March 9, 2015

APPENDIX 5.7-B

Dispersion Meteorology

Submitted to:
BURNCO Rock Products
8157 132 Street
Surrey, BC
V3W 4N5

REPORT

Reference Number: 1114220046-566-R-Rev0-4700

Distribution:

1 Electronic Copy - BURNCO Rock Products
2 Hard Copies - Golder Associates Ltd.

Golder Associates

Table of Contents

TABLES

FIGURES

APPENDICES

1.0 INTRODUCTION

BURNCO Rock Products Ltd. (BURNCO) has proposed to construct and operate an aggregate mine using wet extraction techniques in Howe Sound, British Columbia (BC) (the Project).

This report supplements Chapter 5.7 of the Environmental Assessment Certificate Application/Environmental Impact Statement.

As a part of air assessment, the general approach used to evaluate the potential air quality effects of the Project included the following steps:

- Estimate the air emissions from the Project for the phase of activity (i.e., construction, operations, and closure and reclamation) determined to have the highest (i.e., bounding) quantity of air emissions.
- **Develop a meteorological dataset for use in the dispersion modelling.**
- Predict the concentrations and deposition rates of indicator compounds released from the bounding phase of the project dispersion modelling.
- Use dispersion modelling to predict the concentrations and deposition rates of the non-indicator compounds required as inputs to other disciplines affected by changes in air quality (e.g., human health).
- Compare the predicted indicator compound concentrations to available criteria and standards, and assess the relevant significance of these effects.

This appendix outlines the second step (**bolded**), namely the approach used for developing the meteorological dataset for use in dispersion modelling.

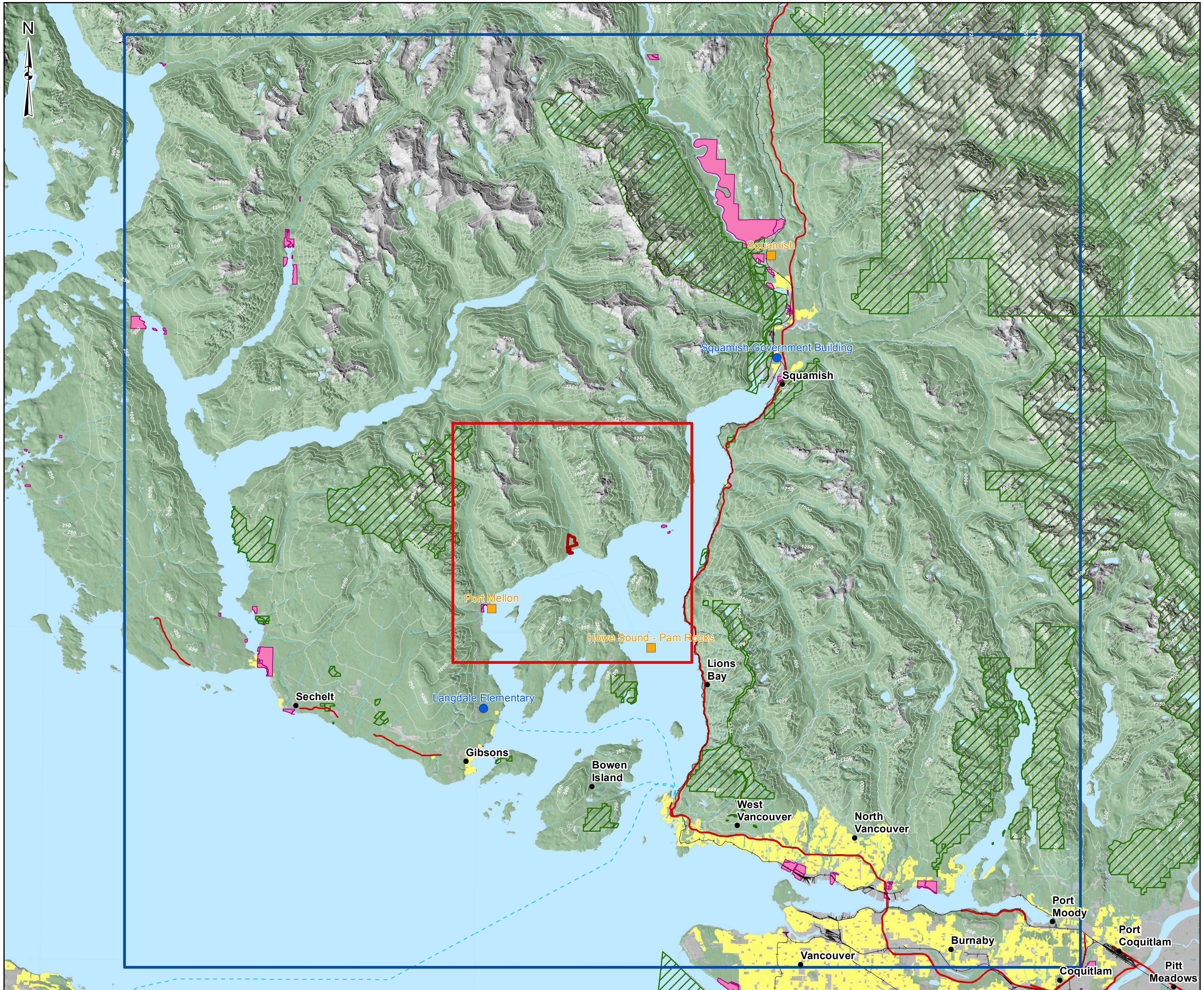
2.0 DISPERSION METEOROLOGY

Representative meteorological input data is required to reliably execute CALPUFF. The Project is located in an area of complex terrain. The Project is located at the mouth of the McNab Creek valley, where the McNab Creek meets Howe Sound. Wind patterns are expected to be influenced by the valley slopes, sea breeze and the land water interface. The complex topography in and around the Project will cause the meteorological conditions to vary from one location to another; specifically from one valley to another. Data from meteorological stations located in such topography (neighbouring valleys) may not be representative of the greater region given the expected localized influences of terrain. There were no reliable meteorological stations located in the Project's valley that was deemed to be representative of the Project's location meteorology; therefore, a 3D CALMET dataset was developed in no-observation mode to characterize the meteorological conditions within the air quality assessment study area, specifically focusing on the project location. Meteorological stations located within modelling domain (neighbouring valleys) would be used to validate the CALMET dataset.

To execute CALMET in no-observation mode mesoscale meteorological data is required for the first guess field in CALMET. The Pennsylvania State University/National Centre for Atmospheric Research mesoscale model (MM5) was executed over the regional area of the Project for 2012 and served as the meteoroidal input to CALMET.

The MM5 and CALMET domains can be seen in Figure 1 along with the meteorological stations that were used to verify the MM5 and CALMET datasets. The following sections details the inputs and validation of both MM5 and CALMET.

Path: X:\Project Data\BC\McNab\Figures\MXD\Air Quality\BURNCO_AIR_Figure_01_CALMET_and_MM5_Domain.mxd



LEGEND

- Air Quality Station
- Meteorological Station
- Project Area
- MM5 Domain
- Calmet Domain
- Park / Protected Area
- Vegetation
- Residential Area
- Indian Reserve
- Waterbody
- Watercourse
- Highway
- Railway
- Ferry
- Contour (250m)

REFERENCE

Elevation and indian reserves from Geobase. Base data from CanVec. DEM from British Columbia Imagery WMS.
Projection: UTM Zone 10 Datum: NAD 83

SCALE

10 0 10

SCALE 1:320,000 KILOMETRES

PROJECT

BURNCO ROCK PRODUCTS LTD.
BURNCO AGGREGATE PROJECT, HOWE SOUND, B.C.

TITLE

CALMET AND MM5 DOMAINS

Golder Associates

PROJECT NO. 11-1422-0046			PHASE No. 4700	
DESIGN	TB	18 Jun. 2013	SCALE AS SHOWN	REV. 0
GIS	DL	03 Mar. 2015		
CHECK	JR	03 Mar. 2015		
REVIEW	SC	03 Mar. 2015		

FIGURE 1

2.1 MM5

When CALMET is executed in no-observation mode the primary meteorological data input will come from MM5. MM5 was executed in-house by Golder and the following sections detail the model initialization and validation.

2.1.1 MM5 Initialization

The MM5 modelling period was the 2012 calendar year (January 1 to December 31, 2012). The MM5 model was executed using the following parameters:

- A total domain of approximately 86 by 84 km (refer to Table 1).
- Three nested domains:
  - the first domain using 36 km resolution;
  - the second domain (nest) using 12 km resolution; and
  - the third domain (next) using 4 km resolution.
- Physics options:
  - Planetary Boundary Layer (PBL) Scheme: medium range forecast (MRF) PBL. This scheme is suitable for high resolution PBL. This scheme uses the National Centers for Environmental Prediction/Oregon State University/Air Force/Hydrologic Research Lab (NOAH) land surface model and its vertical diffusion uses an implicit scheme to allow longer time steps.
  - Explicit Moisture Scheme: Reisner Graupel. This scheme is based on a mixed-phase scheme but with the addition of graupel and ice number concentration prediction equations.
  - Radiation Scheme: RRTM. This scheme is combined with the cloud-radiation shortwave scheme.
- Input Data:
  - FNL (Final) Global Analyses acquired from NCAR (National Center for Atmospheric Research) which has 1 x 1 degree spatial resolution and a 6-hour temporal resolution.
  - Geophysical data: U.S. Geological Survey (USGS) 30 arc seconds (~900 m) digital elevation map and gridded USGS land use data with the same resolution.

Table 1: MM5 Model Domain

Location	Easting (km)	Northing (km)
Southwest	431.497	5,452.194
Northwest	431.497	5,536.424
Southeast	517.257	5,452.194
Northeast	517.257	5,536.424

2.1.2 MM5 Model Output Validation

To determine if the MM5 model is predicting realistic meteorological parameters, the following validation was undertaken:

- Model predicted meteorological parameters (wind speed and direction, temperature and precipitation) were compared against Environment Canada's Squamish Airport (WMO ID 71207) meteorological station (Squamish station) as a part of the quality control process. The Squamish station data was compared to the data extracted from the MM5 cell over the Squamish station location.
- Wind patterns at a grid cell near the land-water interface were extracted and two wind roses were generated: a wind rose showing foliage season afternoon winds and a wind rose showing early morning winds. The two wind roses were plotted to illustrate the diurnal wind patterns.

2.1.2.1 MM5 Data Comparison to Squamish Station

Wind Speed and Direction

The wind rose depicts the relative frequency of wind direction on a 16-point compass, with north, east, south, and west directions going clockwise, whose value is listed adjacent to each of the compass points. Each ring on the wind rose represents a frequency of 2% of the total. The length of the shaded bars on each wind rose petal represents the frequency of wind recorded from a given direction within a certain speed range. Figure 2 presents a comparison wind rose generated from the MM5 data to the Squamish station.

Meteorological station data (Squamish) used for this analysis corresponds to the same temporal period as the MM5 data (January 1, 2012 to December 31, 2012). The comparison shows that there is predominant wind from the south southeast, where the MM5 model predicts weaker wind speeds. A secondary dominant direction is observed, winds blowing from the north northwest. For winds from north northwest the MM5 model predicts stronger wind speeds than observed in Squamish. However, the general wind distribution and frequency patterns are similar for the observed and the MM5 data.

