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CANADA'S BEST MANAGED COMPANIES

August 22, 2014

Ms. Margaret Mears
Trans Mountain Expansion Project Environmental Lead
Kinder Morgan Canada Inc.
Suite 2700, 300-5th Ave SW
Calgary, AB
T2P 5J2

Re: Supplemental Air Quality Report and ESA Significance Ratings
Trans Mountain Expansion Project
RWDI Reference No. 1402013
SREP-NEB-TERA-00020

Email: Margaret_mears@kindermorgan.com

Dear Margaret,

Since the application for the Trans Mountain Expansion Project (the Project) was filed in December, 2013, RWDI AIR Inc. (RWDI) conducted additional dispersion modelling to:

- ensure that evolving engineering design of new tanks and vapour control configurations met the applicable ambient air quality objectives at the Burnaby Terminal and Westridge Marine Terminal;
- inform the engineering design of new tanks and vapour control configurations to the appropriate technology level based on predicted concentrations that are less than applicable ambient air quality objectives and odour detection thresholds;
- provide an updated air quality assessment for the Burnaby Terminal and Westridge Marine Terminal to the National Energy Board (NEB) and interveners;
- correct any errors from the previous air quality assessment; and,
- fulfill commitments for updated air quality modelling made through the NEB Information Request (IR) process.

This supplemental air quality report presents the changes to assumptions, which were used in the 2013 air quality assessment, based on the interim detailed engineering for the Project. Improvements have been made to the assumptions used in the air quality modelling, specifically:

- a more comprehensive suite of crude oil products have been included;
- emission rates from the storage tanks at the Burnaby Terminal have been re-calculated;

- tanker loading simulations have been completed and verified against the results of real-time vapour composition sampling at the Westridge Marine Terminal;
- more stringent process specifications for capture and recovery/destruction of vapours have been developed for the proposed vapour recovery and vapour combustion units at the Westridge Marine Terminal;
- refinements have been made to the approach for estimating nitrogen dioxide (NO_2) levels near the Westridge Marine Terminal; and,
- updated odour detection thresholds were used to evaluate the Project effects based on a more recent publication from the Association of Industrial Hygiene Association.

Updated emissions and dispersion results of Criteria Air Contaminants (CACs) such as oxides of nitrogen and sulphur dioxide; volatile organic compounds (VOC's) such as benzene, toluene, ethyl benzene, xylenes; and hydrogen sulphide (H_2S) and mercaptans, have been created for the Existing and Application (Project) cases. Changes to the assessment methodology and updated modelling results are discussed in the attached Supplemental Air Quality Report dated August 22, 2014.

RWDI has reviewed the findings of this updated air quality assessment for VOC emissions from the storage tanks at the Burnaby Terminal, and VOC and CAC emissions during tanker loading at the Westridge Marine Terminal in the context of the Environmental and Socio-economic Assessment (ESA - Biophysical) (Volume 5A) and has determined that the significance conclusions of the ESA with regard to air quality emissions remain unchanged, based on the results of the updated modelling for both Project-related effects and the Project's contribution to cumulative effects (Sections 7.11.1.4 and 8.4.3 of Volume 5A, NEB Filing IDs A3S1R0 and A3S1R1).

A key difference between the significance evaluation included in the Technical Report (2013) and the significance evaluation included in the attached Supplemental Air Quality Report is the determination of the magnitude of the air emissions indicator. In the Technical Report (2013) and Volume 5A, the determination of the magnitude was completed for those contaminants where regulatory standards existed (e.g., benzene) in the provinces where the facilities were located. In this update, the significance evaluation was completed using some ambient air quality objectives from Alberta, where none exist in BC or Metro Vancouver. The predicted maximum concentrations with ambient background for all specified CACs and VOCs were found to be less than their respective Alberta and Metro Vancouver ambient objectives for all averaging periods for the Application and Cumulative Cases.

We would be happy to respond to any questions or comments that Trans Mountain might have with respect to these documents. Please do not hesitate to contact the undersigned at (403) 232-6771 ext. 6228.

Yours very truly,

RWDI AIR Inc.

David S. Chadder, Hon. B.Sc., QEP
Senior Project Director/Principal

TT/DSC

Attachment

cc: Mr. Jason Smith (TERA, a CH2M HILL Company)

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Trans Mountain Expansion Project

Final Report

Supplemental Air Quality Technical Report
For Technical Update No. 2
SREP-NEB-TERA-00020

RWDI # 1402013
August 22, 2014

SUBMITTED TO
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1. DISCUSSION OF TECHNICAL DOCUMENTS

1.1 Background

In December 2013, Trans Mountain Pipeline ULC (Trans Mountain) submitted its application for a Certificate of Public Convenience and Necessity (CPCN) to the National Energy Board (NEB) for the Trans Mountain Expansion Project (the Project). The CPCN Application consisted of eight volumes including the environmental and socio-economic assessment (ESA). Volume 5C of the ESA included Technical Report 5C-4, Air Quality and Greenhouse Gas Technical Report (RWDI 2013) (NEB Filing IDs A3S1U0 to A3S1U7) (referred to in this document as the “2013 Technical Report”). The technical report is an air quality assessment addressing the emissions of air contaminants and greenhouse gases (GHG) from Trans Mountain Assets including pipelines, pump stations and storage terminals. Emission rates were estimated and dispersion modelling was completed for three operational scenarios, namely, Existing, Application (Project) and Cumulative. Several chemicals were modelled and predicted concentrations were compared to the applicable ambient air quality objectives for Edmonton, Kamloops, Sumas, Burnaby and Westridge Marine Terminals.

As noted in the 2013 Technical Report, the predicted air quality results in the Application were based on preliminary engineering design. Since the filing in December 2013, the engineering design has evolved and improvements have been made to the assumptions that will be used in the air quality modelling for the Burnaby and Westridge Marine Terminals. This supplemental report describes these design changes and provides updated predicted results for the Base Case, Application Case and Cumulative Case.

1.2 Objectives of Supplemental Report

This supplemental report presents the changes to assumptions which were used in the air quality assessment presented in the 2013 Technical Report. As the detailed engineering for the Project evolves, the assumptions used in the technical air quality assessment can be refined. This supplemental report reflects the improvement to a number of assumptions and provides the summary of the updated modelling parameters, assumptions and dispersion model results.

The results of the air quality assessment for the Burnaby Terminal and Westridge Marine Terminal completed as part of this supplemental report reflect the interim engineering design and demonstrate that all ambient air quality objectives will be met. The air quality assessment is an on-going and iterative process which informs and is informed by the engineering design and setting of specifications required of final equipment vendors.

Trans Mountain considered, and is continuing to consider, different vapour control configurations for the Westridge Marine Terminal and tank design configurations and tank vapour adsorption units (TVAU’s) for the Burnaby Terminal. Trans Mountain is committed to meeting the applicable ambient air quality objectives at each terminal and this is the primary criterion for determining tank design and vapour control configurations. The extent to which Trans Mountain will design to reduce emissions below the applicable ambient air quality objective levels will depend on the value (benefit versus cost) and the practical limitations of the technology. Trans Mountain continues to use air quality modelling results to determine tank design and vapour control configuration using an iterative process.

The objectives of this supplemental report are to:

- ensure that updated engineering design of new tanks and vapour control configurations meet the applicable ambient air quality objectives at the Burnaby Terminal and Westridge Marine Terminal;
- inform the engineering design of new tanks and vapour control configurations to the appropriate technology level based on predicted concentrations that are less than applicable ambient air quality objectives and odour detection thresholds;
- provide an updated air quality assessment for the Burnaby Terminal and Westridge Marine Terminal to the NEB and interveners;
- correct any errors from the previous air quality assessment; and,
- fulfill commitments for updated air quality modelling made through the NEB Information Request (IR) process from Interveners.

The air quality modelling presented in this supplemental report was completed as part of the iterative engineering design process and presents a better estimation of the potential effects of the Project. This supplemental report is based on key air quality indicators and is not as comprehensive as the modelling completed as part of the 2013 Technical Report. Dispersion modelling results for Criteria Air Contaminants (CACs), benzene, toluene, ethyl benzene, xylenes (BTEX), hydrogen sulphide (H_2S), and mercaptans were included in this study for the Existing (Base) and Application (Project) Cases. The Cumulative Case were also reviewed and updated qualitatively.

2. ERRATA FROM THE 2013 TECHNICAL REPORT

The first round of IRs from the NEB and Interveners uncovered some inadvertent errors in the air quality assessment completed 2013 Technical Report. These have been corrected in the air quality assessment included in this supplemental report. Specific details on each of the corrections is provided in the individual responses to information requests, as referenced in Table 1 and further details are provided below.

Table 1: Corrections from the 2013 Technical Report

IR Reference	Corrections Include	Discussed in Section
Environment Canada IR 1.03a, IR 1.03b (NEB Filing ID A3Y2K9) Metro Vancouver IR 1.1.6.10a (NEB Filing ID A3Y2V0)	Changes in the land use data for the Burrard Inlet Area	Section 2 Appendix A
Environment Canada IR 1.090, and IR 1.120c (NEB Filing ID A3Y2K9)	Clarification of use of very high ambient BTEX monitoring results (outliers)	Section 2
Del Ponte IR 1.2d (NEB Filing ID A3Y2J0) Pine Ridge Housing IR 1.1a (NEB Filing ID A3Y2Y5) Strata NW313 IR 1.43a (NEB Filing ID A3Y3R5) Varto H IR 1.1C1.1 and 1.1C1.2 (NEB Filing ID A3Y3V6)	Updates to the product throughput at Burnaby Terminal	Section 4.1

Burrard Inlet Area Land-Use Data

The land use assignments in the modelling (CALMET model) completed for the 2013 Technical Report were found to be faulty for the Burrard Inlet Area. It was noted that there were errors in the land use data processing for the Burnaby and Westridge Marine Terminals. Land use assignments for the Burrard Inlet Area have been corrected to reflect the correct current land use in this update (in an updated run of the CALMET model). Updated land use data along with the modelled mixing heights under unstable, neutral, and stable conditions and other meteorological parameters used in the evaluation of atmospheric dispersion of emissions from the Burnaby Terminal and the Westridge Marine Terminal are presented in Appendix A.

Ambient Background BTEX Levels

The 2013 Technical Report indicated that there were two ambient BTEX monitoring results from the Metro Vancouver Burmount station that were very high relative to the other readings over the 5-year period, 2007 to 2011. The 2013 Technical Report referred to these readings as outliers and noted that they were not included in the calculation of the ambient background for the Burnaby Terminal and the Westridge Marine Terminal. In fact, these values were included in the calculation of the ambient background for the Burnaby Terminal and the Westridge Marine Terminal, and the text of the 2013 Technical Report was incorrect. This correction serves as a clarification on how these high values were incorporated. There is no change to the ambient background BTEX concentrations, presented in either the 2013 Technical Report or in this supplemental report.

Product Throughput at Burnaby Terminal

The 2013 Technical Report underestimated the product throughput for the Burnaby Terminal. Section 4.1 further discusses this change. The corrected throughput volumes for the Burnaby Terminal along with other updated volumes by terminal are summarized in Table 4. Volatile organic compound (VOC) emissions were re-calculated based on these updated product volumes and used in the updated dispersion modelling as part of this supplemental report.

3. COMMITMENTS FROM INFORMATION REQUESTS FROM INTERVENERS ROUND 1

The first round of IRs from the NEB and Interveners resulted in additional commitments in the air quality assessment. This supplemental report addresses these commitments. The commitments, references to the original IRs and a reference to where in this document the commitment is addressed in this supplemental report are listed in Table 2. Additional details on each of the corrections are provided in the individual responses to IRs, as referenced below.

Table 2: Additional Air Quality Assessment Commitments

No.	IR Reference	Commitment	Discussed in Section
1.	Environment Canada IR 1.058 (NEB Filing ID A3Y2K9) Commitment number C-100	Trans Mountain proposes to meet with Environment Canada (EC) and the other interveners involved in the Lower Fraser Valley Air Quality Coordinating Committee (LFVAQCC) who are interested, in Q3 2014 to clarify assumptions and methodology for an updated marine air quality/greenhouse gas assessment using the Marine Emission Inventory Tool (MEIT) to be conducted in 2015. (IR: EC requests that the Proponent re-evaluate the Base Case with berth and anchorage emissions included.)	Not discussed in this supplemental report. Meeting to be held in early September 2014.
2.	Environment Canada IR 1.076 (NEB Filing ID A3Y2K9) Commitment number C-101	Trans Mountain suggests that the air quality experts meet with the (LFVAQCC) in Q3 2014 to discuss a possible update to the CMAQ modelling incorporating the MEIT calculated marine emissions and limited CMAQ model performance evaluation.	Not discussed in this supplemental report. Meeting to be held in early September 2014.
3.	Environment Canada IR 1.080 (NEB Filing ID A3Y2K9) Commitment number C-102	Trans Mountain recognizes that updating the photochemical modelling using the updated MEIT would be valuable to EC, Metro Vancouver and the Fraser Valley Regional District (FVRD) and commits to undertaking a similar modelling effort but using the updated MEIT when it is available. Trans Mountain suggests that the air quality experts meet with the (LFVAQCC) in Q3 2014 to discuss a possible update to the CMAQ modelling incorporating the MEIT calculated marine emissions and limited CMAQ model performance evaluation.	Not discussed in this supplemental report. Meeting to be held in early September 2014.

No.	IR Reference	Commitment	Discussed in Section
4.	Fraser Valley Regional District IR 1.02(b) (NEB Filing ID A3Y2K7) Commitment number C-116	Trans Mountain was requested to provide a comprehensive review of equipment and control technology to reduce total VOC (TVOC) emissions at the Westridge Marine Terminal. Trans Mountain is currently engaging equipment vendors and reviewing emission control technologies. In addition, RWDI is providing dispersion modelling to inform design engineering of the emission control equipment and other design updates. The updated air quality assessment, to be provided in late August 2014, will summarize the design changes since the original 2013 NEB filing, the emission control equipment that has been evaluated to date and the equipment currently being considered.	Discussed in Section 4.4.
5.	Metro Vancouver IR 1.1.6.03(d) (NEB Filing ID A3Y2V0) Commitment number C-131	Technical Update No. 1 will be filed with the NEB on August 1, 2014. Metro Vancouver requested an assessment of alternative technologies to the proposed vapour combustion unity (VCU) that will have lower soot emissions, and therefore, do not result in predicted exceedances of the Metro Vancouver objectives for 24-hour $PM_{2.5}$ and PM_{10}.	Commitment was deferred to be included in this update to be filled to NEB on August 22, 2014. Discussed in Sections 4.4 and 5.0.
6.	Metro Vancouver IR 1.1.6.04(b) NEB Filing ID A3Y2V0 Commitment number C-132	Trans Mountain commits to meet with Metro Vancouver to discuss the methodology and results related to meeting applicable ambient air quality objectives.	Not discussed in this supplemental report. Meeting to be held in early September 2014.

No.	IR Reference	Commitment	Discussed in Section
7.	Metro Vancouver IR 1.6.06(a) (NEB Filing ID A3Y2V0) Commitment number C-133	As requested by Metro Vancouver, Trans Mountain will review the significance conclusions in light of the updated air quality assessment being completed to inform engineering design in a cover letter that will be submitted to the NEB in Q3, 2014. Trans Mountain also agrees to use ambient air quality objectives from Alberta, where none exist in BC or Metro Vancouver.	Significance conclusions are presented in the cover letter attached to this supplemental report. Odour thresholds are discussed in Section 4.6. Ambient air quality objectives are shown with results in Section 5.0.
8.	Metro Vancouver IR 1.6.07(a) (NEB Filing ID A3Y2V0) Commitment number C-134	Trans Mountain recognizes that updating the photochemical modelling using the updated MEIT would be valuable to EC, Metro Vancouver and FVRD and commits to undertaking a similar modelling effort but using the updated MEIT when it is available. This update using the CMAQ model would not include all of the additional scenarios (i.e., another ozone episode, typical ozone episode under other meteorological conditions, seasonal and annual time periods) jointly requested by EC, Metro Vancouver and FVRD. Trans Mountain suggests that the air quality experts meet with the (LFVAQCC) in Q3 2014 to discuss a possible update to the CMAQ modelling incorporating the MEIT calculated marine emissions and limited CMAQ model performance evaluation.	Not discussed in this supplemental report. Meeting is to be held in early September 2014.

No.	IR Reference	Commitment	Discussed in Section
9.	City of Burnaby IR 1.28.02a (NEB Filing ID A3Y2E6) Fraser Valley Regional District IR 1.02a (NEB Filing ID A3Y2K7) Environment Canada IR 1.096c and 1.103a (NEB Filing ID A3Y2K9) Metro Vancouver IR 1.1.6.03d, 1.1.6.03f, 1.1.6.06a, 1.1.6.09a, 1.1.6.10a, 1.1.6.10b and 1.1.6.27a (NEB Filing ID A3Y2V0)	Trans Mountain will provide an updated air quality assessment for Burnaby Terminal and Westridge Marine Terminal in Technical Update No. 1 to be filed in Q3 2014. Trans Mountain will provide updated emission estimates and dispersion modelling for the Westridge Marine Terminal as Technical Report No. 1 in Q3 2014.	These commitments are met by the filing of this supplemental report.
10.	City of Burnaby IR 1.28.03a (NEB Filing ID A3Y2E6) Fraser Valley Regional District IR 1.09a (NEB Filing ID A3Y2K7) Environment Canada IR 1.063 (NEB Filing ID A3Y2K9) Living Oceans IR 1.21a (NEB Filing ID A3Y2T4) Metro Vancouver IR 1.1.6.02a, 1.1.6.03a, 1.1.6.03b, 1.1.6.03e, 1.1.6.24a and 1.1.6.01b (NEB Filing ID A3Y2V0) Strata NW313 IR 1.38a, 1.42b, 1.43a (NEB Filing ID A3Y3R5) Varto H IR 1.1.C1.1 (NEB Filing ID A3Y3V6)	Trans Mountain is updating additional dispersion modelling to inform engineering design related to terminal operations during product loading and unloading. Results will be provided in the Technical Update No. 1 to be filed with the NEB in Q3 2014. Results will specifically include rolling 24-h $PM_{2.5}$ and PM_{10} concentrations for the Base Case, Application Case and Cumulative Case.	Commitment was deferred to be included in this update to be filed to NEB on August 22, 2014 and is discussed in Section 5.0.

No.	IR Reference	Commitment	Discussed in Section
11.	Environment Canada IR 1.098 and 1.115 (NEB Filing ID A3Y2K9)	Trans Mountain will produce a model evaluation of the Weather Research & Forecasting Model (WRF) files used in the Application that meets the guidance provided in Section 7.1.3 of the Guidelines for Air Quality Dispersion Modelling in British Columbia (2008) and file with the NEB as part of Technical Update No. 1 in Q3 2014.	Commitment was deferred to be included in this update to be filed to NEB on August 22, 2014 and is discussed in Appendix B.
12.	Living Oceans IR 1.58b (NEB Filing ID A3Y2T4)	Trans Mountain will undertake dispersion modelling of the vapor control equipment at the Westridge Marine Terminal and results, including estimates of emission rates of volatile organic compounds, will be filed with the NEB as Technical Update No. 1 in Q3 2014.	Commitment was deferred to be included in this update to be filled to NEB on August 22, 2014 and is discussed in Sections 4.4 and 5.1.
13.	Metro Vancouver IR 1.1.6.06b (NEB Filing ID A3Y2V0)	Trans Mountain will provide a written justification for the revised assessment as part of Technical Update No. 1 in Q3 2014.	Objectives of this supplemental report are discussed in Section 1.2. Significance conclusions are presented in the cover letter attached to this supplemental report Odour thresholds are discussed in Section 4.6. Ambient air quality objectives are shown with results in Section 5.0.

No.	IR Reference	Commitment	Discussed in Section
14.	Metro Vancouver IR 1.1.6.32a (NEB Filing ID A3Y2V0)	Trans Mountain is updating dispersion modelling in support of engineering design and the results will be filed with the NEB in Q3 2014. A new ambient monitoring station will be installed at the Westridge Marine Terminal in 2015 to meet the requirements of NEB Draft Condition No. 21 which requires methods and schedule for ambient monitoring of contaminants of potential concern in air including particulate matter, carbon monoxide, nitrogen dioxide, sulphur dioxide, hydrogen sulphide and volatile organic compounds.	Commitment to dispersion modelling is met by the filing of this supplemental report. New ambient monitoring station is not discussed in this supplemental report. An ambient monitoring station will be installed at the Westridge Marine Terminal in 2015.

4. CHANGES TO TECHNICAL APPROACH

As noted in the 2013 Technical Report, the predicted air quality results in the Application were based on preliminary engineering design. Improvements have been made to the assumptions that will be used in the air quality modelling, specifically:

- a more comprehensive suite of crude oil products have been included;
- the emission rates from the storage tanks at the Burnaby Terminal have been re-calculated;
- tanker loading simulations have been completed and verified against the results of real-time vapour composition sampling at the Westridge Marine Terminal;
- more stringent process specifications for capture and recovery/destruction of vapours have been developed for the proposed vapour recovery (VRU) and vapour combustion units (VCU) at the Westridge Marine Terminal;
- refinements have been made to the approach for estimating nitrogen dioxide (NO_2) levels near the Westridge Marine Terminal; and,
- odour detection thresholds used to evaluate the Project effects have been updated.

Sections 4.1 to 4.6 below further discuss each of these changes individually.

4.1 Crude Oil Products

As noted in Section 3.4.2.2 of Technical Report 5C-4 in Volume 5C, Air Quality and Greenhouse Gas Technical Report (RWDI December 2013, NEB Filing ID A3S1U0), the existing pipeline currently transports heavy crude, light and synthetic crude, as well as refined products, in a series or in a “batch train”. Table 3 lists the volumes of each of the five representative products by terminal as included in this supplemental report for the Base Case.

Table 3: Updated Product Throughput by Terminal (Existing Pipeline), Base Case (in bbl/day)

Product	Edmonton Terminal	Kamloops Terminal	Sumas Terminal	Burnaby Terminal	Westridge Marine Terminal
Heavy Crude	70,000	-	16,000	54,000	49,418
Light Sour/Light Synthetic	170,000	13,000	125,000	58,000	13,582
Refined Product	47,000	-	-	34,000	-
Total	287,000	13,000	141,000	146,000	63,000

Note: "-" indicates no product storage.

With Project expansion, the proposed pipeline (Line 2) will be used to mainly transport heavy crude and the modified existing pipeline (Line 1) will be used to mainly transport light crude, synthetic crude and refined products. Each pipeline may be used to transport many different grades or varieties of product. Each product is associated with different petroleum properties and a different chemical composition. Bulk properties such as the product vapor pressure affect its tendency to vaporize and form fugitive emissions. The chemical composition of the products affects the relative abundance of each compound, such as BTEX, H_2S, or mercaptans. The total throughput of each product grade in the pipeline varies and is dependent on market demand.

Since the initial Trans Mountain facility emissions modelling were completed and filed in the 2013 Technical Report, updated process specifications for the Trans Mountain pipeline terminals have been prepared including updated tank product assignments. This supplemental report includes changes in the selection of representative products used in the air quality assessment. The air quality assessment now uses six representative products: High TAN[1] Dilbit and Low TAN Dilbit) to represent super heavy grades, High TAN Synbit/Dilsynbit to represent heavy grades, light sour and synthetic/sweet grades, and ethanol blended gasoline (to represent iso-octane) to represent refined products. These products were selected to be conservatively representative for each listed category based on their high vapor pressure and BTEX, H_2S and mercaptans contents.

Table 4 lists the volumes of each of the five representative products by terminal as included in this supplemental report for the Application Case.

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[1] TAN – Total Acid Number indicates the quantity of acidifying compounds present in a petrochemical sample.

Table 4: Updated Product Throughput by Terminal (Line 1 and Line 2 combined), Application Case (in bbl/day)

Product	Edmonton Terminal	Kamloops Terminal	Sumas Terminal	Burnaby Terminal	Westridge Marine Terminal
High TAN Dilbit, Low TAN Dilbit	508,500	-	47,000	461,500	461,500
High TAN Synbit and Dilsynbit	31,500	-		31,500	31,500
Light Sour	58,000	-	58,000	-	-
Light Synthetic, Light Sweet	235,500	12,500	62,000	186,000	135,500
Refined Product	44,000			31,500	
Total	877,500	12,500	167,000	710,500	628,500

Note: “-“ indicates no product storage.

4.2 Burnaby Storage Tank Emission Rates

As part of this technical update, the emission rates from the storage tanks at the Burnaby Terminal have been re-calculated since the December 2013 filing. The emission rates from the storage tanks at the Burnaby Terminal have changed in the Existing and Application Cases due to changes in the modelled product types, assumed volumes of products stored and selection of the tank design for new tanks. Additional crude oil products including those with higher mercaptan levels and hydrogen sulphide than Cold lake Winter Blend used in the 2013 Technical Report were selected for updated modelling to evaluate off-site odour potential. Details with respect to the Project design are provided in the August 22, 2014 Facilities Update of the Technical Update No. 2 filing.

4.3 Tanker Loading Vapour Composition

As part of this supplemental report, the composition of vapours produced during the loading of tankers at the Westridge Marine Terminal has been amended. Emissions of CACs and VOCs during tanker loading result from the vaporization of product being loaded and from the displacement of inert gas in the tanker cargo holds.

In this supplemental report, the air quality assessment has been updated to include improved information on the vapour composition during tanker loading for the Base Case and Application Case. Trans Mountain has retained a consulting engineering company to complete HYSIS model process simulations of tanker loading to estimate the vapour composition. The simulation results have been verified against the results of real-time vapour composition sampling at the Westridge Marine Terminal during tanker loading. The simulation was performed based on the inert gas concentrations specified by Wartsila, which are based on inert gas generated by an independent generator. Based on personal communication with Trans Mountain, it was noted that most tankers will not have an independent generator but rather will use inert gas derived from the vessel's boiler exhaust. For this reason, RWDI estimated CACs emissions based on generic emission factors from 2010 National Marine Emissions Inventory for Canada for boilers (SNC-Lavalin 2012). This resulted in higher emission rates than those provided by simulation for CACs. Mercaptans, H_2S, toluene, ethyl benzene and xylene emissions were taken from the simulation results and resulted emission rates were calculated based on the expected equipment total reduction efficiency. Modelled benzene emission rates were based on vendor guaranteed values.

