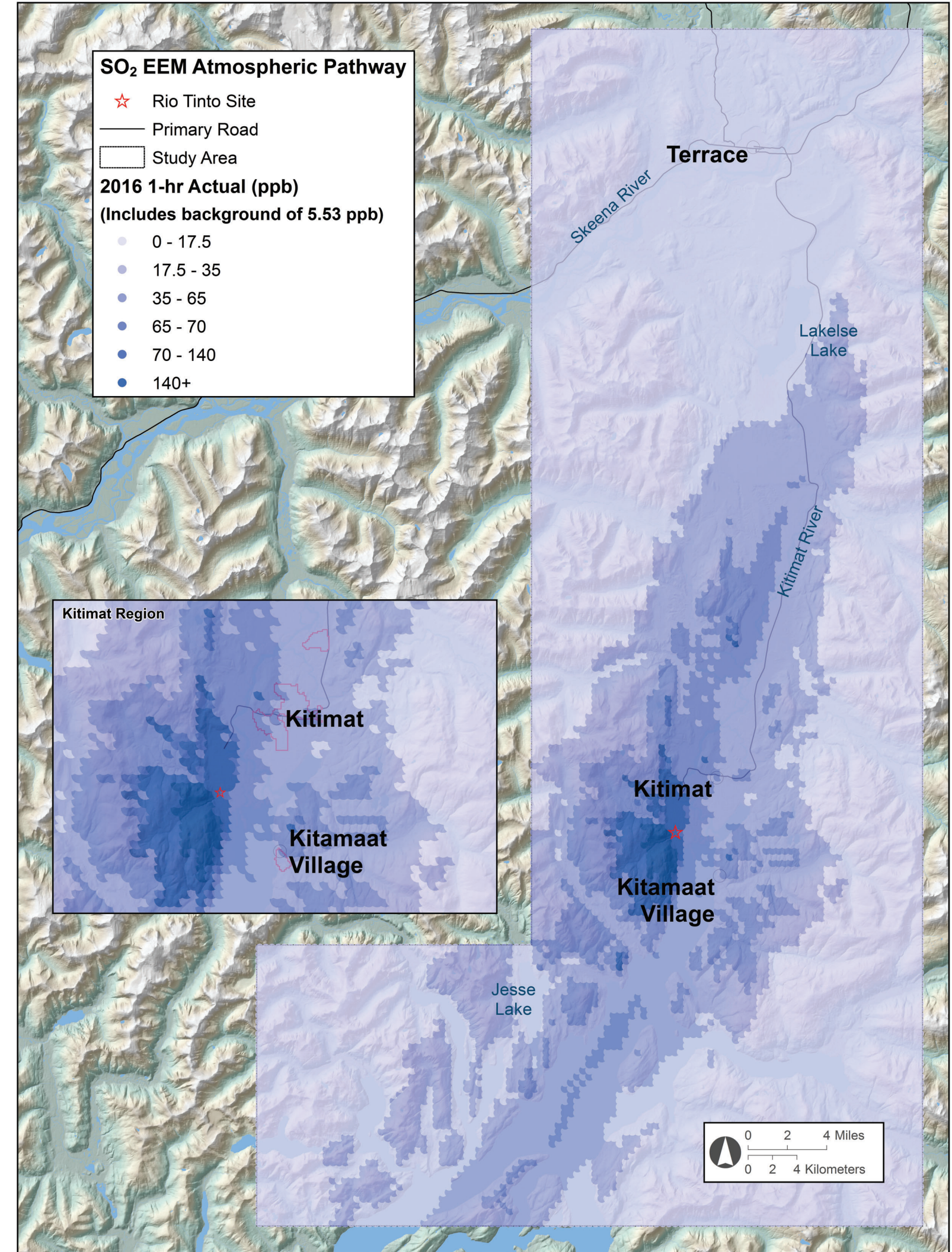
- -64.77 - -40
- -40 - -20
- -20 - -15
- -15 - -10
- -10 - -5
- -5 - -2.5
- -2.5 - 2.5
- 2.5 - 10
- 10 - 20
- 20 - 50
- 50 - 80
- 80 - 120
- 120 - 480.41