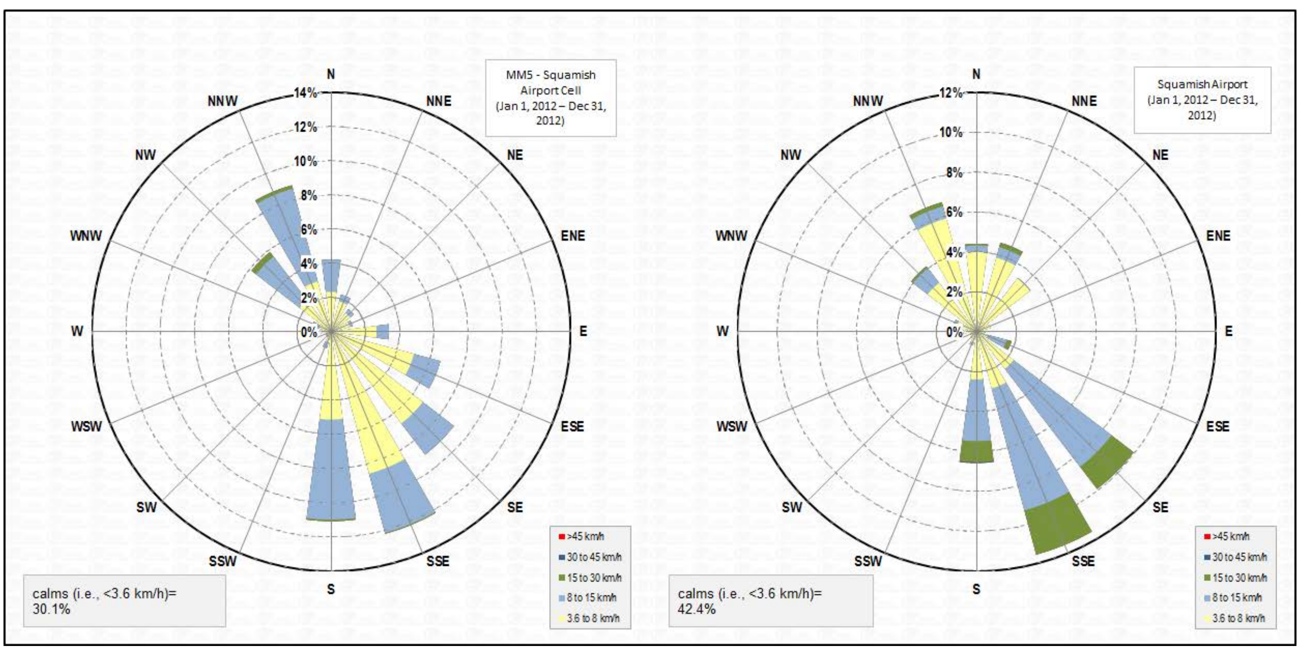


Figure 2: Comparison of Wind Roses Generated Using MM5 Model Results and Data from Meteorological Station

Temperature

Figure 3 compares the temperature between the MM5 data and Squamish. The graph displays the hourly predicted (MM5) and recorded (Squamish) temperature data for the modelling period. It is observed that the MM5 model generally predicts colder temperatures than those observed at the Squamish station. From Figure 3 it is observed that both datasets, MM5 and Squamish, generally share the same distribution pattern.

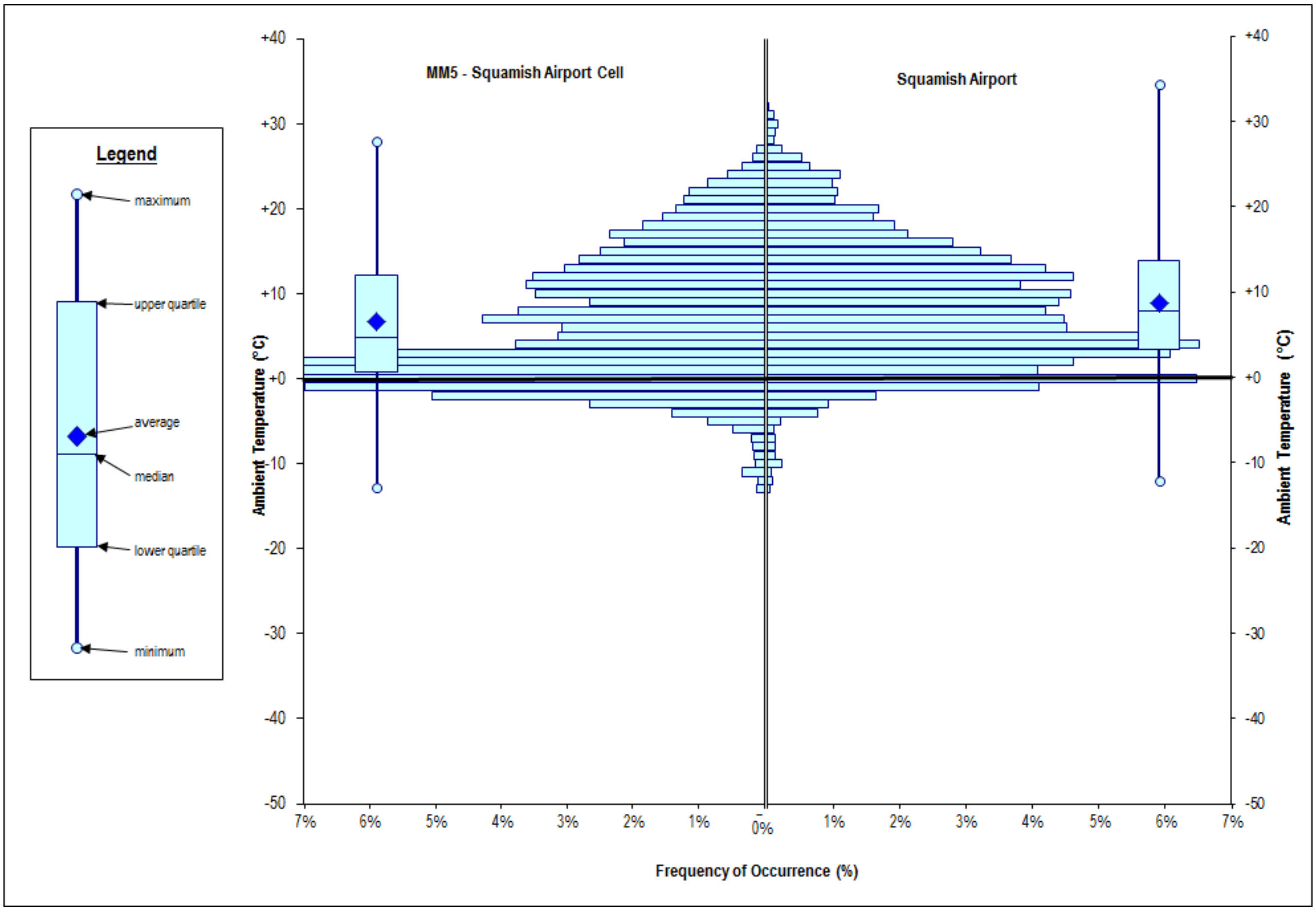
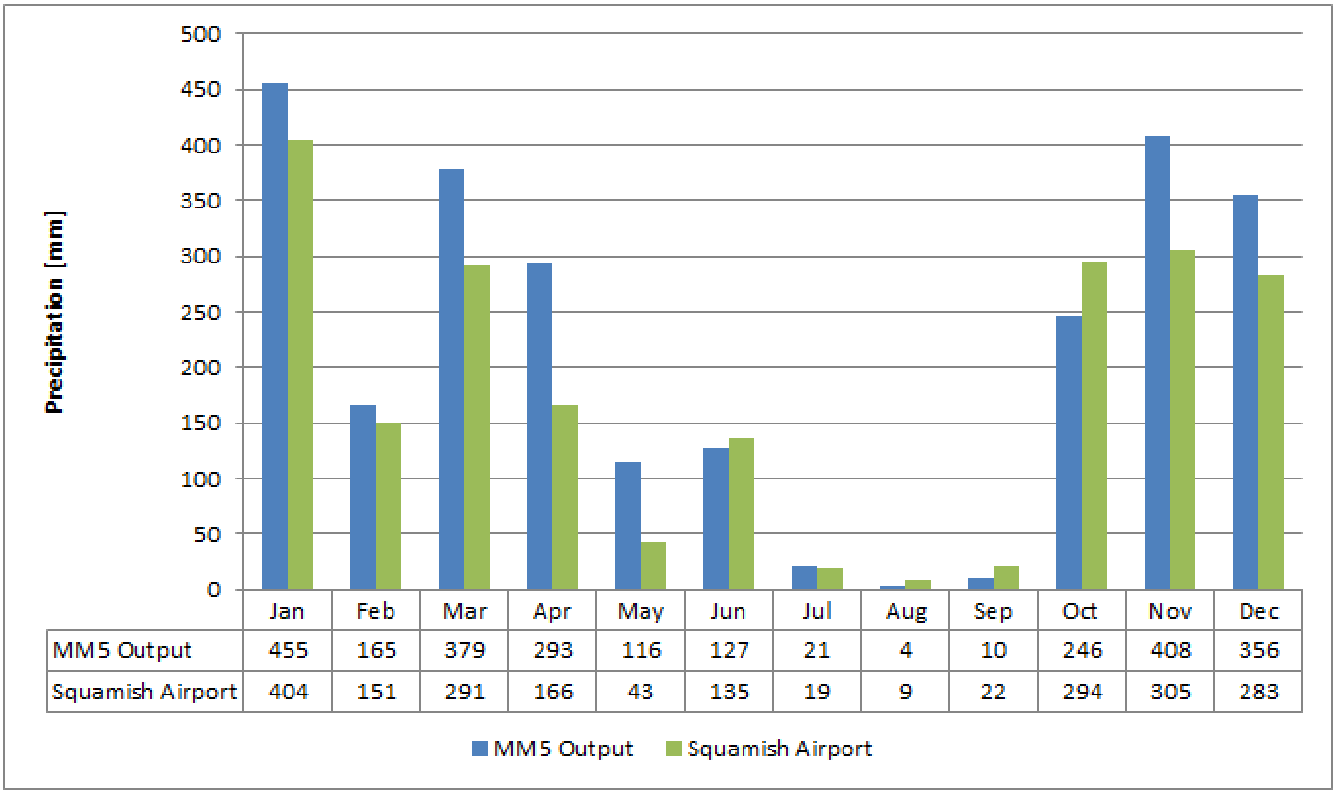


Figure 3: Comparison of Temperature Data Using MM5 Model Results and Data from Meteorological Station

Precipitation

A precipitation comparison (MM5 and Squamish station) is presented in Figure 4. The figure shows that the precipitation distribution observed in Squamish was captured well by MM5. On a monthly basis it is observed (Figure 4) that generally MM5 predicted greater precipitation than the observed dataset, and annually the MM5 model overestimated precipitation by 22%.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
MM5 Output	455	165	379	293	116	127	21	4	10	246	408	356
Squamish Airport	404	151	291	166	43	135	19	9	22	294	305	283

Figure 4: Comparison of Precipitation Data Using MM5 Model Results and Data from Meteorological Station

2.1.2.2 MM5 Land-Water Interface Diurnal Wind Roses

Data from the MM5 grid cell over the Project was extracted. The project lies on the land water interface; therefore, MM5 data over the Project location should illustrate the land breeze (early morning) and sea breeze (summer afternoon) phenomena. Figure 5 and Figure 6 illustrate the land and sea breeze phenomena captured by MM5.