In this update, combustion emissions of CACs associated with operation of the VCU in the Base and Application Cases were estimated based on the United States Environmental Protection Agency (US EPA), AP-42, Chapter 1.5: Liquefied Petroleum Gas Combustion (US EPA 2008) for particulate matter and carbon monoxide. The nitrogen oxides emission rates were estimated two ways, first, based on a vendor performance guarantee with an emission factor of 64.4 g/GJ heat input, and second, using AP42, Chapter 1.5 which created a value of 61.0 g/GJ. To be conservative, the manufacturer's value of 64.4 g/GJ was selected for use in the CALPUFF model. The 2013 Technical Report assumed emission rates from US EPA (1991) AP-42, Chapter 13.5 Table 13.5-1 Emission Factors for Flare Operations which in hindsight was overly conservative.

As noted in Section 4.1 of this supplemental report, the proposed tank assignment of products has been amended. Also, as noted in Section 4.4, the 2013 Technical Report did not include the use of the inert gas displacement system employed during tanker loading; thus, collection of CACs (inert gases) such as oxides of nitrogen from tanker loading were not included in the 2013 Technical Report. Both of these changes will also affect the composition of vapours collected during tanker loading and emission rates for the Base Case and Application Case which were captured in this technical update. The SO_2 emission rates were estimated based on 100% conversion of mercaptans and H_2S into SO_2 applying mass conservation law.

In this supplemental report, the air quality assessment has been updated to include updated information on the possible tanker loading scenarios, focusing on scenarios which would include simultaneous loading of three vessels at once, although infrequent, it is expected to be the worst-case from an emissions scenario. While three vessels can be loaded at once, it is expected to occur only <5% of the total loading time in a year. Operational requirements result in a staggering of the loading start times for each vessel; thus, the highest fugitive vapour emission rates from each vessel would not occur simultaneously. It is theoretically (physically) possible to load the same crude oil onto three ships simultaneously if there are enough tanks containing that type of crude oil. However, for logistical and practical reasons this is somewhat unlikely for high volume crude oil (such as High-Tan Dilbit) and extremely unlikely for low volume crude oil (such as High-Tan Synbit). Therefore, for the updated modelling it was assumed that the same product would not be loaded into all three vessels simultaneously. For this supplemental report, worst-case loading scenarios were developed for 1-hour, 24-hour and annual averaging periods.

Under the Base Case, the fugitive emissions from marine vessel loading are collected and destroyed by the existing VCU at the Westridge Marine Terminal. For the 1-hour and 24-hour averaging period, instantaneous peaking and daily average emission rates were modelled representing heavy crude, respectively. For the annual averaging period, emission rates were modelled based on weighted annual average emissions from loading of heavy crude and light sour based on the throughput provided in Table 3 for the Westridge Marine Terminal and annual time spent at berth.

The Application Case will include two new VRUs, and a new VCU for peak periods when three tankers are being loaded, otherwise the VCU will act as a back-up or standby unit.

For the 1-hour averaging period, two possible worst-case loading scenarios were modelled. Scenario 1 modelled VRU #1 with the instantaneous peak emission rate and VRU #2 and the VCU were modelled using daily average emission rates. Scenario 2 modelled the VCU with the instantaneous peak emission rate and VRU #1 and VRU #2 were modelled using daily average emission rates. For all emission rates, the product which resulted in the highest emission rates for all contaminants was selected.

For the 24-hour averaging period, all three vapour control units (VRU #1, VRU #2 and VCU) were modelled using daily average emission rates. Two scenarios were modelled varying which products would be loaded. Scenario 1 assumed vapours from loading the two products with the highest contaminant emission rates were modelled in the VRUs and the product with the third highest contaminant emission rates was modelled in the VCU. Scenario 2 assumed vapours from loading the product with the highest contaminant emission rate was modelled in the VCU and the products with the second and third highest contaminant emission rates were modelled in the VRUs.

For the annual averaging period, emission rates were modelled based on weighted annual average of all products. Emissions were distributed between the VRUs and VCU based on their utilization percent in a year.

Based on the updated design from the vendors, it was confirmed that it is most likely that fugitive emissions from three product loadings will be uniformly mixed together before directed to VCU or VRUs. This will allow “dilution” of the worst product emissions and should result in lower predicted concentrations than those demonstrated for Scenario 1 and Scenario 2 in this report. The estimated mercaptan emission rates are based on combined streams from three vessels (i.e., a mixed flow in the header pipe preceding the control equipment).

4.4 Tanker Loading at the Westridge Marine Terminal

Since the December 2013 filing, two leading manufacturers of vapour recovery and combustion equipment have been engaged to provide specific engineering details on the vapour recovery and vapour combustion units to be installed at the Westridge Marine Terminal.

As noted in Section 3.4.2.2 of the 2013 Technical Report (NEB Filing ID A3S1U0), fugitive emissions from marine vessel loading are collected and destroyed by a VCU at the Westridge Marine Terminal. Destruction efficiencies for the existing VCU were estimated based on manufacturer design information available for this unit. For the December 2013 filing, the air quality assessment was based on preliminary engineering design for the proposed Project, which included two new vapour recovery units (VRUs), and a new VCU to be used only when three tankers are loaded. Details with respect to the updated project design are provided in the August 22, 2014 Facilities Update of the Technical Update No. 2 filing. Updated vapour control efficiencies for equipment at the Westridge Marine Terminal are provided in Section 5.1.2.

4.5 NO_2 Estimation

Emissions of total oxides of nitrogen from the Westridge Marine Terminal and from marine traffic are comprised of nitrogen oxide (NO) and NO_2. In order to use the chemical reaction scheme within CALPUFF, individual mass emissions of NO and NO_2 are required as input values.

Total NO_X emission rates were calculated from emission factors. Typically, emission factors of NO_X are expressed in terms of NO_2. The estimated mass emission rates of NO_X represents the total mass emission rate of NO_2 after all NO has been oxidized to NO_2, rather than the sum of the NO and NO_2 mass emission rates. Effectively all of the NO_X is reported as NO_2. In the 2013 Technical Report, it was assumed that 90% of the NO_X emissions (reported as NO_2) by mass would be in the form of NO, and 10% by mass would be in the form of NO_2. In effect, the percentage split of NO_X was completed on a mass basis; however, the accepted practice is to split total NO_X into NO and NO_2 on a molar basis rather than a mass basis. Calculating emission rates of NO using a NO_X split ratio based on mass basis (rather than a molar basis) resulted in an over-estimation of NO_X emissions by 35%.

In this supplemental filing, total NO_X rates were split into NO and NO_2 emission rates on a molar basis. Therefore, the NO emission rates used as input into the CALPUFF model are lower than in the December filing, solely as an effect of the NO_X splitting methodology.

4.6 Odour Detection Thresholds

In the 2013 Technical Report, existing and predicted ambient odour concentrations were compared against Alberta's Ambient Air Quality Objective for H_2S for the 1-hour averaging period and BC's Ambient Air Quality Objective for total reduced sulphur (TRS) for the 1-hour averaging period. Speciated VOC and mercaptan concentrations were compared to their respective odour detection thresholds for 3-minute average concentrations in Table 4.46 of the 2013 Technical Report (NEB Filing ID A3S1U1).

In this technical update, modelled concentrations of BTEX, mercaptans, and H_2S were also compared to their respective odour detection thresholds. The odour detection thresholds were updated in this supplemental report to reflect recently published values. Odour detection thresholds were selected from the American Industrial Hygiene Association's (AIHA) literature review (AIHA 1989, 2013) and can vary widely between published studies. In the more recent report by the AIHA (2013), published odour detection thresholds are listed, but no critique of the validity of the thresholds was conducted nor are there recommended thresholds. In the original AIHA report version (1989), an in-depth critique of published values for odour detection threshold was included. To determine odour detection thresholds for this assessment, the most recent AIHA version (2013) was considered but the published values were screened to remove data that had already been previously removed by the AIHA (1989) along with any duplicate numbers. A geometric mean for odour detection was calculated based on the filtered data which is representative of 50% of the population with a normal sense of smell.

The odour detection thresholds used in the 2013 Technical Report were compared to the updated odour detection thresholds in Table 5.

Table 5: Comparison of Odour Detection Thresholds used in the 2013 Technical Report and in this Technical Update (in µg/m^3)

Pollutant	Thresholds Used in December 2013 Filing	Thresholds Used in Supplemental Report
		Odour Detection Threshold Geometric Mean[4]
Benzene	195,000[1]	39,429
Toluene	6,040[1]	4,682
Ethyl benzene	400[2]	490
Xylenes	86,900[1]	1,534
H_2S	13.1[1]	3.9
Mercaptans	13[3]	13

Notes:
[1] Geometric mean odour threshold value from "Acceptable Values" from AIHA (1989).
[2] Minimum odour threshold values from "All Referenced Values" from AIHA (1989). (No “acceptable values” were reported).
[3] Threshold based on Ontario Ambient Air Quality Criteria 2012.
[4] Geometric Mean was based on screened values obtained from AIHA (2013).

5. UPDATED MODELLING PARAMETERS AND RESULTS

Trans Mountain has committed that the maximum predicted concentrations from for the Project will meet the applicable ambient air quality objectives. The updated predicted results are anticipated to be more representative of expected Project-related effects than the 2013 results since new information from the iterative engineering design process is included. Updated modelled parameters and dispersion modelling results for CACs, BTEX, H_2S, and mercaptans for the Existing (Base) and Application (Project) cases for the Westridge Marine Terminal and Burnaby Terminal are presented in this section. The modelling parameters and predicted results are still based on preliminary design and may change as the design continues to evolve.

5.1 Modelled Parameters for the Westridge Marine Terminal

5.1.1 Base Case

The updated modelling for the Base Case of the Westridge Marine Terminal considered one VCU along with the tanks holding jet kerosene product. As a modelling conservatism, emissions from the tanker auxiliary engine and boiler during loading at the existing berth location were also included in the modelling. Stack parameters for the existing VCU and total reduction efficiency are provided in Table 6 and Table 7, respectively.

Table 6: Stack Parameters for the Existing VCU, Base Case

Control	Stack Height (m)	Stack Diameter (m)	Exit Temperature (K)	Exit Velocity (m/s) [1]
VCU	21.3	3.5	1255.2	8.2

Note: [1] Exit velocity for VCU was estimated based on the stoichiometric exhaust to gas ratio.

Table 7: Collection and Destruction Efficiencies for the Existing VCU, Base Case

Compound	Collection Efficiency	Total Destruction Efficiency
H_2S and Mercaptans	100%	70% [1]
BTEX	100%	98%

Note: [1] Recent guidance from the manufacturer has revised the destruction efficiency for H_2S and mercaptans to 99% as well as benzene provided that the operating temperature of the VCU is maintained between 778 and 843 C.

Maximum hourly and annual emission rates for the existing VCU, which were estimated based on the approach discussed in Section 4.3, are provided in Table 8 and Table 9, respectively.

Table 8: Existing VCU Maximum Hourly Emission Rates, Base Case (in g/s)

Contaminant	Existing VCU
Sulphur dioxide	1.4200
Oxides of nitrogen	4.8420
Inhalable particulate matter - PM_{10}	0.1983
Respirable particulate matter - $PM_{2.5}$	0.1983
Carbon monoxide	2.5094
Hydrogen sulphide	0.0480
Mercaptans	0.2490
Benzene	0.0668
Toluene	0.0273
Ethyl benzene	0.0085
Xylenes	0.0363

Note: All CAC emissions (SO_2, NO_X, PM and CO) include inert gas and combustion emissions. H_2S mercaptans and BTEX emissions include undestroyed emissions from tanker loading of heavy crude product.

Table 9: Existing VCU Annual Emission Rates, Base Case (in t/y)

Contaminant	Existing VCU
Sulphur dioxide	4.9783
Oxides of nitrogen	11.335
Inhalable particulate matter - PM_{10}	0.3774
Respirable particulate matter - $PM_{2.5}$	0.3774
Carbon monoxide	5.5657
Hydrogen sulphide	0.2515
Mercaptans	0.7527
Benzene	0.1862
Toluene	0.0880
Ethyl benzene	0.0236
Xylenes	0.0973

Note: All CAC emissions (SO_2, NO_X, PM and CO) include inert gas and combustion emissions. H_2S, mercaptans and BTEX emissions include undestroyed emissions from tanker loading of heavy crude and light sour products based on annual throughput.

Stack parameters for the tanker auxiliary engine and boiler at the existing berth are provided in Table 10. With the exception of stack height, which is estimated specifically for Aframax vessels calling at the Westridge Marine Terminal, all stack parameters represent a bulk average for all marine vessels, as recommended by the United States Environmental Protection Agency (US EPA), California Air Resources Board, and Environment Canada (Boulton *et a*l. 2008).

Table 10: Stack Parameters for the Marine Auxiliary Engine and Boiler

Stack Height (m)	Stack Diameter (m)	Exit Temperature (K)	Exit Velocity (m/s)
37.0	0.80	555.2	25.0

Maximum hourly and annual emission rates for the marine auxiliary engine and boiler, which were estimated based on the approach discussed in the Marine Air Quality and Greenhouse Gas Marine Transportation Technical Report (RWDI 2013) (NEB Filing ID A3S1U0), are provided in Table 11 and Table 12, respectively. Maximum hourly boiler and auxiliary engine emissions remain the same for each tanker in the Base Case and Application Case. However, the time-in-mode at berth is expected to change as a part of the Project. Time-in-mode will decrease from 34 hours (Base Case) to 25.5 hours (with Project) for Aframax vessels. Time-in-mode will increase from 9 hours (Base Case) to 9.2 hours (with Project) for barges.

Table 11: Boiler and Auxiliary Engine Maximum Hourly Emission Rates (per tanker, in g/s)

Contaminant	Boiler	Auxiliary Engine
SO_2	0.06	0.09
NO_X	0.38	2.84
PM_{10}	0.02	0.06
$PM_{2.5}$	0.01	0.05
CO	0.14	0.22

Table 12: Existing Boilers and Auxiliary Engines Annual Emission Rates (in t/y)

Contaminant	Boiler	Auxiliary Engine
SO_2	0.31	0.42
NO_X	1.92	14.04
PM_{10}	0.08	0.29
$PM_{2.5}$	0.07	0.26
CO	0.72	1.11

Note: Annual emissions are estimated based on number of vessels per year and total time spent at berth.

Fugitive emissions are released from storage tanks as a result of working and storage losses. Working losses are associated with tank filling and withdrawing; whereas, storage losses are continuous emissions from rim seals, deck fittings and deck seams. Emissions from storage tanks are dependent on the physical characteristics of the tanks, the type of product stored, tank filling and withdrawal rates, total product throughput, and the surrounding meteorological conditions. Tank parameters for the Base Case are provided in Table 13. Tank emission rates were estimated following the same approach as discussed in Section 3.4.2.2 of the 2013 Technical Report. Resultant maximum hourly and annual emission rates are summarized in Table 14 and Table 15, respectively. Working losses are based on the maximum number of pumps in operation at the same time; therefore, the maximum hourly emissions do not include working losses from all tanks. As a modelling conservatism, the tanks with the highest predicted working loss emissions were modelled for each contaminant. These have been highlighted in grey in Table 14. For the annual case, the working losses for each tank are included, based on annual throughput.

Table 13: Westridge Storage Tank Details and Assumed Product, Base Case

Tank ID	Product Stored	Roof Type	Existing Scrubber
WR 93	Jet kerosene	Vertical Fixed Roof Tank	No
WR 201	Jet kerosene	Vertical Fixed Roof Tank	No
WR 202	Jet kerosene	Vertical Fixed Roof Tank	No

Table 14: Westridge Storage Tanks Maximum Hourly Emission Rates, Base Case (in g/s)

Tank ID	Maximum Hourly Emission Rate					
	H_2S	Mercaptans	Benzene	Toluene	Ethyl benzene	Xylenes
WR 93	0	0	5.35E-03	8.92E-02	3.95E-02	7.35E-02
WR 201	0	0	2.27E-05	3.79E-04	1.68E-04	3.12E-04
WR 202	0	0	2.25E-05	3.75E-04	1.66E-04	3.09E-04

Note: All emission rates include standing losses, and some emission rates include both standing and working losses. The number of tanks with working losses is based on the maximum number of pumps in operation at the same time. The emissions that include working losses have been highlighted in grey.

Table 15: Westridge Storage Tanks Annual Emission Rates, Base Case (in t/y)

Tank ID	Annual Emission Rate					
	H_2S	Mercaptans	Benzene	Toluene	Ethyl benzene	Xylenes
WR 93	0	0	1.24E-03	2.07E-02	9.17E-03	1.71E-02
WR 201	0	0	2.52E-04	4.19E-03	1.86E-03	3.46E-03
WR 202	0	0	2.49E-04	4.15E-03	1.84E-03	3.43E-03

Notes: All emission rates include both standing and working losses.
Working losses for each tank are based on annual throughput.

5.1.2 Application Case

The updated modelling for Application Case of the Westridge Marine Terminal considered two VRUs and one VCU along with three tanks holding jet kerosene product and two new tanks designed to hold synthetic crude oil[2]. Emissions from auxiliary engines and boilers during loading at the proposed new berth locations were also included in the modelling. Stack parameters for two new VRUs and one VCU are provided in Table 16. The stack parameters are still based on preliminary design. As mentioned in Section 4.3 of this report the following modelling scenarios were considered:

One-hour (and three-minute) averaging period:

- Scenario 1: VRU #1 was modelled based on instantaneous peak emission rate (worst product was selected for each contaminant). VRU #2 and the VCU were modelled using daily average emission rates (worst products were selected for each contaminant).
- Scenario 2: The VCU was modelled based on instantaneous peak emission rate (worst product was selected for each contaminant). VRU #1 and VRU #2 were modelled using daily average emission rates (worst products were selected for each contaminant).

24-hour averaging period: VRU #1, VRU #2 and VCU were modelled using daily average emission rates (worst products were selected for each contaminant).

- Scenario 1: The worst two products were modelled in the VRUs and the third worst product was modelled in the VCU.
- Scenario 2: The worst product was modelled in the VCU and the second and third worst products were modelled in the VRUs.

Annual Averaging period:

- Emission rates were modelled based on weighted annual average of all products. Emissions were distributed between the VRUs and VCU based on their utilization percent in a year. Each VRU will be utilized approximately 47% of the time in a year while the VCU will be only utilized approximately 5% of the time.

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[2] Two tanks holding synthetic crude oil (conservatively modelled as light sour product) will not be part of the revised design.

Table 16: Stack parameters for the Proposed VCU and VRUs, Application Case

Control	Stack Height (m)[1]	Stack Diameter (m)[2]	Exit Temperature (K)[3, 4]	Exit Velocity (m/s)[5, 6]
VRU #1 and #2 All Modelled Scenarios	19.8	0.36	288.6	12.8
VCU Scenario 1 (1 and 24-hour averaging periods)	21.3	3.5	1,255	5.6
VCU Scenario 2 (1 and 24-hour averaging periods)				11.9
VCU (annual averaging period)				5.6

Notes: [1] Stack height is based on preliminary analysis to inform engineering design and may change.
[2] Stack diameter is based on preliminary vendor design specifications (July 22, 2014) and may change.
[3] The VRU exit temperature is assumed to be at ambient air temperature.
[4] The VCU exit temperature is based on the existing VCU combustor operating temperature.
[5] The VRU exit velocity is based on preliminary vendor design specifications (July 22, 2014).
[6] The VCU exit velocities were estimated based on the stoichiometric exhaust to gas ratios and are within vendor provided ranges.

This supplemental report includes the expected collection and destruction efficiencies of the proposed vapour control systems based on manufacturer specifications of the units to be installed at the Westridge Marine Terminal. The collection and destruction efficiencies are shown in Table 17 and Table 18, respectively.

Table 17: Collection and Reduction Efficiencies for the Proposed VRU, Application Case

Compound	Collection Efficiency	H_2S and Mercaptans Removal Efficiency	VRU Reduction Efficiency	Total Reduction Efficiency
H_2S and Mercaptans	100%	99.9%	n/a	99.9%
BTEX		n/a	98%	98%

Notes: “n/a” indicates not applicable.
Efficiencies are based on preliminary engineering design and may change.

Table 18: Collection and Destruction Efficiencies for the Proposed VCU, Application Case

Compound	Collection Efficiency	H_2S and Mercaptans Removal Efficiency	Combustion Efficiency	Total Destruction Efficiency
H_2S and Mercaptans	100%	99.9%	98%	99.998%
BTEX	100%	n/a	98%	98%

Notes: "n/a" indicates not applicable
Efficiencies are based on preliminary engineering design and may change.

The collection efficiency is 100% because the exhausted vapours are piped directly to the VRUs or VCU. For this supplemental report, VOC emissions from vapours created during tank filling and from the displacement of inert gas in the cargo holds are based on HYSIS model process simulation results.

Maximum hourly emission rates for both scenarios are summarized in Table 19 and Table 20, respectively. Annual emission rates are provided in Table 21. Benzene and mercaptan emission rates are the same for both scenarios. The benzene emission rates are based on preliminary vendor design specifications. The mercaptan emission rates are based on combined streams from three vessels (i.e. a mixed flow in the header preceding the control equipment) The VOC emissions were assumed to be not mixed in the header pipe (i.e., each tanker would be connected to one control device). This will be re-visited later when equipment vendor designs are reviewed.

Table 19: VCU/VRU Hourly Emission Rates - Worst Case to VRU (Scenario 1), Application Case (in g/s)

Contaminant	VCU	VRU 1	VRU 2
Sulphur dioxide	0.0235	0.0216	0.0216
Oxides of nitrogen	3.1901	1.3298	1.3298
Inhalable particulate matter - PM_{10}	0.0930	0.0006	0.0006
Respirable particulate matter - $PM_{2.5}$	0.0930	0.0005	0.0005
Carbon monoxide	1.5194	0.4973	0.4973
Hydrogen sulphide	2.83E-06	0.0048	0.0002
Mercaptans	0.0002	0.0080	0.0080
Benzene	0.0028	0.0028	0.0028
Toluene	0.0156	0.0431	0.0190
Ethyl benzene	0.0014	0.0085	0.0014
Xylenes	0.0045	0.0363	0.0058

Notes: Emissions are based on preliminary engineering design and may change.
Benzene emission rates are based on preliminary vendor design specifications (August 4, 2014).
Mercaptan emission rates are based on a mixed flow in the header preceding the control equipment.
All VCU CAC emissions (SO_2, NO_X, PM and CO) include inert gas and combustion emissions. All VRU CAC emissions include inert gas emissions. H_2S, mercaptans and BTEX emissions include undestroyed emissions from tanker loading.

Table 20: VCU/VRU Hourly Emission Rates - Worst Case to VCU (Scenario 2), Application Case (in g/s)

Contaminant	VCU	VRU 1	VRU 2
Sulphur dioxide	0.0603	0.0216	0.0216
Oxides of nitrogen	6.2699	1.3298	1.3298
Inhalable particulate matter - PM_{10}	0.2461	0.0006	0.0006
Respirable particulate matter - $PM_{2.5}$	0.2461	0.0005	0.0005
Carbon monoxide	3.2116	0.4973	0.4973
Hydrogen sulphide	0.0001	0.0001	0.0002
Mercaptans	0.0002	0.0080	0.0080
Benzene	0.0028	0.0028	0.0028
Toluene	0.0431	0.0156	0.0190
Ethyl benzene	0.0085	0.0014	0.0014
Xylenes	0.0363	0.0045	0.0058

Notes: Emissions are based on preliminary engineering design and may change.
Benzene emission rates are based on preliminary vendor design specifications (August 4, 2014).
Mercaptan emission rates are based on a mixed flow in the header preceding the control equipment.
All VCU CAC emissions (SO_2, NO_X, PM and CO) include inert gas and combustion emissions. All VRU CAC emissions include inert gas emissions. H_2S, mercaptans and BTEX emissions include undestroyed emissions from tanker loading.

Table 21: VCU/VRU Annual Emission Rates, Application Case (in t/y)

Contaminant	VCU	VRU 1	VRU 2
Sulphur dioxide	0.0400	0.2889	0.2889
Oxides of nitrogen	5.9723	17.7675	17.7675
Inhalable particulate matter - PM_{10}	0.1924	0.0074	0.0074
Respirable particulate matter - $PM_{2.5}$	0.1924	0.0068	0.0068
Carbon monoxide	2.9097	6.6447	6.6447
Hydrogen sulphide	7.99E-06	0.0034	0.0034
Mercaptans	2.86E-05	0.0120	0.0120
Benzene	0.0037	0.0311	0.0311
Toluene	0.0195	0.1635	0.1635
Ethyl benzene	0.0023	0.0194	0.0194
Xylenes	0.0088	0.0738	0.0738

Notes: Emissions are based on preliminary engineering design and may change.
Benzene emission rates are based on preliminary vendor design specifications (August 4, 2014).
All VCU CAC emissions (SO_2, NO_X, PM and CO) include inert gas and combustion emissions. All VRU CAC emissions include inert gas emissions. H_2S, mercaptans and BTEX emissions include undestroyed emissions from tanker loading.

Maximum hourly emission rates for each marine auxiliary engine and boiler for each of the three berth locations are the same as in the Base Case, as provided in Table 11. The Westridge Marine Terminal berths increase from one to three, and the frequency of tanker visits also increases. The annual emission rates for the marine auxiliary engine and boiler are provided in Table 22.