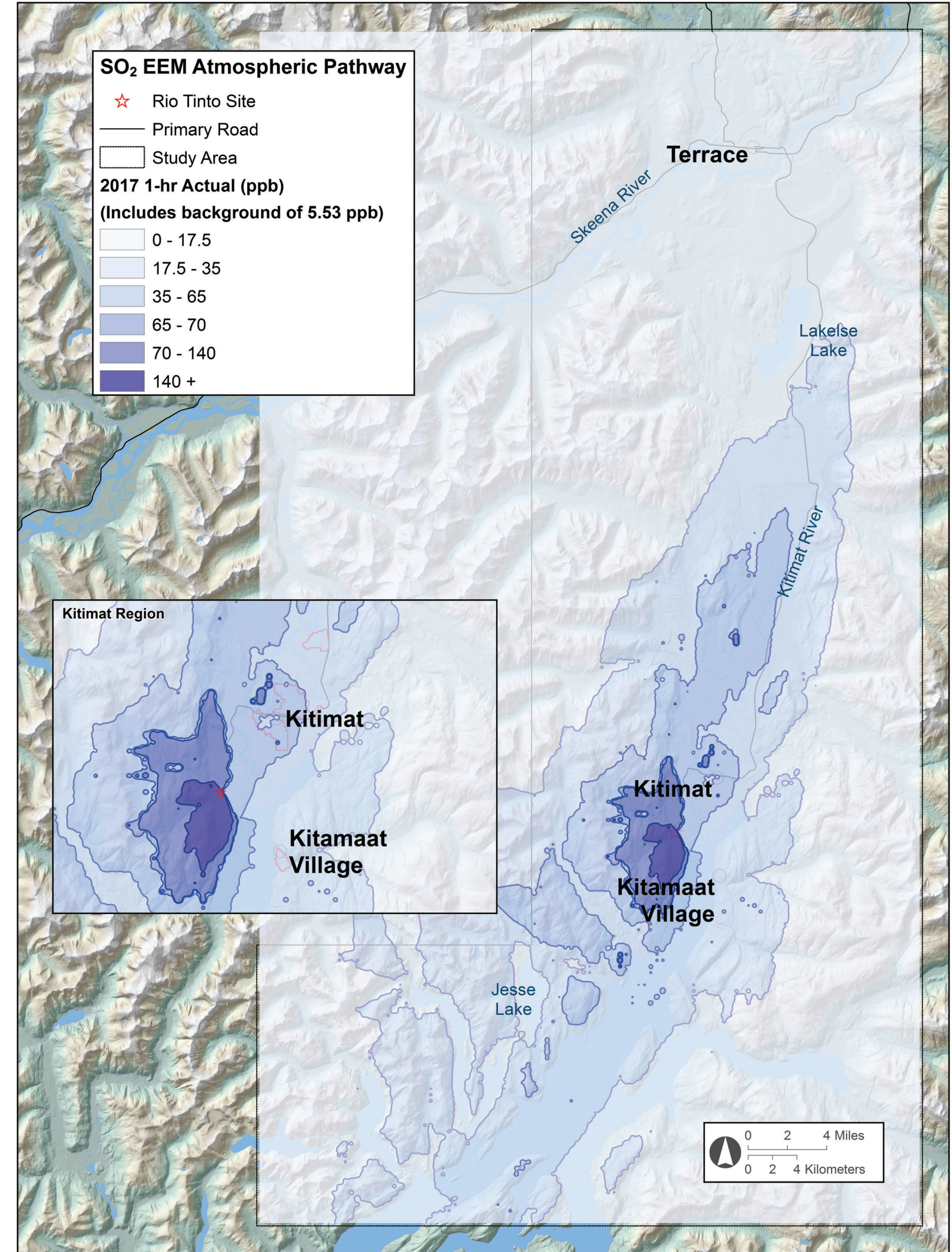
0 0.9 1.8 Miles

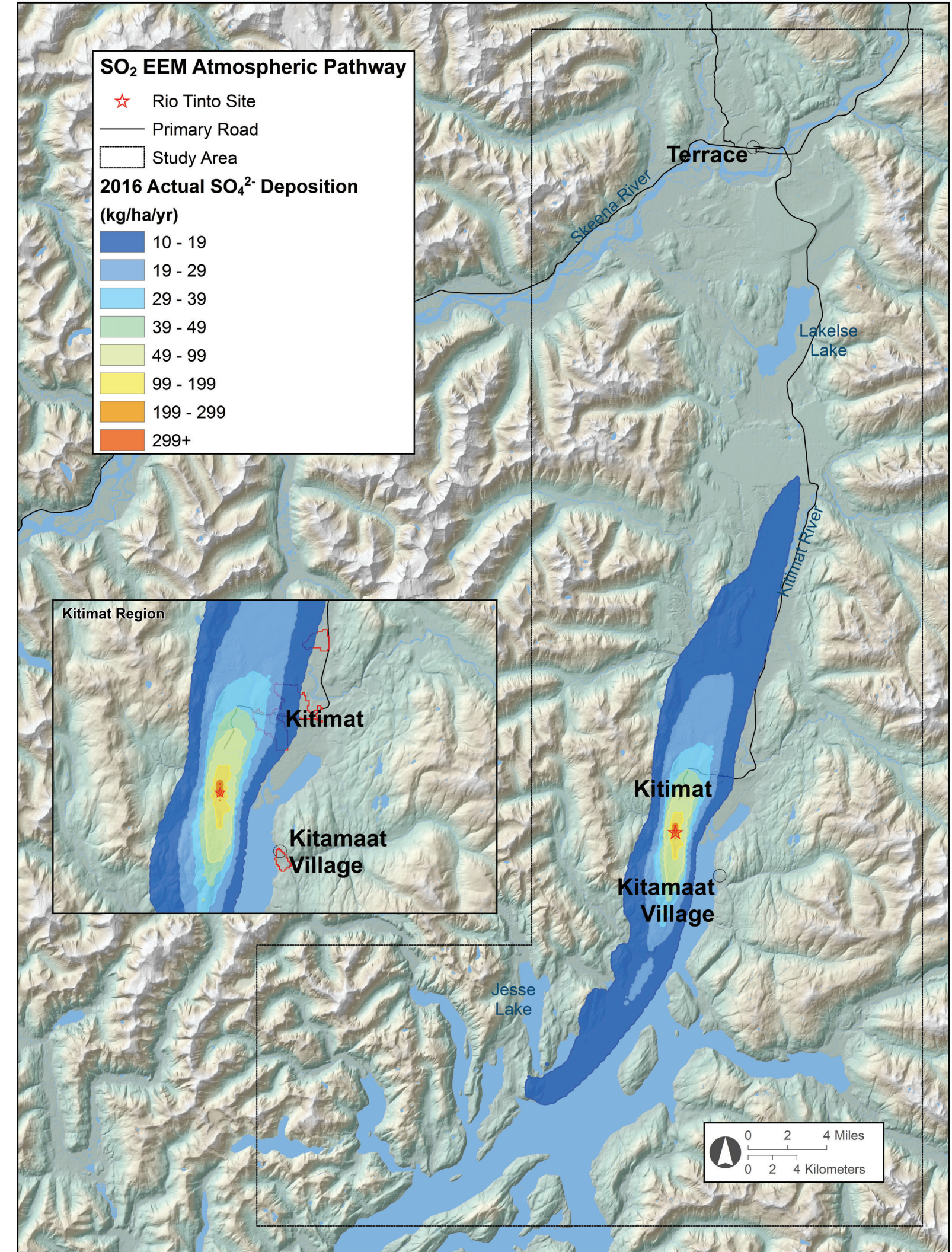
0 1 2 Kilometers

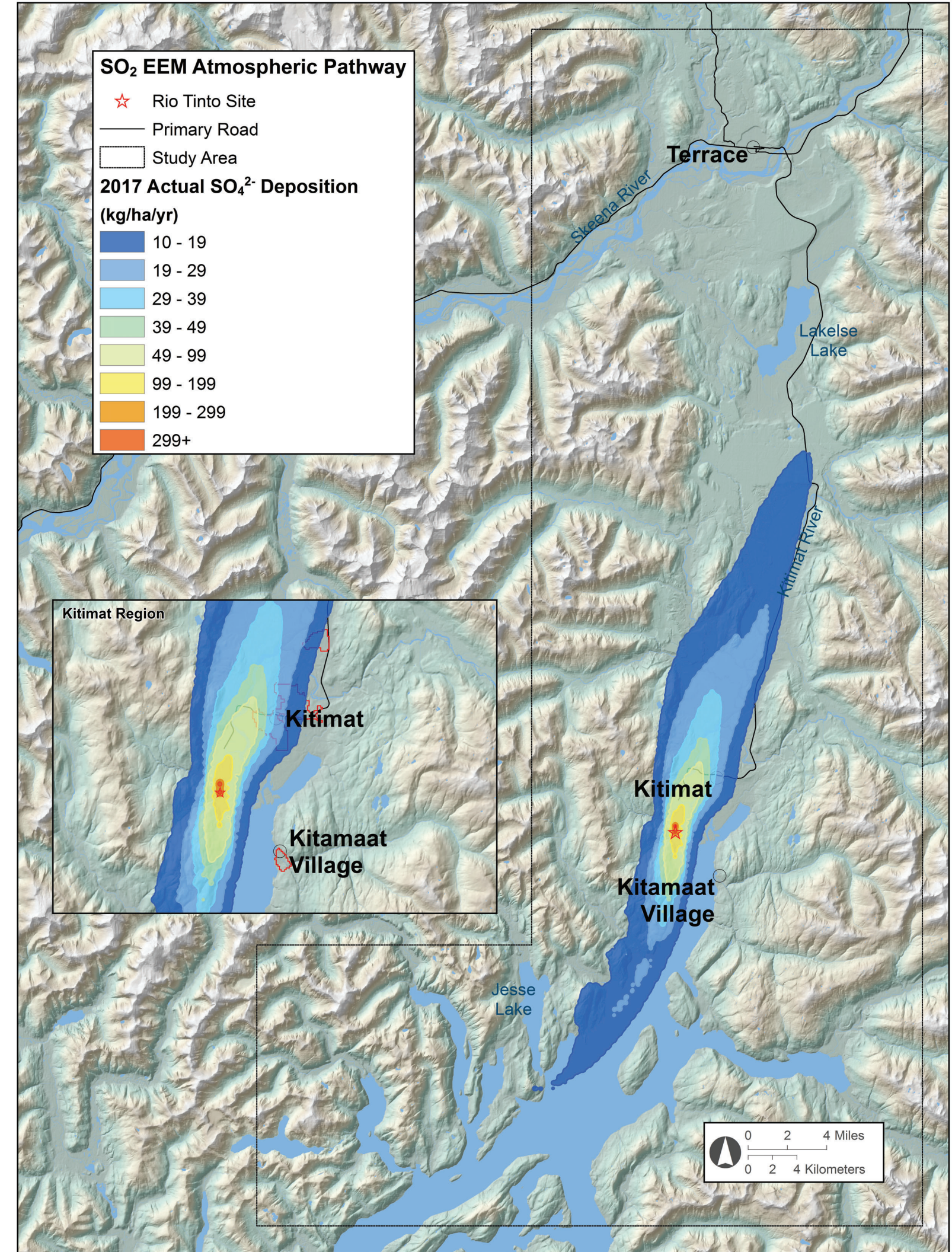

SO_2 EEM Atmospheric Pathway
Rio Tinto Site
Primary Road
Study Area
2016 Annual Actual (ppb)
(Includes background of 0.47 ppb)
0 - 1.25
1.25 - 2.5
2.5 - 4
4 - 5
5 - 10
10+
Terrace
Skeena River
Lakelse Lake
Kitimat River
Kitimat Region
Kitimat
Kitamaat Village
Kitimat
Kitamaat Village
Jesse Lake
0 2 4 Miles
0 2 4 Kilometers

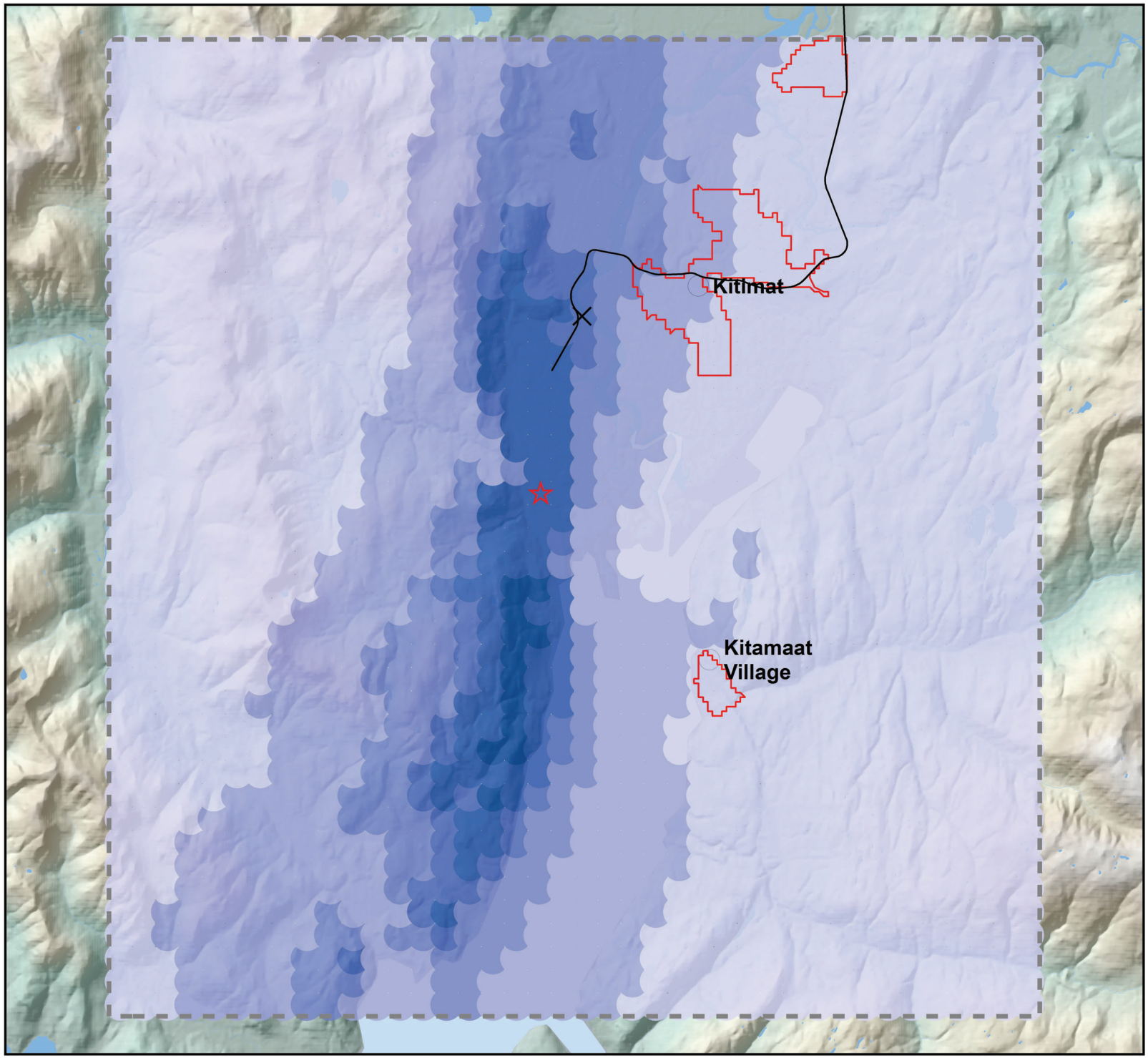

SO_2 EEM Atmospheric Pathway
Rio Tinto Site
Primary Road
Study Area
2017 Annual Actual (ppb)
(Includes background of 0.47 ppb)
0 - 1.25
1.25 - 2.5
2.5 - 4
4 - 5
5 - 10
10 +
Terrace
Skeena River
Lakelse Lake
Kitimat River
Kitimat Region
Kitimat
Kitamaat Village
Kitimat
Kitamaat Village
Jesse Lake
0 2 4 Miles
0 2 4 Kilometers


SO2 EEM Atmospheric Pathway
Rio Tinto Site
Primary Road
Study Area
2016 1-hr Actual (ppb)
(Includes background of 5.53 ppb)
0 - 17.5
17.5 - 35
35 - 65
65 - 70
70 - 140
140+
Terrace
Skeena River
Lakelse Lake
Kitimat River
Kitimat Region
Kitimat
Kitamaat Village
Kitimat
Kitamaat Village
Jesse Lake
0 2 4 Miles
0 2 4 Kilometers


SO2 EEM Atmospheric Pathway
Rio Tinto Site
Primary Road
Study Area
2017 1-hr Actual (ppb)
(Includes background of 5.53 ppb)
0 - 17.5
17.5 - 35
35 - 65
65 - 70
70 - 140
140 +
Terrace
Skeena River
Lakelse Lake
Kitimat River
Kitimat Region
Kitimat
Kitamaat Village
Kitimat
Kitamaat Village
Jesse Lake
0 2 4 Miles
0 2 4 Kilometers


SO_2 EEM Atmospheric Pathway
Rio Tinto Site
Primary Road
Study Area
2016 Actual SO_4^{2-} Deposition
(kg/ha/yr)
10 - 19
19 - 29
29 - 39
39 - 49
49 - 99
99 - 199
199 - 299
299+
Terrace
Skeena River
Lakelse Lake
Kitimat River
Kitimat Region
Kitimat
Kitamaat Village
Kitimat
Kitamaat Village
Jesse Lake
0 2 4 Miles
0 2 4 Kilometers


SO_2 EEM Atmospheric Pathway
Rio Tinto Site
Primary Road
Study Area
2017 Actual SO_4^{2-} Deposition
(kg/ha/yr)
10 - 19
19 - 29
29 - 39
39 - 49
49 - 99
99 - 199
199 - 299
299+
Terrace
Skeena River
Lakelse Lake
Kitimat River
Kitimat Region
Kitimat
Kitamaat Village
Kitimat
Kitamaat Village
Jesse Lake
0 2 4 Miles
0 2 4 Kilometers



SO_2 EEM Atmospheric Pathway

- Rio Tinto Site
- Kitimat River Water Intake
- Primary Road
- Residential Area
- Study Area

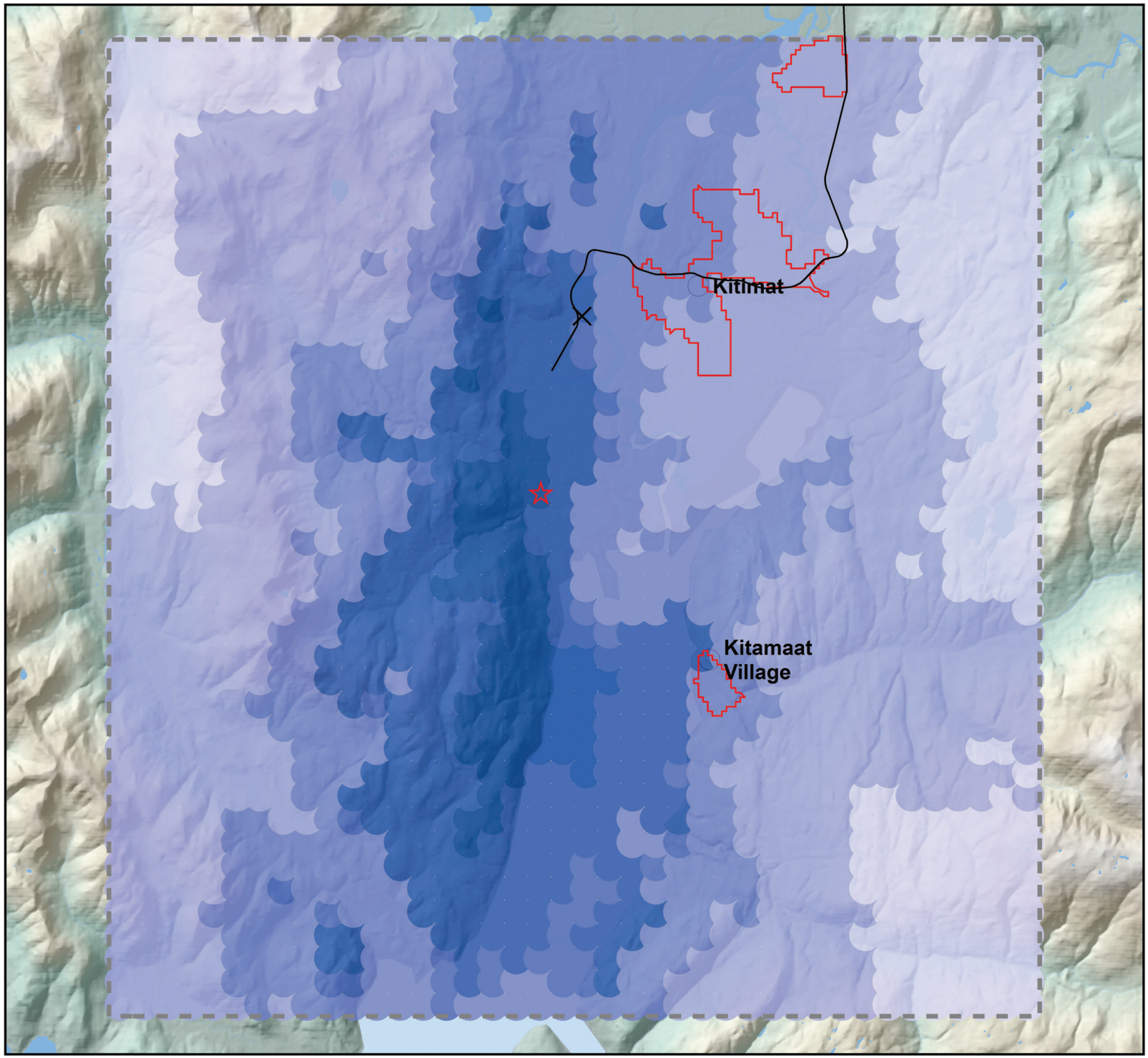
2016 Annual Actual (ppb)

(Includes background of 0.47 ppb)

- 0 - 1.25
- 1.25 - 2.5
- 2.5 - 4
- 4 - 5
- 5 - 10
- 10+

0 0.9 1.8 Miles

0 1 2 Kilometers



SO_2 EEM Atmospheric Pathway

- Rio Tinto Site
- Kitimat River Water Intake
- Primary Road
- Residential Area
- Study Area