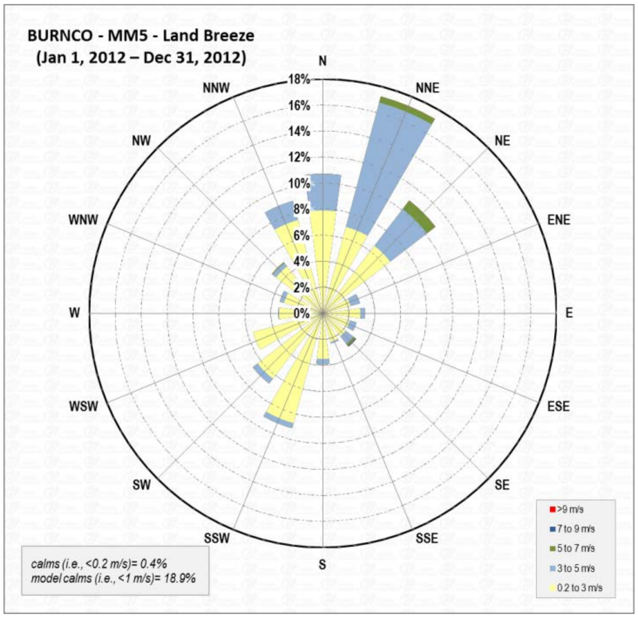


Figure 5: Wind Rose Plot Illustrating Land Breeze from MM5 Cell over the Project Location

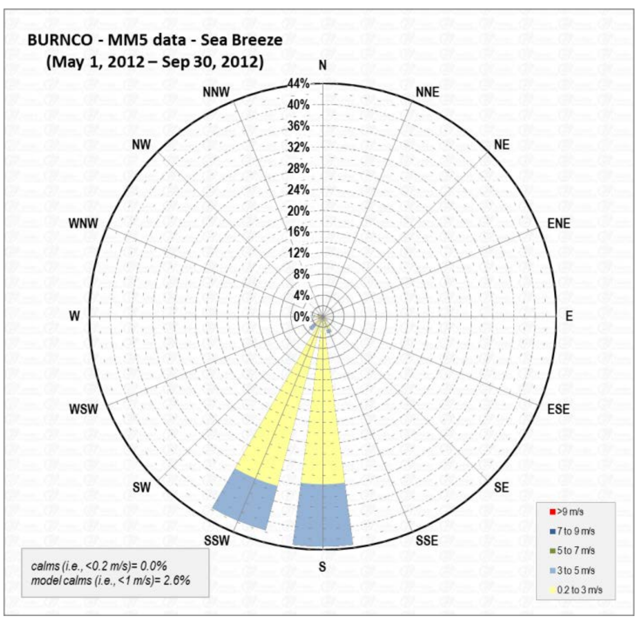


Figure 6: Wind Rose Plot Illustrating Sea Breeze from MM5 Cell over the Project Location

Figure 5 and Figure 6 demonstrate that the MM5 data was able to capture the phenomena of land and sea breeze.

2.2 CALMET Modelling

CALMET was executed in 3D mode and this data was input into the air dispersion model CALPUFF. The in-house generated MM5 data set (discussed in Section 2.1) was used as the initial guess field in CALMET in no-observation mode. Two CALMET meteorological datasets were generated.

- The first dataset was generated specifically for the air quality assessment and was a 22 km by 22 km domain centred at Project site.
- The second meteorological dataset was an 85 km by 83 km domain and was generated to assist other disciplines in assessing the effect of air quality.

This report focuses on the CALMET dataset that was used for the air quality assessment. For details regarding second CALMET dataset refer to Chapter 9.1 of the Environmental Assessment Certificate Application/Environmental Impact Statement.

2.2.1 CALMET Terrain Features

CALMET produces three-dimensional wind fields based on parameterized treatments of terrain effects, such as slope flows, terrain blocking effects, and kinematic effects. Such varying weather parameters are possible since each grid cell within the vertical boundary layer is influenced by its terrain elevation and geophysical parameters.

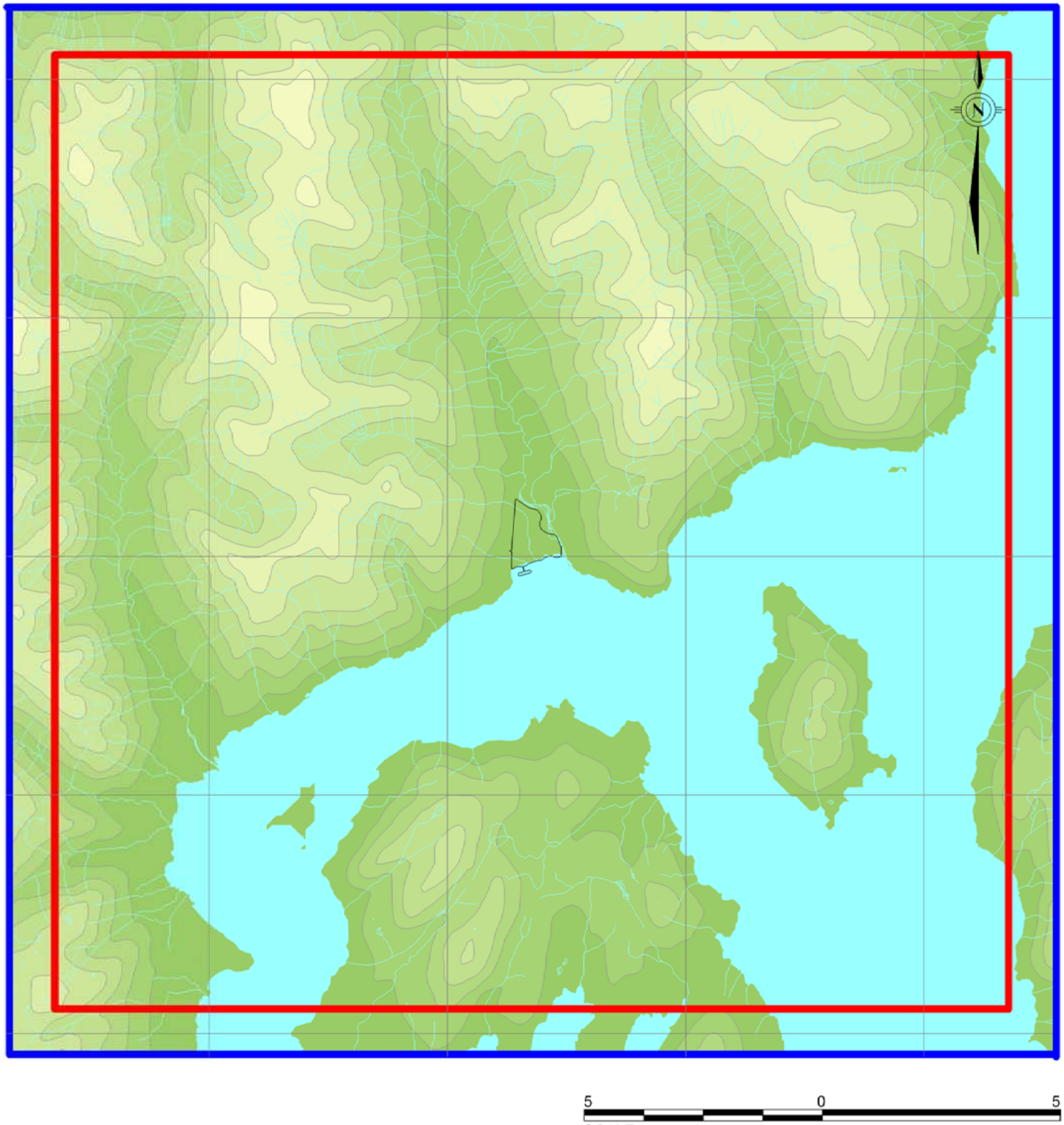
Sections 2.2.1 to 2.2.2 discuss the initialization of model domain, terrain elevation, land use, and the geophysical parameters.

2.2.1.1 Domain

The air quality CALMET modelling domain used in the air quality assessment was a 22 by 22 km rectangle centred on the Project, the modelling grid's spatial resolution was 100 m (this CALMET domain is equivalent to the air quality assessment Local Study area, the Regional Study area domain description can be found in Chapter 5.7 of the Environmental Assessment Certificate Application/Environmental Impact Statement). There are a total of 10 vertical layers separated at 0, 20, 50, 100, 200, 400, 800, 1200, 1600, 2200 and 3000 m. The CALMET modelling domain coordinates are in Table 2. The CALMET and CALPUFF modelling domains are illustrated in Figure 7.

Table 2: CALMET Domain Coordinates

Location	Easting (km)	Northing (km)
Southwest	460.771	5,479.514
Northwest	460.771	5,501.514
Southeast	482.771	5,479.514
Northeast	482.771	5,501.514



LEGEND

- Project Boundary
- CALPUFF domain
- CALMET domain

Terrain elevation (masl): 0, 200, 400, 600, 800, 1000, 1200, 1400, 1600

REFERENCES

DEM provided by GeoBase
Projection: UTM Zone 10 Datum: NAD 83

PROJECT
BURNCO ROCK PRODUCTS LTD.
AGGREGATE PROJECT, HOWE SOUND, B.C.

TITLE
CALMET AND CALPUFF MODEL DOMAINS

PROJECT	11-1422-0046		PHASE No.4700
DESIGN	SD	11 Apr. 13	SCALE AS SHOWN REV. 0
AIR	TB	06 May. 14	**FIGURE: 7**
CHECK	JR	23 Feb. 15	
REVIEW	SC	28 Feb. 15	

Golder Associates

//bur1-d-filesrv1/Active/_2011/1422/11-1422-0046 Burnco McNab Creek EA/Phase 4700 Air Climate/06 Data/Modelling/domain/CALMETCALPUFF.srf

2.2.1.2 Terrain Elevation

Terrain data used within the CALMET model were GEOBase's *Canadian Digital Elevation Data* (Government of Canada et al. 1999) 1:250,000 digital elevation model (DEM) which is approximately 90 by 90 m. GeoBase is a federal, provincial and territorial government initiative that is overseen by the Canadian Council on Geomatics. The terrain data will be converted to a 100 by 100 m dataset using global information system (GIS) software; the elevations were spatially averaged over each meteorological grid cell. The terrain data used in the CALMET domain is illustrated in Figure 7.