Table 22: Application Boilers and Auxiliary Engines Annual Emission Rates (in t/y)

Contaminant	Boiler	Auxiliary Engine
SO_2	2.29	3.21
NO_X	14.08	106.31
PM_{10}	0.58	2.18
$PM_{2.5}$	0.53	2.00
CO	5.26	8.41

Note: Annual emissions are estimated based on number of vessels per year and total time spent at berth.

Tank parameters for the Application Case are provided in Table 23. Resultant hourly and annual emission rates are summarized in Table 24 and Table 25 respectively. The new crude tanks were modelled with scrubbers, i.e. applying a reduction efficiency of 64% for BTEX only.

Table 23: Westridge Storage Tank Details and Assumed Product, Application Case

Tank ID	Product Stored	Roof Type	Scrubber [1]
WR 93	Jet kerosene	Vertical Fixed Roof Tank	No
WR 201	Jet kerosene	Vertical Fixed Roof Tank	No
WR 202	Jet kerosene	Vertical Fixed Roof Tank	No
Crude 1 [2]	Synthetic crude oil	Internal Floating Roof Tank	Yes
Crude 2 [2]	Synthetic crude oil	Internal Floating Roof Tank	Yes

Notes: [1] New crude tanks were modelled applying a total reduction efficiency of 64% for BTEX only (marked in grey).
[2] Two tanks holding synthetic crude oil (conservatively modelled as light sour product) will no longer be part of the revised design.

Table 24: Westridge Storage Tanks Maximum Hourly Emission Rates, Application Case (in g/s)

Tank ID	Maximum Hourly Emission Rate					
	H_2S	Mercaptans	Benzene	Toluene	Ethyl benzene	Xylenes
WR 93	0	0	5.35E-03	8.92E-02	3.95E-02	7.35E-02
WR 201	0	0	2.27E-05	3.79E-04	1.68E-04	3.12E-04
WR 202	0	0	2.25E-05	3.75E-04	1.66E-04	3.09E-04
Crude 1	2.40E-05	2.09E-05	3.42E-05	3.27E-05	3.58E-06	1.04E-05
Crude 2	2.40E-05	2.09E-05	3.42E-05	3.27E-05	3.58E-06	1.04E-05

Notes: All emission rates include standing losses, and some emission rates include both standing and working losses. The number of tanks with working losses is based on the maximum number of pumps in operation at the same time. The emission rates that include working losses have been highlighted in grey.

Two tanks holding synthetic crude oil (conservatively modelled as light sour product) will no longer be part of the revised design.

Table 25: Westridge Storage Tanks Annual Emission Rates, Application Case (in t/y)

Tank ID	Annual Emission Rate					
	H_2S	Mercaptans	Benzene	Toluene	Ethyl benzene	Xylenes
WR 93	0	0	1.24E-03	2.07E-02	9.17E-03	1.71E-02
WR 201	0	0	2.52E-04	4.19E-03	1.86E-03	3.46E-03
WR 202	0	0	2.49E-04	4.15E-03	1.84E-03	3.43E-03
Crude 1	1.16E-04	1.02E-04	6.90E-04	6.60E-04	7.24E-05	2.09E-04
Crude 2	1.16E-04	1.02E-04	6.90E-04	6.60E-04	7.24E-05	2.09E-04

Notes: All emission rates include both standing and working losses.
Working losses for each tank are based on annual throughput.

Two tanks holding synthetic crude oil (conservatively modelled as light sour product) will no longer be part of the revised design.

5.2 Dispersion Modelling Results for the Westridge Marine Terminal

5.2.1 Base and Application Cases

Table 26 summarizes the results for all contaminants for the Base and Application Cases at Westridge Marine Terminal Only, with ambient background. No ambient background was available for mercaptans. All of the modelled concentrations are below their respective ambient air quality objectives. For the Annual Case, maximum results for Scenario 1 and Scenario 2 are presented. For most of the modelled contaminants, the predicted concentrations are higher for the Application Case, compared to the Base Case. For Base Case SO_2 and H_2S results, the predicted concentrations are slightly lower than in the Application Case. This is related to the proposed carbon guard beds upstream of the VCU and VRUs, which are expected to remove 99.9% of H_2S and mercaptans before entering VCU and VRUs, while in the Base Case there is no upstream control for the existing VCU, any reduced sulphurs are oxidised to SO_2.

Table 27 presents the maximum predicted concentrations for PM_{10} and $PM_{2.5}$ for the 24-hour averaging period, calculated using rolling averages. These values are almost identical to the maximum predicted concentrations in Table 26.

Table 26: Maximum Predicted Concentrations Including Ambient Background for the Base and Application Cases at the Westridge Marine Terminal (in µg/m^3)

Pollutant	Averaging Period	Ambient Background	Base Case (with Ambient Background)	Application Case (With Ambient Background)	Alberta Objective	Metro Vancouver Objective
Inhalable particulate matter - PM$_{10}$	24-hour	20.1	21.4	22.0	n/a	50
	Annual	8.3	8.4	8.5	n/a	20
Respirable particulate matter - PM$_{2.5}$	24-hour	12.5	13.7	14.3	80	25
	Annual	3.3	3.4	3.5	30	8
Carbon monoxide	1-hour	605.0	649.0	1076.0	15,000	30,000
	8-hour	543.0	555.0	695.0	6000	10,000
Oxides of nitrogen	1-hour	111.0	345.0	1491.0	n/a	n/a
	24-hour	88.7	153.0	409.0	n/a	n/a
	Annual	26.7	31.1	45.1	n/a	n/a
Nitrogen dioxide[2]	1-hour	111.0	84.0	149	300	200
	24-hour	88.7	66.6	90.3	n/a	200[1]
	Annual	26.7	20.0	28.9	45	40
Sulphur dioxide	1-hour	26.3	51.1	48.5	450	450
	24-hour	17.4	20.1	21.8	125	125
	Annual	2.7	2.9	3.2	30	30
Benzene	1-hour	5.1	12.3	14.0	30	n/a
	Annual	0.55	0.56	0.58	3.0	n/a
Ethyl benzene	1-hour	2.7	56.4	56.5	2000	n/a
Toluene	1-hour	14.3	135.0	136.0	1880	n/a
	24-hour	5.7	40.7	42.7	400	n/a
Xylenes	1-hour	13.1	113.0	114.0	2300	n/a
	24-hour	5.2	34.1	35.3	700	n/a
Hydrogen sulphide	1-hour	0.0	0.81	2.81	14.0	7[3]
	24-hour	0.18	0.25	0.22	4.0	3[3]
Mercaptans	10-minute	-	7.0	12.4	13[4]	13[4]

Notes: Results are based on preliminary design and may change.
"n/a" indicates not applicable.
[1] National objectives are presented for 24-hour NO$_2$, since there are no Metro Vancouver objectives.
[2] NO$_2$ is calculated from NO$_X$ concentrations.
[3] H$_2$S is compared to the BC TRS objective. There are no BC or Metro Vancouver objectives for H$_2$S.
[4] No objectives for total mercaptans exist in BC and Alberta. Ontario Objectives were applied.

Table 27: Maximum Predicted 24-Hour Rolling Average Concentrations Including Ambient Background for the Base and Application Cases (in µg/m^3)

Pollutant	Averaging Period	Ambient Background	Base Case (with Ambient Background)	Application Case (with Ambient Background)	Alberta Objective	Metro Vancouver Objective
PM_{10}	24-hour	20.1	21.4	22.1	n/a	50
$PM_{2.5}$	24-hour	12.5	13.7	14.4	80	25

Note: Results are based on preliminary design and may change.

Table 28 presents the maximum predicted 3-minute concentrations for the Base and Application Cases at Westridge Marine Terminal, compared to the odour detection thresholds as discussed in Section 4.6. All of the modelled results lie below their respective odour detection thresholds for the Base Case, but for the Application Case, H_2S and mercaptans exceeded their detection thresholds. The exceedances of odour threshold geometric mean for H_2S and mercaptans were predicted to occur 0.034% and 0.023% of the time based on one year of modelled data. The receptors with maximum predicted 3-minute concentrations greater than the odour thresholds for H_2S and mercaptans are shown in Figure 1 and Figure 2, respectively. The maximum predicted 3-minute concentrations greater than the odour thresholds for both pollutants are located along the property line, both along the shoreline and the southeast side of Westridge Marine Terminal. For H_2S, there is also one receptor just east of the fenceline where the 3-minute maximum predicted concentrations exceeded the odour threshold. Most of these areas are controlled by terminal fencing and one receptor is located in the forest just southeast of the fenceline. It is highly unlikely that the public would access these areas with elevated 3-minute maximum predicted concentrations particularly at the same time that three tankers would be loading and with the adverse dispersion conditions found in the CALPUFF model. There are no elevated results suggesting nuisance odours close to or within the residential areas.

Table 28: Maximum 3-minute Predicted Concentrations Including Ambient Background for the Base and Application Cases, Westridge Marine Terminal Only (in µg/m^3)

Pollutant	Odour Threshold Geometric Mean[1]	Base Case			Application Case		
		1-hour Maximum Concentration	3-minute Maximum Concentration	Percentage of Odour Threshold	1-hour Maximum Concentration	3-minute Maximum Concentration	Percentage of Odour Threshold
Benzene	39,429	12.3	28.6	<0.1%	14.0	32.5	<0.1%
Ethyl benzene	490	56.4	130	26.6%	56.5	131	26.7%
Toluene	4682	135	313	6.7%	136	315	6.7%
Xylenes	1534	113	261	17.0%	114	263	17.1%
H_2S	3.89	0.81	1.9	48.3%	2.8	6.5	167%
Mercaptans	13	4.2	9.8	75.0%	7.5	17.4	134%

Notes: Results are based on preliminary design and may change.

[1] Geometric Mean is based on AIHA, 2013 with the exception of mercaptans which is based on Ontario Regulation.

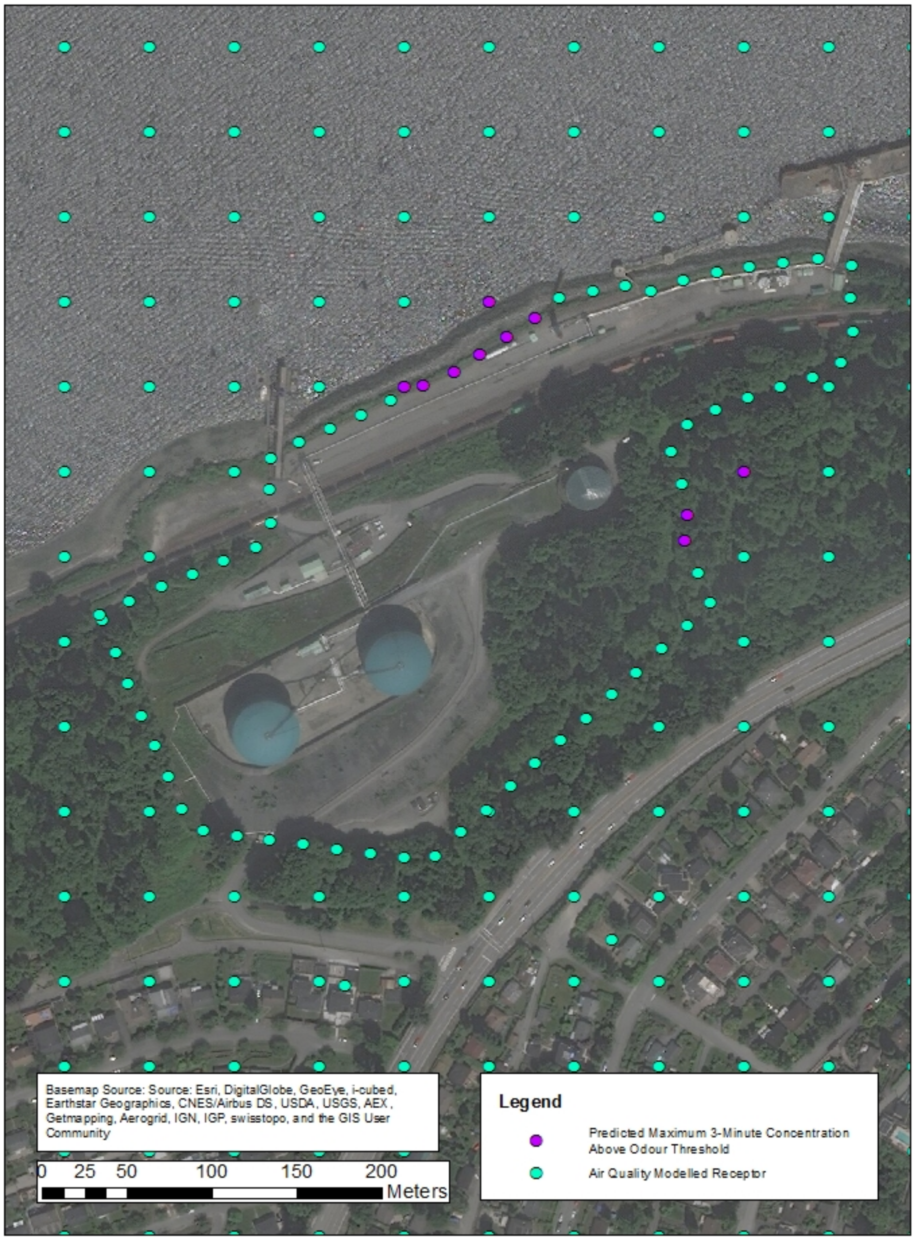
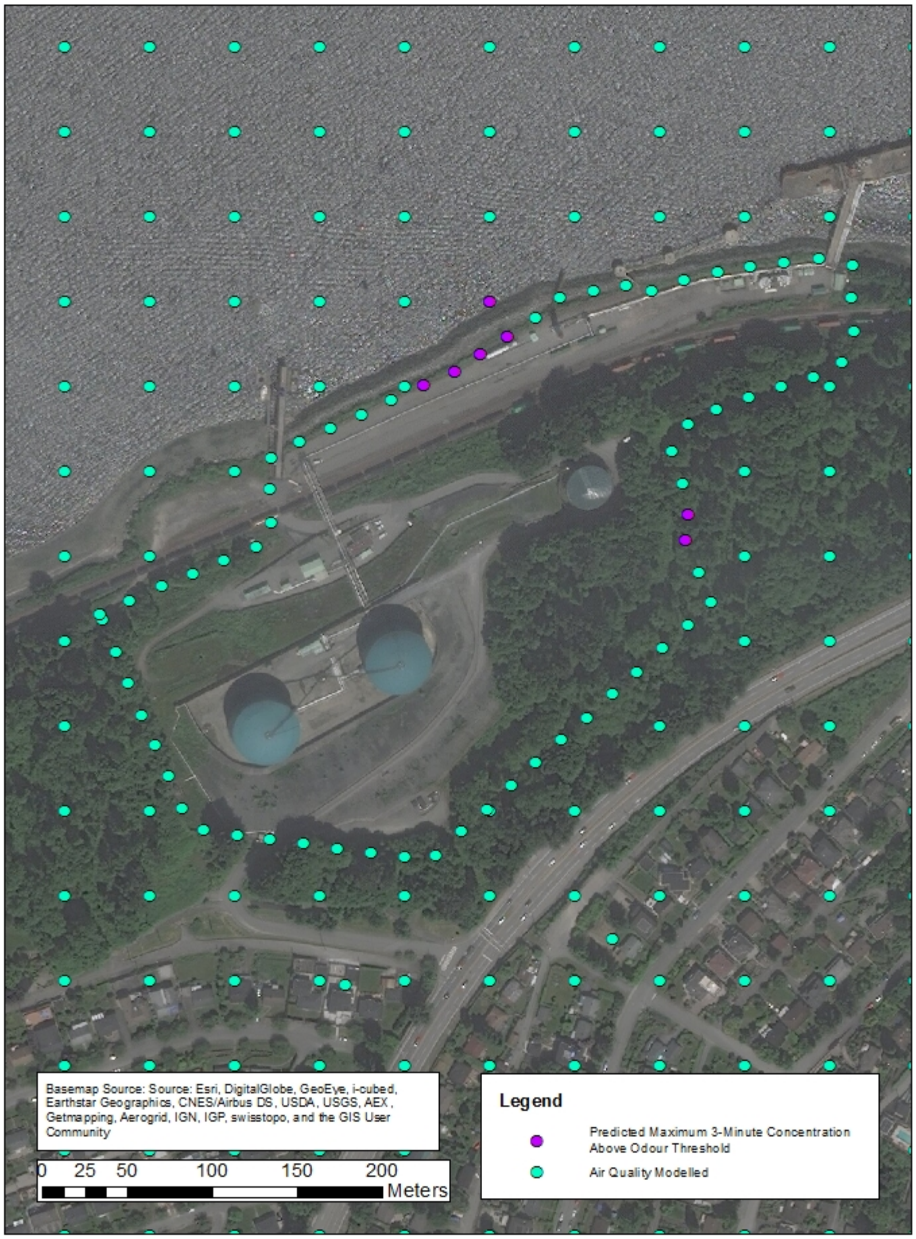


Figure 1: Location of Air Quality Modelled Receptors (Blue Dots) and Receptors with Predicted Maximum 3-Minute H_2S Concentrations Greater than the Odour Detection Threshold (Purple Dots)



Basemap Source: Source: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Figure 2: Location of Air Quality Modelled Receptors (Blue Dots) and Receptors with Predicted Maximum 3-Minute Mercaptans Concentrations Greater than the Odour Detection Threshold (Purple Dots)

5.3 Modelled Parameters for the Burnaby Terminal

5.3.1 Base Case

The updated modelling for the Base Case of the Burnaby Terminal considered thirteen tanks holding heavy crude, light crude and refined products. Tank parameters for the Base Case are provided in Table 29. Resultant hourly and annual emission rates are summarized in Table 30 and Table 31, respectively. Four tanks were modelled with scrubbers which are designed for odour control with a removal efficiency of 76%.

Table 29: Burnaby Storage Tank Details and Assumed Product, Base Case

Tank ID	Product Stored (a)	Roof Type	Existing Scrubber ([1]
B 71	Refined Products	External Floating Roof Tank	No
B 72	Light Crude	External Floating Roof Tank	No
B 73	Refined Products	Domed External Floating Roof Tank	No
B 74	Light Crude	External Floating Roof Tank	No
B 81	Light Crude	Domed External Floating Roof Tank	No
B 82	Heavy Crude	External Floating Roof Tank	No
B 83	Heavy Crude	External Floating Roof Tank	No
B 84	Heavy Crude	External Floating Roof Tank	No
B 85	Heavy Crude	External Floating Roof Tank	No
B 86	Light Crude	Domed External Floating Roof Tank	Yes
B 87	Heavy Crude	Domed External Floating Roof Tank	Yes
B 88	Heavy Crude	Domed External Floating Roof Tank	Yes
B 90	Heavy Crude	Domed External Floating Roof Tank	Yes

Note: [1] Applied scrubber total reduction efficiency was 76%

Table 30: Burnaby Storage Tanks Maximum Hourly Emission Rates, Base Case (in g/s)

Tank ID	Maximum Hourly Emission Rate					
	H_2S	Mercaptans	Benzene	Toluene	Ethyl benzene	Xylenes
B 71	0	0	1.61E-03	8.01E-03	5.54E-04	2.72E-03
B 72	1.73E-04	5.95E-05	2.70E-04	2.58E-04	2.83E-05	8.18E-05
B 73	0	0	7.96E-04	4.42E-03	3.06E-04	1.50E-03
B 74	2.08E-04	8.98E-05	4.07E-04	7.88E-04	8.64E-05	2.50E-04
B 81	9.60E-05	1.02E-05	4.62E-05	4.42E-05	4.84E-06	1.40E-05
B 82	0	1.48E-04	9.07E-04	1.58E-04	6.64E-06	5.99E-05
B 83	0	1.48E-04	9.07E-04	1.58E-04	6.64E-06	5.99E-05
B 84	0	1.48E-04	9.07E-04	1.58E-04	6.64E-06	5.99E-05
B 85	0	5.60E-05	3.44E-04	1.83E-04	7.70E-06	6.95E-05
B 86	1.46E-05	1.28E-05	2.08E-05	1.99E-05	2.18E-06	6.31E-06
B 87	0	2.65E-05	5.85E-05	3.12E-05	1.31E-06	5.63E-05
B 88	0	2.65E-05	5.85E-05	3.12E-05	1.31E-06	1.18E-05
B 90	0	2.65E-05	5.85E-05	3.12E-05	1.31E-06	1.18E-05

Note: All emission rates include standing losses, and some emission rates include both standing and working losses. The number of tanks with working losses is based on the maximum number of pumps in operation at the same time. The emission rates that include working losses have been highlighted in grey.

Table 31: Burnaby Storage Tanks Annual Emission Rates, Base Case (in t/y)

Tank ID	Annual Emission Rate					
	H_2S	Mercaptans	Benzene	Toluene	Ethyl benzene	Xylenes
B 71	0	0	2.36E-02	1.04E-01	7.21E-03	3.54E-02
B 72	1.20E-03	1.04E-03	4.73E-03	4.53E-03	4.97E-04	1.44E-03
B 73	0	0	1.14E-02	5.05E-02	3.49E-03	1.72E-02
B 74	1.54E-03	1.35E-03	6.11E-03	5.84E-03	6.41E-04	1.85E-03
B 81	4.94E-04	4.32E-04	1.96E-03	1.87E-03	2.05E-04	5.94E-04
B 82	0	8.48E-04	5.21E-03	2.78E-03	1.17E-04	1.05E-03
B 83	0	8.48E-04	5.21E-03	2.78E-03	1.17E-04	1.05E-03
B 84	0	8.48E-04	5.21E-03	2.78E-03	1.17E-04	1.05E-03
B 85	0	9.55E-04	5.86E-03	3.13E-03	1.31E-04	1.19E-03
B 86	5.35E-04	4.67E-04	7.62E-04	7.30E-04	8.00E-05	2.31E-04
B 87	0	5.35E-04	1.18E-03	6.31E-04	2.65E-05	2.39E-04
B 88	0	5.35E-04	1.18E-03	6.31E-04	2.65E-05	2.39E-04
B 90	0	5.35E-04	1.18E-03	6.31E-04	2.65E-05	2.39E-04

Notes: All emission rates include both standing and working losses.
Working losses for each tank are based on annual throughput.

5.3.2 Application Case

The updated modelling for the Application Case of the Burnaby Terminal considered twenty six tanks holding a number of different products. Tank parameters for the Application Case including stored product are provided in Table 32. All of the new tanks were modelled as Internal Floating Roof Tanks (IFRT) in the Application Case. Resultant hourly and annual emission rates are summarized in Table 33 and Table 34, respectively. Four existing tanks were modelled with scrubbers (i.e., applying a total reduction efficiency of 76% for odour control only). Emission rates for H_2S and mercaptans were developed assuming Tank Vapour Absorption Units (TVAUs) on all of the proposed tanks, with a total odour control efficiency of 76%.

Table 32: Burnaby Storage Tank Details and Assumed Product, Application Case

Tank ID	Product Stored	Roof Type [1,2]	Scrubber [3]
B 71	Chevron Split	External Floating Roof Tank	No
B 72	ISO Octane	External Floating Roof Tank	No
B 73	Chevron Crude	Internal Floating Roof Tank	No
B 74	High TAN Dilbit	Internal Floating Roof Tank	Yes
B 75	High TAN Dilbit	Internal Floating Roof Tank	Yes
B 76	High TAN Dilbit	Internal Floating Roof Tank	Yes
B 77	Light Synthetic/Sweet	Internal Floating Roof Tank	Yes
B 78	High TAN Dilbit	Internal Floating Roof Tank	Yes
B 79	Light Synthetic/Sweet	Internal Floating Roof Tank	Yes
B 80	High TAN Dilbit	Internal Floating Roof Tank	Yes
B 81	Chevron Crude	Domed External Floating Roof Tank	No
B 82	High TAN Dilbit	External Floating Roof Tank	No
B 83	Chevron Split	External Floating Roof Tank	No
B 84	High TAN Dilbit	External Floating Roof Tank	No
B 85	Light Synthetic/Sweet	External Floating Roof Tank	No
B 86	High TAN Dilbit	Domed External Floating Roof Tank	Yes
B 87	Light Synthetic/Sweet	Internal Floating Roof Tank	Yes
B 88	High TAN Dilbit	Internal Floating Roof Tank	Yes
B 89	Light Synthetic/Sweet	Internal Floating Roof Tank	Yes
B 90	High TAN Dilbit	Internal Floating Roof Tank	Yes
B 91	High TAN Synbit/Dilsynbit	Internal Floating Roof Tank	Yes
B 93	High TAN Synbit/Dilsynbit	Internal Floating Roof Tank	Yes
B 95	High TAN Synbit/Dilsynbit	Internal Floating Roof Tank	Yes
B 96	High TAN Dilbit	Internal Floating Roof Tank	Yes
B 97	Low TAN Dilbit	Internal Floating Roof Tank	Yes
B 98	Low TAN Dilbit	Internal Floating Roof Tank	Yes

Notes: [1] All proposed tanks are highlighted in grey.
[2] New tanks were modeled as IFRT (with TVAUs for H_2S and mercaptans)
[3] Applied scrubber total reduction efficiency was 76% for the existing tanks and 76% for mercaptans and H_2S only for the new tanks (marked in grey).