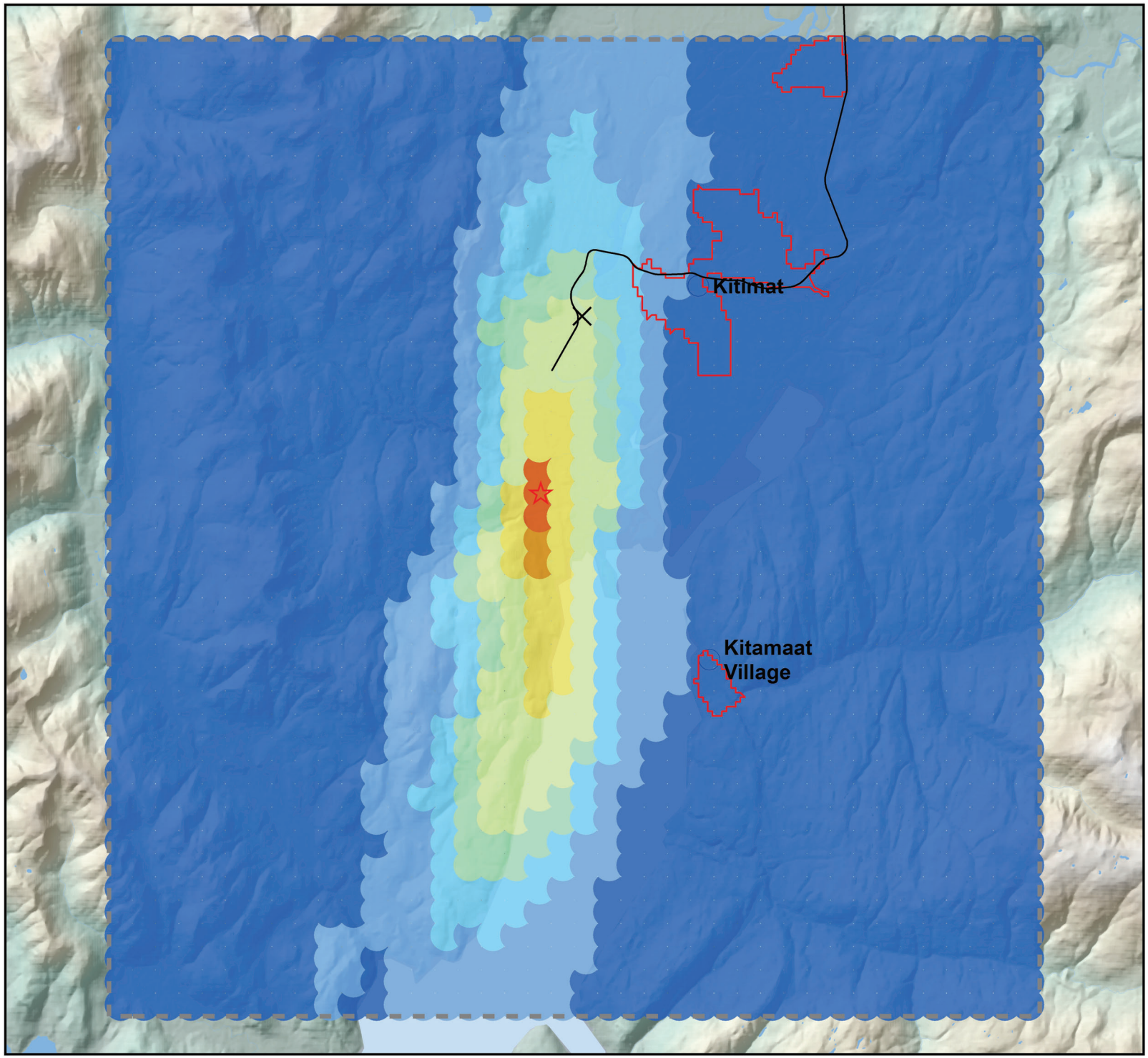
2016 1-hr Actual (ppb)

(Includes background of 5.53 ppb)

- 0 - 17.5
- 17.5 - 35
- 35 - 65
- 65 - 70
- 70 - 140
- 140+

0 0.9 1.8 Miles

0 1 2 Kilometers



SO_2 EEM Atmospheric Pathway

- Rio Tinto Site
- Kitimat River Water Intake
- Primary Road
- Residential Area
- Study Area

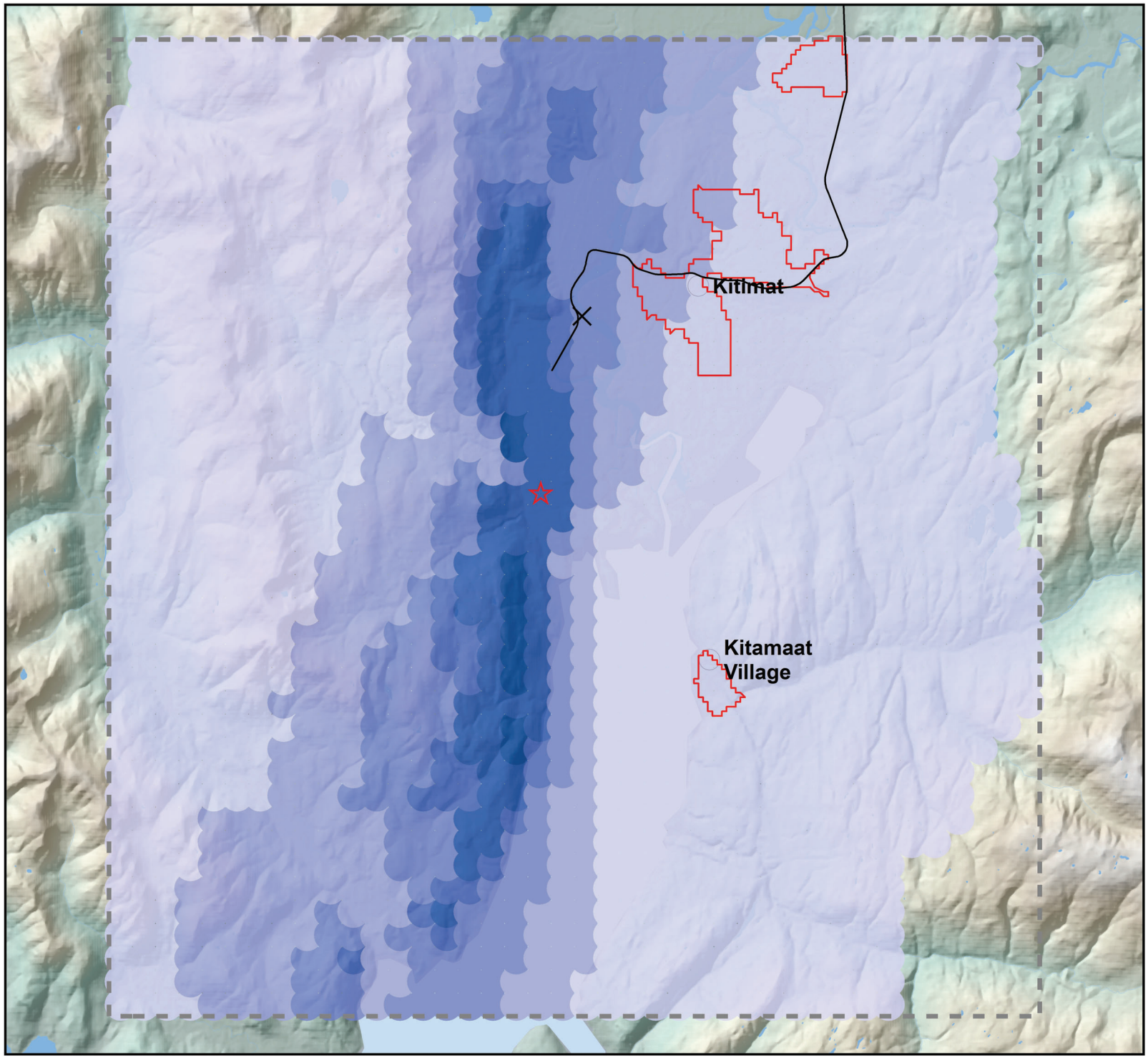
2016 Actual SO_4^{2-} Deposition

(kg/ha/hr)

- 10 - 19
- 19 - 29
- 29 - 39
- 39 - 49
- 49 - 99
- 99 - 199
- 199 - 299
- 299+

0 0.9 1.8 Miles

0 1 2 Kilometers



SO_2 EEM Atmospheric Pathway

- Rio Tinto Site
- Kitimat River Water Intake
- Primary Road
- Residential Area
- Study Area

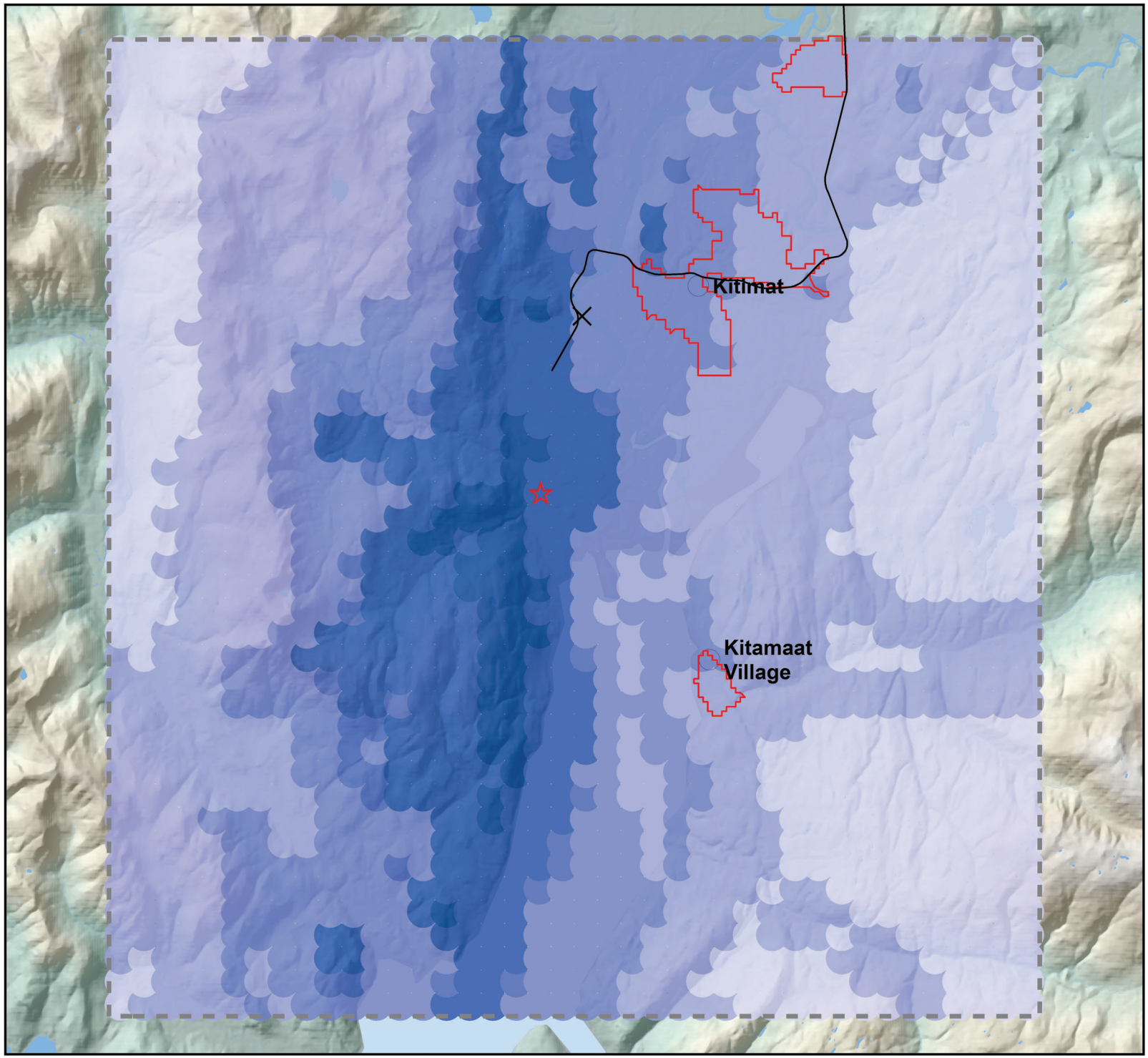
2017 Annual Actual (ppb)

(Includes background of 0.47 ppb)

- 0 - 1.25
- 1.25 - 2.5
- 2.5 - 4
- 4 - 5
- 5 - 10
- 10+

0 0.9 1.8 Miles

0 1 2 Kilometers



SO_2 EEM Atmospheric Pathway

- Rio Tinto Site
- Kitimat River Water Intake
- Primary Road
- Residential Area
- Study Area