2.2.2 CALMET Land Use Features

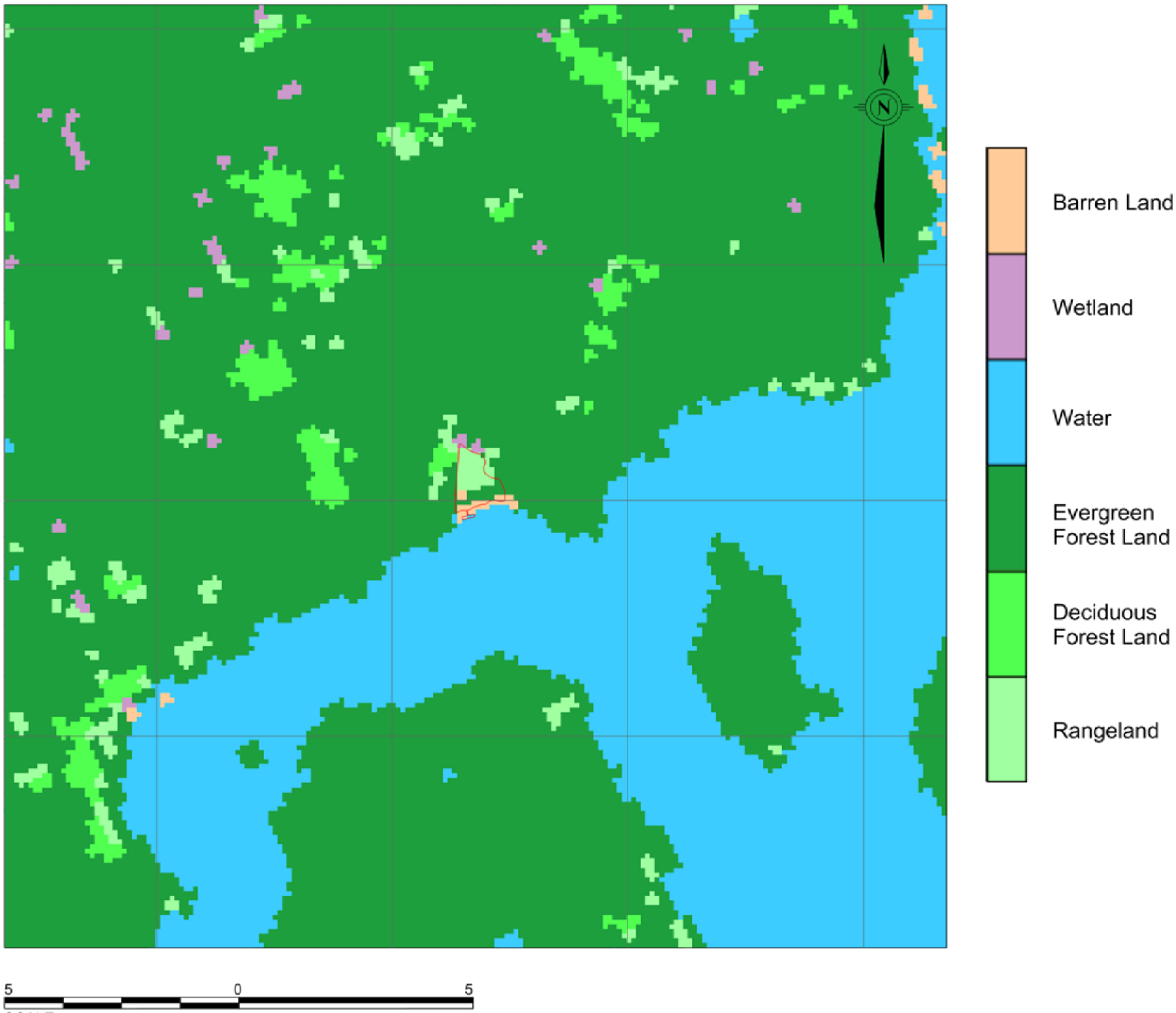
Land use (land cover) data used within CALMET was provided in *Land Cover Map of Canada 2005* (Canada Centre for Remote Sensing et al. 2008) obtained from Natural Resources Canada (NRC). The land cover data provided by NRC (250 by 250 m resolution), was downscaled to a 100 by 100 m grid using GIS. The land use class conversion from NRC to CALMET land use category is shown in Table 3. Six different CALMET land use categories were used; they are rangeland, deciduous forest land, evergreen forest land, water, wetland and barren land. Land use categories over the CALMET domain are illustrated in Figure 8.

Table 3: Land Use Categories

NRC Land Use Code	NRC Land Use Category	CALMET Code	CALMET Category
1	Temperate or Subpolar Needle-leaved Evergreen Closed Tree Canopy	42	Evergreen Forest Land
2	Cold Deciduous Closed Tree Canopy	41	Deciduous Forest Land
3	Mixed Needle-leaved Evergreen – Cold Deciduous Closed Tree Canopy	42	Evergreen Forest Land
4	Mixed Needle-leaved evergreen – Cold Deciduous Closed Young Tree Canopy	42	Evergreen Forest Land
5	Mixed Cold Deciduous – Needle-leaved Evergreen Closed Tree Canopy	42	Evergreen Forest Land
6	Temperate or Subpolar Needle-leaved Evergreen Medium Density, Moss-shrub Understory	42	Evergreen Forest Land
7	Temperate or Subpolar Needle-leaved Evergreen Medium Density, Lichen-shrub Understory	42	Evergreen Forest Land
8	Temperate or Subpolar Needle-leaved Evergreen Low Density, Shrub-moss Understory	42	Evergreen Forest Land
9	Temperate or Subpolar Needle-leaved Evergreen Low Density, Lichen (Rock) Understory	42	Evergreen Forest Land
10	Temperate or Subpolar Needle-leaved Evergreen Low Density, Poorly Drained	42	Evergreen Forest Land
11	Cold Deciduous Broad-leaved, Low to Medium Density	41	Deciduous Forest Land
12	Cold Deciduous Broad-leaved, Medium Density, Young Regenerating	41	Deciduous Forest Land
13	Mixed Needle-leaved Evergreen – Cold Deciduous, Low to Medium Density	42	Evergreen Forest Land
14	Mixed Cold Deciduous – Needle-leaved Evergreen, Low to Medium Density	41	Deciduous Forest Land

NRC Land Use Code	NRC Land Use Category	CALMET Code	CALMET Category
15	Low Regenerating Young Mixed Cover	42	Evergreen Forest Land
16	High-low Shrub Dominated	30	Rangeland
18	Herb-shrub-bare Cover	30	Rangeland
19	Wetlands	60	Wetland
20	Sparse Needle-leaved Evergreen, Herb-shrub Cover	42	Evergreen Forest Land
23	Herb-shrub Poorly Drained	60	Wetland
25	Low Vegetation Cover	70	Barren Land
32	Lichen-spruce Bog	60	Wetland
37	Water Bodies	50	Water
38	Mixes of Water and Land	50	Water

CALMET DOMAIN



LEGEND

BURNCO fenceline

REFERENCES

Land use provided by Land Cover Map of Canada 2005
Projection: UTM Zone 10 Datum: NAD 83.

PROJECT
BURNCO ROCK PRODUCTS LTD.
AGGREGATE PROJECT, BRITISH COLUMBIA

TITLE
LAND USE CATEGORIES WITHIN CALMET MODEL

Golder Associates	PROJECT NO. 11-1422-0046			PHASE No. 4700
	DESIGN	TB	02 Aug. 13	SCALE AS SHOWN REV. 0
	AIR	TB	25 Apr. 14	**FIGURE: 8**
	CHECK	JR	23 Feb. 15	
	REVIEW	SC	28 Feb. 15	

//bur1-d-filesrv1/Active/_2011/1422/11-1422-0046/Phase 4700/06 Data/Modelling/geo.dat/Local- geo.dat/Land Use/Land Use categories.srf

2.2.2.1.1 Geophysical Parameters

The CALMET model requires surface geophysical parameters to calculate the meteorological conditions near the surface level. The geophysical parameters used in CALMET are roughness length, albedo, Bowen ratio, soil heat flux, leaf area index and anthropogenic heat flux. The CALMET model allows each land use class to have a user defined geophysical value.

Geophysical parameter values are subject to change seasonally. Some examples of how geophysical parameters may change seasonally include albedo values altering as water bodies freeze and leaf area index values altering as plant foliage change between seasons. For this Project, it was determined that there are two seasons as described below:

- foliage period – May 1 to September 30, and
- non-foliage period – January 1 to April 30 and October 1 to December 31.

The following sections below will discuss the geophysical parameters and the source of geophysical parameter values.

2.2.2.1.1.1 Roughness Length

Roughness length is a measure of the drag experienced by wind above surface. This parameter is expressed in meters, where smaller values represent smooth surface and larger values represent rough surface. The default roughness length value for "barren land" was used (Scire et al. 2000) for both seasons since it is expected that this land use class will not undergo a seasonal change. A guideline document prepared by British Columbia (BC) Ministry of Environment (MoE) (2008), *Guidelines for Air Quality Dispersion Modelling in British Columbia* (hereafter referred to as the BC Modelling Guidelines) was referenced for the other five land use types. Table 4 presents roughness lengths used for foliage and non-foliage seasons.

Table 4: Roughness Length Used in CALMET

Land Use Description	Roughness Length (m)	
	Foliage Season	Non-foliage Season
Rangeland	0.1	0.001
Deciduous Forest Land	1.3	0.5
Evergreen Forest Land	1.3	1.3
Water	0.0001	0.0001
Wetland	0.2	0.05
Barren Land	0.05	0.05

2.2.2.1.1.2 Albedo

Albedo is a ratio of the reflected incoming solar radiation by the ground surface. This parameter ranges from 0 to 1; where 0 is a surface that absorbs all incoming solar radiation, and 1 is a surface that reflects all incoming solar radiation. For the air quality assessment, the default albedo value for "barren land" was used for both seasons (Scire et al 2000). For the other five land use types, values were taken from Table 9.4 of the BC Modelling Guidelines (BC MoE 2008). Table 5 below shows albedo values used within CALMET for this study.

Table 5: Albedo Values Used in CALMET Model

Land Use Type	Albedo (unit less)	
	Foliage Season	Non-foliage Season
Rangeland	0.18	0.6
Deciduous Forest Land	0.12	0.5
Evergreen Forest Land	0.12	0.35
Water	0.1	0.14
Wetland	0.14	0.3
Barren Land	0.3	0.3

2.2.2.1.1.3 Bowen Ratio

Bowen ratio is a ratio of the sensible to latent heat flux at the ground surface. The default value for “barren land” was used for Bowen ratio for both foliage and non-foliage seasons. For the other five land types, values presented, in Table 9.5 of the BC Modelling Guidelines (BC MoE 2008) were used. Table 6 shows Bowen ratios used for the air quality assessment.

Table 6: Bowen Ratios Used in CALMET Model

Land Use Type	Bowen Ratio (unit less)	
	Foliage Season	Non-foliage Season
Rangeland	0.8	1
Deciduous Forest Land	0.3	1
Evergreen Forest Land	0.3	0.8
Water	0.1	0.1
Wetland	0.1	0.1
Barren Land	1	1

2.2.2.1.1.4 Soil Heat Flux

The soil heat flux constant is a function of the surface properties and is used to compute the flux of heat into the soil. The default CALMET values were used for all six land types, with no seasonal variability. Table 7 presents soil heat flux values used for the air quality assessment.

Table 7: Soil Heat Flux Values Used in CALMET Model

Land Use Type	Soil Heat Flux (W/m^2)
Rangeland	0.15
Deciduous Forest Land	0.15
Evergreen Forest Land	0.15
Water	1
Wetland	0.25
Barren Land	0.15

2.2.2.1.1.5 Leaf Area Index

Leaf area index (LAI) is a ratio of area of leaves per unit area. LAI parameters were defined based on *Canada Wide Leaf Area Index from SPOT-VEGETATION* (NRC et al. 2004). These LAI files were processed by GIS to match each land use grid cell to a LAI value. This data was tabulated and the average LAI value was calculated for each land use category. This procedure was used for both foliage and non-foliage seasons. Table 8 shows the LAI values used in CALMET.