Table 33: Burnaby Storage Tanks Maximum Hourly Emission Rates, Application Case (in g/s)

Tank ID	Maximum Hourly Emission Rate					
	H_2S [1]	Mercaptans [1]	Benzene	Toluene	Ethyl benzene	Xylenes
B 71	0	5.96E-06	7.59E-05	8.21E-05	5.40E-05	1.75E-04
B 72	0	0	1.95E-03	8.61E-03	5.96E-04	2.92E-03
B 73	0	2.60E-06	3.31E-05	3.58E-05	4.91E-05	1.59E-04
B 74	0	1.52E-05	2.62E-04	1.40E-04	5.87E-06	5.29E-05
B 75	0	1.52E-05	2.62E-04	1.40E-04	5.87E-06	5.29E-05
B 76	0	1.52E-05	2.62E-04	1.40E-04	5.87E-06	5.29E-05
B 77	0	1.08E-06	5.74E-05	6.21E-05	6.61E-06	2.15E-05
B 78	0	1.70E-05	2.92E-04	1.56E-04	6.55E-06	5.91E-05
B 79	0	1.21E-06	6.42E-05	6.94E-05	7.39E-06	2.40E-05
B 80	0	1.52E-05	2.62E-04	1.40E-04	5.87E-06	5.29E-05
B 81	0	9.99E-07	1.27E-05	1.38E-05	1.47E-06	4.76E-06
B 82	0	8.87E-05	1.31E-03	6.98E-04	8.20E-06	7.40E-05
B 83	0	6.33E-06	8.06E-05	8.72E-05	9.28E-06	3.01E-05
B 84	0	8.87E-05	1.31E-03	6.98E-04	8.20E-06	7.40E-05
B 85	0	7.35E-06	9.36E-05	1.01E-04	1.08E-05	3.50E-05
B 86	0	1.76E-05	1.74E-05	9.30E-06	3.91E-07	3.52E-06
B 87	0	3.39E-06	1.04E-05	1.12E-05	1.19E-06	3.88E-06
B 88	0	4.78E-05	4.72E-05	2.52E-05	1.06E-06	9.56E-06
B 89	0	1.08E-06	5.74E-05	6.21E-05	6.61E-06	2.15E-05
B 90	0	4.78E-05	4.72E-05	2.52E-05	1.06E-06	9.56E-06
B 91	6.58E-04	2.45E-03	1.13E-05	1.48E-05	2.34E-06	7.46E-06
B 93	6.58E-04	2.45E-03	1.13E-05	1.48E-05	2.34E-06	7.46E-06
B 95	6.58E-04	2.45E-03	1.13E-05	1.48E-05	2.34E-06	7.46E-06
B 96	0	1.23E-05	2.11E-04	1.13E-04	4.74E-06	4.27E-05
B 97	0	1.52E-05	2.62E-04	1.40E-04	5.87E-06	5.29E-05
B 98	0	1.41E-05	2.42E-04	1.29E-04	5.43E-06	4.90E-05

Notes: All emission rates include standing losses, and some emission rates include both standing and working losses. The number of tanks with working losses is based on the maximum number of pumps in operation at the same time. The emission rates that include working losses have been highlighted in grey.

[1] Emission rates for H_2S and mercaptans were developed assuming TVAUs for odour control on the proposed tanks, with a total control efficiency of 76%.

Table 34: Burnaby Storage Tanks Annual Emission Rates, Application Case (in t/y)

Tank ID	Annual Emission Rate					
	H_2S[1]	Mercaptans[1]	Benzene	Toluene	Ethyl benzene	Xylenes
B 71	0	1.22E-04	1.56E-03	1.68E-03	1.79E-04	5.81E-04
B 72	0	0	2.45E-02	1.08E-01	7.50E-03	3.68E-02
B 73	0	7.39E-05	9.41E-04	1.02E-03	1.08E-04	3.52E-04
B 74	0	4.95E-04	8.50E-03	4.54E-03	1.91E-04	1.72E-03
B 75	0	4.95E-04	8.50E-03	4.54E-03	1.91E-04	1.72E-03
B 76	0	4.95E-04	8.50E-03	4.54E-03	1.91E-04	1.72E-03
B 77	0	3.56E-05	1.89E-03	2.04E-03	2.18E-04	7.06E-04
B 78	0	5.43E-04	9.32E-03	4.98E-03	2.09E-04	1.89E-03
B 79	0	3.90E-05	2.07E-03	2.24E-03	2.38E-04	7.74E-04
B 80	0	4.95E-04	8.50E-03	4.54E-03	1.91E-04	1.72E-03
B 81	0	7.04E-05	8.97E-04	9.70E-04	1.03E-04	3.35E-04
B 82	0	2.05E-03	8.46E-03	4.52E-03	1.90E-04	1.71E-03
B 83	0	1.47E-04	1.87E-03	2.03E-03	2.16E-04	7.00E-04
B 84	0	2.05E-03	8.46E-03	4.52E-03	1.90E-04	1.71E-03
B 85	0	1.61E-04	2.05E-03	2.22E-03	2.36E-04	7.67E-04
B 86	0	2.46E-04	1.01E-03	5.41E-04	2.27E-05	2.05E-04
B 87	0	2.56E-05	3.26E-04	3.52E-04	3.75E-05	1.22E-04
B 88	0	3.56E-04	1.47E-03	7.83E-04	3.29E-05	2.96E-04
B 89	0	3.56E-05	1.89E-03	2.04E-03	2.18E-04	7.06E-04
B 90	0	3.56E-04	1.47E-03	7.83E-04	3.29E-05	2.96E-04
B 91	1.37E-03	5.10E-03	4.46E-04	5.82E-04	9.24E-05	2.94E-04
B 93	1.37E-03	5.10E-03	4.46E-04	5.82E-04	9.24E-05	2.94E-04
B 95	1.37E-03	5.10E-03	4.46E-04	5.82E-04	9.24E-05	2.94E-04
B 96	0	3.27E-04	5.61E-03	2.99E-03	1.26E-04	1.13E-03
B 97	0	4.95E-04	8.50E-03	4.54E-03	1.91E-04	1.72E-03
B 98	0	4.64E-04	7.97E-03	4.26E-03	1.79E-04	1.61E-03

Notes: All emission rates include both standing and working losses.
Working losses for each tank are based on annual throughput.
[1] Emission rates for H_2S and mercaptans were developed assuming TVAUs for odour control on the proposed tanks, with a total control efficiency of 76%.

5.4 Dispersion Modelling Results for the Burnaby Terminal

5.4.1 Base and Application Cases

Table 35 summarizes the results for all contaminants for the Base and Application Cases at the Burnaby Terminal Only, with ambient background. No ambient background was available for mercaptans. All of the modelled concentrations are below their respective ambient air quality objectives.

Table 35: Maximum Predicted Concentrations Including Ambient Background for the Base and Application Cases, Burnaby Terminal Only Assuming all New Tanks are IFRTs with TVAUs for H_2S and Mercaptans Control Only (in µg/m^3)

Pollutant	Averaging Period	Ambient Background	Base Case (With Ambient Background)	Application Case (With Ambient Background)	Alberta Objective	BC Objective
Benzene	1-hour	5.1	6.7	7.4	30	n/a
	Annual	0.55	0.58	0.61	3	n/a
Ethyl benzene	1-hour	2.7	3.2	3.5	2000	n/a
Toluene	1-hour	14.3	21.2	24.3	1880	n/a
	24-hour	5.7	6.4	8.0	400	n/a
Xylenes	1-hour	13.1	15.5	16.7	2300	n/a
	24-hour	5.2	5.5	6.0	700	n/a
Hydrogen sulphide	1-hour	0.0	0.28	0.85	14	7[1]
	24-hour	0.18	0.25	0.39	4	3[1]
Mercaptans	10-min	-	0.26	5.3	13[2]	13[2]

Notes: [1] In BC, H_2S was compared to the total reduced sulphur (TRS) objective. There are no BC objectives for H_2S.
[2] No objectives for total mercaptans exist in BC and Alberta. Ontario Objectives were applied.

Table 36 presents the 3-minute maximum modelled concentrations for the Base and Application Cases at the Burnaby Terminal, compared to the odour detection thresholds discussed in Section 4.6. All of the modelled results lie below their respective odour detection thresholds for the Base and Application Cases.

Table 36: Maximum 3-minute Predicted Concentrations Including Ambient Background for the Base and Application Cases, Burnaby Terminal Only (in µg/m^3)

Pollutant	Odour Threshold Geometric Mean [1]	Base Case			Application Case		
		1-hour Maximum Concentration	3-minute Maximum Concentration	Percentage of Odour Threshold	1-hour Maximum Concentration	3-minute Maximum Concentration	Percentage of Odour Threshold
Benzene	39,429	6.7	15.5	<0.1%	7.4	17.1	<0.1%
Ethyl benzene	490	3.2	7.4	1.5%	3.5	8.0	1.6%
Toluene	4682	21.2	49.2	1.0%	24.3	56.2	1.2%
Xylenes	1534	15.5	35.8	2.3%	16.7	38.5	2.5%
H_2S	3.89	0.28	0.64	16.6%	0.85	2.0	50.6%
Mercaptans	13	0.16	0.37	2.8%	3.2	7.5	57.7%

Note: [1] Geometric mean is based on AIHA, 2013 with the exception of mercaptans which is based on Ontario Regulation

6. CUMULATIVE CASE

In Section 8.1.4.2 of Volume 5A (NEB Filing ID A3S1R1), three projects in the Air Quality RSA were publicly announced and/or were undergoing regulatory review during the time period when the Trans Mountain terrestrial air quality assessments were being developed for the Westridge Marine Terminal and Burnaby Terminal. These projects (i.e., Neptune Bulk Terminals Ltd Coal Handling Infrastructure Upgrade and Expansion (Neptune), James Richardson Terminal Ltd Grain Storage Capacity project (Richardson) and Fraser Surrey Docks Direct Coal Transfer (Fraser Surrey) were selected because of their announced intentions to discharge contaminants of interest that may have the potential to combine with similar emissions from the Project especially at the Westridge Marine Terminal. The websites for the proponents of these projects were visited in pursuit of a project-specific air quality assessment where the results could be used to evaluate whether they would be expected to combine with the air quality effects from the Trans Mountain Project. Air quality assessments for neither of the Neptune or Richardson projects were available at the Trans Mountain project inclusion list cutoff date in May 31, 2013. This cutoff date was six months before the NEB filing deadline in December 2013 and represents the final date for new information to be considered for Project cumulative effects. It was assumed that if these projects were to proceed, they would be required by Metro Vancouver to meet the applicable ambient quality objectives. Port Metro Vancouver (PMV) issued a permit (No. 2012-099) for the Richardson project (PMV 2014a) in 2014. No air quality assessment was found on the PMV or Richardson websites. PMV has also issued a permit (No. 2012-066) for the Neptune project (PMV 2014b) in 2014. No air quality assessment was found on the PMV or Neptune websites but a state-of-the-art dust suppression system was proposed and

Neptune has a valid GVRD Air Quality Management permit. Both projects are currently under construction.

The third proposed development of note is the Surrey Fraser project, which is located approximately 10 km south of the Burnaby Terminal. A detailed air quality assessment of CACs was completed for this project by the proponent and included emissions from ship engines as well as fugitive particulate emissions from coal loading (PMV 2014c). The predicted results indicated exceedances of the ambient air quality objectives for NO_2 near the freighters over water due to engine exhaust. As well, increases in ambient particulate matter levels were predicted to occur. A site-specific particulate matter management plan was developed to reduce the amount of fugitives from coal handling and loading. This facility is required to meet applicable Metro Vancouver ambient air quality objectives on land. With this plan in place and through the benefit of atmospheric dispersion over the 10 km to the Air Quality RSA, it is expected that emissions from the Surrey Fraser coal facility will not act in combination with the Project, particularly the Westridge Marine Terminal and Burnaby Terminal, to cause a cumulative increase in existing ambient air quality levels in the Air Quality RSA (i.e., no spatial overlap in emissions from the developments is anticipated that would result in a decrease in air quality); therefore, a quantitative assessment for the Surrey Fraser facility in relation to the Project is not required. PMV is currently reviewing the permit application and associated environmental studies and has identified areas that require further information particularly on the potential effects of the project on human health (PMV 2014c).

In summary and based on the three major industrial projects identified in 2013, no quantitative assessment was completed for the Cumulative Case for the reasons stated above.

7. CONCLUSIONS

This supplemental report presents the changes to the assumptions which were used in the air quality assessment presented in the 2013 Technical Report. As the detailed engineering for the Project evolves, the assumptions used in the technical air quality assessment were refined. This technical update reflects the improvement to a number of assumptions and provides the summary of the updated modelling parameters, assumptions and dispersion model results. RWDI AIR Inc. (RWDI) conducted additional dispersion modelling to:

- ensure that updated engineering design of new tanks and vapour control configurations met the applicable ambient air quality objectives at the Burnaby Terminal and Westridge Marine Terminal;
- inform the engineering design of new tanks and vapour control configurations to the appropriate technology level based on predicted concentrations that are less than applicable ambient air quality objectives. Provide an assessment results comparison with the updated odour detection thresholds;
- provide an updated air quality assessment for the Burnaby Terminal and Westridge Marine Terminal to the National Energy Board (NEB) and interveners;
- correct any errors from the previous air quality assessment; and,

- fulfill commitments for updated air quality modelling made through the NEB Information Request (IR) process.

The results of the air quality assessment for the Burnaby Terminal and Westridge Marine Terminal completed as part of this supplemental report reflect the interim engineering design and demonstrate that all ambient air quality objectives could be met. The air quality assessment is an on-going and iterative process which informs and is informed by the engineering design and setting of specifications required of final equipment vendors. Improvements have been made to the assumptions used in the air quality modelling, specifically:

- a more comprehensive suite of crude oil products have been included;
- emission rates from the storage tanks at the Burnaby Terminal have been re-calculated;
- tanker loading simulations have been completed and verified against the results of real-time vapour composition sampling at the Westridge Marine Terminal;
- more stringent process specifications for capture and recovery/destruction of vapours have been developed for the proposed vapour recovery and vapour combustion units at the Westridge Marine Terminal;
- refinements have been made to the approach for estimating nitrogen dioxide (NO_2) levels near the Westridge Marine Terminal; and,
- updated odour detection thresholds were used to evaluate the Project effects based on a more recent publication from the Association of Industrial Hygiene Association.

Trans Mountain considered, and is continuing to consider, different vapour control configurations for the Westridge Marine Terminal and tank design configurations and tank vapour adsorption units (TVAU's) at Burnaby Terminal for odour control only. Trans Mountain is committed to meeting the applicable ambient air quality objectives and odour detection thresholds at each storage terminal to assist with determining storage tank design and vapour control configurations. Trans Mountain continues to use air quality modelling results to determine tank design and vapour control configuration using an iterative process.

In summary, the predicted maximum concentrations with ambient background for all specified criteria air contaminants such as sulphur dioxide and volatile organic compounds such as benzene were found to be less than their respective Alberta and Metro Vancouver ambient objectives for all averaging periods for the Application and Cumulative Cases.

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APPENDIX A

CALMET MODELLING UPDATE

1. INTRODUCTION

This Appendix provides details on CALMET (Section 2) and CALPUFF (Section 4) inputs that are not provided in the main text of the Supplemental Air Quality Technical Report for Technical Update No. 2. It covers the Air Quality Regional Study Area (RSA) for the Burnaby Terminal and Westridge Marine Terminals. Some CALMET outputs are shown and briefly discussed in Section 3 to demonstrate that CALMET produces meteorological inputs for CALPUFF that qualitatively agree with expected meteorological conditions. The CALMET section reflects updated land use data along with the modelled mixing heights under unstable, neutral, and stable conditions and other meteorological parameters used in the evaluation of atmospheric dispersion of emissions from the Burnaby Terminal and the Westridge Marine Terminal. The CALPUFF section has not changed since the 2013 Technical Report.

2. CALMET INPUTS

This section presents the input parameters needed to run CALMET. These are divided into two broad categories: geophysical parameters, which specify surface properties as a function of season and land-use type; and model switch settings, which specify how CALMET will process the input.

2.1 Geophysical Parameters

Tables A.1 to A.6 are based on five seasons, identified based on climate normal data from Vancouver International Airport (Environment Canada 2013), and described in the main text of the 2013 Technical Report. Surface roughness, albedo, and Bowen ratio are mostly based on recommended values from the United States Environmental Protection Agency (US EPA) for the conterminous United States (US EPA 2013). Soil heat flux values are CALMET default values. Leaf area index is based on generic values for land-use type, which have been used previously for Canada (Zhang et al. 2002, 2003). Anthropogenic heat flux was calculated based on the anthropogenic heat flux provided in Boundary Layer Climates (Oke 1987) and scaled by population density as published by Statistics Canada (2011).

Table A.1: Seasonal values of surface roughness length by land cover characterization category (in m).

Land cover characterization Category	Season 1 (Summer)	Season 2 (Autumn)	Season 3 (Winter 1)	Season 4 (Winter 2)	Season 5 (Spring)
Urban	0.40	0.40	0.30	0.30	0.40
Agricultural	0.20	0.20	0.02	0.01	0.03
Rangeland	0.15	0.15	0.02	0.01	0.03
Deciduous Forest	1.30	1.30	0.60	0.50	1.00
Coniferous Forest	1.30	1.30	1.30	1.30	1.30
Mixed Forest	1.30	1.30	0.90	0.80	1.10
Water	0.001	0.001	0.001	0.002(a)	0.001
Wetland(b)	0.20	0.20	0.20	0.10	0.20
Barren Land	0.05	0.05	0.05	0.05	0.05

Notes:
Source: Modified from US EPA (2013)
a. Value borrowed from “Perennial Snow or Ice”.
b. Values based on emergent herbaceous wetlands.

Table A.2: Seasonal values of albedo by land cover characterization category.

Land cover characterization Category	Season 1 (Summer)	Season 2 (Autumn)	Season 3 (Winter 1)	Season 4 (Winter 2)	Season 5 (Spring)
Urban	0.16	0.16	0.18	0.45	0.16
Agricultural	0.20	0.20	0.18	0.60	0.14
Rangeland	0.20	0.20	0.18	0.60	0.14
Deciduous Forest	0.16	0.16	0.17	0.50	0.16
Coniferous Forest	0.12	0.12	0.12	0.35	0.12
Mixed Forest	0.14	0.14	0.14	0.42	0.14
Water	0.10	0.10	0.10	0.70(a)	0.10
Wetland(b)	0.14	0.14	0.14	0.30	0.14
Barren Land	0.20	0.20	0.20	0.60	0.20

Notes:
Source: Modified from US EPA (2013)
a. Value borrowed from “Perennial Snow or Ice”.
b. Values based on emergent herbaceous wetlands.

Table A.3: Seasonal values of Bowen ratio by land cover characterization category.

Land cover characterization Category	Season 1 (Summer)	Season 2 (Autumn)	Season 3 (Winter 1)	Season 4 (Winter 2)	Season 5 (Spring)
Urban	0.80	1.00	1.00	0.50	0.80
Agricultural	0.50	0.70	0.70	0.50	0.30
Rangeland	0.50	0.70	0.70	0.50	0.30
Deciduous Forest	0.30	1.00	1.00	0.50	0.70
Coniferous Forest	0.30	0.80	0.80	0.50	0.70
Mixed Forest	0.30	0.90	0.90	0.50	0.70
Water	0.10	0.10	0.10	0.50(a)	0.10
Wetland(b)	0.10	0.10	0.10	0.50	0.10
Barren Land	1.50	1.50	1.50	0.50	1.50

Notes:
Source: Modified from US EPA (2013)
a. Value borrowed from “Perennial Snow or Ice”.
b. Values based on emergent herbaceous wetlands.

Table A.4: Seasonal values of soil heat flux by land cover characterization category (in W/m^2).

Land cover characterization Category	Season 1 (Summer)	Season 2 (Autumn)	Season 3 (Winter 1)	Season 4 (Winter 2)	Season 5 (Spring)
Urban	0.25	0.25	0.25	0.15(a)	0.25
Agricultural	0.15	0.15	0.15	0.15	0.15
Rangeland	0.15	0.15	0.15	0.15	0.15
Deciduous Forest	0.15	0.15	0.15	0.15	0.15
Coniferous Forest	0.15	0.15	0.15	0.15	0.15
Mixed Forest	0.15	0.15	0.15	0.15	0.15
Water	1.00	1.00	1.00	0.15	1.00
Wetland	0.25	0.25	0.25	0.15	0.25
Barren Land	0.15	0.15	0.15	0.15	0.15

Notes:
Source: CALMET defaults
a. Value borrowed from “Perennial Snow or Ice”.

Table A.5: Seasonal values of leaf area index by land cover characterization category

Land cover characterization Category	Season 1 (Summer)	Season 2 (Autumn)	Season 3 (Winter 1)	Season 4 (Winter 2)	Season 5 (Spring)
Urban	0.30	0.20	0.10	0.00	0.20
Agricultural	2.00	1.50	1.00	0.00	1.00
Rangeland	1.00	1.00	1.00	1.00	1.00
Deciduous Forest	3.40	1.90	0.10	0.00	0.80
Coniferous Forest	5.00	5.00	5.00	5.00	5.00
Mixed Forest	4.50	3.50	2.30	2.30	3.30
Water	0.00	0.00	0.00	0.00	0.00
Wetland(a)	0.20	0.20	0.10	0.00	0.10
Barren Land	0.00	0.00	0.00	0.00	0.00

Notes:
Source: Modified from Zhang et al. (2002, 2003)
a. Values based on wetlands with plants

Table A.6: Seasonal values of anthropogenic heat flux in modelled domains (in W/m^2)

Domain	Season 1 (Summer)	Season 2 (Autumn)	Season 3 (Winter 1)	Season 4 (Winter 2)	Season 5 (Spring)
Burnaby and Westridge Marine Terminals RSA	6.9	8.1	9.3	10.6	8.7

Notes:
Source: Modified from Oke (1987)
Values used to represent all urban grid cells within model domain.

2.2 CALMET Model “Switch” Settings

Table A.7 shows the model switch settings used in CALMET Group 5 of the Air Quality RSA for the Burnaby and Westridge Marine Terminals. The settings were selected according to the *Guidelines for Air Quality Dispersion Modelling in British Columbia* (BC Ministry of Environment [MOE] 2008) or to model defaults. Table A.8 shows the model switch settings used in Group 6 of each RSA for the Project.

Table A.7: CALMET model switch settings Group 5 - Wind Field Options and Parameters for the Burnaby and Westridge Marine Terminals RSA

Parameter	Default	Project	Comments
IWFCOD	1	1	Diagnostic wind module used
IFRADJ	1	1	Froude number adjustment effects computed
IKINE	0	0	Kinematic effects not computed
IOBR	0	0	No adjustment to vertical velocity profile at top of model domain
ISLOPE	1	1	Slope flow effects computed
IEXTRP	-4	-4	Similarity Theory used except layer 1 data at upper air stations ignored
ICALM	0	1	Frequency of calms are realistic
BIAS	NZ*0	0, 0, 0, 0, 0, 0, 0, 0, 0, 0	Not used since no upper air station data
RMIN2	4	-1	Used to ensure extrapolation of all surface stations for IEXTRP = -4
IPROG	0	14	Used WRF prognostic model output for initial guess field
ISTEPGS	3600	3600	Time step (seconds) of the prognostic model input data
IGFMET	0	0	Use coarse CALMET fields as initial guess fields
LVARY	F	T	Closest station used if no stations are within RMAX
RMAX1	NA	5	Local effects minimized to ensure smoothness over model domain
RMAX2	NA	10	Upper air stations not used
RMAX3	NA	10	Over-water stations not used
RMIN	0.1	0.1	Small value used as recommended
TERRAD	NA	5	Identified from main terrain feature of influence (Burrard Inlet)
R1	NA	0.3	Approximately half the minimum resolution required to resolve TERRAD (Minimum resolution is 1/10th of TERRAD or 0.4 to 0.5 km)
R2	NA	1	Upper air stations not used
RPROG	NA	0	Not used since IPROG = 14
DIVLIM	5×10^{-6}	5×10^{-6}	Not used since IKINE = 0
NITER	50	50	Not used since IKINE = 0

Parameter	Default	Project	Comments
NSMTH	2,(mxnz-1)*4	2, 4, 4, 4, 4, 4, 4, 4, 4, 4	Default number of passes in the smoothing procedure
NINTR2	99	99	All stations can be used
CRITFN	1	1	Default critical Froude number used
ALPHA	0.1	0.1	Not used since IKINE = 0
FEXTR2	NZ*0	0, 0, 0, 0, 0, 0, 0, 0, 0, 0	Not used since IEXTRP = -4
NBAR	0	0	Barriers not used
KBAR	NZ	10	Level (1 to NZ) up to which barriers apply
XBAR, YBAR, XEBAR, YEBAR	0, 0, 0, 0	0, 0, 0, 0	Not used since NBAR = 0
IDIOPT1	0	0	Surface temperatures computed internally
ISURFT	-1	-1	Diagnostic module surface temperatures based on 2-D spatially varying temperature field
IDIOPT2	0	0	Lapse rate computed internally
IUPT	-1	-1	Upper air stations not used
ZUPT	200	200	Lapse rate computed for default depth
IDIOPT3	0	0	Domain-averaged wind components computed internally
IUPWND	-1	-1	Upper air stations not used
ZUPWND	1, 1000	1, 1000	Default used
IDIOPT4	0	0	Observed surface wind components for wind field module
IDIOPT5	0	0	Observed upper air wind components for wind field module

Table A.8: CALMET model switch settings Group 6 - Mixing Height, Temperature and Precipitation Parameters

Parameter	Default	Project	Comments
CONSTB	1.41	1.41	Neutral, mechanical equation
CONSTE	0.15	0.15	Convective mixing height equation
CONSTN	2400	2400	Stable mixing height equation
CONSTW	0.16	0.16	Over water mixing height equation
FCORIO	1.0E-4	1.0E-04	Absolute value of Coriolis (1/s)
IAVEZI	1	1	Conduct spatial averaging
MNMDAV	1	1	Maximum search radius in averaging
HAFANG	30	30	Half-angle of upwind looking cone for averaging
ILEVZI	1	1	Layer of winds used in upwind averaging
IMIXH	1	1	Method to compute the convective mixing height
THRESHL	0	0	Threshold buoyancy flux required to sustain convective mixing height growth overland (W/m^3)
THRESHW	0.05	0.05	Threshold buoyancy flux required to sustain convective mixing height growth overwater (W/m^3)
IZICRLX	1	1	Flag to allow relaxation of convective mixing height to equilibrium value
TZICRLX	800	800	Relaxation time of convective mixing height to equilibrium value (s)
ITWPROG	0	2	Option for overwater lapse rates used in convective mixing height growth
ILUOC3D	16	16	Land use category ocean in 3D.DAT datasets
DPTMIN	0.001	0.001	Minimum potential temperature lapse rate in the stable layer above the current convective missing height (K/m)
DZZI	200	200	Depth of layer above current convective mixing height through which lapse rate is computed (m)
ZIMIN	50	50	Default minimum overland mixing height (m)
ZIMAX	3000	3000	Default maximum overland mixing height (m)
ZIMINW	50	50	Default minimum over-water mixing height (m)
ZIMAXW	3000	3000	Default maximum over-water mixing height (m)
ICOARE	10	10	COARE with no wave parameterization