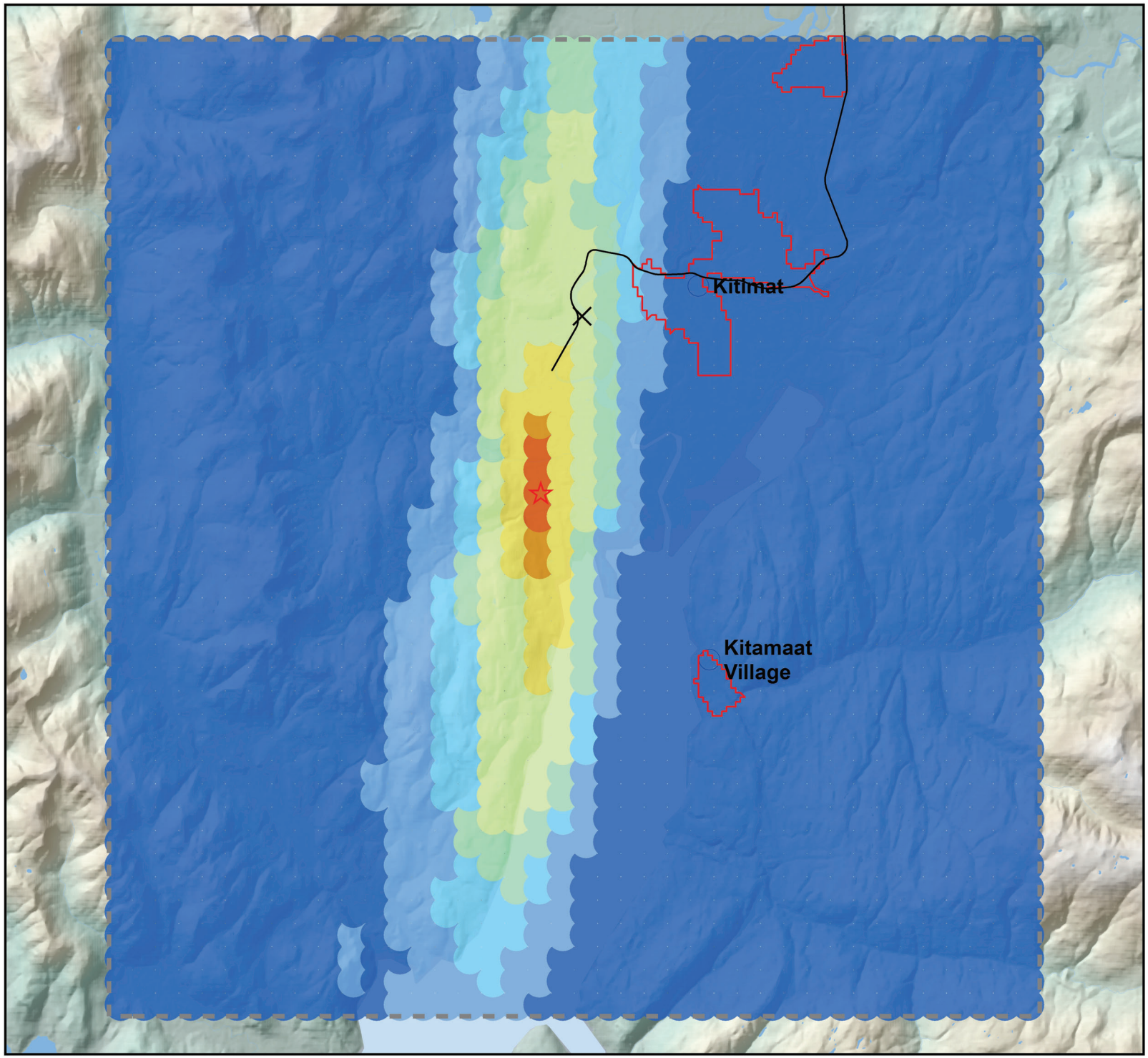
2017 1-hr Actual (ppb)

(Includes background of 5.53 ppb)

- 0 - 17.5
- 17.5 - 35
- 35 - 65
- 65 - 70
- 70 - 140
- 140+

0 0.9 1.8 Miles

0 1 2 Kilometers



SO_2 EEM Atmospheric Pathway

- Rio Tinto Site
- Kitimat River Water Intake
- Primary Road
- Residential Area
- Study Area

2017 Actual SO_4^{2-} Deposition

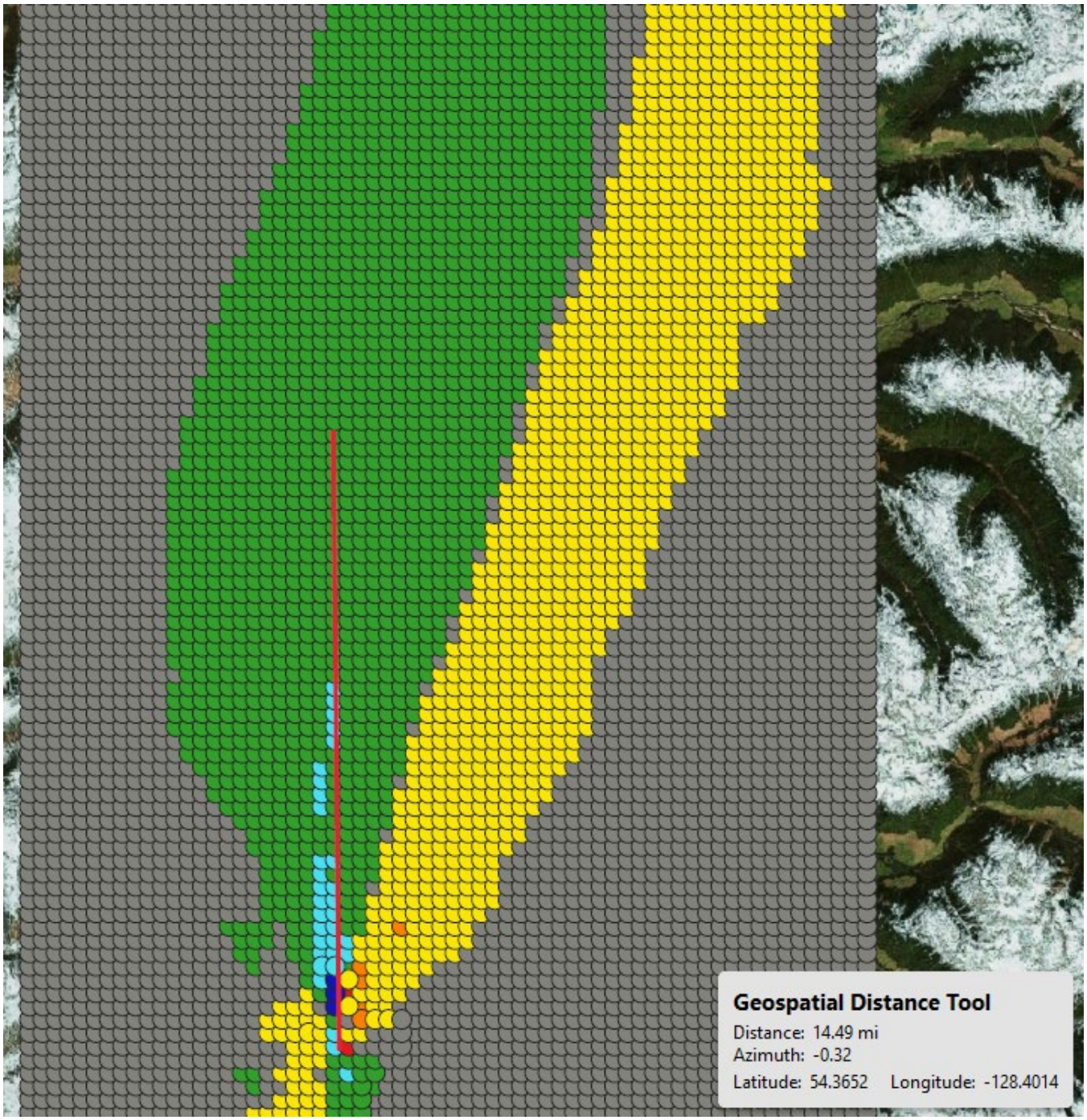
(kg/ha/yr)

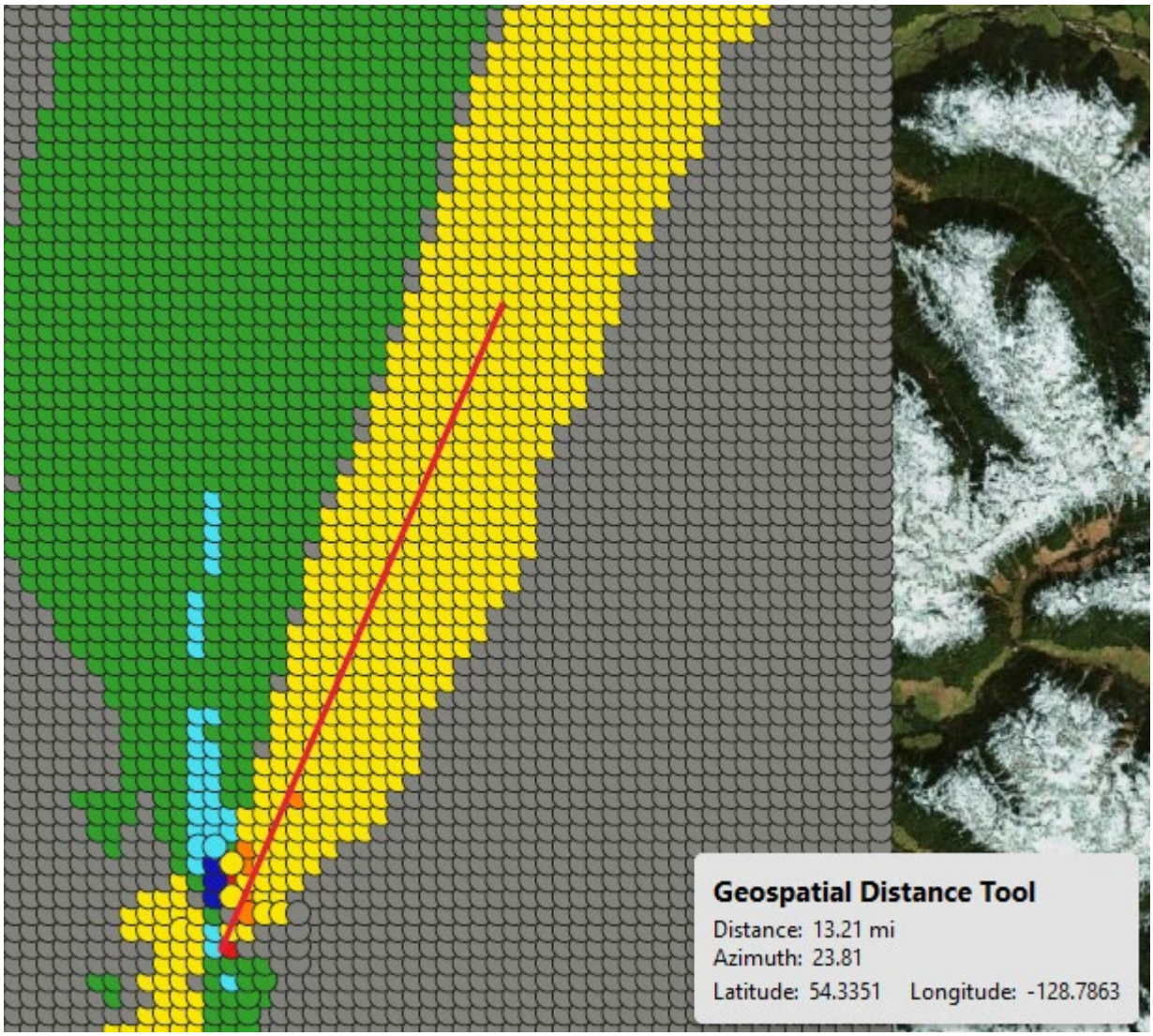
- 10 - 19
- 19 - 29
- 29 - 39
- 39 - 49
- 49 - 99
- 99 - 199
- 199 - 299
- 299+

0 0.9 1.8 Miles

0 1 2 Kilometers

Attachment 2
2018 Initial Model Measurements


Geospatial Distance Tool
Distance: 14.49 mi
Azimuth: -0.32
Latitude: 54.3652 Longitude: -128.4014


Geospatial Distance Tool
Distance: 13.21 mi
Azimuth: 23.81
Latitude: 54.3351 Longitude: -128.7863

Attachment 3
Model Performance Evaluation

MODEL PERFORMANCE EVALUATION

Regional scale model performance evaluation

The SO_2 concentrations predicted by the updated CALPUFF model for the actual scenario (actual emission rates, varying monthly) are compared to monitoring data to understand and evaluate the CALPUFF model performance. Only 2016 and 2017 are evaluated due to the Yacht Club missing wind speed data in 2018. For model performance evaluation, more realistic background values are used based on Williams Lake SO_2 monitoring data. The lower, more realistic background values are needed for model evaluation, so we can better understand model performance in areas with low SO_2 concentrations. If the Terrace-Skeena background used for effects assessments had been used for model evaluation, the model results in low concentration areas would be skewed. For example, even if the model result had been zero, the comparison using Terrace-Skeena for background would have shown the model over-predicted annual average concentrations at Kitamaat Village and Whitesail, because the Terrace-Skeena annual average SO_2 concentrations were higher than the Kitamaat Village and Whitesail annual average concentrations.[2]

SO_2 concentration results are calculated by CALPUFF in units of micrograms per meter cubed ($\mu g/m^3$). However, this appendix often presents SO_2 results in units of parts per billion (ppb) in order to stay consistent with the monitoring data and the CAAQS. It is possible to move between ppb and $\mu g/m^3$ by a factor of 2.614 $(\mu g/m^3)/(ppb)$.[3]

Evaluation of annual and individual hourly results and maximum hourly summary results are performed and summarized in Table A-1 and A-2 below. For annual average results, the updated model slightly improved over-prediction at Haul Road and Kitamaat Village and slightly increased over-prediction at Riverlodge and Whitesail. The model continues to over-predict the 99th percentile of daily 1-hour peak concentration at all stations and years, except now 2016 shows a slight under-prediction at Kitamaat Village. This one under-prediction was only slightly lower (19 ppb model result compared to 20 ppb), and previous 2018 CR results had also slightly under-predicted at Kitamaat Village. For all other comparisons, the model over-predicted by 20% (2017 Kitamaat Village) to 47% (2016 Whitesail), aligning fairly closely to CR comparisons which had a maximum 1-hour 99% over-prediction of 51% (also at Whitesail in 2016).[4]

[2] The Terrace-Skeena annual average concentrations were 0.4 to 0.5 ppb in 2016 – 2018. The Kitamaat Village annual average concentrations were 0.20 to 0.38 ppb, and Whitesail annual average concentrations were 0.41 ppb in 2017 and 0.35 ppb in 2018.

Based on 2017 and 2018 data, the Williams Lake background concentrations are 1.8 ppb for the 1-hour, 99th percentile daily peak SO_2: 1.8 ppb; and 0.26 ppb for annual average.

[3] The 2.614 $(\mu g/m^3)/(ppb)$ factor converts from a mass concentration basis to a volume concentration basis of SO_2 based on the molecular weight of SO_2 and standard atmospheric conditions. In this case, standard conditions are 1 atm and approximately 25 C, precisely corresponding to the 1-hour SO_2 B.C. AQO levels listed of 70 ppb and 183 $\mu g/m^3$ (https://www2.gov.bc.ca/assets/gov/environment/air-land-water/air/reports-pub/aqotable.pdf).