Table 8: LAI Values Used in CALMET Model

Land Use Type	Leaf Area Index (m^2/m^2)	
	Foliage Season	Non-foliage Season
Rangeland	4.7	3.44
Deciduous Forest Land	4.89	3.35
Evergreen Forest Land	5.79	4.4
Water	0	0
Wetland	4.71	2.8
Barren Land	0.05	0.05

2.2.2.1.1.6 Anthropogenic Heat Flux

Anthropogenic heat flux is used to estimate the heat flux at surface as a result of human activities. The CALMET default value of 0.0 W/m^2 was used for all land use types for both the foliage and non-foliage season.

2.2.3 CALMET Model Initialization

The CALMET model allows users to select various options that best fit the meteorological conditions of each Project. Due to the complex nature of the terrain within the study area and not having a representative meteorological station in the Project's valley, the CALMET model was initialized using the in-house MM5 data and executed in no-observation mode (discussed in Sections 2.0 and 2.1). The model was executed for the 2012 calendar year (January 1 to December 31, 2012).

The detailed CALMET model switches used for this Project are listed in Appendix A. CALMET switch settings were generally consistent with recommended values specified in the BC Modelling Guidelines (BC MoE 2008); where switch settings differ from recommended values a rational is provided in Appendix A.

2.2.4 CALMET Model Output Validation

To determine if the CALMET models are predicting realistic meteorological parameters, the following validation was undertaken:

- Model predicted meteorological parameters (wind speed and direction, temperature and precipitation) were compared against observation data measured at existing meteorological stations in both the major and nested domains.
- Two locations were selected (in the valley that the Project is located in) and model predicted meteorological parameters were extracted. These locations are referred as validation point 1 (in nested domain) and validation point 2 (in major domain). These points were selected based on the valley structure near the Project to ensure the wind patterns are influenced by the surrounding terrain features.

- Stability class is a measure of the ability of air to move vertically in the atmosphere; stability class provides an indication of a plume's ability to disperse in the atmosphere. Stability class predictions at the Project location were analyzed to determine if stability classes are behaving as expected.
- Mixing height is the depth of the atmosphere driven by mechanical and turbulent mixing. Plume dispersion will occur in the mixing zone, the area below the mixing height. Mixing height predictions at the Project location were analyzed to determine if mixing heights are behaving as expected.
- Wind vectors are the composite of wind direction and wind speed. Figures showing the wind pattern over the nested domain were plotted for different atmospheric conditions, for different heights and for three consecutive hours to illustrate that winds are behaving as expected.
- Wind patterns at the Project location (nested domain) were extracted and diurnal wind roses were plotted to illustrate night and daily wind patterns.
- Temperature at the Project location (nested domain) was extracted and plotted that illustrate night and daily temperature patterns seasonally.

2.2.4.1 CALMET Validation with Meteorological Station Data

CALMET model predictions were validated against the data from Port Mellon meteorological station (WMO ID 71605) located 8.5 km south-west of the Project. The data from the CALMET grid cell over the Port Mellon meteorological station was compared to the data measured by the meteorological station. Port Mellon station is operated by Environment Canada, and the meteorological data were downloaded from Environment Canada's historic data website (Environment Canada 2014).

As observed in Figure 1, there are two meteorological stations within the CALMET domain. Based on the distance between the Port Mellon station and the Project and the similarity in the physical setting (both sites are located at the mouth of a Valley) it was determined that the CALMET validation will focus on Port Mellon. The reasons for not including Pam Rocks in the model validation are discussed in Sections 2.2 and 3.3 of Appendix 5.7-D of the Environmental Assessment Certificate Application/Environmental Impact Statement.

2.2.4.1.1 Wind Speed and Direction

Figure 9 illustrates the hourly wind roses comparing CALMET and Port Mellon Station data for 2012. The CALMET wind data were taken from the surface layer (10 m above ground). The figure shows that CALMET predicts a lower frequency of calm periods. However, the dominant northerly wind pattern, as observed in Port Mellon, is captured well by the CALMET model. The wind speed distribution is also well predicted by CALMET. The similarities in predominant wind direction and wind speed distribution suggest that CALMET was able to incorporate the complex terrain features surrounding the Port Mellon station and generate a representative wind pattern when compared to observation data. This also suggests that CALMET was likely able to generate winds around the BURNCO Project site, with similar valley structure surrounding the site and a large water body on the south.

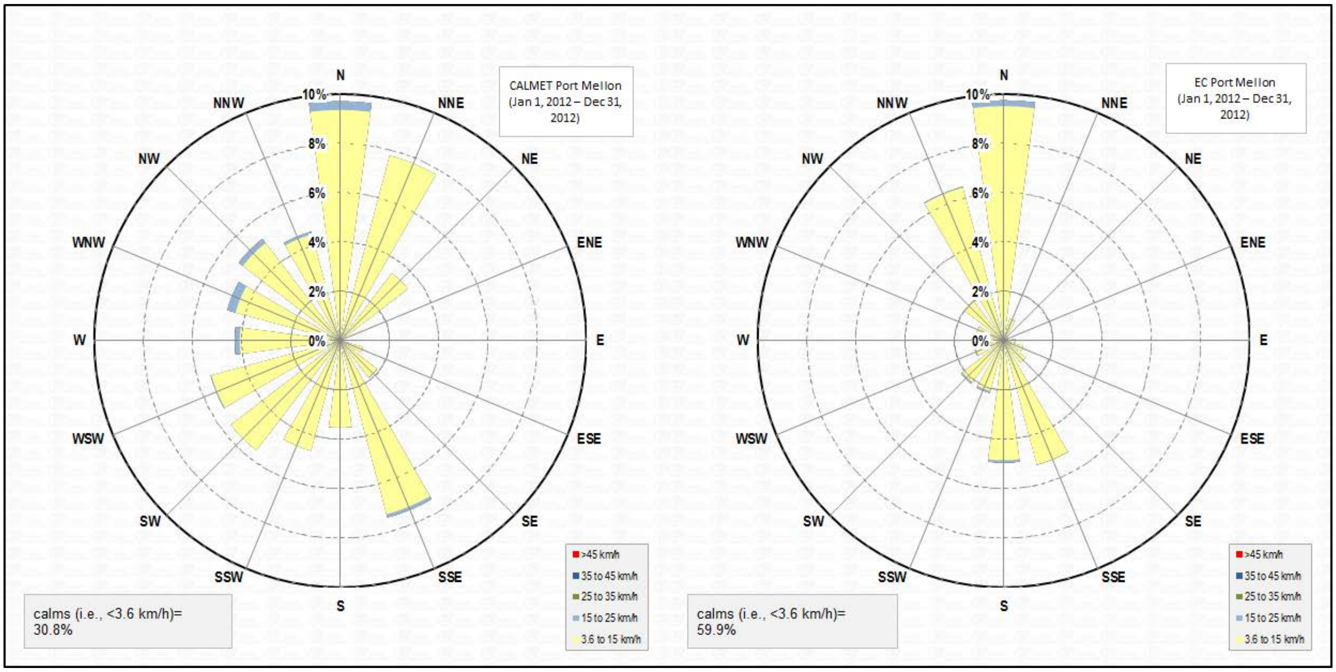


Figure 9: Comparison Wind Roses Generated Using CALMET Model Results and Data from Port Mellon

2.2.4.1.2 Temperature

Figure 10 presents a temperature distribution comparison between CALMET and Port Mellon. It is observed that for the majority of the time both the modelled and observed temperature range between 0 to 20°C. The CALMET model shows a slightly broader distribution, and colder predictions than the observation data. This wider distribution is reflected in the maximum, minimum, mean and median plots in Figure 10. CALMET predicts highest frequency of temperature occurrence around 0°C, while the observation data's highest frequency of temperature occurrences is around 6°C.

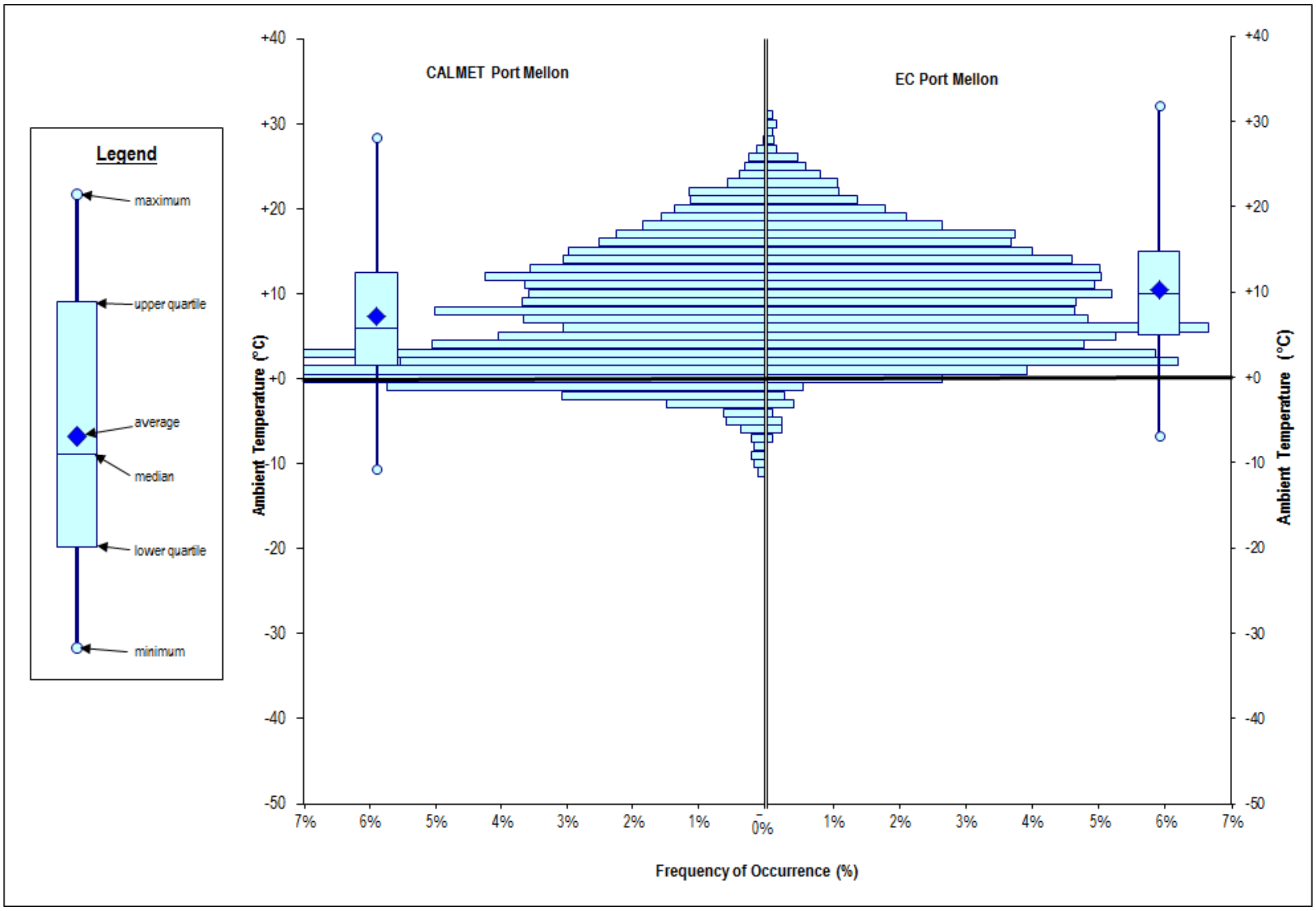


Figure 10: Comparison Temperature Graph Generated Using CALMET Model Results and Data from Port Mellon

2.2.4.1.3 Precipitation

With regards to the air quality assessment precipitation validation on the CALMET dataset (first or local dataset) was not completed because wet deposition was not included in the air quality assessment (which would result in the most conservative model predicted concentrations), as well precipitation data was not available at either the Port Mellon or Pam Rocks meteorological stations.