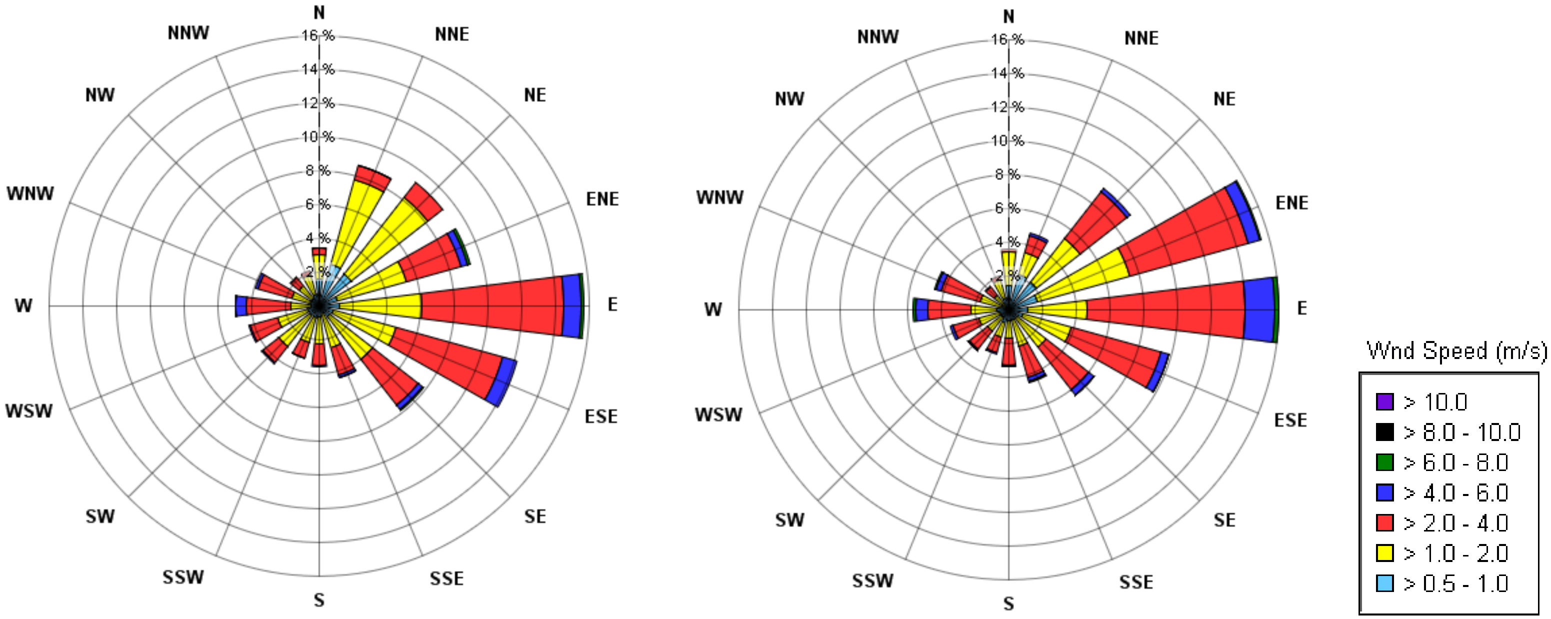
Parameter	Default	Project	Comments
DSHELF	0	0	Coastal/shallow water length scale
IWARM	0	0	COARE warm layer computation
ICOOL	0	0	COARE cool skin layer computation
IRHPROG	0	1	3D relative humidity from prognostic data
ITPROG	0	1	3D temperature from surface stations
IRAD	1	1	Default interpolation type
TRADKM	500	500	Default radius of influence for temperature interpolation (km)
NUMTS	5	6 (Edmonton) 5 (Kamloops) 5 (Sumas) 11 (Burnaby)	Allow all surface stations to be included for temperature interpolation
IAVET	1	1	Conduct spatial averaging of temperatures
TGDEFB	-.0098	-.0098	Default temperature gradient below the mixing height over water (K/m)
TGDEFA	-.0045	-.0045	Default temperature gradient above the mixing height over water (K/m)
JWAT1	-	99	No over water temperature interpolation used
JWAT2	-	99	No over water temperature interpolation used
NFLAGP	2	2	Method of interpolation
SIGMAP	100	100	Radius of Influence (km)
CUTP	0.01	0.01	Default minimum precipitation rate cut-off (mm/h)

3. CALMET RESULTS

The CALMET model was assessed by reviewing various model outputs and, where possible, comparing to observations. These outputs include: surface wind roses for various monitoring locations, CALMET-derived stabilities and mixing heights and domain wind vector plots under various stability and flow regimes.

3.1 Surface Winds

The combined frequency distribution of wind speed and direction as observed and as modelled by CALMET at the Burnaby Burmount station are shown as wind roses in Figure A.1. Observed and modelled surface wind roses are very similar. The predominant wind directions are from the east, east-northeast and east-southeast. The percentage of calms derived from CALMET was higher (3.68%) relative to those observed (0.88%).



Calms: 0.88%

Observed

Calms: 3.68%

Modelled (CALMET)

Figure A.1: Observed and modelled wind roses at Burnaby Burmount station

In CALMET, the Pasquill-Gifford (PG) stability scheme is used to classify atmospheric stratification in the boundary layer over land. These classes range from unstable (Classes A, B and C), through neutral (Class D) to stable (Classes E and F). Normally, unstable conditions are associated with daytime, ground-level heating, which results in thermal turbulence activity in the boundary layer. Stable conditions are primarily associated with night-time cooling, which results in the suppression of the turbulence levels and temperature inversion at lower levels. Neutral conditions are mostly associated with high wind speeds or overcast sky conditions.

The frequency distributions of CALMET-derived PG stability classes for the Burmount station are shown in Figure A.2. The most frequent stability class is Class D or neutral. This is a result of the large percentages of higher wind speeds seen in the wind roses shown above, as well as the frequency of overcast sky conditions.

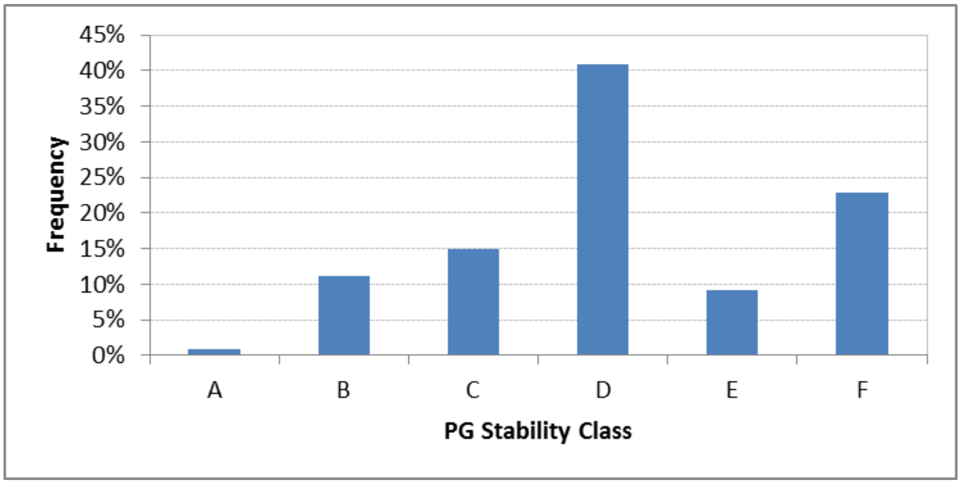
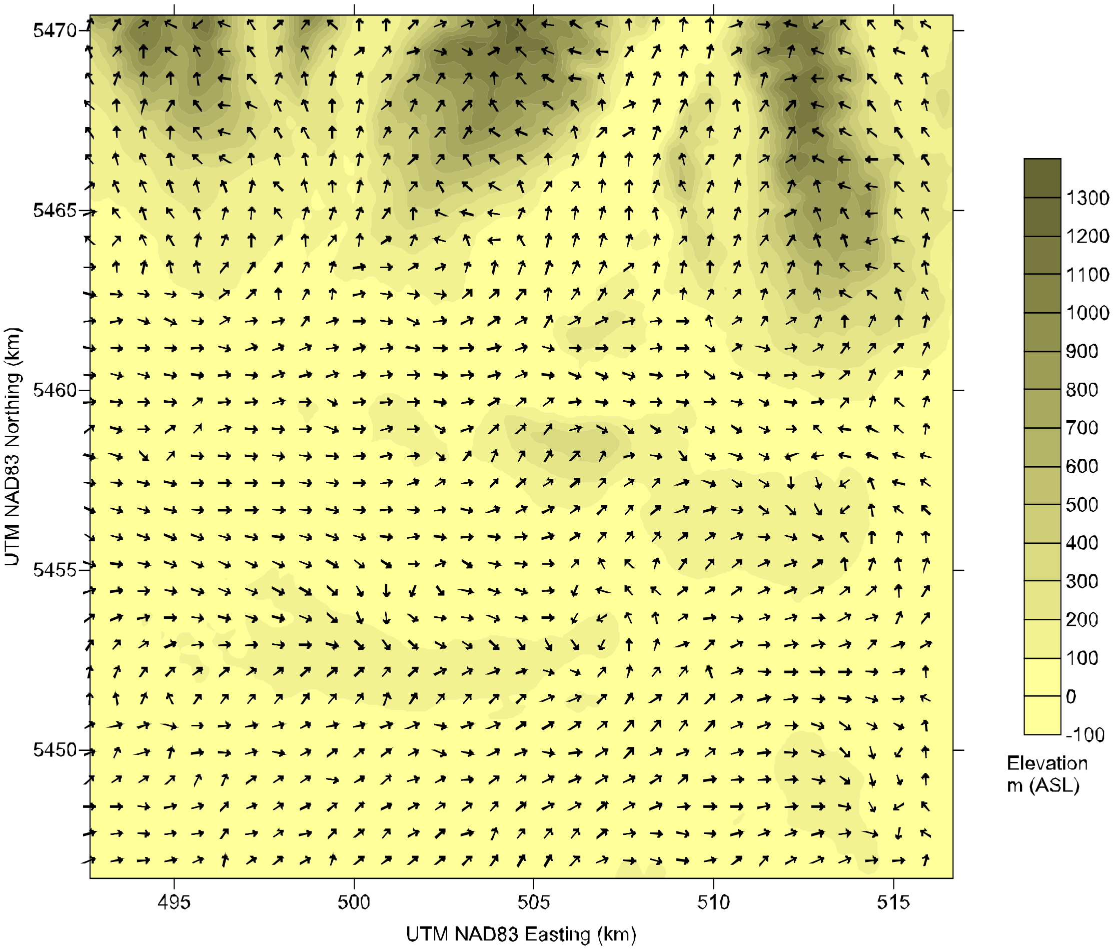


Figure A.2: Frequency of modelled Pasquill-Gifford stability classes for Burnaby Burmount station

3.2 Modelled Wind Fields

A common approach used to evaluate a meteorological model's ability to replicate wind flow patterns is through the use of wind field plots. Wind fields plots representing unstable, neutral, and stable conditions for Burnaby are illustrated in Figures A.3 to A.5, respectively to provide an overview of how CALMET performed under different conditions. In general, CALMET-derived wind fields follow the expected terrain flows under various stability and flow regimes, flowing up slope during unstable, daytime conditions and down slope during stable, night-time conditions. Under neutral conditions, the characteristic high wind speeds result in less noticeable terrain effects and wind fields are fairly uniform across the model domain.

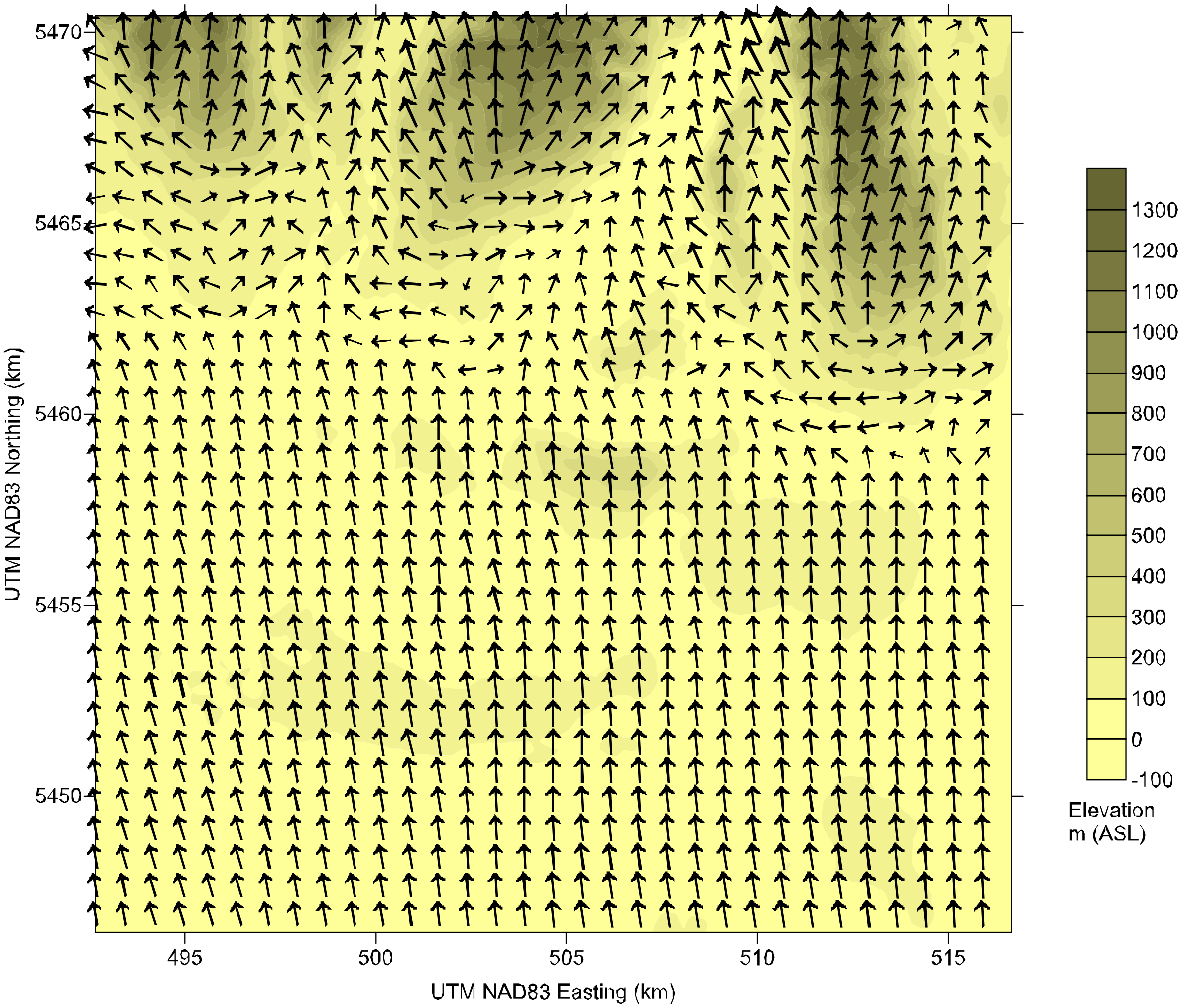


Unstable

September 11, 2011 10:00

Arrow lengths show relative wind speed from 0 to 18.5 m/s.

Figure A.3: Modelled wind fields at 10 m above grade during unstable conditions at Burnaby

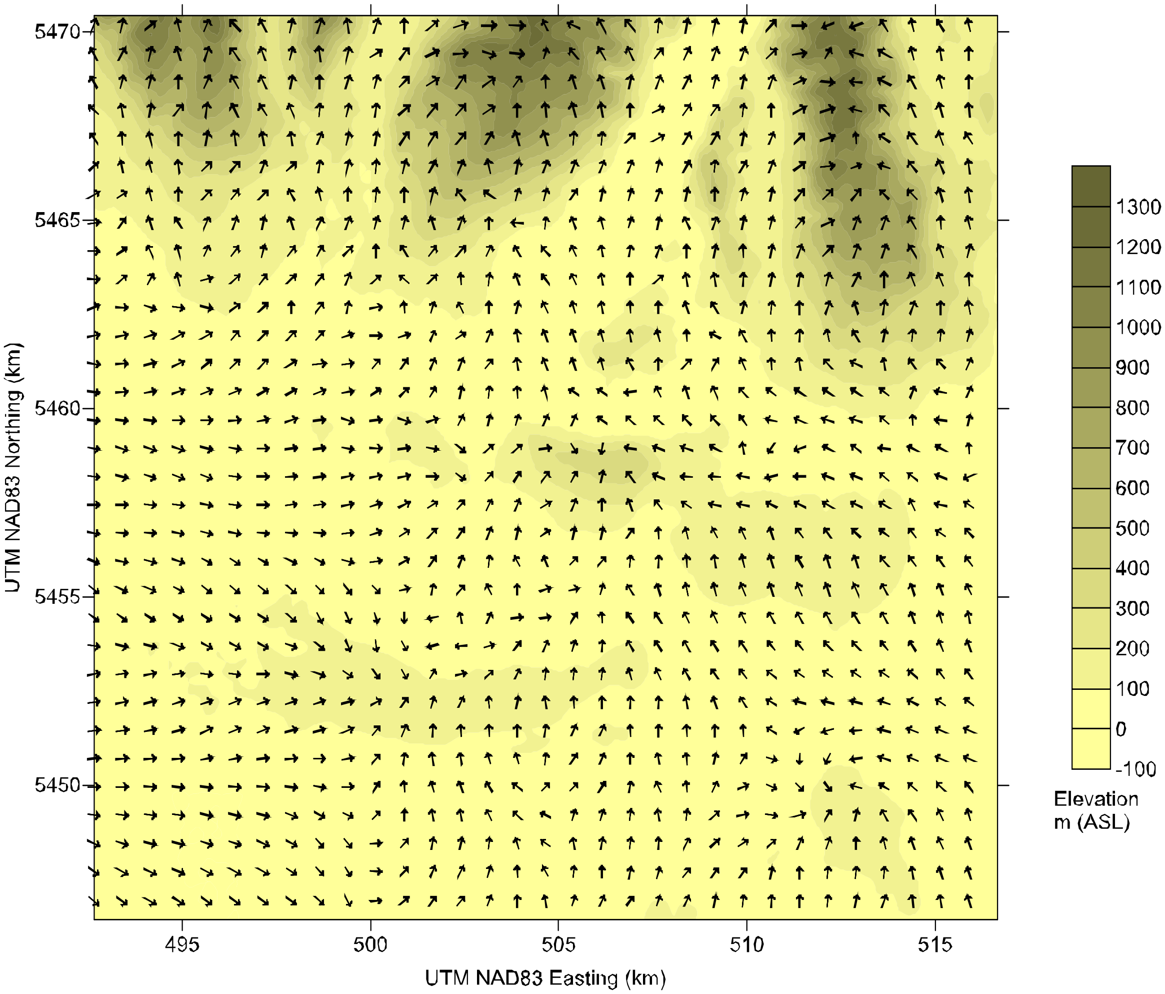


Neutral

November 22, 2011 4:00

Arrow lengths show relative wind speed from 0 to 18.5 m/s.

Figure A.4: Modelled wind fields at 10 m above grade during neutral conditions at Burnaby



Stable

January 1, 2011 19:00

Arrow lengths show relative wind speed from 0 to 18.5 m/s.

Figure A.5: Modelled wind fields at 10 m above grade during stable conditions at Burnaby

3.3 Mixing Heights

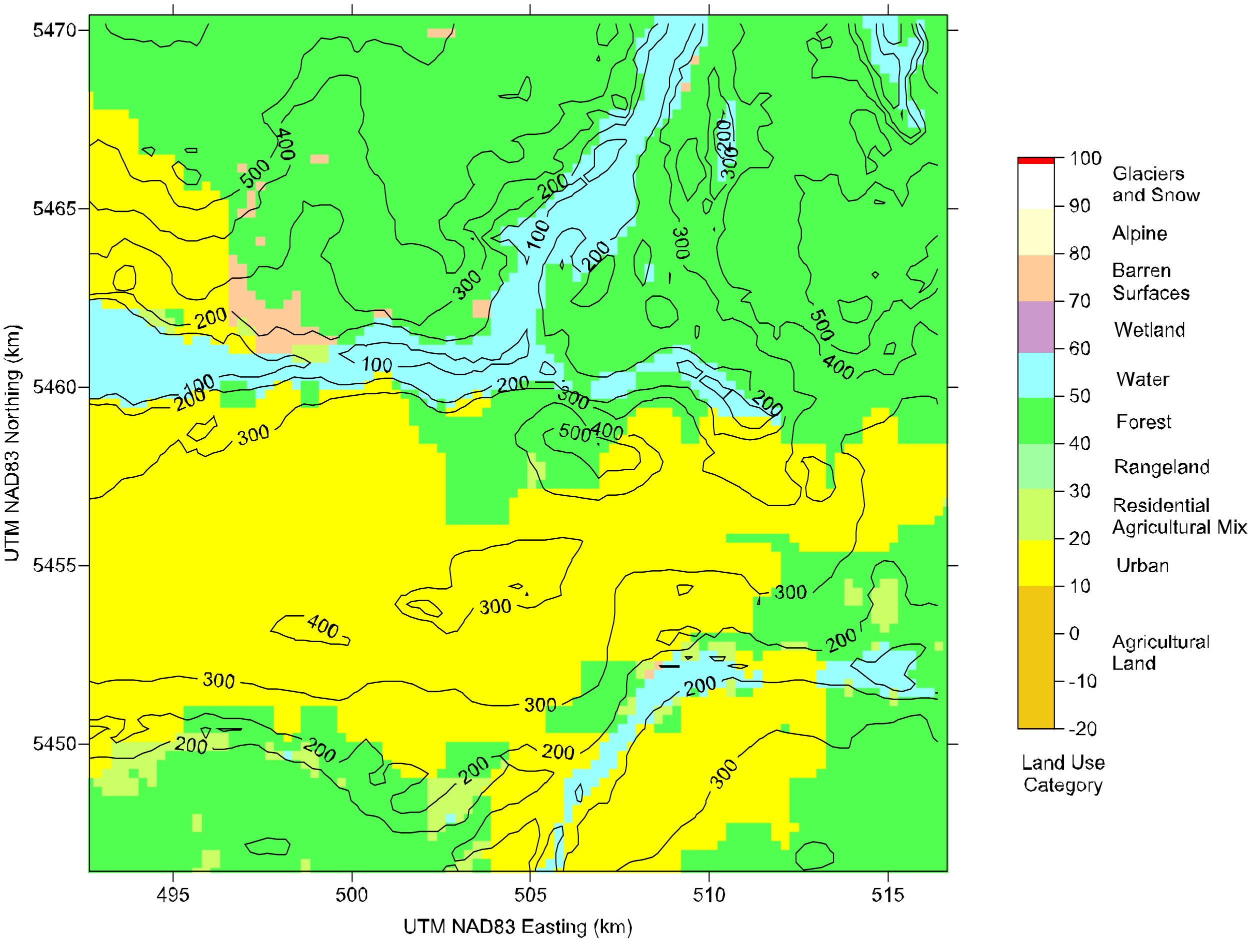
Mixing heights are estimated in CALMET through methods that are based on either surface heat flux (thermal turbulence) and vertical temperature profiles, or friction velocities (mechanical turbulence). Table A.9 shows the average modelled mixing heights by Pasquill-Gifford stability class. Overall, the highest mixing heights are associated with unstable conditions (Classes A, B and C), while the lowest mixing heights are associated with stable conditions (Classes E and F).

The spatial distribution of mixing heights under unstable, neutral, and stable conditions at Burnaby is shown in Figures A.6 to A.8, respectively. Spatial changes in mixing height align with changes in the land use. Mixing height tends to be lowest over water and increases with distance more quickly in areas where surface roughness is greater (i.e., where surface elements are larger).

Diurnal variations in mixing heights at Burnaby are shown in Figure A.9, respectively for a typical summer day (July 23) and a typical winter day (January 8 or 9). Mixing heights tend to increase during the day and decrease during the night, although daytime mixing heights may be suppressed during stable winter conditions due to weak solar insolation, high reflectivity of snow covered surfaces, low wind speeds and synoptic subsidence.