[4] Percentage under-prediction or over-prediction calculated as the difference between the CALUFF result and observation, as a percent of the CALPUFF result.

Table A3-1. Summary of CALPUFF Model Comparison to Continuous Monitoring Data, Annual Average SO_2 (ppb).

	Monitoring Data [1] (SO_2 ppb)	Original CR CALPUFF [2] (SO_2 ppb)	Corrected CALPUFF [2] (SO_2 ppb)	Monitoring Data [1] (SO_2 ppb)	Original CR CALPUFF [2] (SO_2 ppb)	Corrected CALPUFF [2] (SO_2 ppb)
	2016			2017		
Kitamaat Village	0.38	0.58	0.54	0.29	0.52	0.51
Haul Road	4.22	7.12	6.78	3.77	7.33	7.20
Riverlodge	0.50	1.49	2.15	0.43	1.54	2.02
Whitesail	0.53	0.82	1.17	0.41	0.86	1.15

[1] Monitoring data annual average for 2016, 2017.

[2] CALPUFF results for actual scenario, regional-scale using actual smelter emission rates from 2016 to 2018, varying monthly. Model results for performance evaluation apply a background based on Williams Lake (0.26 ppb), which is more appropriate to represent realistic results because we expect minimal contribution from non-smelter SO2 for 2016 – 2018 actual conditions. Results with a higher background are used for new model future 35 and 42 tpd effect assessment in order to be cautious in risk assessments. The annual average background concentration used for the new 2016 -2018 model is 0.47 ppb based on monitoring at Terrace-Skeena Middle School.

Table A3-2. Summary of regional scale CALPUFF model comparison to continuous monitoring data, 99th percentile of daily 1-hour peak SO_2 (ppb).

	Monitoring Data [1] (SO_2 ppb)	Original CR CALPUFF [2] (SO_2 ppb)	Corrected CALPUFF [2] (SO_2 ppb)	Monitoring Data [1] (SO_2 ppb)	Original CR CALPUFF [2] (SO_2 ppb)	Corrected CALPUFF [2] (SO_2 ppb)
	2016			2017		
Kitamaat Village	20	25	19	12	17	15
Haul Road	75	99	108	66	100	105
Riverlodge	22	34	40	28	37	42
Whitesail	15	30	28	21	41	35

[1] Monitoring data 1-hour average for 2016, 2017.

[2] CALPUFF results for actual scenario, regional-scale using actual smelter emission rates from 2016 to 2017, varying monthly. Model results for performance evaluation apply a background based on Williams Lake (1.8 ppb), which is more appropriate to represent realistic results because we expect minimal contribution from non-smelter SO_2 for 2016 – 2018 actual conditions. Results with a higher background (5.53 ppb based on monitoring at Terrace-Skeena Middle School) are used for new model future 35 and 42 tpd effect assessment in order to be cautious in risk assessments.

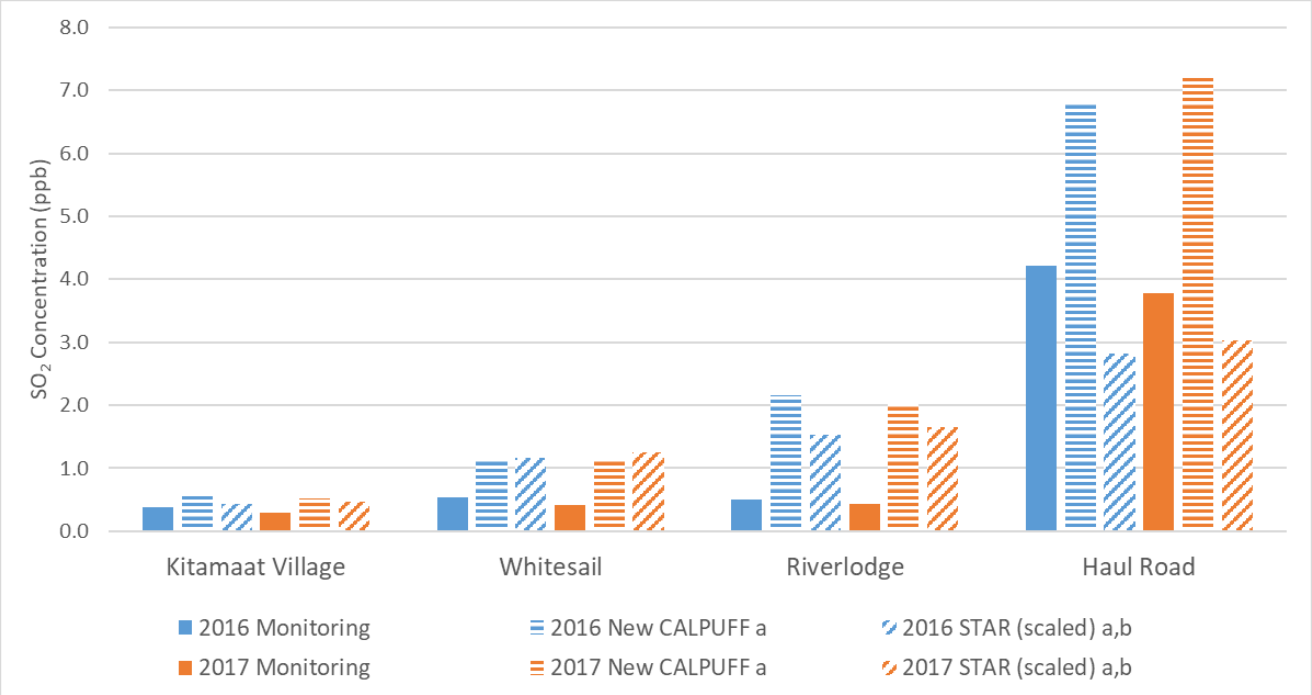


Figure A3-1. Continuous SO_2 (ppb) monitoring concentrations compared to updated CALPUFF model results and scaled STAR model concentrations, 99% of 1-hour daily peak, regional-scale (Williams Lake 1-hour background of 1.8 ppb applied).

Table A3-3 below provides the performance statistics for the regional-scale model for both the original CR model and the updated model. The original CR model statistics are provided in gray text as reference. Overall, the performance statistics are similar between the two models, with some slight improvements for Kitimaat Village and Haul Road and slightly higher error for Riverlodge and Whitesail. The root mean squared error (RMSE), mean bias error (MBE), and mean absolute error (MAE) represent the difference (or error) between the model result versus the observation at each monitor for each hour (paired in space and time as illustrated in Figure A3-2). The MBE represents the same differences seen when comparing the annual average concentrations. The MBE values indicate that the updated model overall slightly under-predicts at Kitamaat Village, slightly over-predicts Whitesail and over-predicts moderately at Haul Road and Riverlodge. The MAE indicates the mean error is larger when looking at absolute error for each hour, averaged over the two model years. For example, the model over-predicts some hours and under-predicts some hours, which averages out to only -0.2 $\mu g/m^3$ for Kitamaat Village, but the average over-prediction or under-prediction is approximately 1.22 $\mu g/m^3$ when looking at the absolute difference. The percentages are provided to demonstrate that while the Haul Road has the largest MBE and MAE on an absolute basis, the 18.9 $\mu g/m^3$ error put in context as a percentage of the monitored concentration is lower than Whitesail, which has an MAE of only 2.7 $\mu g/m^3$.

Table A3-3. Regional scale model performance evaluation statistics. Williams Lake annual background of 0.27 ppb, (0.69 μg/m^3) is applied.

Model	Monitor	RMSE (μg/m^3)	MBE (μg/m^3)	MAE (μg/m^3)	MBE% [1]	MAE% [1]
Original CR Model	Kitamaat Village	3.60	0.66	1.27	87%	167%
	Haul Road	34.06	8.49	17.72	83%	174%
	Riverlodge	9.47	2.86	3.71	235%	304%
	Whitesail	6.16	1.21	2.10	109%	189%
Updated Model (Corrected for Wind Direction)	Kitamaat Village	3.26	-0.20	1.22	-23%	139%
	Haul Road	35.69	7.08	18.86	68%	181%
	Riverlodge	10.93	3.49	4.68	287%	385%
	Whitesail	7.28	1.12	2.72	91%	222%

[1] MBE% and MAE% are expressed as MBE and MAE divided by the annual average observed concentrations, respectively, at each receptor.

Dispersion models are not expected to agree perfectly when paired in time and space (as done for the Table A3-3 performance statistics). In addition, the ability to predict an accurate annual average and 99th percentile daily peak (even if the day is not the same) is the most important metric for evaluating the model's ability to accurately predict future concentrations or deposition rates to assess risk of impacts to receptors. As such, quantile-quantile plots (Q-Q plots) are commonly used to evaluate model performance. Figure A3-2 illustrates the comparison paired in time (max hour each day from 2016 to 2018 for visualizing), while Figure A3-3 compares the hourly model data (all hours from 2016 to 2018) versus monitoring data sorted highest to lowest (Q-Q plot). The comparisons illustrate that the model predicts concentrations and distribution similar to monitoring data at each station (e.g., Kitamaat Village concentrations are low (below 10 ppb) most days with a few (5 to 10) occurrences of 1-hour peaks in the 20 – 30 ppb range for both datasets). However, while the model's overall predictions compare closely to the monitored concentrations, the model results do not generally predict the peaks on the same day or hour.

The Q-Q plots in Figure A3-3 and A-4 illustrate that the model generally predicts concentrations between 100% and 200% of the monitored concentrations, with the exception of slight under-prediction at Kitamaat Village for the two highest hours over and some over-prediction above 200% at the lowest quantile concentrations, particularly for Riverlodge and Haul Road. The updated model performance is about the same at all stations with some slight improvements at Haul Road.

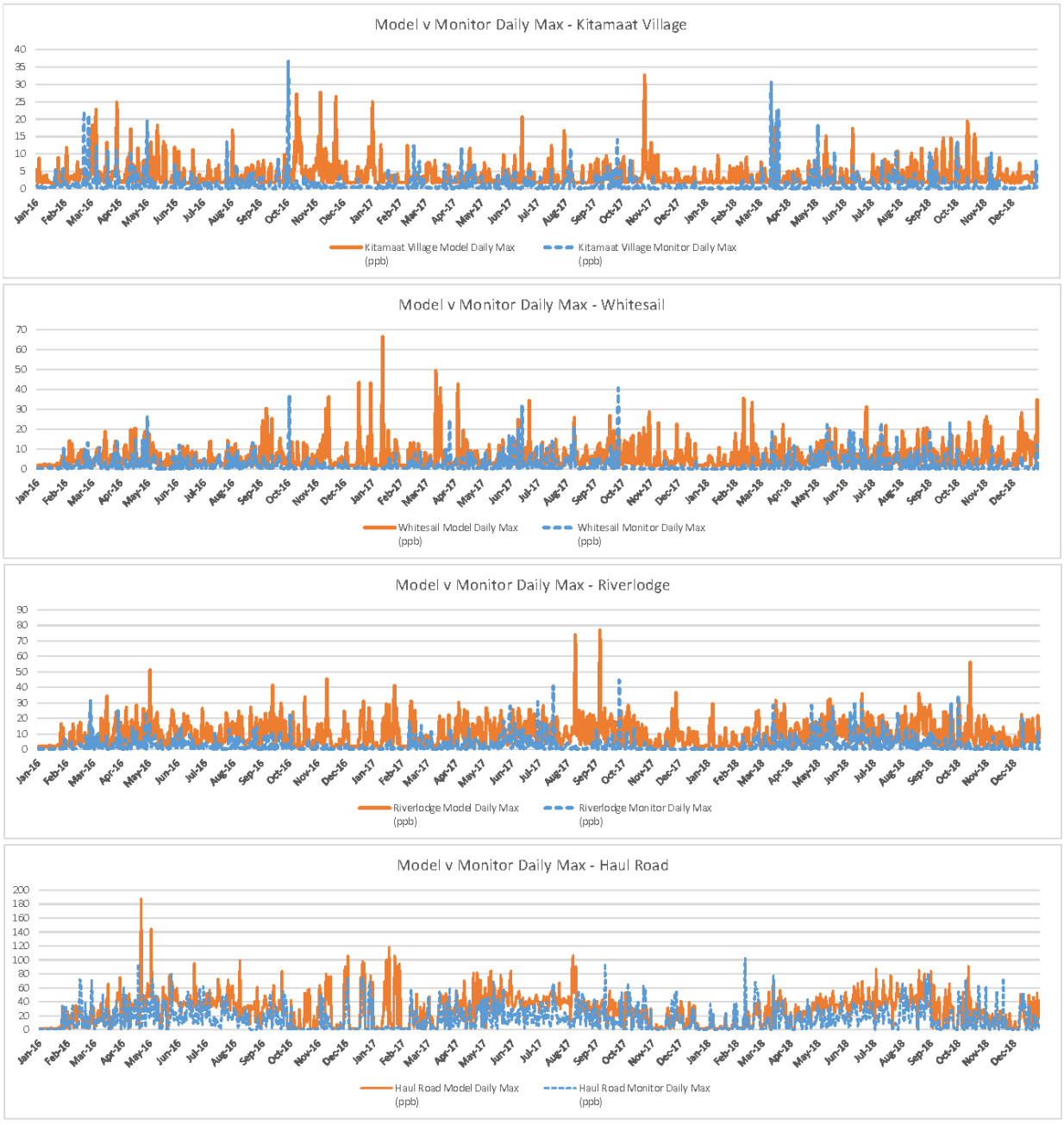


Figure A3-2. Comparison of modelled SO_2 concentrations (actual scenario) against continuous monitoring network SO_2, 2016-2018, timeseries (paired in time). The model data include the 1-hour background concentration (1.80 ppb).