As stated in 2.1.2.2 a larger CALMET dataset (second or regional dataset) was generated for other disciplines. The second dataset underwent precipitation validation since wet deposition would be incorporated into the CALPUFF executions for the other disciplines. The regional CALMET dataset was generated with all the meteorological switches same as the local dataset. The distinctive difference between the two CALMET datasets is the grid resolution. The local dataset has a grid resolution of 100 m as stated in Section 2.2.1.1 and the regional dataset has a grid size resolution of 250 m.

The precipitation validation was conducted using observation data from the Squamish station. Figure 11 shows the comparisons between the regional CALMET and the Squamish station data; it is observed that the regional CALMET predicted higher precipitation than the observed record, but CALMET was able to capture the monthly trend well. MM5 (the meteorological input to CALMET) is known to overestimate the amount of precipitation, and this is likely the cause of CALMET's precipitation over-prediction. For further details on the regional CALMET model, see Chapter 9.1 of the Environmental Assessment Certificate Application/Environmental Impact Statement.

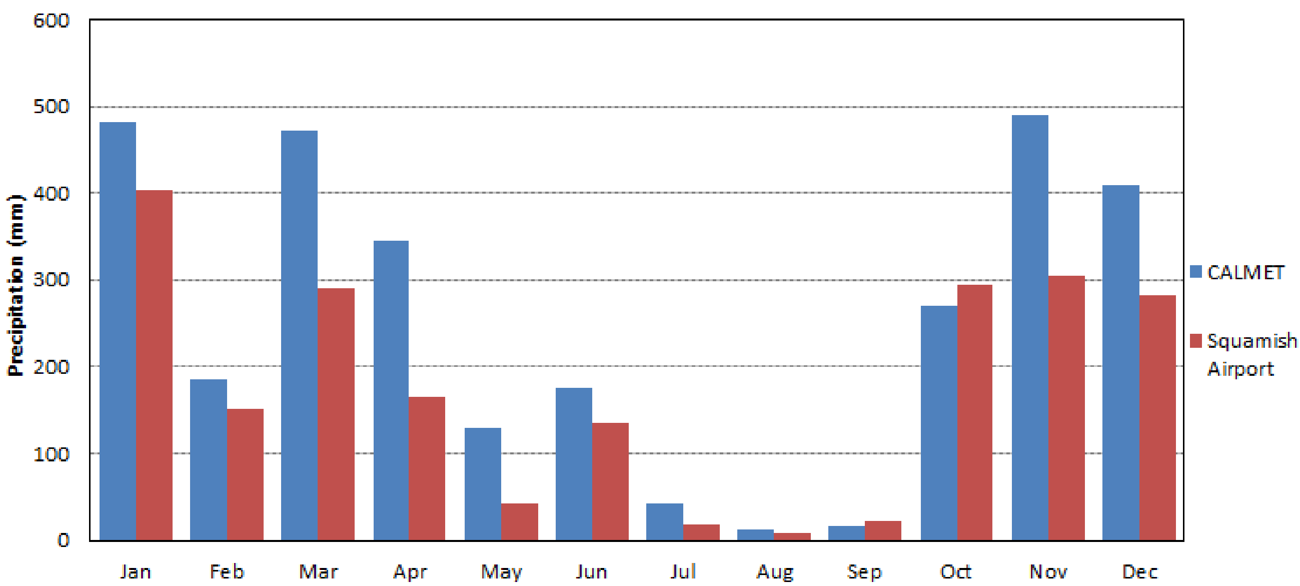


Figure 11: Regional CALMET Model Precipitation and Observed Precipitation at Squamish Airport Station

2.2.4.2 Project and Valley Locations Wind Validation

As previously mentioned, the Project is located in an area of complex terrain. To ensure the CALMET is predicting meteorological conditions due to the complex terrain, a couple validation points were selected in areas where the terrain would dictate the predominant wind directions. These locations are referred as validation point 1 and validation point 2, shown in Table 9.

As seen in Figure 1, the Project is located in the mouth of a valley. The valley extends north-west from the project for about 12 km where it intersects another valley (similar to a "T" intersection) that is in the west-east direction. Validation point 1 is located approximately mid-way along the 12 km portion of valley. Validation point 1 winds are expected to be largely influenced by the valley structure running north-west. Validation point 2 is located at the intersection between the two valleys. Validation point 2 is expected to be influenced by both valley structures.

The two validation points are approximately 6 km apart. If the CALMET predictions show that the wind patterns are influenced by the terrains, it is an indication that the model is able to simulate the wind flow along the complex terrains.

Table 9: Location of Validation Points

Description	UTM Zone 10	
	Easting (m)	Northing (m)
Validation Point 1	469,816	5,497,318
Validation Point 2	469,246	5,501,463

Figure 12 illustrates the annual wind rose generated using CALMET model results at validation point 1 for 2012. Validation point 1 is along the river in the valley north from the Project. The valley structure surrounding the validation point 1 shows that the wind is more likely to flow to and from north and south. This is consistent with the CALMET model output, and suggests that the CALMET is able to incorporate the valley structure.

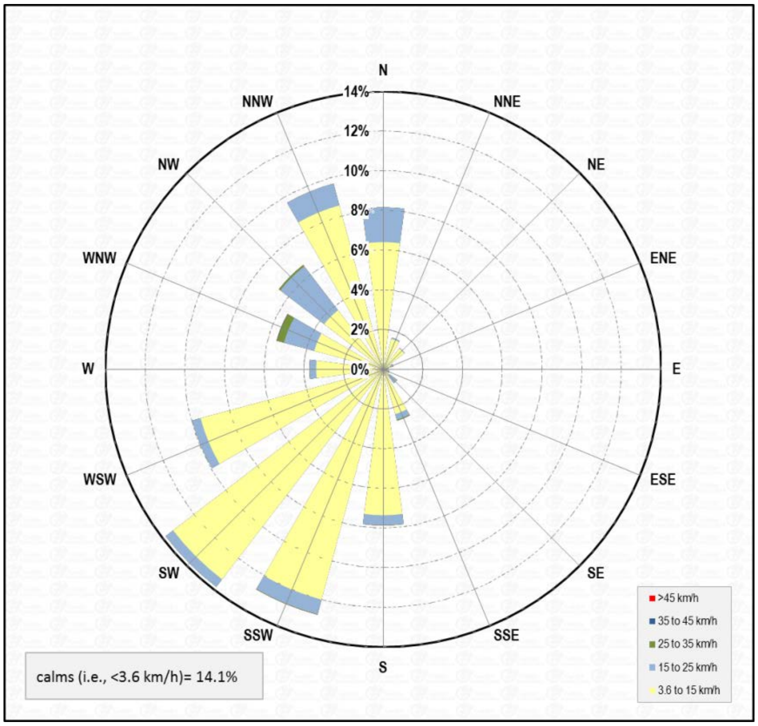


Figure 12: Wind Roses Generated Using CALMET Model Results from Validation Point 1

Figure 13 illustrates the annual wind rose generated using CALMET model results at validation point 2 for 2012. Validation point 2 is at the intersection of the two valleys (the McNab valley runs north west and the other valley runs west to east). The predominant south-east directions in the CALMET model results illustrate that the winds at validation point 2 are dominated by the winds from the valley with the north-west orientation. Figure 13 shows that wind patterns are consistent with the local terrain, and this is an indication that the model is able to incorporate the wind flow in the region surrounding the Project.

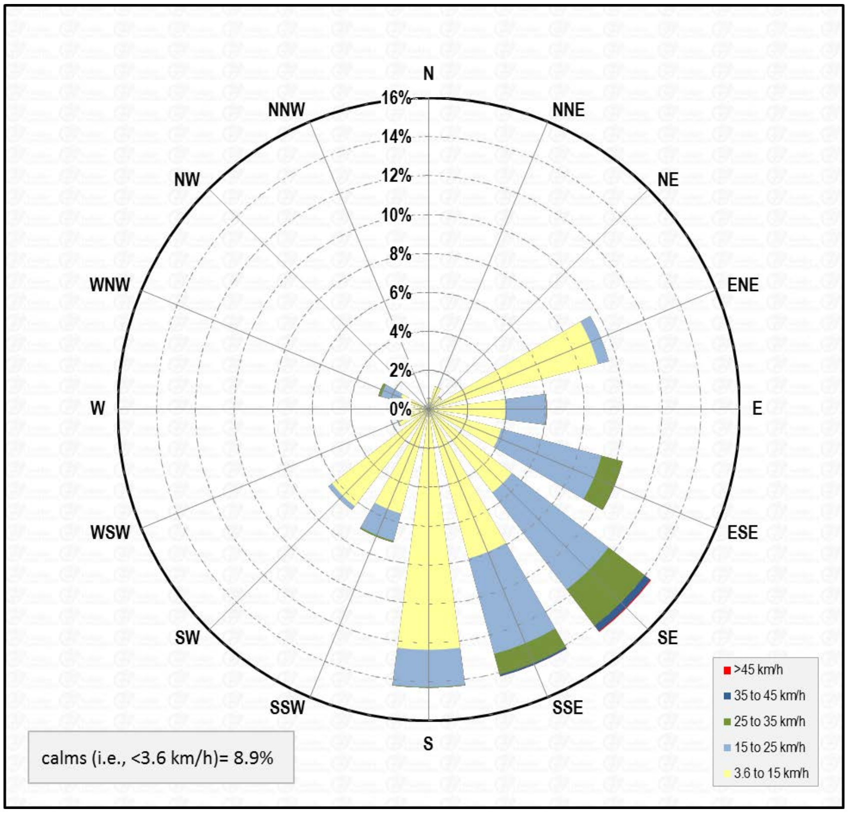


Figure 13: Wind Rose Generated Using CALMET Model Results at Validation Point 2

2.2.4.3 Atmospheric Stability

Atmospheric Stability is the measure of a parcel of air's ability to move vertically in the atmosphere. Stability is an indication of a plume's ability to disperse in the atmosphere, as the dispersion is a function of the air flow in the atmosphere. Since stability plays an important role in the air movement, CALMET generated hourly Pasquill-Gifford (P-G) stability class was analysed as a part of the CALMET model validation process. Figure 14 shows the hourly P-G stability class distribution from the Project site. Stability is largely influenced by the heating of the surface. As the figure shows, unstable classes follow a bell curve pattern where unstable conditions are more frequent in the afternoon, between 12:00 to 16:00. Unstable conditions are less frequent at dawn because the heating has just begun to provide the necessary energy for the atmospheric condition to be unstable. The solar heating peaks in the afternoon, and the warmed air remains unstable. The heating declines in the afternoon to evening, and the atmosphere starts to cool. This in turn changes the stability class from unstable to neutral to stable. At night, no solar radiation input is available and the atmospheric condition is neutral or stable. Neutral conditions are most dominant at night between 21:00 and 04:00. Figure 14 shows that the model prediction is consistent with what is expected of the stability class distribution from this region. This indicates that CALMET is predicting vertical movement as expected.