Table A.9: Average modelled mixing height by Pasquill-Gifford Stability Class (in m)

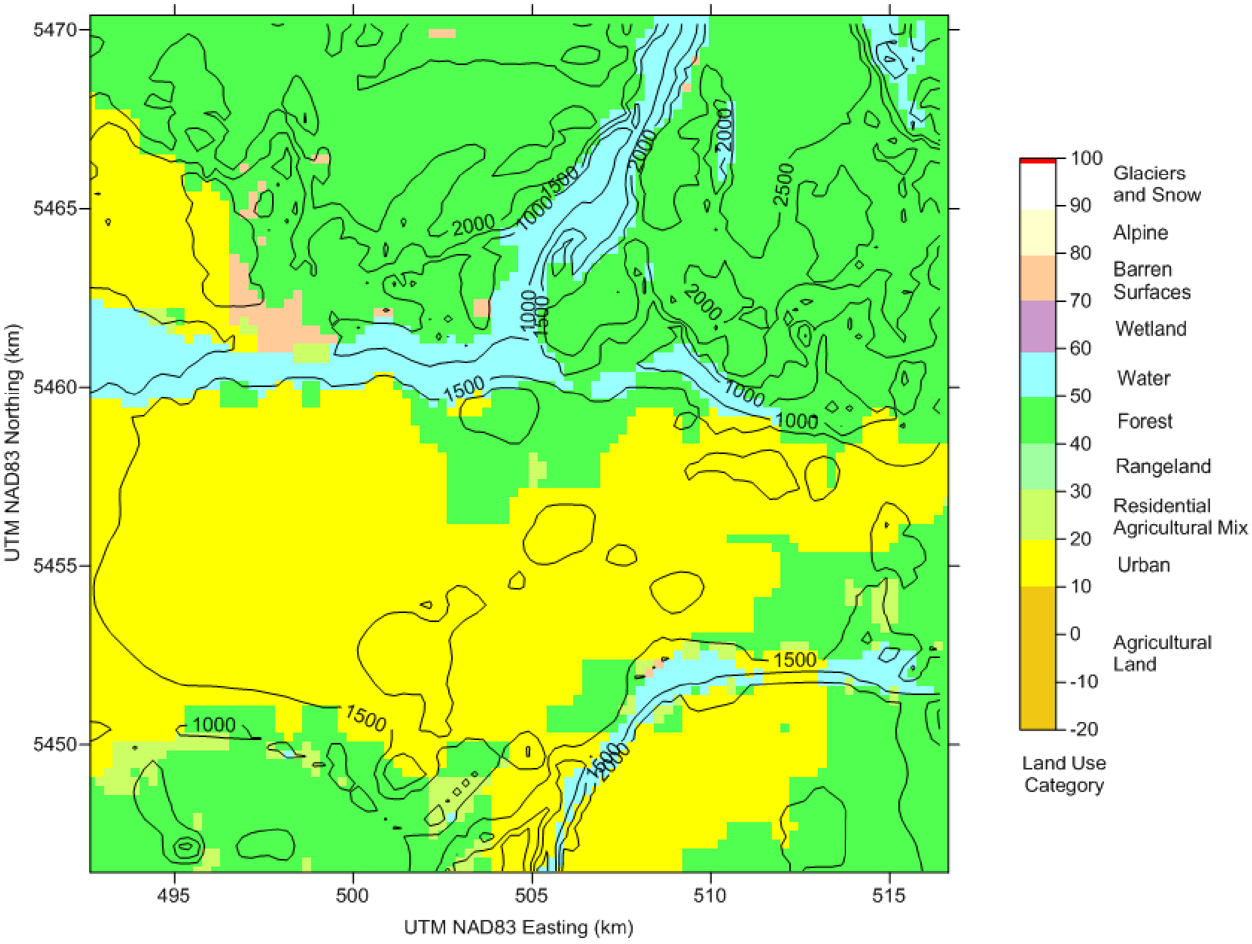
Station	A	B	C	D	E	F
Burmount	1,007	845	640	444	234	76



Unstable

September 11, 2011 10:00

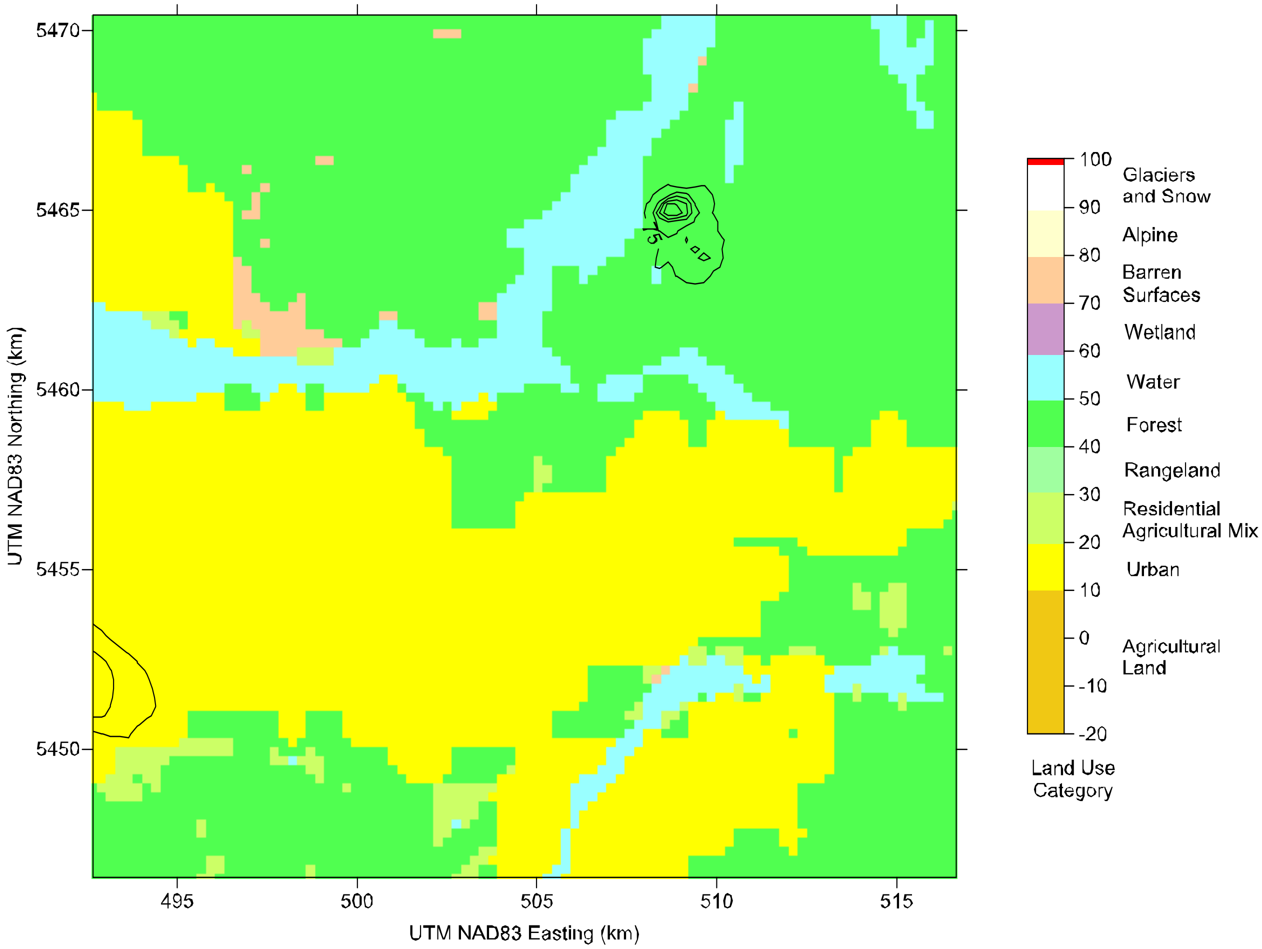
Figure A.6: Modelled mixing heights at Burnaby (contour lines, labels in m) overlaid on top of land cover characterization during unstable atmospheric conditions (contour interval is 100 m)



Neutral

November 22, 2011 4:00

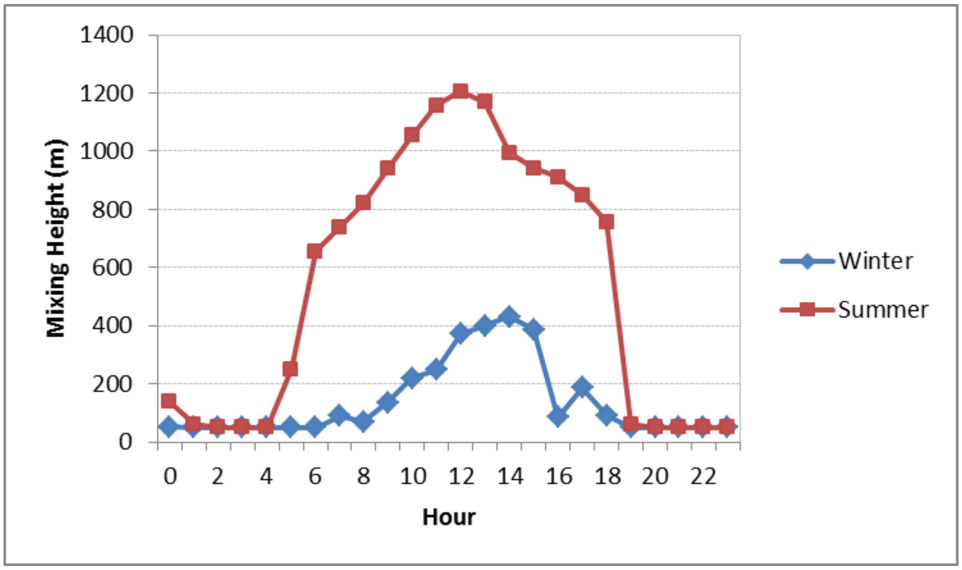
Figure A.7: Modelled mixing heights at Burnaby (contour lines, labels in m) overlaid on top of land cover characterization during neutral atmospheric conditions (contour interval is 500 m)



Stable

January 1, 2011 19:00

Figure A.8: Modelled mixing heights at Burnaby (contour lines, labels in m) overlaid on top of land cover characterization stable atmospheric conditions (contour interval is 50 m)



Burmount

Figure A.9: Diurnal variation of modelled mixing heights at Burnaby

3.4 Precipitation

CALMET-derived precipitation patterns at Burmount are compared to observed precipitation for the same period and to 30-year climate normals (1971 to 2000) (Environment Canada 2013) in Figure A.10. The overall monthly precipitation patterns predicted by the CALMET model are representative of actual conditions. The greatest amount of precipitation is expected to occur in the winter months from November to January at Burnaby.

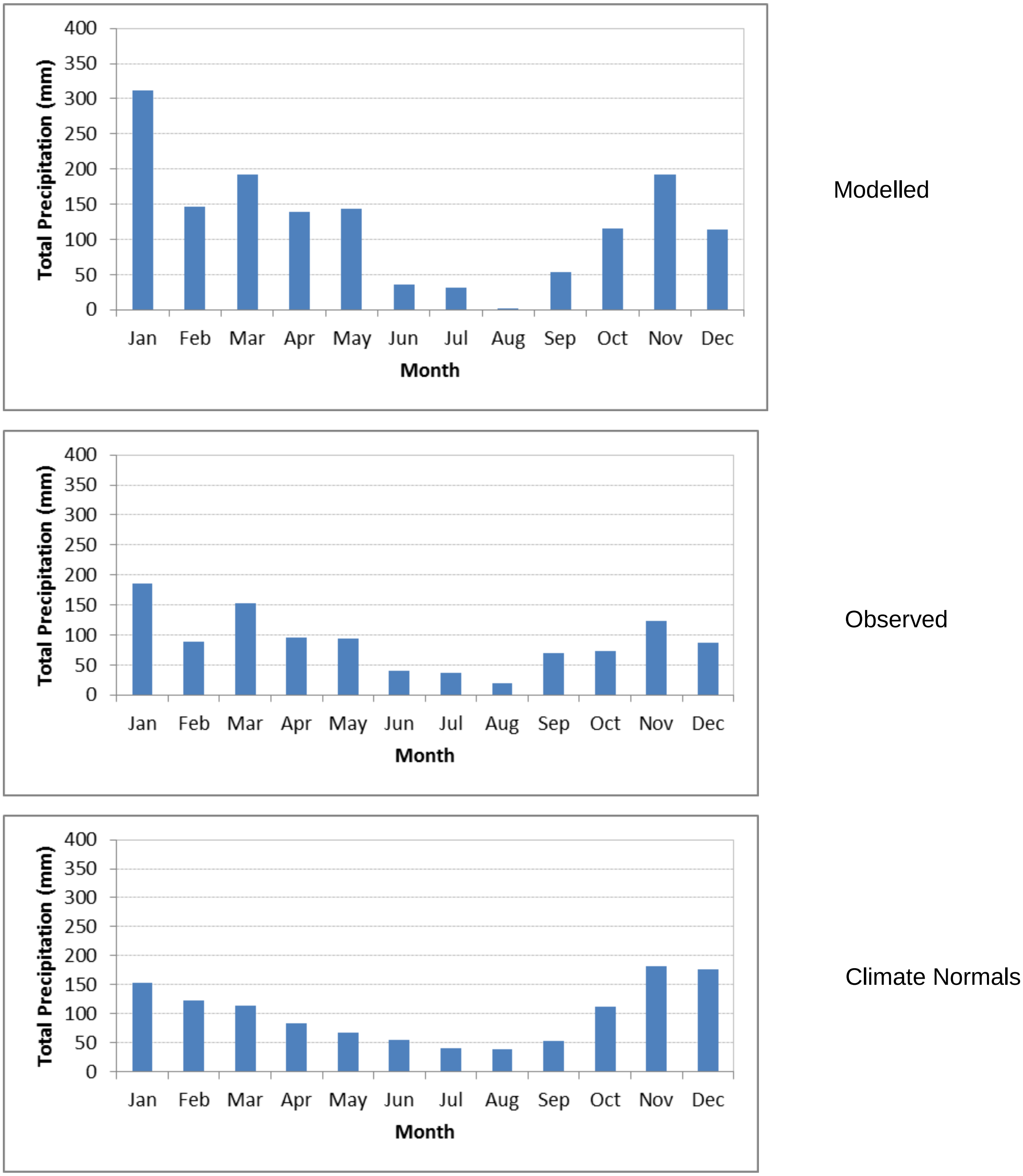


Figure A.10: Comparison of modelled precipitation at Burmount with 2011 observations and climate normals at Vancouver International Airport

4. CALPUFF INPUTS

All technical options relating to the CALPUFF dispersion model were set according to the *Guidelines for Air Quality Dispersion Modelling in British Columbia* (BC MOE 2008), or to model defaults. These include parameters and options such as the calculation of plume dispersion coefficients, the plume path coefficients used for terrain adjustments, exponents for the wind speed profile, and wind speed categories. A list of the technical options is shown in Table A.10.

Table A.10: CALPUFF model switch settings

Parameter	Default	Project	Comments
MGAUSS	1	1	Gaussian distribution used in near field
MCTADJ	3	3	Partial plume path terrain adjustment
MCTSG	0	0	Sub-grid scale complex terrain not modelled
MSLUG	0	0	Near-field puffs not modelled as elongated
MTRANS	1	1	Transitional plume rise modelled
MTIP	1	1	Stack tip downwash used
MBDW	1	2	PRIME method used
MSHEAR	0	0	Vertical wind shear not modelled
MSPLIT	0	0	Puffs are not split
MCHEM	1	0	Chemical transformation not modelled
MAQCHEM	0	0	Aqueous phase transformation not modelled
MWET	1	1	Wet removal modelled for all sources
MDRY	1	1	Dry deposition modelled for all sources
MTILT	0	0	Gravitational settling not modelled
MDISP	3	2	Near-field dispersion coefficients internally calculated from sigma-v, sigma-w using micrometeorological variables as recommended by guidelines
MTURBVW	3	3	Not used since MDISP = 2
MDISP2	3	2	Not used since MDISP = 2
MCTURB	1	1	Standard CALPUFF subroutines used to compute turbulence sigma-v & sigma-w
MROUGH	0	0	PG sigma-y, sigma-z not adjusted for roughness

Parameter	Default	Project	Comments
MPARTL	1	1	Partial plume penetration of elevated inversion
MTINV	0	0	Strength of temperature inversion computed from default gradients
MPDF	0	1	PDF used for dispersion under convective conditions as recommended for MDISP = 2
MSGTIBL	0	0	Sub-grid TIBL module not used for shoreline
MBCON	0	0	Boundary concentration conditions not modelled
MSOURCE	0	0	Individual source contributions not saved
MFOG	0	0	Do not configure for FOG model output
MREG	1	0	Do not test options specified to see if they conform to United States Environmental Protection Agency regulatory values

5. REFERENCES

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APPENDIX B

WEATHER RESEARCH FORECASTING (WRF) MODEL EVALUATION

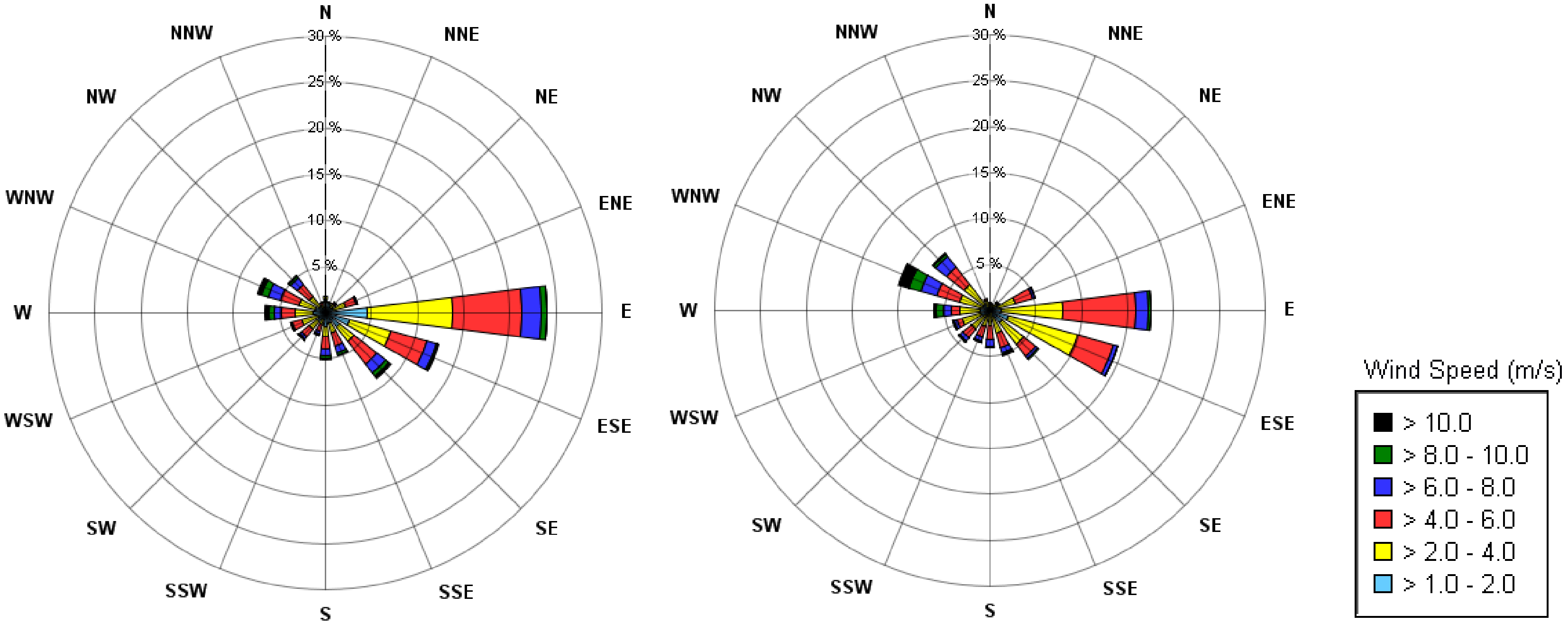
1. WRF MODEL EVALUATION Introduction

The Weather Research and Forecast (WRF) model was used to develop prognostic meteorological inputs to drive air quality dispersion modelling using the CALMET/CALPUFF model system. As per the Guidelines for Air Quality Dispersion Modelling in British Columbia (BC Ministry of Environment 2008), the WRF fields were examined to ensure that they capture local conditions to an extent reasonable for a regulatory air quality study. The model evaluation was done by comparing modelled and observed surface winds and temperature at three locations: Vancouver International Airport (YVR); Abbotsford Airport (YXX); and Burnaby-Burmount (Metro Vancouver station T22). Vancouver International Airport (YVR) and Abbotsford Airport (YXX) were chosen as the two airport locations within the innermost 1 km model domain. Burnaby-Burmount (T22) is the Metro Vancouver station closest to the Westridge Marine Terminal that most closely adheres to World Meteorological Organization guidance for siting (e.g., a 10 m wind height and 2 m temperature height). In addition, wind fields and profiles for certain times were examined to ensure that they make qualitative sense, for example, that expected terrain effects and boundary layer structures are present. The nearest upper air observations are hundreds of kilometers distant from the inner WRF domain used for dispersion modelling, so the examination of upper air files is qualitative only.

1.2. Surface Winds

The combined frequency distribution of wind speed and wind direction as observed and as modelled by WRF at the Vancouver International Airport (YVR), Abbotsford Airport (YXX) and Burnaby-Burmount (T22) stations are shown as wind roses in Figure B.1 to Figure B.3, respectively.

Observed and modelled surface wind roses are similar at Vancouver International Airport (YVR). Both the modelled and observed predominant wind directions at Vancouver International Airport (YVR) are from the east and east-southeast, with similar speed distribution as well. The observed and modelled surface wind roses at Abbotsford Airport (YXX) also show similar general patterns, though the speeds tend to be higher with a more southerly dominance for the observed. The model predicts a greater frequency of wind speeds in the 2.0 to 6.0 m/s range than observed at that station, resulting in a smaller percentage of high wind speeds (> 6.0 m/s) and of very low wind speeds (< 2.0 m/s) than the observed dataset. This is likely to due to local terrain influences near the airport location that are not captured by the 1 km WRF resolution. However, the model still captures the general pattern. Observed and modelled surface wind roses at Burnaby-Burmount (T22) also show the same general patterns. The predominant wind directions for both the observed and modelled surface wind roses are east and east-southeast. However, the frequency of stronger winds in the modelled surface wind rose is greater than in the observed surface wind rose.



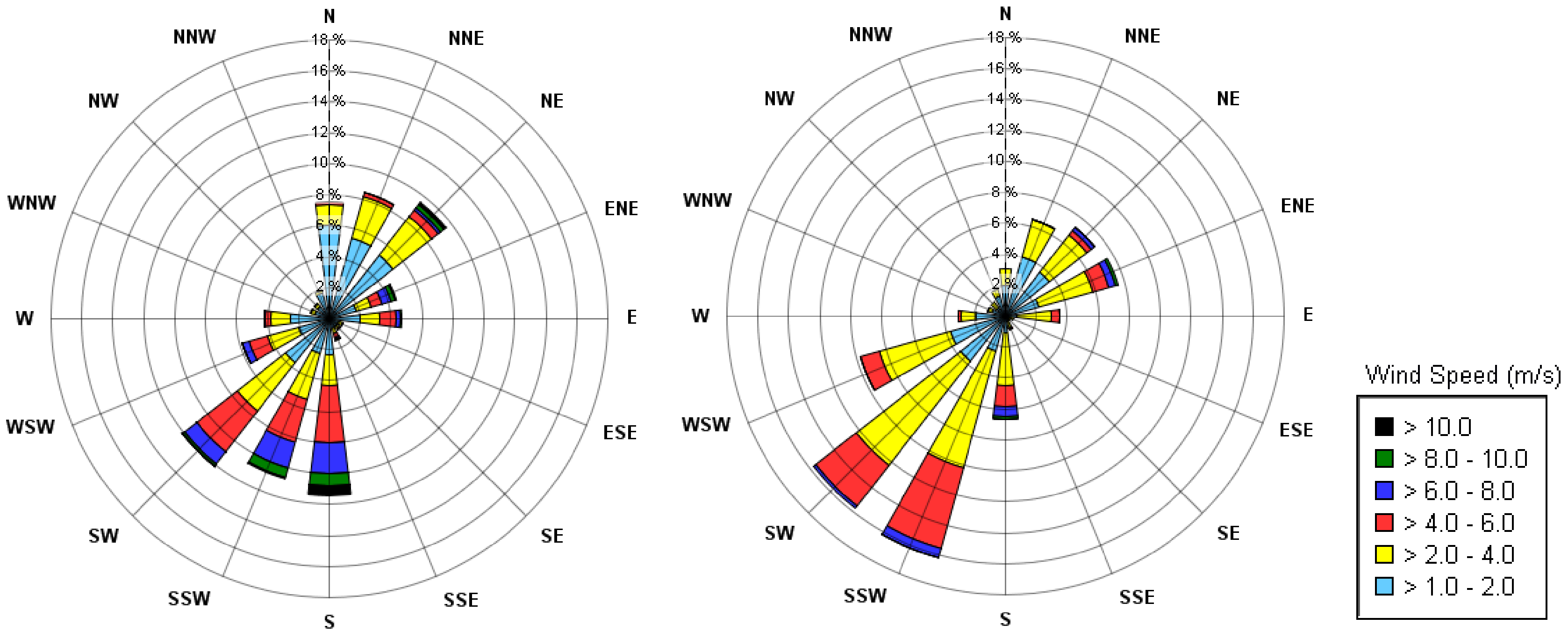
Calms: 5.62%

Observed

Calms: 6.23%

Modelled (WRF)

Figure B.1: Observed and Modelled Wind Roses at Vancouver International Airport (YVR)



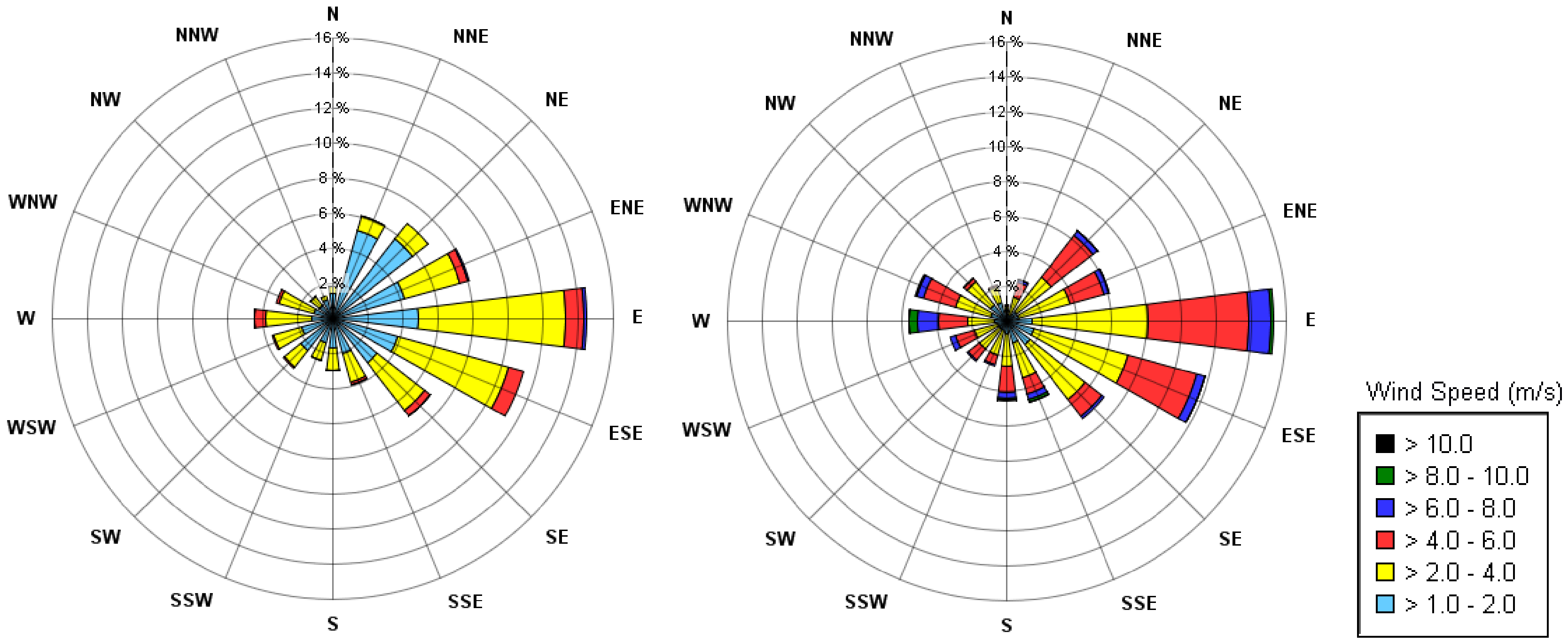
Calms: 13.26%

Observed

Calms: 14.66%

Modelled (WRF)

Figure B.2: Observed and Modelled Wind Roses at Abbotsford Airport (YXX)



Calms: 16.98%

Observed

Calms: 15.31%

Modelled (WRF)

Figure B.3: Observed and Modelled Wind Roses at Burnaby-Burmount (T22)

1.3. Surface Temperature

Statistical scores were calculated to measure the performance of the WRF model surface temperatures. These are shown in Table B.1. The mean bias values therein suggest that the observed temperatures were generally higher than those predicted by the model at all three stations, particularly for the Burnaby-Burmount (T22) station. Mean Gross Error was within the benchmark for Vancouver International Airport (YVR) and Abbotsford Airport (YXX) and very close to it for Burnaby-Burmount (T22). The index of agreement (IOA) is above the recommended benchmark at all three locations. From the point of view of these statistical scores, this WRF run can be considered adequate for dispersion modelling.