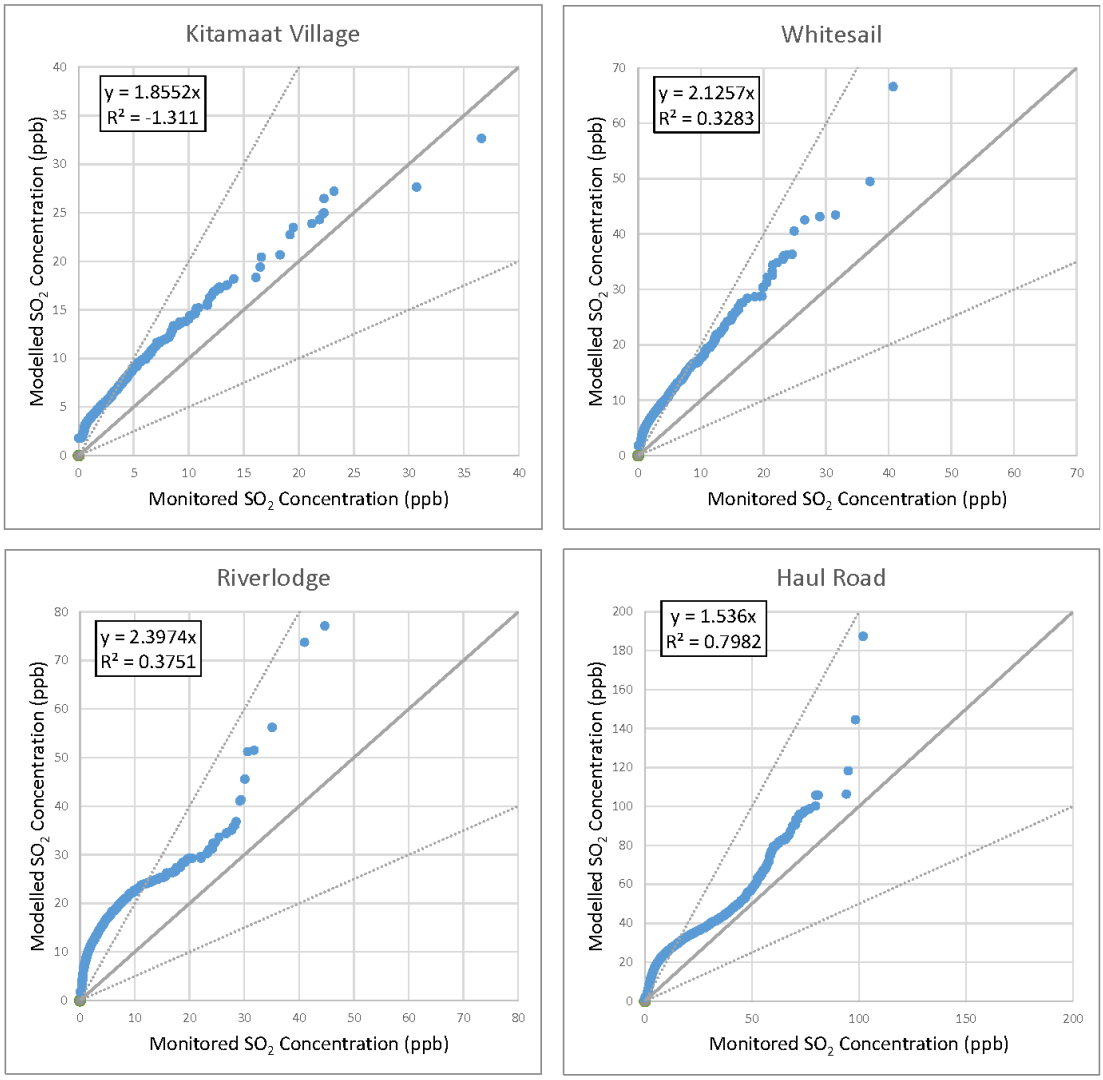


Figure A3-3. Comparison of original CR model SO_2 concentrations (actual scenario) against continuous monitoring network SO_2, 2016-2018, Q-Q plot (ordered by rank). The 1-to-1 line (solid) and 2-to-1 lines (dashed) are shown. Best fit linear regression equation and R^2 value shown for 0 intercept. The model data include the model performance 1-hour background concentration (1.80 ppb at Williams Lake).

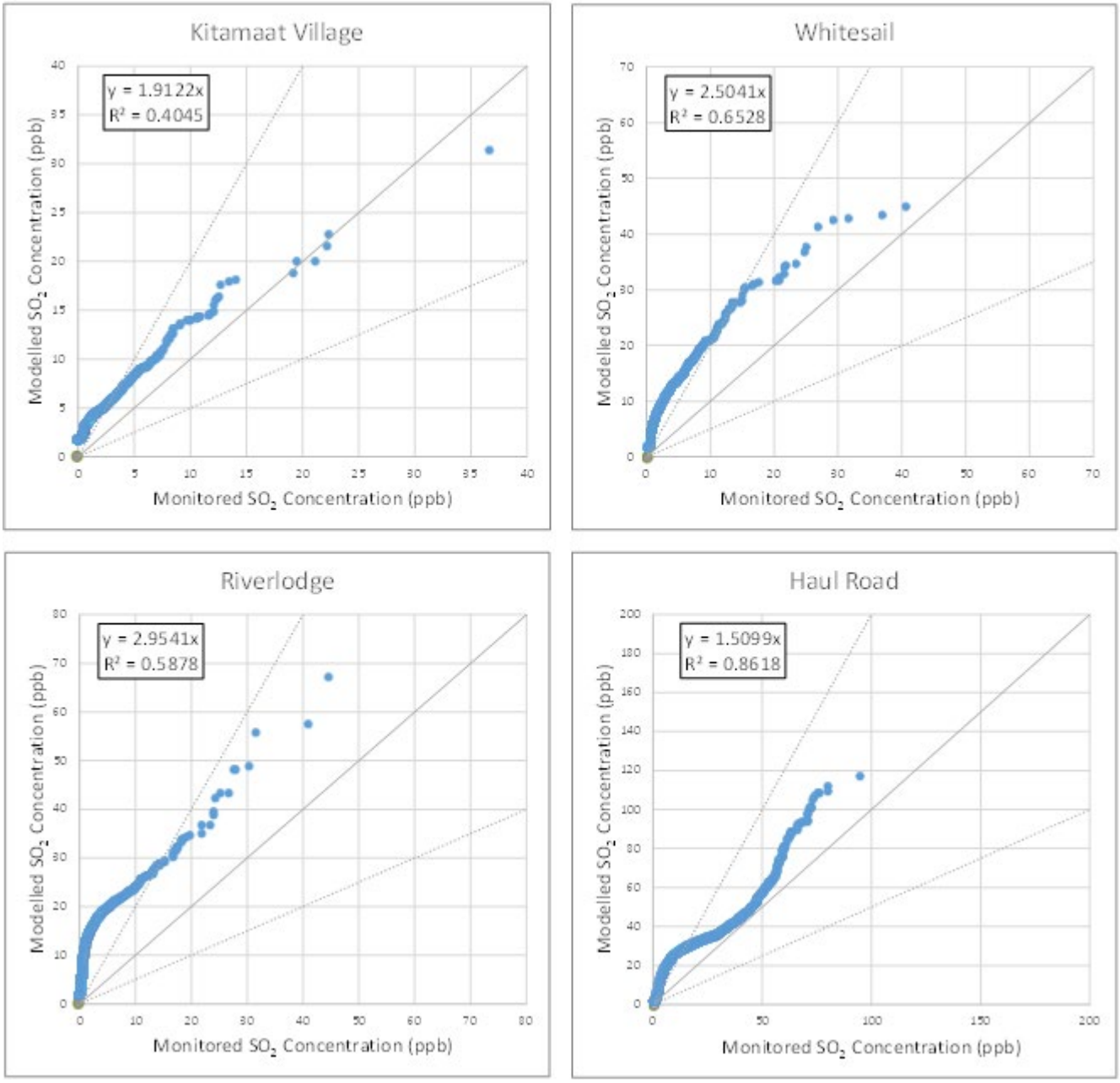


Figure A3-4. Comparison of updated model SO_2 concentrations (actual scenario) against continuous monitoring network SO_2, 2016-2018, Q-Q plot (ordered by rank). The 1-to-1 line (solid) and 2-to-1 lines (dashed) are shown. Best fit linear regression equation and R^2 value shown for 0 intercept. The model data include the model performance 1-hour background concentration (1.80 ppb at Williams Lake).

We also used the passive sampling measurements to evaluate the 2016–2017 CALPUFF model performance. Model data were averaged over the same periods as measured by the passive samplers for each sampling period at each site. As shown in the following tables and figures, the updated regional CALPUFF model performance is similar to the CR model performance. Both models over-predict long term (June – October) average concentrations in most locations (model results 150% to 500% of monitored concentrations). For the comparison that over-predicted at the highest rate, the corrected model over-predicts more-so: at V00 on the east side of the valley the updated model predicts 7 µg/m^3 versus 5 µg/m^3 modelled in the CR

compared to 0.34 µg/m^3 measured (only monitored in 2016). Model concentrations at the few sites to the south of the smelter (V11 - V13) remained generally lower than the monitored concentrations (under-predictions), ranging from 69% (V13 in 2017) to 127% (V12 in 2016) of monitored concentrations. Site V10 near the smelter's west boundary, maintained fairly good agreement with model results, but changed from agreeing very closely (model/monitor of 101%, 121%, and 102%) to slight under-predictions (78% and 77%). Overall, the updated model over-predicts to a lesser degree at the majority of the valley network sites compared to the original CR model and results in higher over-prediction at the urban sites.

Table A-4. Regional scale model CALPUFF compared to passive monitoring data - 2016.

Sensor ID	UTM X (m)	UTM Y (m)	Passive Average [a] (µg/m^3)	CALPUFF Original Average [b] (µg/m^3)	CALPUFF Original/ Passive	CALPUFF Corrected Average [b] (µg/m^3)	CALPUFF Corrected/ Passive
V00	530,167	6,016,477	0.34	5.02	1457%	7.02	2039%
V01	524,948	6,017,458	1.80	5.38	300%	3.81	212%
V02	523,130	6,015,390	1.47	5.49	373%	3.30	224%
V03	520,931	6,009,416	2.99	5.73	192%	2.79	93%
V04	520,767	6,003,740	0.92	8.80	959%	4.69	511%
V05	520,539	5,999,300	3.17	11.29	356%	6.63	209%
V06	520,944	5,996,297	2.27	9.22	406%	9.10	401%
V07	521,361	5,993,907	1.35	6.54	483%	8.99	663%
V08	519,935	5,992,321	3.94	13.05	331%	11.44	290%
V09	518,980	5,989,246	4.68	24.03	513%	18.51	395%
V10	519,028	5,985,441	7.13	7.23	101%	5.59	78%
V11	519,426	5,979,635	7.53	5.79	77%	5.46	72%
V12	518,339	5,977,238	4.96	6.45	130%	6.28	127%
V14/U12	520,488	5,990,243	2.11	8.10	384%	10.01	475%
A01	519,527	5,986,823	8.78	23.43	267%	24.48	279%
A02	521,538	5,989,580	0.81	4.61	572%	6.69	830%
A03	523,619	5,991,025	0.64	2.82	439%	3.66	569%
A04	527,457	6,025,573	0.61	4.02	656%	3.48	569%
U01	522,026	5,988,725	0.62	3.72	602%	4.42	714%
U02	522,781	5,989,708	0.60	3.29	545%	3.80	630%
U03	524,345	5,989,883	0.59	2.51	428%	2.87	490%
U04	524,362	5,990,295	0.57	2.51	440%	2.88	505%
U05	525,606	5,993,817	0.31	2.23	724%	2.58	837%
U06	522,947	5,989,308	0.73	3.02	413%	3.45	471%
U07	522,841	5,988,229	0.55	2.96	542%	3.27	598%
U08	522,866	5,991,066	0.76	3.86	509%	5.01	662%
U09	523,917	5,990,370	0.52	2.33	449%	2.39	460%
U10	523,807	5,991,260	0.65	2.96	456%	3.75	579%
U11	523,311	5,989,855	0.70	3.20	457%	3.81	544%
U13	524,981	5,989,675	0.67	2.29	341%	2.54	379%
U14	522,286	5,989,250	0.68	3.57	522%	4.25	621%
U15	523,232	5,980,798	0.47	2.05	436%	1.96	418%

[a] The passive data in this table is not adjusted for calibration with the continuous SO_2 analyzers.

[b] The following background value from Williams Lake is added to account for non-modelled sources of SO_2.

30-day Average Background: 0.46 ppb 1.21 (µg/m^3)

(2nd High over 2017-2018, 96th%) (1ppb = 2.614 µg/m^3 SO_2)

Table A-5. Regional scale model CALPUFF compared to passive monitoring data - 2017.