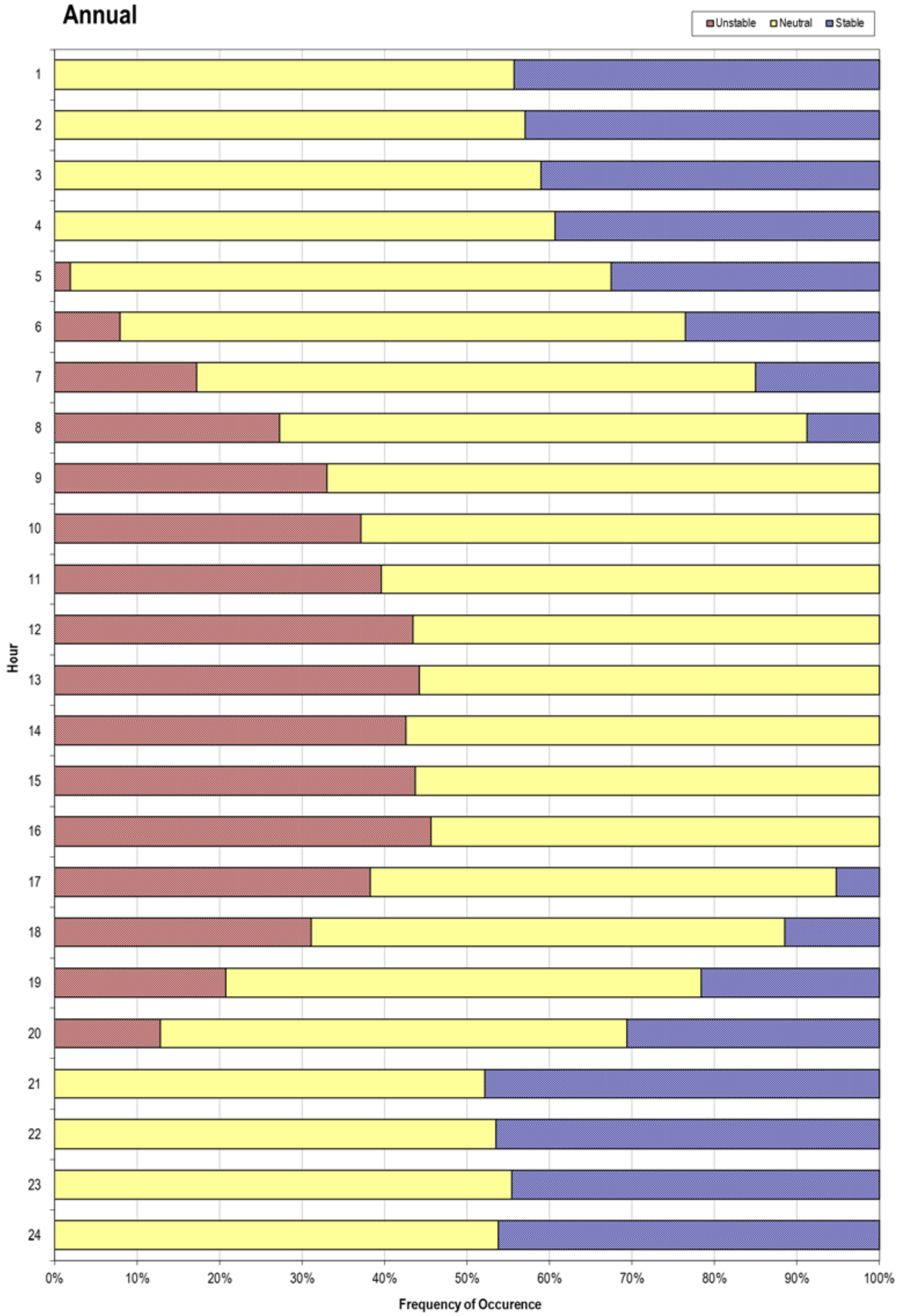


Figure 14: Hourly P-G stability class at the Project

2.2.4.4 Mixing Height

Atmospheric events are partly driven by the heating and cooling of the earth's surface. The mixing layer is an important part of the dispersion meteorology because this zone of turbulence determines the vertical movement of air and the depth of this layer, referred to as the mixing height, bounds the upper limit of the vertical movement. The depth of mixed layer is a function of factors such as the heating and cooling of surface, sinking of cooled air or surrounding terrain features. One strong driver of mixing height is the solar radiation energy. As the sun rises, the land is heated, and warm air rises, causing turbulence in air. As the day progresses, this continuous heating and the increase in intensity causes even more turbulence which expands the zone of turbulent air to expand, which also causes the mixing height to increase. The solar radiation energy peaks at around 15:00, but the heat input is still present at a weaker intensity. As the day progresses into evening, and night, the atmosphere begins to cool down, and the mixing height decreases. Therefore, the shallowest mixed depth is typically observed in the morning, right before dawn (Figure 15). This mixing height pattern described above matches the CALMET meteorological predictions.

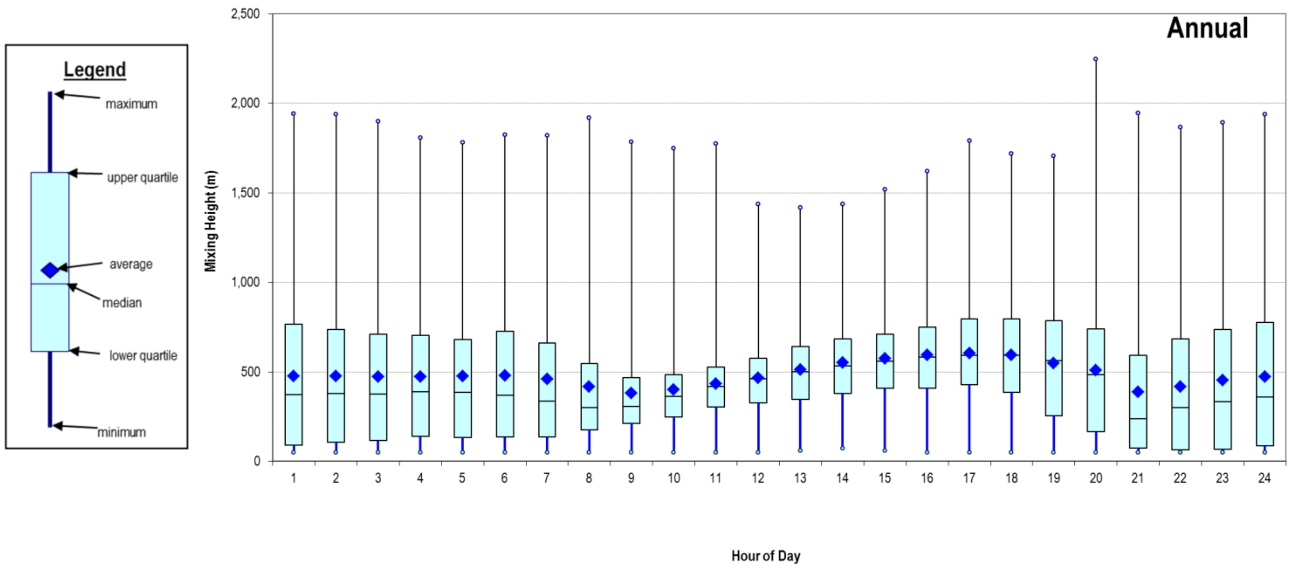


Figure 15: Hourly mixing height distribution at the Project

2.2.4.5 Wind Vectors

Stability and mixing height are indicators that help determine the vertical motion of air. Horizontal air movement is another important component in dispersion meteorology. This section discusses the horizontal wind movement (wind speed and wind direction) in the CALMET model.

2.2.4.5.1 Stable and Very Unstable Conditions

As discussed in 2.2.4.3, stability is an important meteorological indicator in determining plume dispersion potential. In stable conditions, air is stagnant and does not move vertically. In unstable conditions, air experiences acceleration in motion and can move freely vertically. Stable and unstable air is determined by the vertical temperature profile in the atmosphere. Warm air rises, and as air is lifted it cools down if the surrounding environmental temperature is colder than the lifted air. The lifted air continues to move due to the temperature difference between the lifted air and the surrounding air. This is an example of an unstable condition. Unstable condition promotes vertical movement in air, and the resulting air movement is air moving along with the terrain features such as mountain. This air flow phenomenon is referred as up-slope wind, which is often observed on an unstable day.

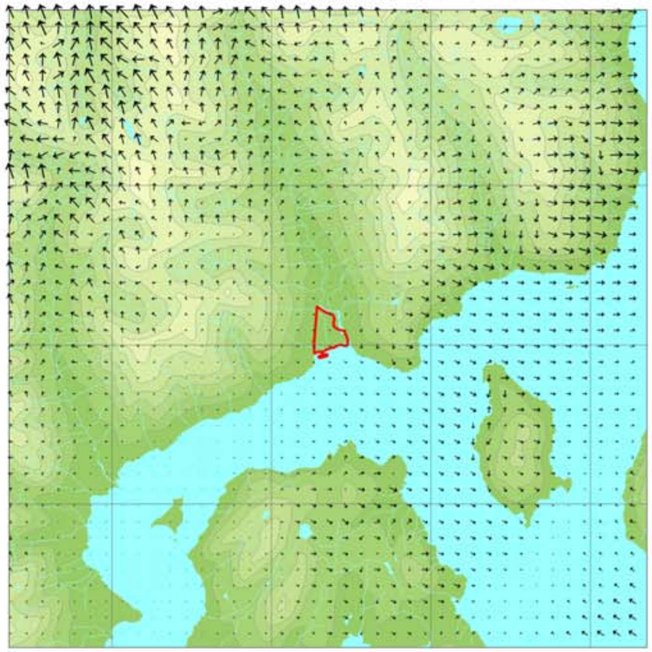
For a stable condition, the vertical environmental temperature profile is such that the surrounding air is warmer than the air in motion. The cold air (lifted air) sinks and moves back to its original position, and the result is a stagnant atmosphere. Stable conditions inhibit vertical movement in air, and if the environment is continued to cool, air becomes denser and sinks downward. The resulting air movement is driven by the sinking motion of air, along terrain features. This air flow phenomenon is referred as down-slope wind, which is often observed on a cool stable night. Therefore, stability affects the meteorological conditions, as well as the dispersion pattern, which makes it an important validation component in the model.

As a part of the CALMET validation process, wind vectors from three different heights - 10, 300, and 1,400 m - were examined. In wind vector figures arrows indicate the wind directions, while the size of the arrows is scaled according to the predicted wind speeds. The wind profile is expected to change as the height changes because terrain influences will be less. The following sections show the wind vectors extracted from CALMET domain for three consecutive hours on a stable day and an unstable day.