Scatter plots of observed and modelled surface temperatures at the Vancouver International Airport (YVR), Abbotsford Airport (YXX) and Burnaby-Burmount (T22) stations are shown in Figure B.4 to Figure B.6. These show overall good agreement between modelled and observed temperatures. A small systematic bias toward under-predicting temperatures is noted for all three stations, particularly for low temperatures at the Burnaby-Burmount station (T22). This explains the negative mean bias in Table B.1.

Table B.1: Comparison of statistics between modelled and observed temperature at all three stations.

Metric	Benchmark	YVR	YXX	T22
Mean Bias(1)	≤ 0.5 °C and ≥ -0.5 °C	-1.20	-1.17	-1.59
Mean Gross Error(2)	≤ 2 °C	**1.94**	**1.81**	2.03
RMSE[3]		2.54	2.27	2.61
IOA[4]	≥ 0.8	**0.95**	**0.97**	**0.96**

Notes:

1) Mean Bias is the mean difference between the model prediction and the observed data (sign included).
2) Mean Gross Error is the mean of the absolute value of the difference between the model prediction and the observed data.
3) Root-mean-square error is the square root of the mean of the squared difference between model prediction and observed data.
4) Index of agreement (IOA) (Emery *et al.* 2001 and Tesche *et al.* 2001) combines bias, gross error and RMSE into a single parameter that measures the match between predicted and observed values.

$$IOA = 1 - \frac{IJ \times RMSE^2}{\left(\sum_{j=1}^{J}\sum_{i=1}^{I}\left|P_j^i - M_O\right| + \left|O_j^i - M_O\right|\right)^2}$$

where, ***RMSE*** is the root mean square error;
P and ***O*** are model predicted and observed values, respectively; and
Mo is mean of observed values.

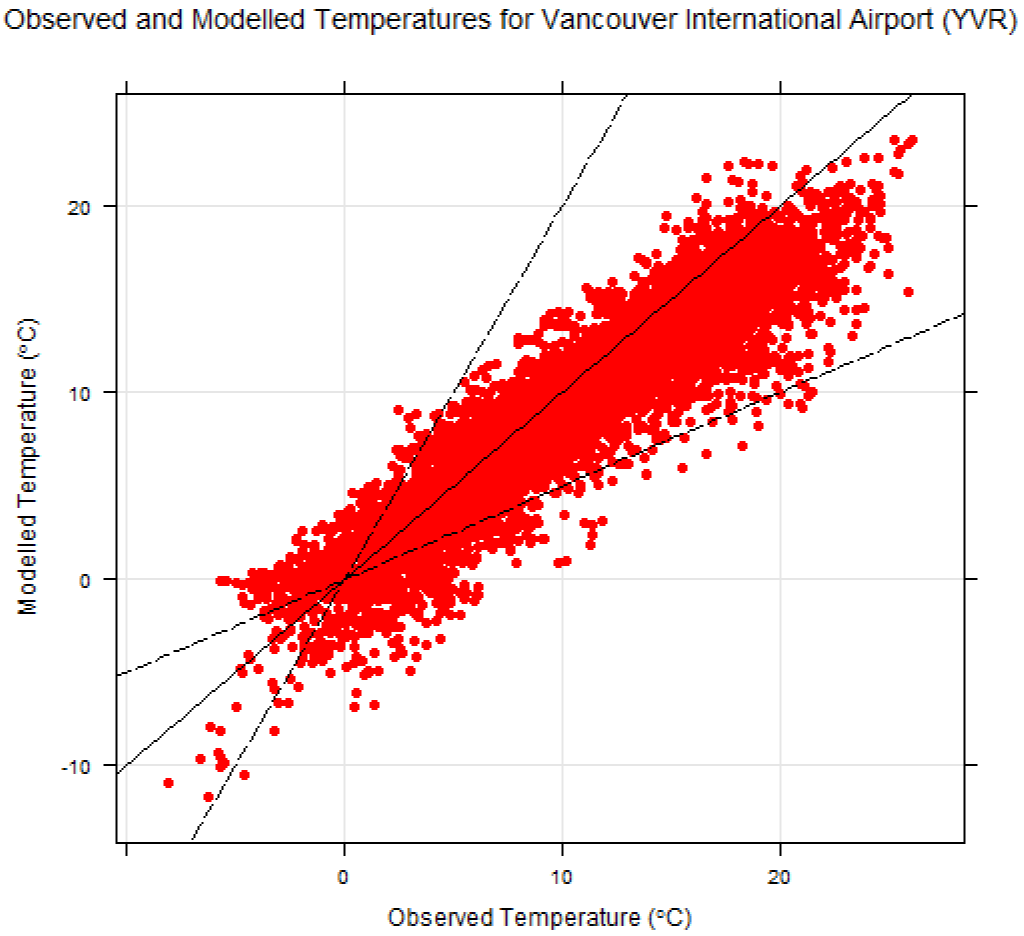


Figure B.4: Scatter plot of Observed and Modelled Temperature for Vancouver International Airport (YVR). The solid line is a 1:1 relationship; the dashed lines are 1:2 and 2:1 relationships, respectively.

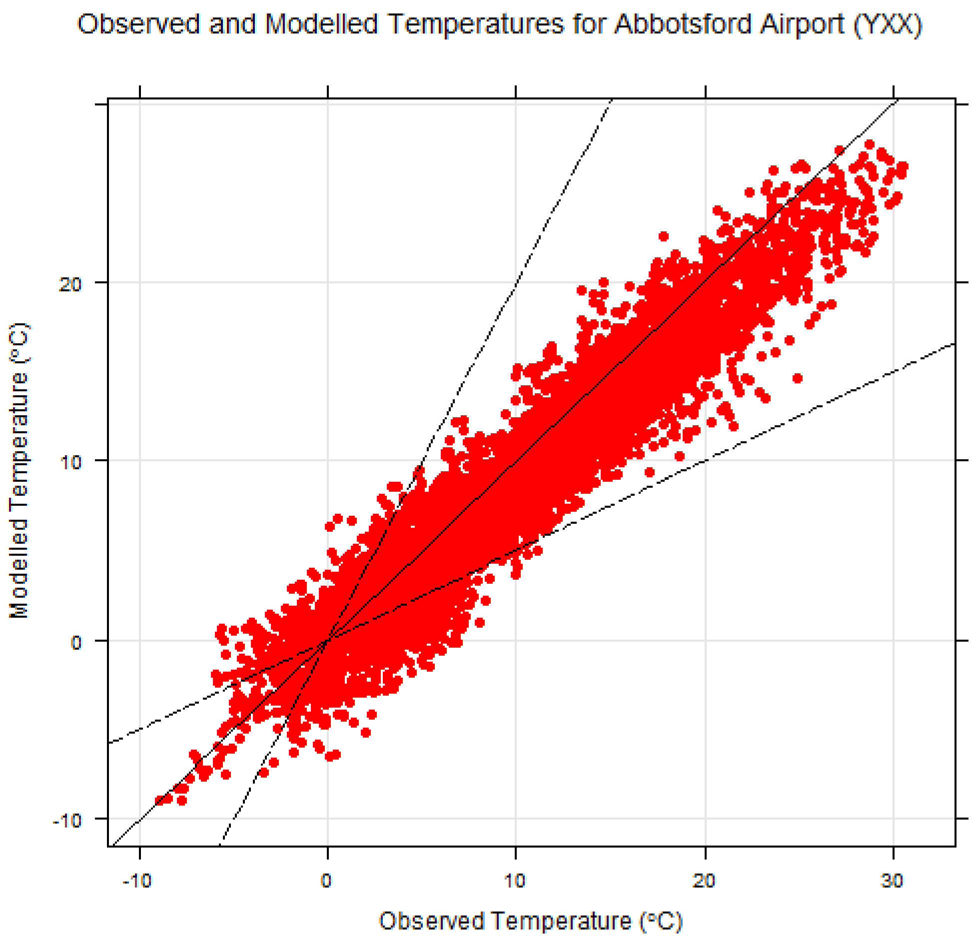


Figure B.5 Scatter plot of Observed and Modelled Temperature for Abbotsford Airport (YXX). The solid line is a 1:1 relationship; the dashed lines are 1:2 and 2:1 relationships, respectively.

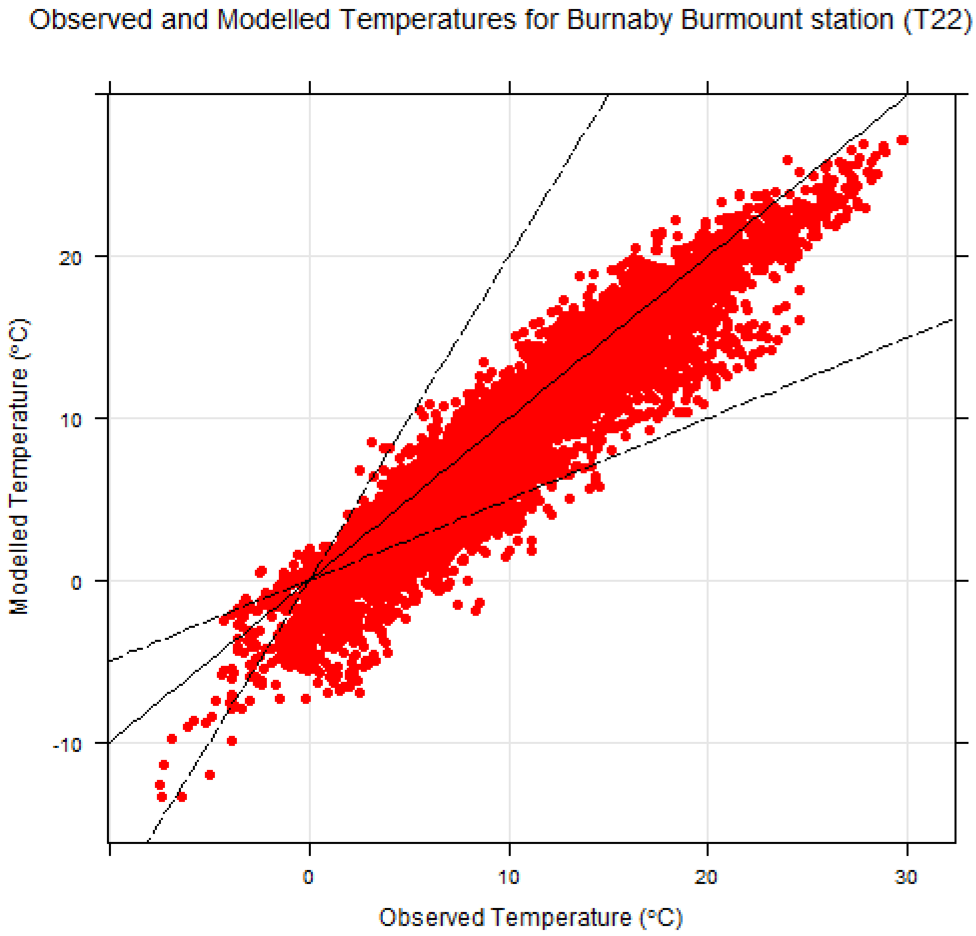


Figure B.6 Scatter plot of Observed and Modelled Temperature for Burnaby-Burmount (T22). The solid line is a 1:1 relationship; the dashed lines are 1:2 and 2:1 relationships, respectively.

1.4. Vertical Temperature Profiles

Figures B.7 to B.9 show the three modelled vertical profiles of air temperature for Vancouver International Airport (YVR) and Figures B.10 to B.12 show the three modelled vertical profiles of air temperature for Abbotsford Airport (YXX). Specific time periods were selected to match the stable, neutral and unstable Pasquill Gifford (P-G) stability class example periods shown in the CALMET model evaluation provided in Appendix A of this report.

It should be noted that there are no available upper air sounding data to perform a valid comparison between modelled and observed data. Also, the Pasquill-Gifford classes provided by CALMET are not solely a function of environmental lapse rate, but instead are calculated based on a number of variables that enhance atmospheric dispersion such as wind speed and the standard deviation of wind direction at ground level. As a consequence, further mention of qualifiers such as stable, neutral and unstable are preceded by “CALMET P-G” to remind the reader of this distinction.

For Vancouver International Airport (YVR), the example of the CALMET P-G stable case shown in Figure B.7 displays a strong surface inversion and an overall stable profile. The CALMET P-G neutral case, shown in Figure B.8, shows a neutral profile. For the CALMET P-G unstable case, shown in Figure B.9, the profile is mildly unstable in the immediate surface layer (first 100 m) which is what the P-G classification takes into account.

For Abbotsford Airport (YXX), the example of the CALMET P-G stable case, shown in Figure B.10, displays a strong surface inversion and an overall stable profile. The CALMET P-G neutral case, shown in Figure B.11, displays an overall neutral profile. For the CALMET P-G unstable case, shown in Figure B.12, a mildly unstable, almost neutral profile is predicted in general.

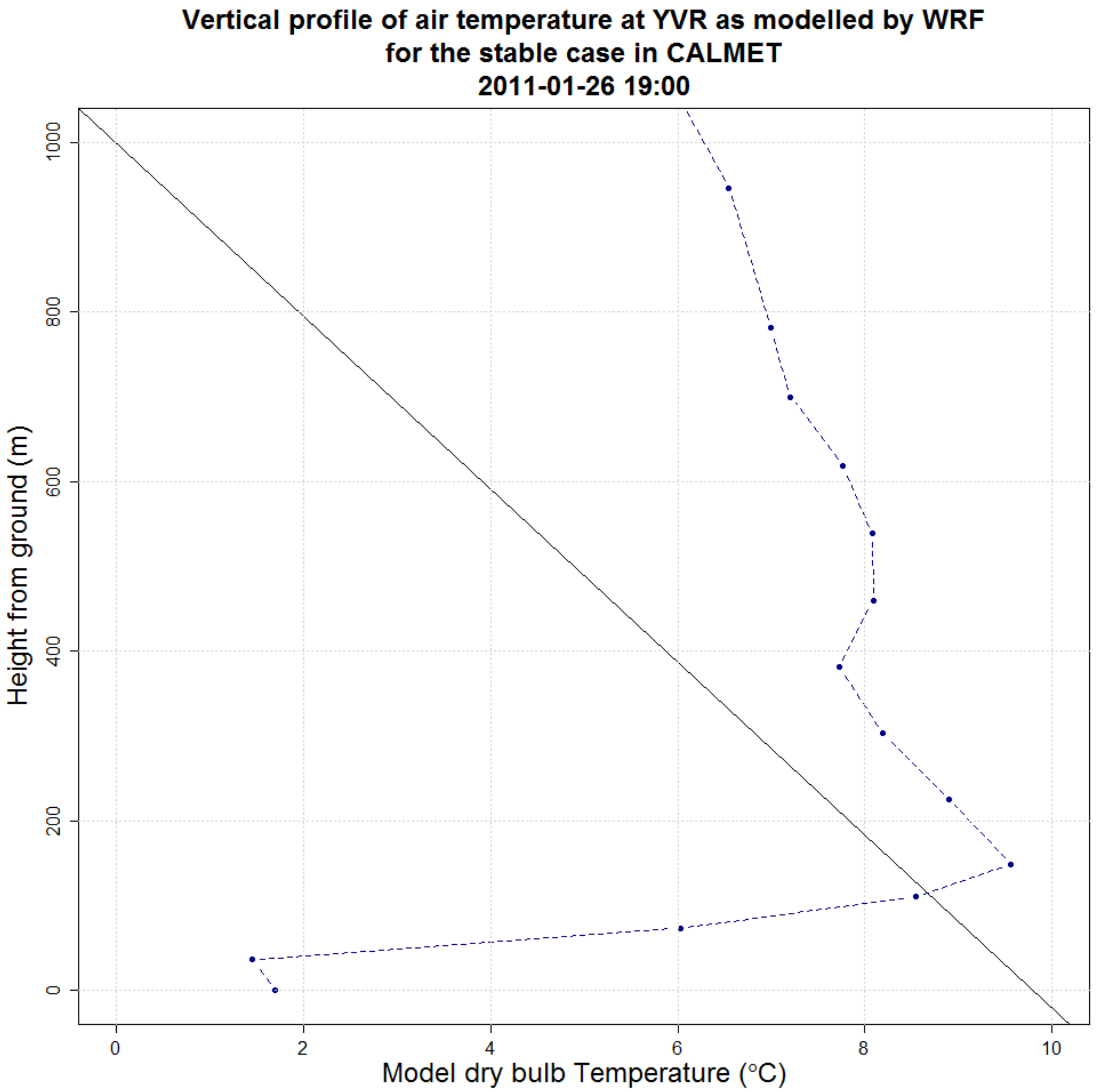


Figure B.7: Stable vertical profile of air temperature modelled for Vancouver International Airport (YVR). The solid line represents the dry adiabatic lapse rate.

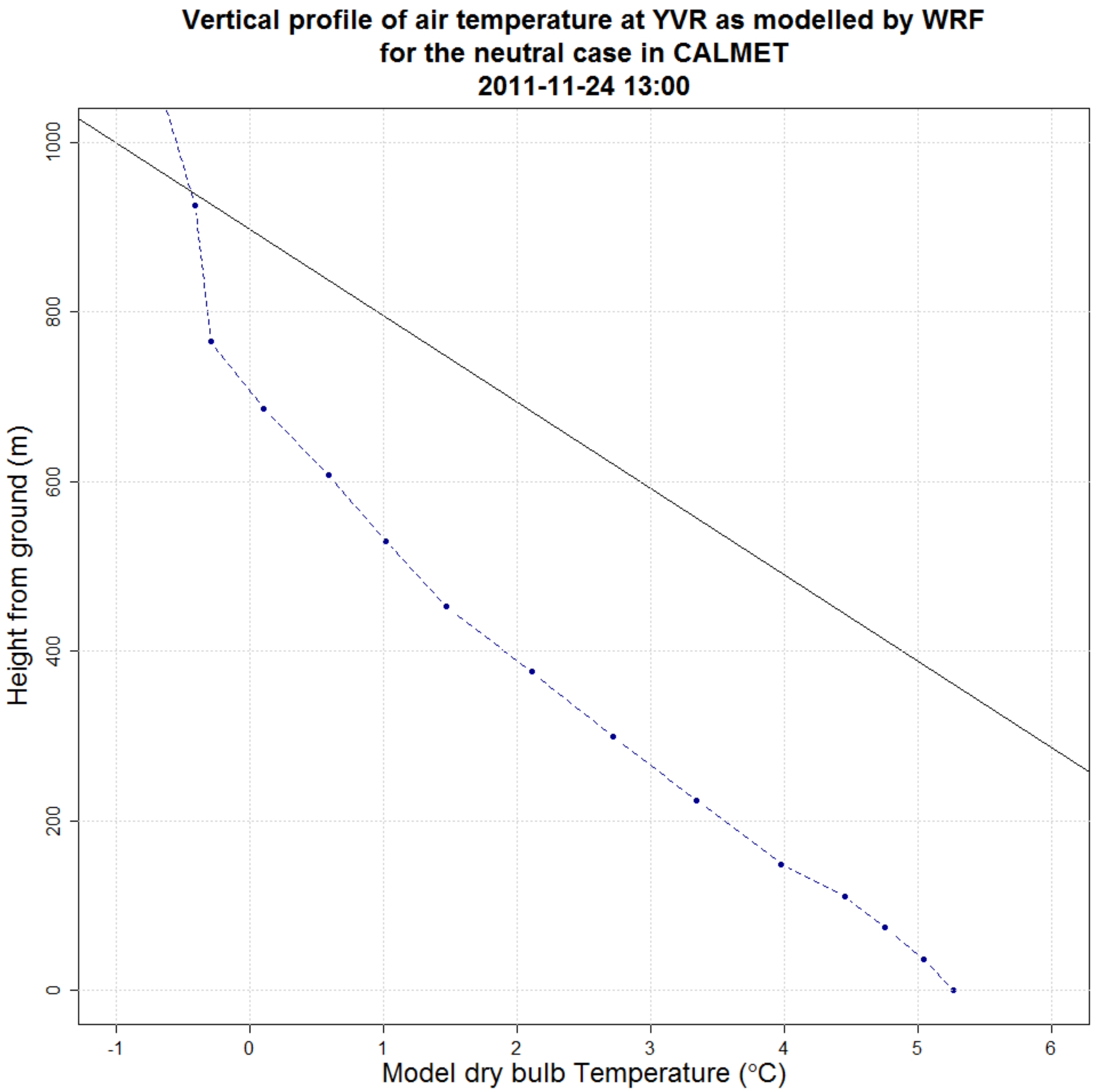


Figure B.8: Neutral vertical profile of air temperature modelled for Vancouver International Airport (YVR). The solid line represents the dry adiabatic lapse rate.

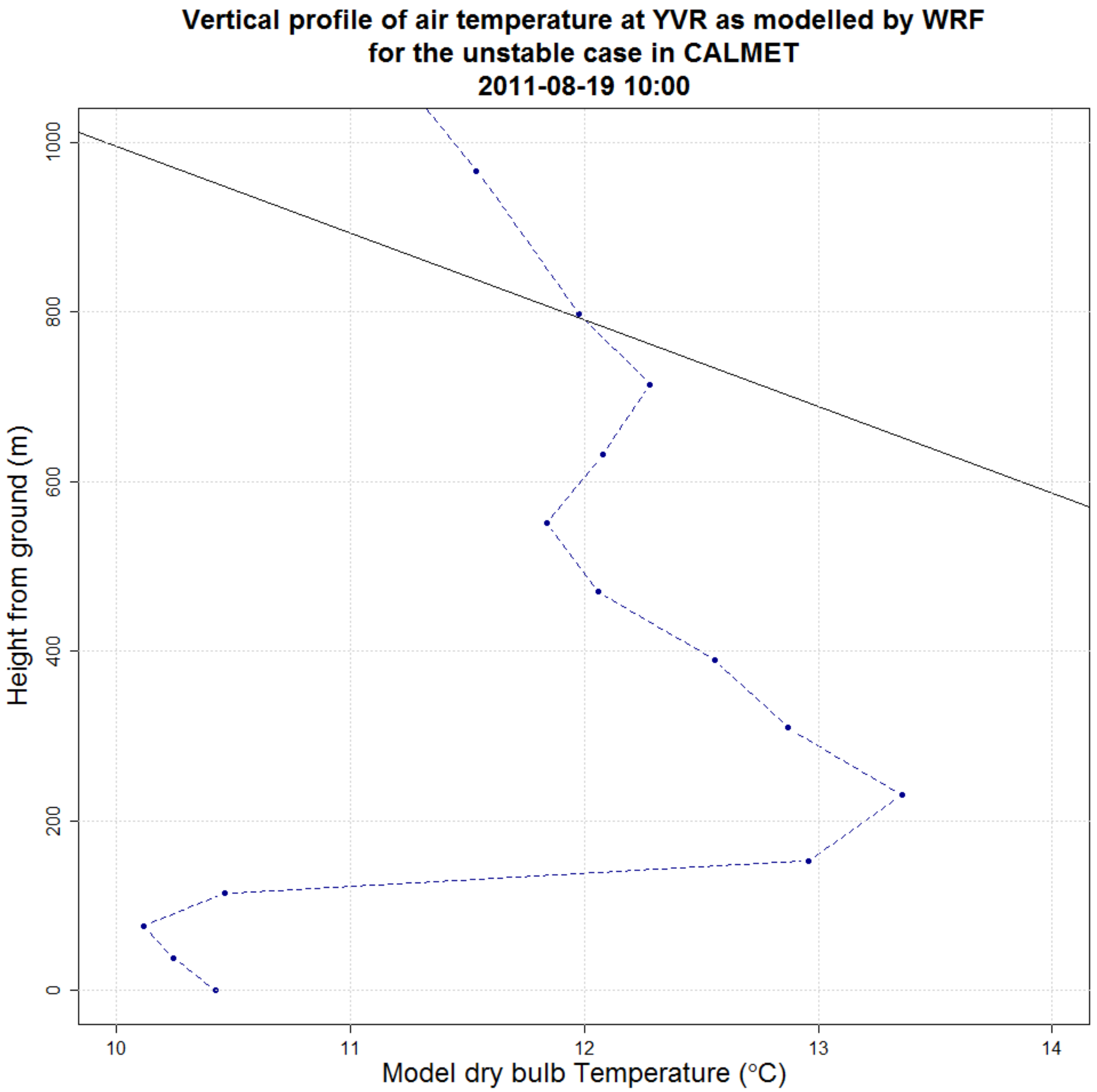


Figure B.9: Unstable vertical profile of air temperature modelled for Vancouver International Airport (YVR). The solid line represents the dry adiabatic lapse rate.