Sensor ID	UTM X (m)	UTM Y (m)	Passive Average [a] (µg/m³)	CALPUFF Average [b] (µg/m³)	CALPUFF/ Passive	CALPUFF Corrected Average [b] (µg/m³)	CALPUFF Corrected/ Passive
V01	524,948	6,017,458	1.97	5.53	280%	3.66	185%
V02	523,130	6,015,390	1.52	5.05	332%	3.11	204%
V03	520,931	6,009,416	4.24	7.27	171%	3.75	88%
V04	520,767	6,003,740	2.05	10.48	512%	5.85	286%
V04B	520,436	6,003,249	2.15	10.74	500%	2.07	97%
V05	520,539	5,999,300	5.41	11.75	217%	7.36	136%
V06	520,944	5,996,297	3.89	10.74	276%	9.63	247%
V07	521,361	5,993,907	2.08	8.60	413%	9.64	463%
V07B	520,285	5,993,190	3.48	13.26	381%	2.79	80%
V08	519,935	5,992,321	6.18	13.38	216%	11.65	188%
V09	518,980	5,989,246	7.88	29.54	375%	21.82	277%
V10	519,028	5,985,441	10.40	12.59	121%	7.97	77%
V11	519,426	5,979,635	7.91	6.06	77%	6.06	77%
V12	518,339	5,977,238	5.36	5.84	109%	6.05	113%
V13	516,405	5,976,686	5.50	3.61	66%	3.29	60%
V14/U12	520,488	5,990,243	3.28	11.93	364%	12.57	384%
A01	519,527	5,986,823	10.73	24.32	227%	23.70	221%
A02	521,538	5,989,580	1.01	5.42	538%	6.90	684%
A03	523,619	5,991,025	0.83	3.08	370%	3.59	431%
A04	527,457	6,025,573	0.76	4.39	580%	3.42	452%
U01	522,026	5,988,725	0.91	3.82	419%	4.17	457%
U02	522,781	5,989,708	0.76	3.23	427%	3.48	461%
U03	524,345	5,989,883	0.77	2.69	350%	2.66	346%
U04	524,362	5,990,295	0.85	2.68	313%	2.69	314%
U05	525,606	5,993,817	0.33	2.34	716%	2.52	773%
U06	522,947	5,989,308	0.88	2.97	339%	3.05	348%
U07	522,841	5,988,229	0.81	2.84	352%	2.86	353%
U08	522,866	5,991,066	0.76	3.95	520%	5.22	688%
U09	523,917	5,990,370	0.87	2.84	326%	2.98	342%
U10	523,807	5,991,260	0.78	3.03	390%	3.54	455%
U11	523,311	5,989,855	0.93	3.17	339%	3.38	363%
U13	524,981	5,989,675	0.72	2.43	338%	2.35	328%
U14	522,286	5,989,250	0.89	3.64	409%	4.01	451%

[a] The passive data in this table is not adjusted for calibration with the continuous SO_2 analyzers.

[b] The following background value from Williams Lake is added to account for non-modelled sources of SO_2.

30-day Average Background: 0.46 ppb 1.21 (µg/m³)

(2nd High over 2017-2018, 96th%) (1ppb = 2.614 µg/m³ SO_2)

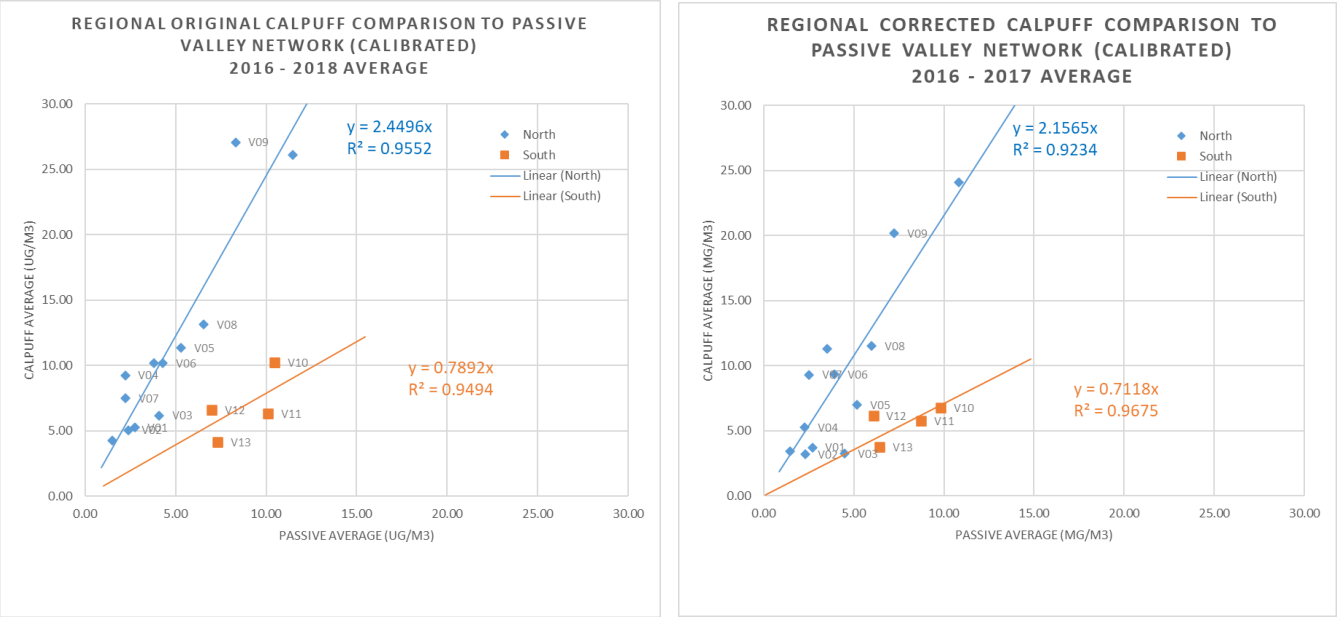


Figure A3-5. Comparison of modelled SO_2 concentrations (actual scenario) against average passive sample data in the valley network (calibrated passive data and background included in model results).

Figure A-16 compares model to monitor data for the original CALPUFF analysis (left) compared to the updated CALPUFF analysis (right). The updated model over-predicts to a lesser degree for the sites to the north (updated model prediction about 2.16 times measured levels compared to 2.45 times for the original CR model) and has slightly lower linear agreement (R^2 of 0.92 compared to 0.95). The sites to the south have a slightly lower under-prediction and slightly improved linear agreement in the updated model.

Local scale model performance evaluation

The local scale model performance evaluation followed the same approach as the regional scale evaluation with the exception that the passive monitoring data comparison is not used.

- Actual scenario (actual emission rates, varying monthly) CALPUFF results are compared to continuous monitoring data.
- For model performance evaluation, more realistic background values are used based on Williams Lake SO_2 monitoring data.

Table A3-6 and Figure A3-6 summarize comparison of annual average modelled concentrations estimated at each monitoring station compared to the monitoring data each year. Table A3-7 and Figure A3-7 summarize the 1-hour 99th percentile of daily peak concentrations. The local-scale model over-predicted both annual average and 99th percentile of daily 1-hour peak concentrations at all stations and years. The updated model over-predicted annual average concentrations by 16% (2016 Whitesail) to 74% (2016 Kitamaat Village) and 99th percentile of daily 1-hour peak at similar levels from 44% (2016 Haul Road) to 79% (2016 Riverlodge).[5] The local-scale updated (and original CR) model generally over-predicted concentrations more than the regional scale model, particularly at the Riverlodge monitor for annual average and the Kitamaat Village monitor for 1-hour.

Table A3-6. Summary of local scale CALPUFF model comparison to continuous monitoring data, annual average SO_2 (ppb).

	Monitoring Data [1] (SO_2 ppb)	Original CR CALPUFF [2] (SO_2 ppb)	Corrected CALPUFF [2] (SO_2 ppb)	Monitoring Data [1] (SO_2 ppb)	Original CR CALPUFF [2] (SO_2 ppb)	Corrected CALPUFF [2] (SO_2 ppb)
	2016			2017		
Kitamaat Village	0.38	1.43	0.98	0.29	0.63	0.54
Haul Road	4.22	7.92	7.56	3.77	8.14	7.85
Riverlodge	0.50	1.64	2.40	0.43	1.49	1.99
Whitesail	0.53	0.63	1.16	0.41	0.53	0.97

[1] Monitoring data annual average for 2016, 2017.

[2] CALPUFF results for actual scenario, local-scale using actual smelter emission rates from 2016 to 2017, varying monthly. Model results for performance evaluation apply a background based on Williams Lake (0.26 ppb), which is more appropriate to represent realistic results because we expect minimal contribution from non-smelter SO_2 for 2016 – 2018 actual conditions. Results with a higher background are used for new model future 35 and 42 tpd effect assessment in order to be cautious in risk assessments. The annual average background concentration used for the new 2016 -2018 model is 0.47 ppb based on monitoring at Terrace-Skeena Middle School.

[5] Percentage under-prediction or over-prediction calculated as the difference between the CALUFF result and observation, as a percent of the CALPUFF result.

Table A3-7. Summary of local scale CALPUFF model comparison to continuous monitoring data, 99th percentile of daily 1-hour peak SO_2 (ppb).

	Monitoring Data [1] (SO_2 ppb)	Original CR CALPUFF [2] (SO_2 ppb)	Corrected CALPUFF [2] (SO_2 ppb)	Monitoring Data [1] (SO_2 ppb)	Original CR CALPUFF [2] (SO_2 ppb)	Corrected CALPUFF [2] (SO_2 ppb)
	2016			2017		
Kitamaat Village	20	157	63	12	52	25
Haul Road	75	97	107	66	119	118
Riverlodge	22	42	45	28	43	44
Whitesail	15	18	34	21	26	43

[1] Monitoring data 1-hour average for 2016, 2017.

[2] CALPUFF results for actual scenario, local-scale using actual smelter emission rates from 2016 to 2017, varying monthly. Model results for performance evaluation apply a background based on Williams Lake (1.8 ppb), which is more appropriate to represent realistic results because we expect minimal contribution from non-smelter SO_2 for 2016 – 2017 actual conditions. Results with a higher background (5.53 ppb based on monitoring at Terrace-Skeena Middle School) are used for new model future 35 and 42 tpd effect assessment in order to be cautious in risk assessments.

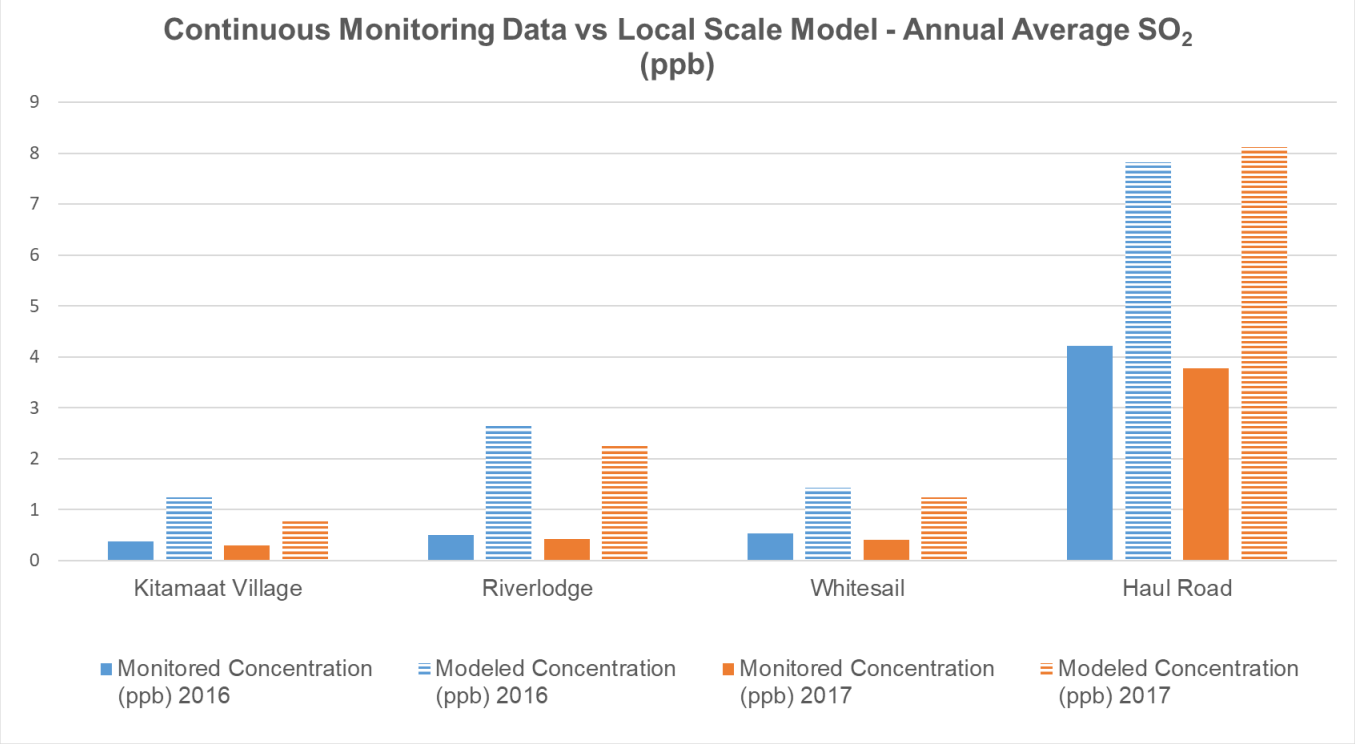


Figure A3-6. Continuous SO_2 (ppb) monitoring concentrations compared to new CALPUFF model results and scaled STAR model concentrations, annual average, local-scale (Williams Lake annual background of 0.26 ppb applied).

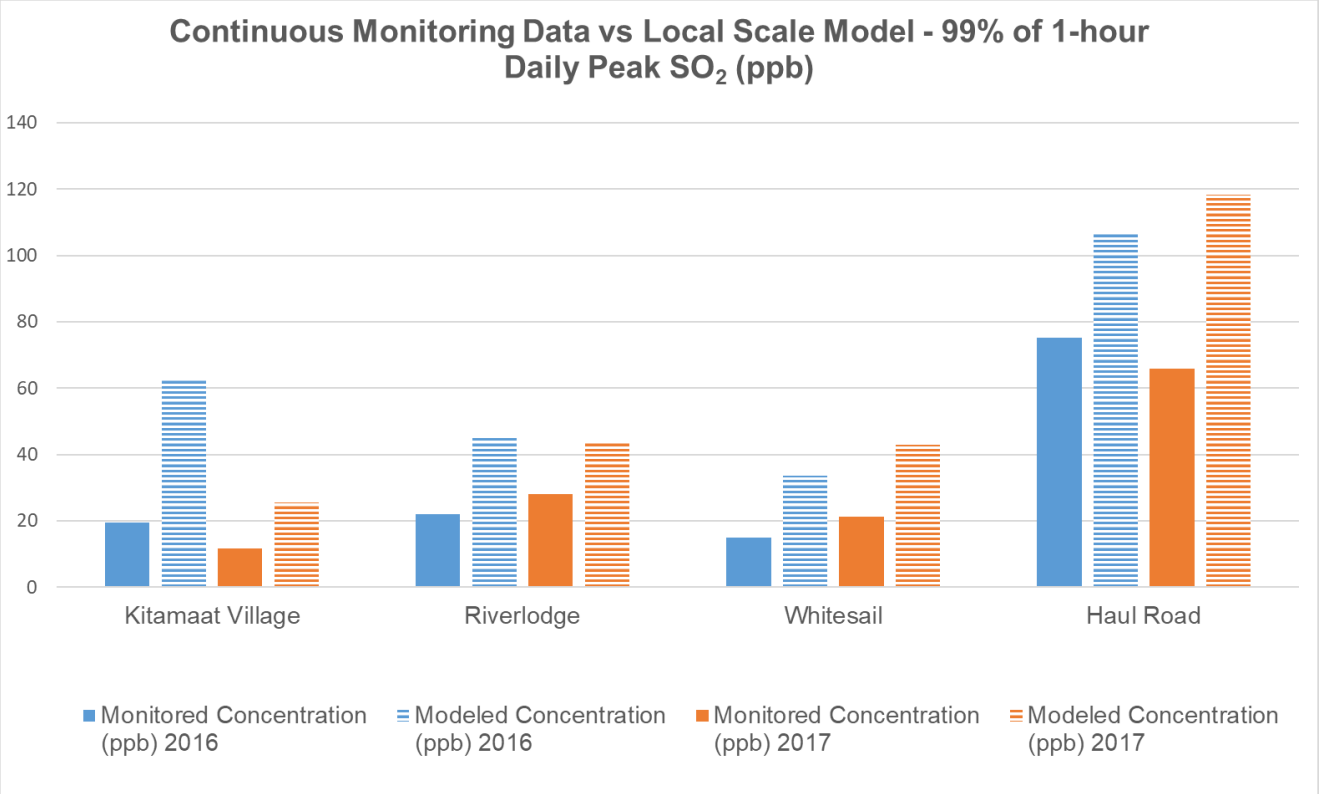


Figure A3-7. Continuous SO_2 (ppb) monitoring concentrations compared to new CALPUFF model results and scaled STAR model concentrations, 99% of 1-hour daily peak, local-scale (Williams Lake annual background of 1.8 ppb applied).

Table A3-3 below provides the performance statistics for the regional-scale model. The RMSE, MBE, and MAE represent the difference (or error) between the model result versus the observation at each monitor for each hour (paired in space and time). The MBE represents the same differences seen when comparing the annual average concentrations (illustrated in Figure A3-6). Like the regional scale performance, the MBE values indicate that the local-scale model overall slightly over-predicts at Kitamaat Village and Whitesail and over-predicts moderately at Haul Road and Riverlodge. The MAE and RMSE values are also similar to the regional scale evaluation, except the Kitamaat Village error is noticeably higher (meaning the local scale does not estimate as well at Kitamaat Village) and the Whitesail error values are noticeably lower (the local-scale model predicts better at Whitesail). The wind correction model update improved local scale performance at Kitamaat Village and performance at Riverlodge declined somewhat.

Table A0-8. Local scale model performance evaluation statistics. Williams Lake annual background of .27 ppb, (0.69 μg/m$^{3)}$ is applied.

Model	Monitor	RMSE (μg/m^3)	MBE (μg/m^3)	MAE (μg/m^3)	MBE% [1]	MAE% [1]
Original CR Model	Kitamaat Village	10.54	1.51	2.12	199%	279%
	Haul Road	37.95	10.29	19.04	101%	187%
	Riverlodge	10.89	2.83	3.86	232%	316%
	Whitesail	4.92	0.43	1.49	38%	133%
Updated Model (Corrected for Wind Direction)	Kitamaat Village	7.02	1.09	1.75	124%	199%
	Haul Road	39.68	9.67	19.81	93%	190%
	Riverlodge	12.54	4.51	5.31	371%	437%
	Whitesail	7.70	1.57	2.52	128%	205%

[1] MBE% and MAE% are expressed as MBE and MAE divided by the annual average observed concentrations, respectively, at each receptor.

The Q-Q plots in 8 below illustrate the over-prediction at Kitamaat Village and relatively good performance at Whitesail as noted above, giving a more complete picture of how the values compare across the range of concentrations. Haul Road modelled concentrations generally fall within the 100% to 200% of monitored values for all but the highest and lowest concentrations. Riverlodge model results also show relatively good performance at the higher concentrations but over-predicts the annual average nearly three times and lower to mid range concentrations over three times. The updated model (Figure A3-9) shows similar patterns at all four monitoring stations.

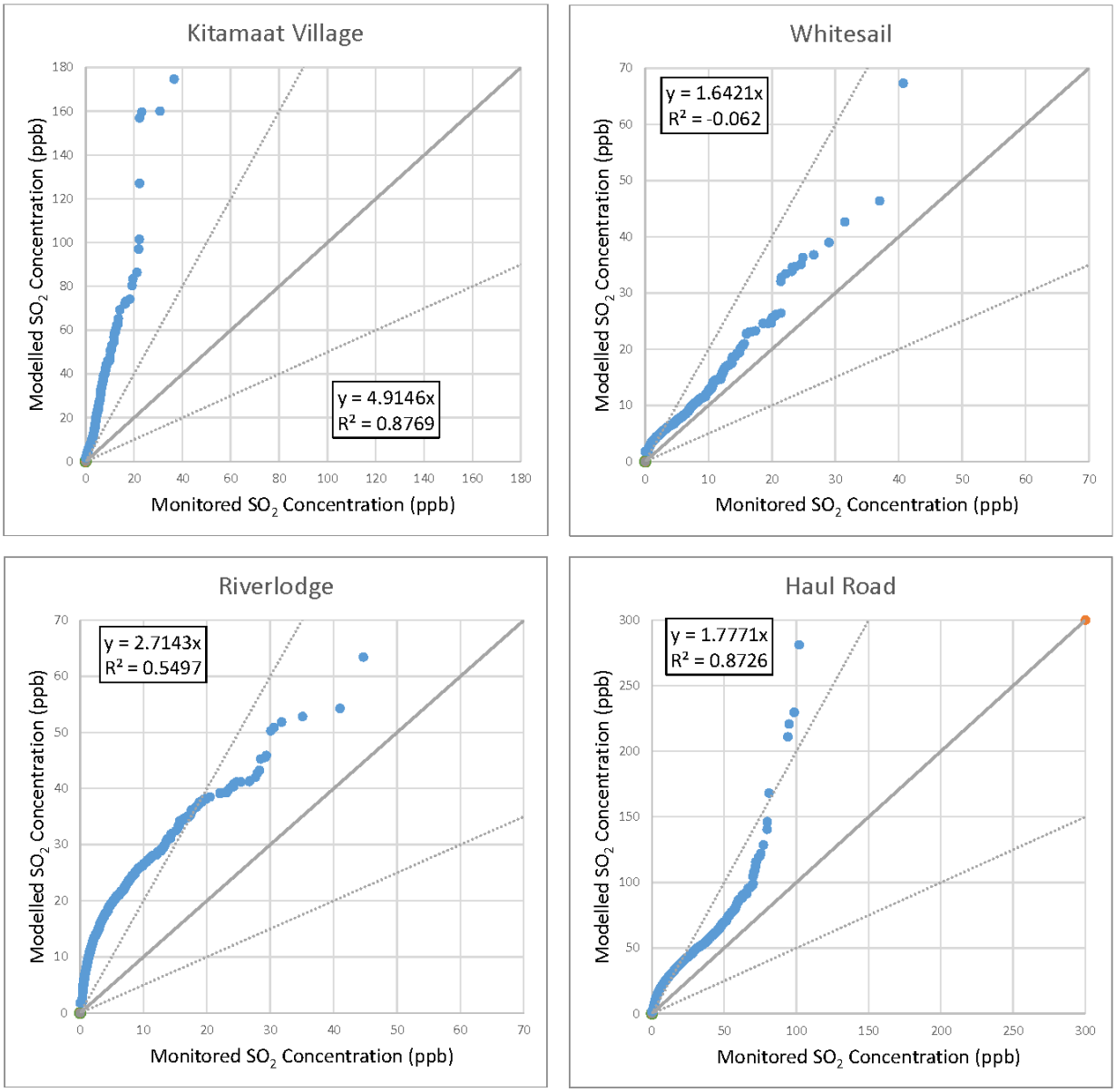


Figure A3-8. Comparison of local-scale original CR model SO_2 concentrations (actual scenario) against continuous monitoring network SO_2, 2016-2018, Q-Q plot (ordered by rank). The 1-to-1 line (solid) and 2-to-1 lines (dashed) are shown. Best fit linear regression equation and R^2 value shown for 0 intercept. The model data include the model performance 1-hour background concentration (1.80 ppb at Williams Lake).

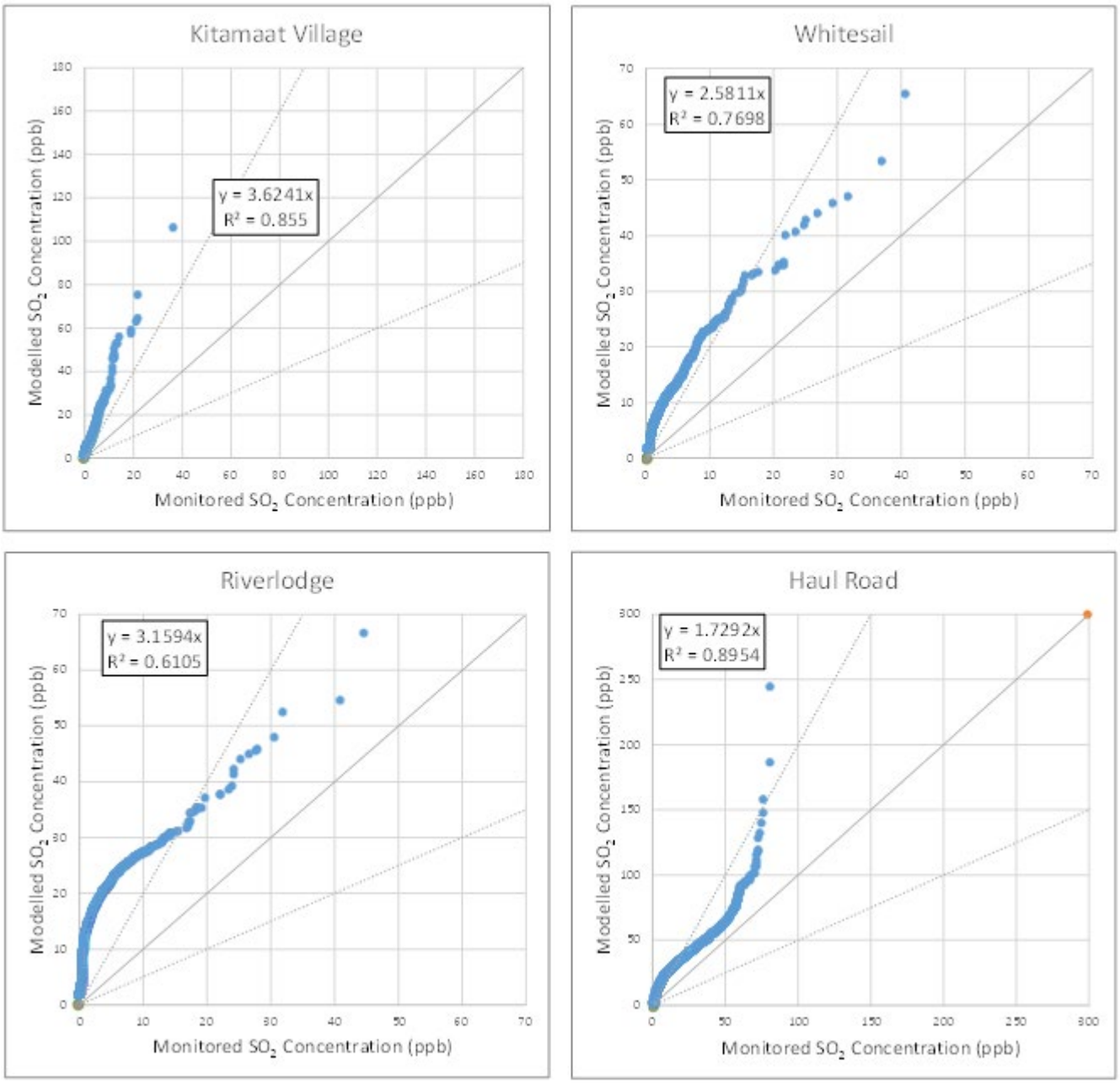


Figure A3-9. Comparison of local-scale updated model SO_2 concentrations (actual scenario) against continuous monitoring network SO_2, 2016-2018, Q-Q plot (ordered by rank). The 1-to-1 line (solid) and 2-to-1 lines (dashed) are shown. Best fit linear regression equation and R^2 value shown for 0 intercept. The model data include the model performance 1-hour background concentration (1.80 ppb at Williams Lake).