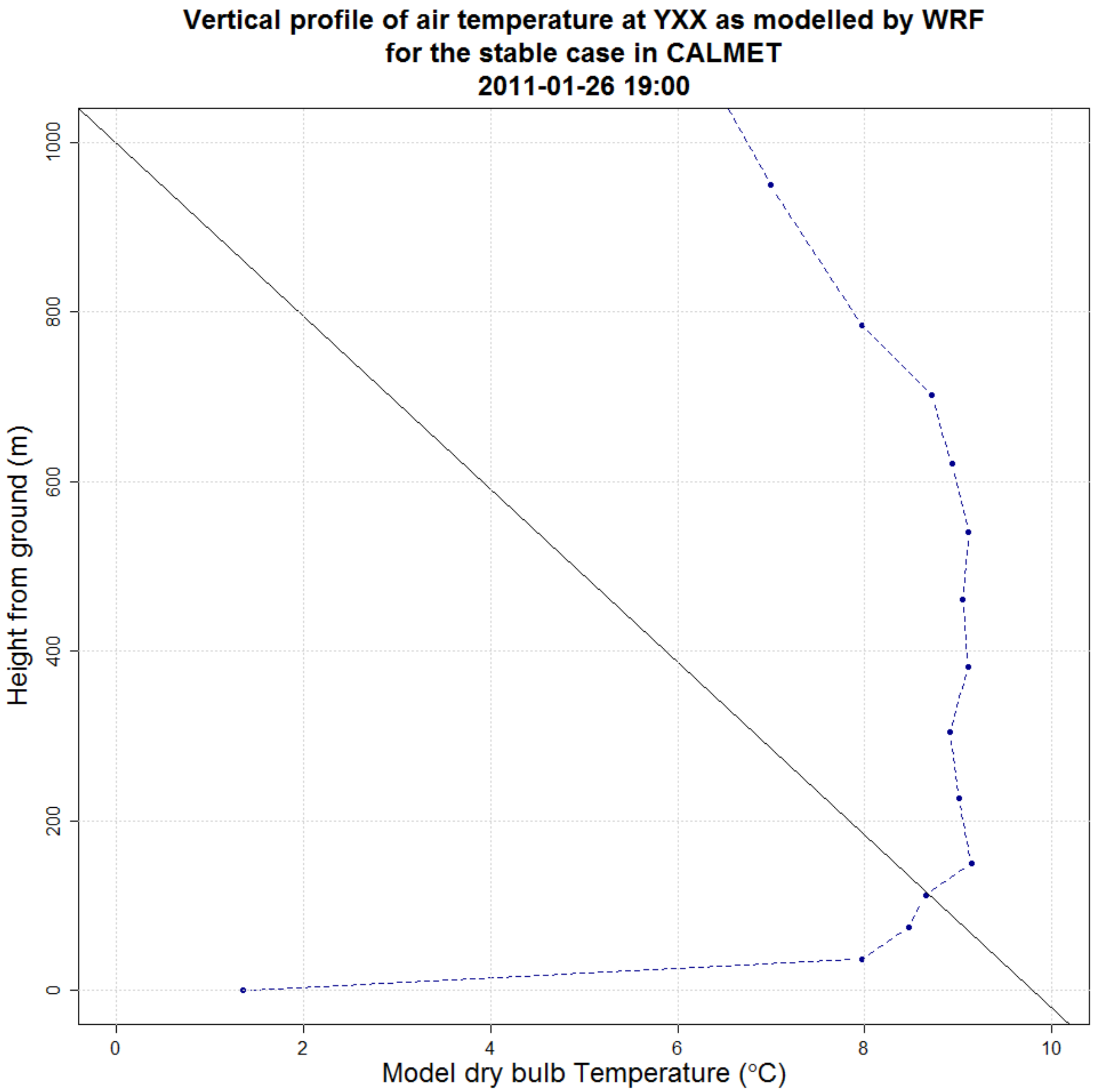


Figure B.10: Stable vertical profile of air temperature modelled for Abbotsford Airport (YXX). The solid line represents the dry adiabatic lapse rate.

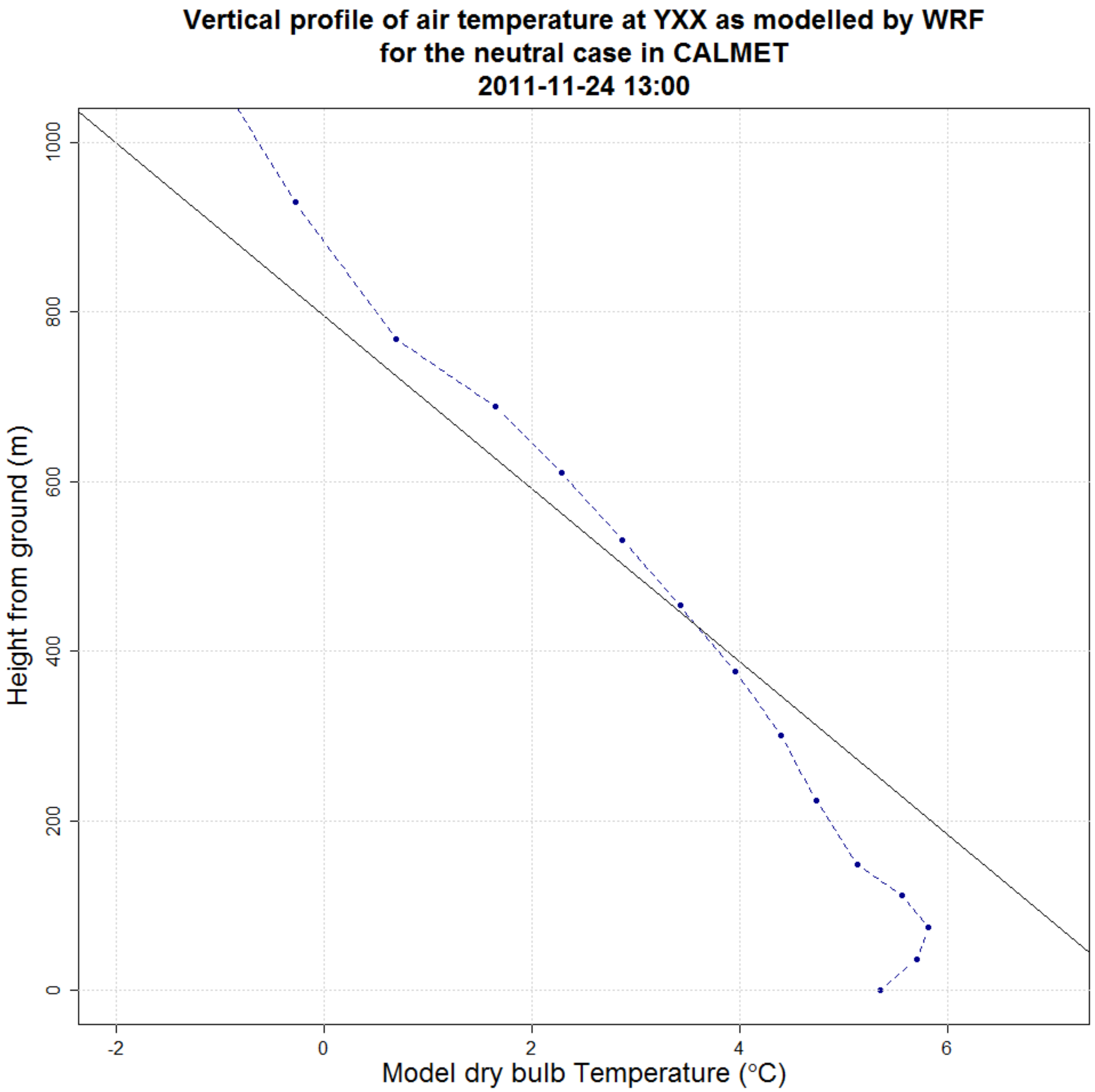


Figure B.11: Neutral vertical profile of air temperature modelled for Abbotsford Airport (YXX). The solid line represents the dry adiabatic lapse rate.

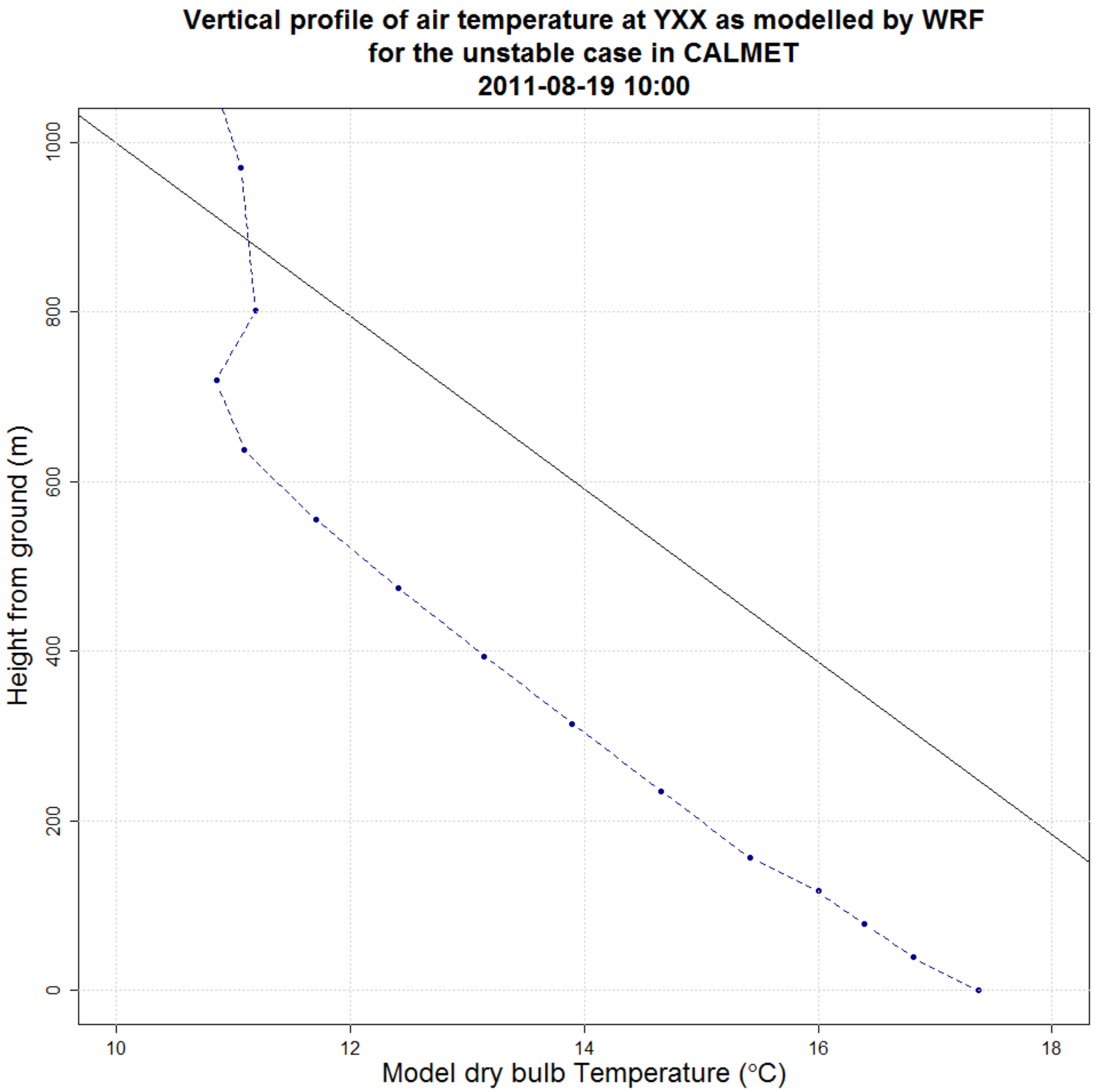


Figure B.12: Unstable vertical profile of air temperature modelled for Abbotsford Airport (YXX). The solid line represents the dry adiabatic lapse rate.

1.5. Modelled Wind Fields

A common approach used to evaluate a meteorological model's ability to replicate wind flow patterns is through the use of wind field plots. Wind field plots from the same periods used for the vertical temperature profiles in the previous section, selected based on Pasquill-Gifford classification output from a CALMET run, are illustrated in Figures B.13 to B.15 to provide an overview of how WRF performed under different conditions. As it is impossible to observe the entire wind field, these model results are not compared against observations but are instead presented on their own to check whether the WRF output "makes sense".

The wind field for the CALMET P-G stable case in Figure B.13 shows very light land breezes, mostly from the Lower Mainland and the Olympic peninsula, and downhill flows, mostly on Vancouver island, consistent with what would be expected for stable conditions. The wind field for the CALMET P-G neutral case in Figure B.14 shows higher wind speeds that are less affected by terrain and fairly uniform wind fields across the domain as expected. The wind field for the CALMET P-G unstable case in Figure B.15 shows the beginning of a sea-breeze and upslope flow as should be expected in unstable conditions

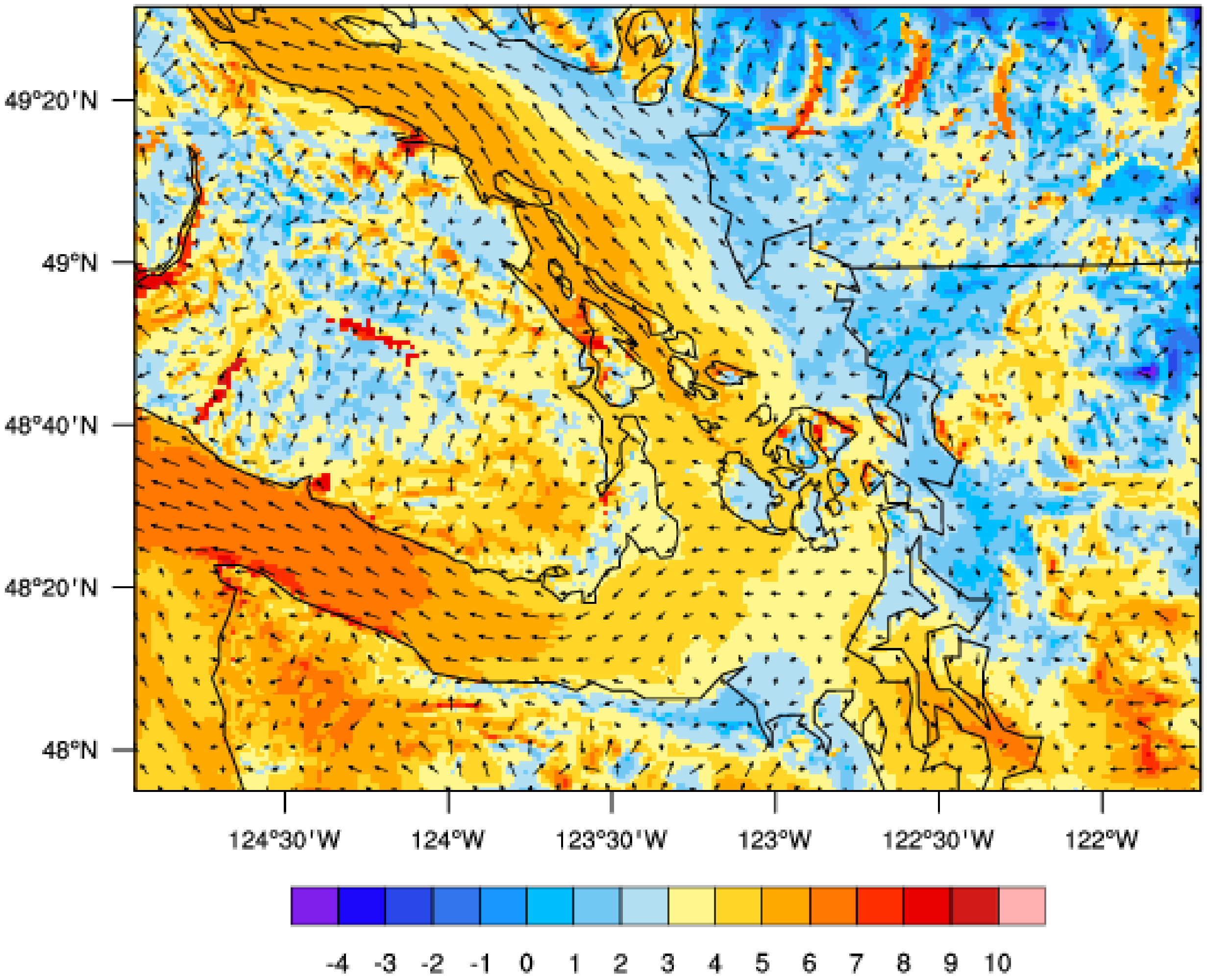


Figure B.13: Modelled Wind Fields at 10 m above Ground Level during Stable Conditions. January 26, 2011, at 19:00 h was chosen because this period corresponded to stable conditions in the CALMET analysis.

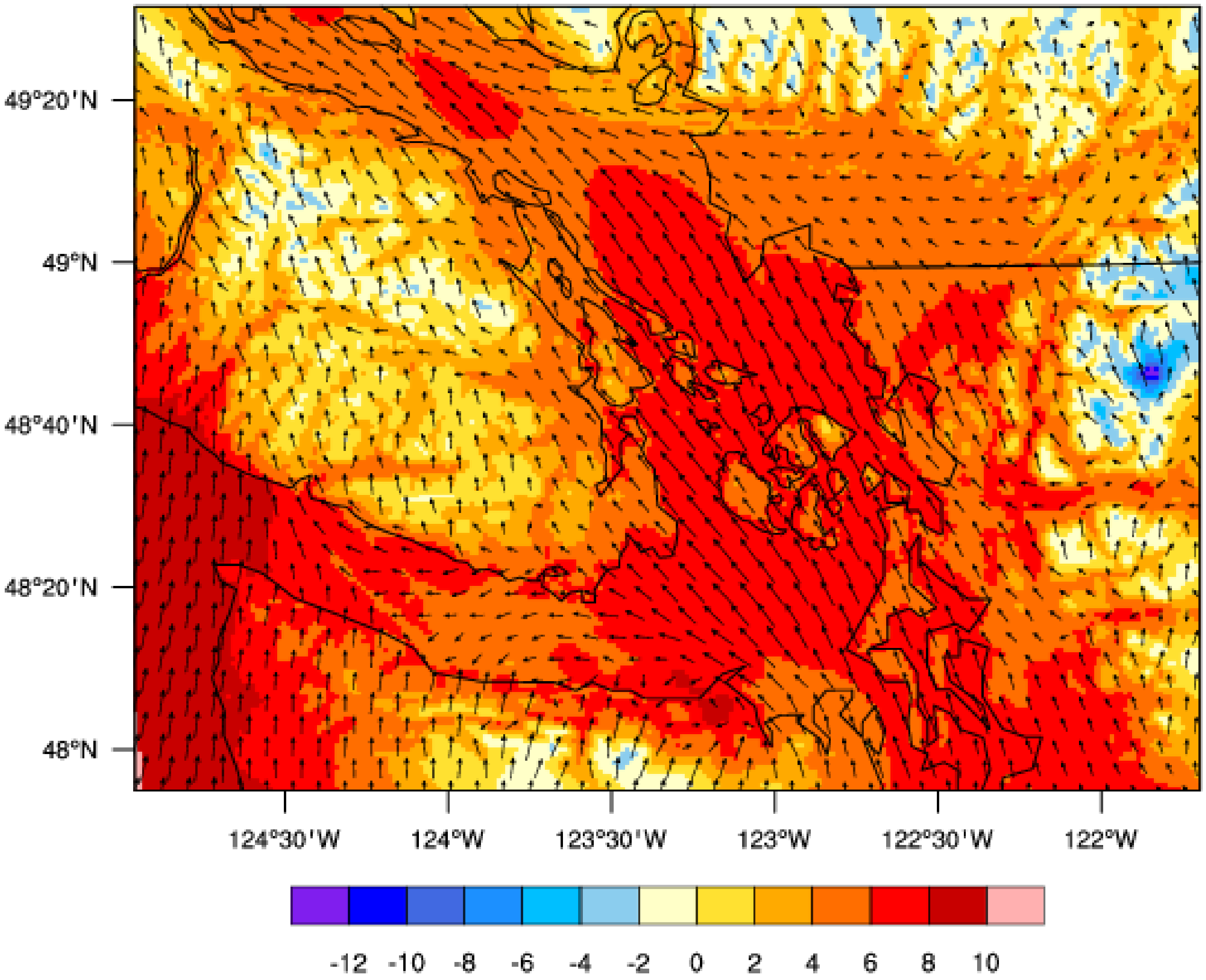


Figure B.14: Modelled Wind Fields at 10 m above Ground Level during Neutral Conditions. November 24, 2011, at 13:00 h was chosen because this period corresponded to neutral conditions in the CALMET analysis.

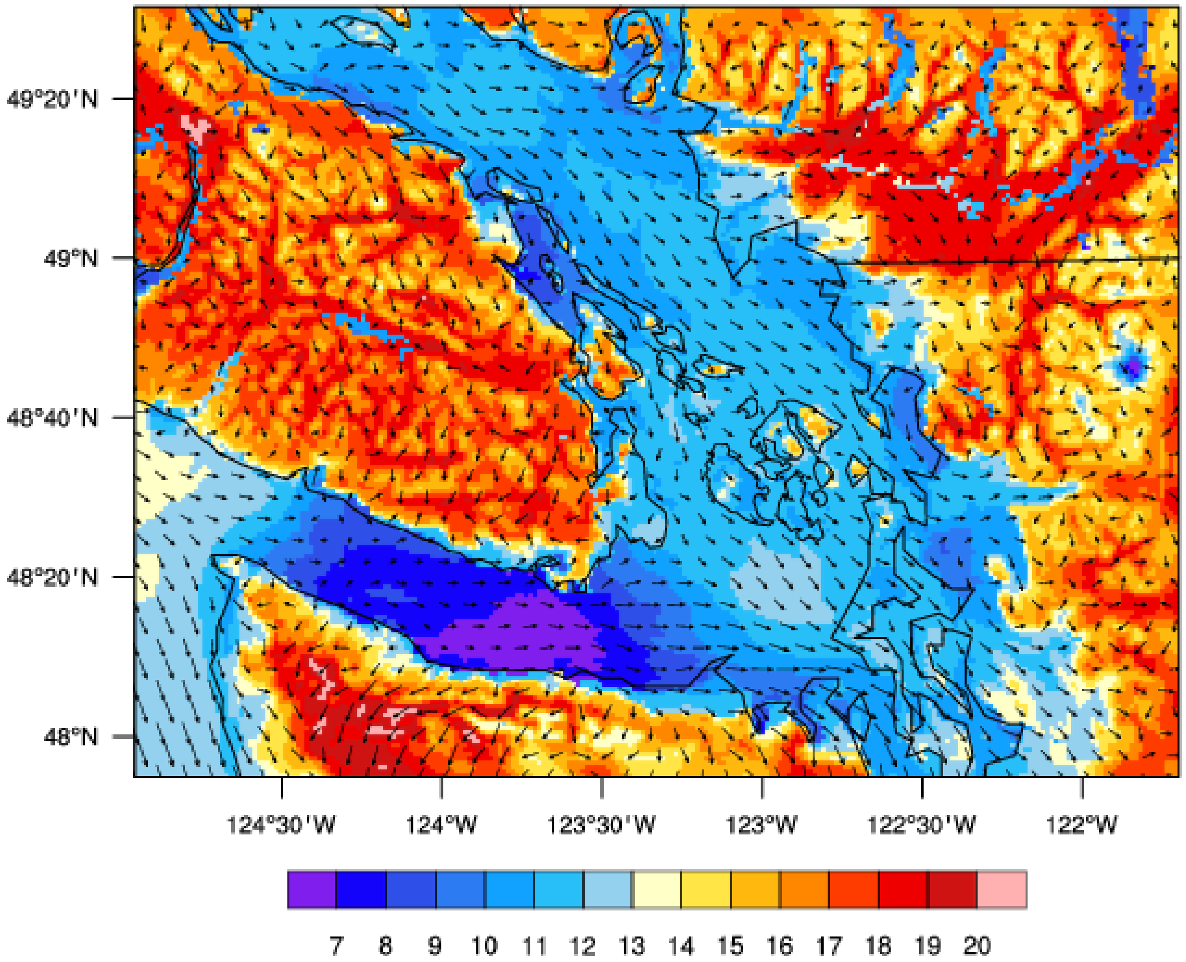


Figure B.155: Modelled Wind Fields at 10 m above Ground Level during Unstable Conditions. August 19, 2011, at 10:00 h was chosen because this period corresponded to unstable conditions in the CALMET analysis.

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