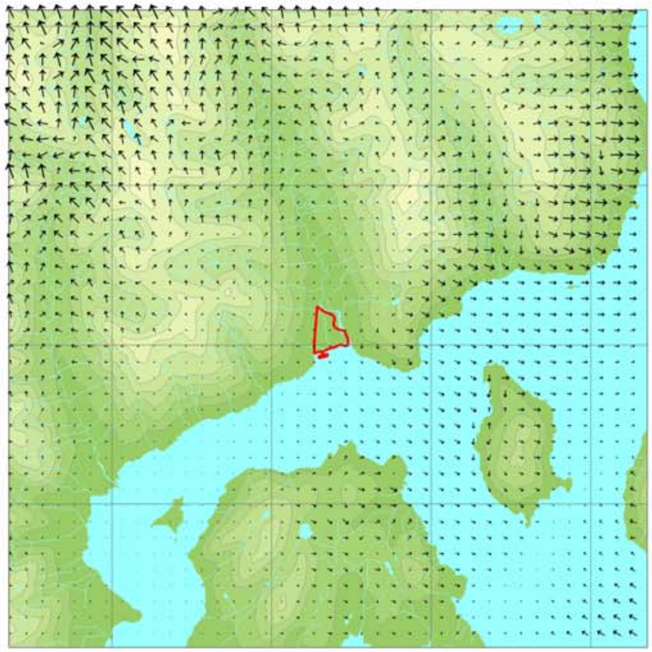
Figure 16, Figure 17 and Figure 18 show wind vector plots on a stable day for hours 05:00, 06:00 and 07:00 at 10, 300 and 1400 m heights above the ground surface.

The winds illustrated in Figure 16 (at 10 m above surface) experience drag from terrain features such as trees, buildings, or landscapes. This trend is well captured in the areas northwest and northeast of the Project location. On a stable day, the atmosphere hinders the vertical motions of air. Figure 16 shows the winds at night, which means that there is no heating by solar radiation. The atmosphere has no source of heat and as the air cools down, and cold air shrinks which results in the sinking motion in atmosphere. The resulting wind pattern is called drainage flow, where the winds flow from higher elevation to lower elevation, typically along mountains. Figure 16 shows that the wind vectors predicted are matching what is expected of the winds at these three hours for a stable day.

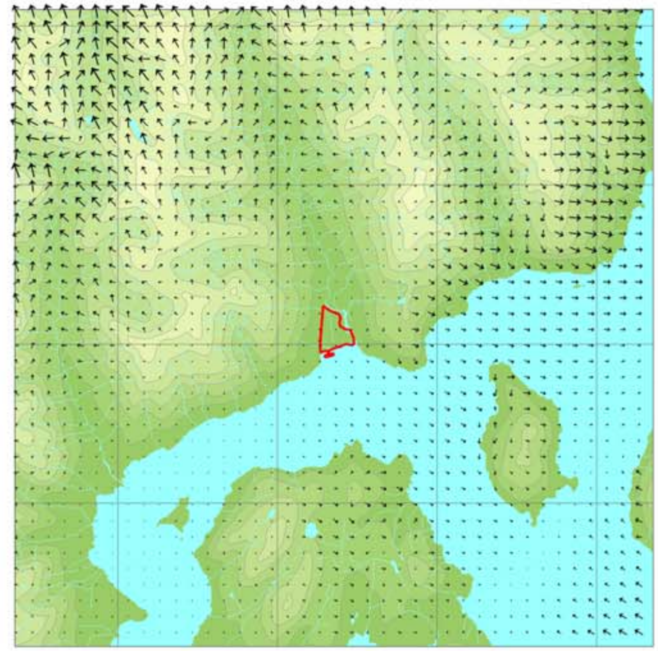
HOUR 0500 (UTC-800)



HOUR 0600 (UTC-800)



HOUR 0700 (UTC-800)



5 0 5
KILOMETERS

LEGEND

Elevations are shown at 200 m contour intervals.

BURNCO fenceline.

Wind vector range (m/s)

0.0		Minimum
2.5	↑	25%
5.0	↑	50%
7.5	↑	75%
10	↑	Maximum

N

REFERENCES

DEM provided by GeoBase
Projection: UTM Zone 10 Datum: NAD 83.

PROJECT
BURNCO ROCK PRODUCTS LTD.
BURNCO AGGREGATE PROJECT, HOWE SOUND, B.C.

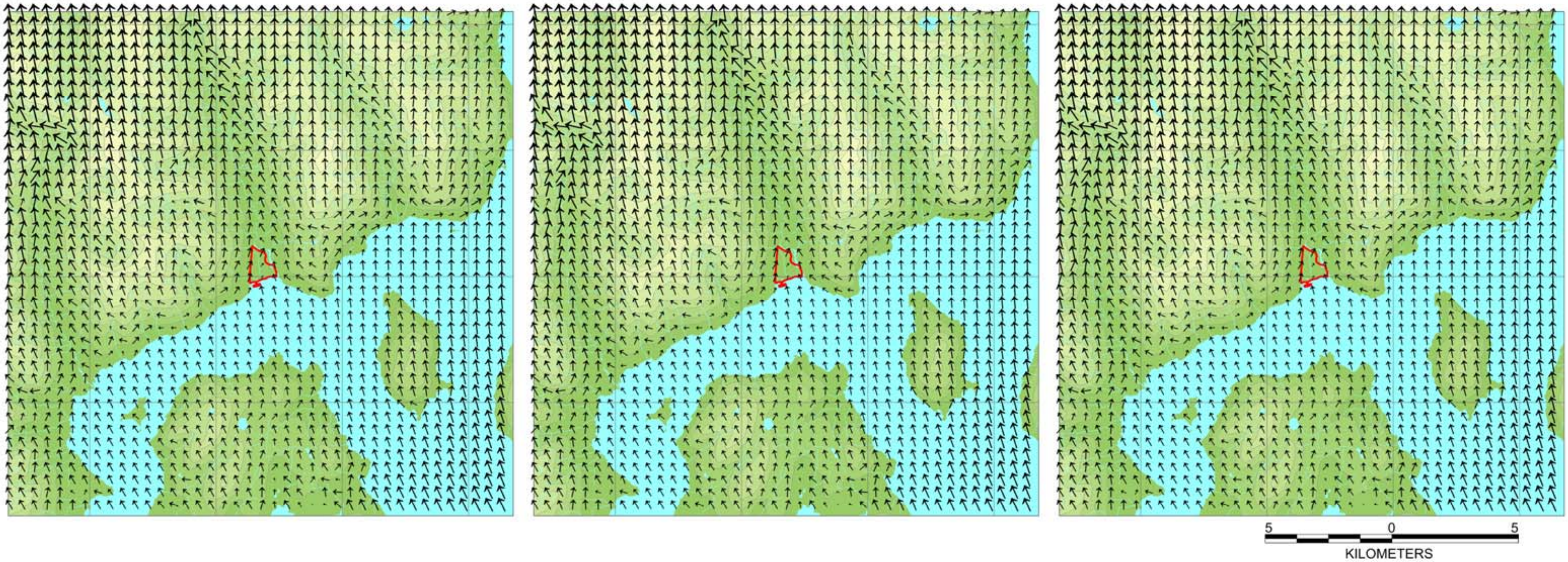
TITLE
STABLE DAY- WIND VECTOR PLOTS AT 10 M
JANUARY 8, 2012

Golder Associates

PROJECT NO. 11-1422-0046			PHASE No. 4700
DESIGN	TB	02 Aug. 13	SCALE AS SHOWN REV. 0
AIR	JR	29 Oct. 14	
CHECK	JR	23 Feb. 15	**FIGURE: 16**
REVIEW	SC	27 Feb. 15	

Figure 17 shows the wind vectors at 300 m from a stable day. When compared to Figure 16, the wind directions are different from what was predicted at 10 m; however, drainage flows are still evident in the wind patterns. Wind profiles undergo directional change as the height increases due to veering or backing. This is especially true on a stable night. Another thing to note is that wind shear is more dominant where there is a sudden change of terrain feature. This is shown quite well, as the winds above water undergo more drastic change than overland when compared to the surface wind vectors.

HOUR 0500 (UTC-800) | HOUR 0600 (UTC-800) | HOUR 0700 (UTC-800)



LEGEND

Elevations are shown at 200 m contour intervals.

BURNCO fenceline.

Wind vector range (m/s)

0.0		Minimum
2.5	↑	25%
5.0	↑	50%
7.5	↑	75%
10	↑	Maximum

REFERENCES

DEM provided by GeoBase
Projection: UTM Zone 10 Datum: NAD 83.

PROJECT
BURNCO ROCK PRODUCTS LTD.
BURNCO AGGREGATE PROJECT, HOWE SOUND, B.C.

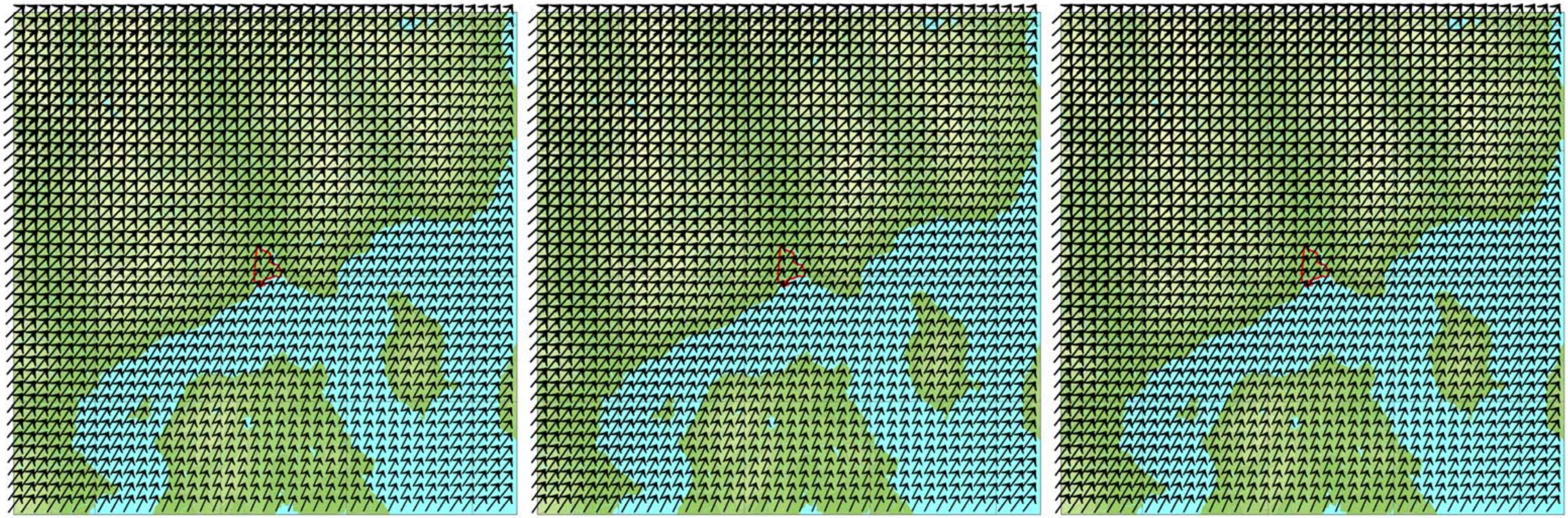
TITLE
STABLE DAY- WIND VECTOR PLOTS AT 300 M
JANUARY 8, 2012

Golder Associates				
PROJECT NO.11-1422-0046			PHASE No.4700	
DESIGN	TB	02 Aug. 13	SCALE AS SHOWN	REV. 0
AIR	JR	29 Oct. 14	**FIGURE: 17**	
CHECK	JR	23 Feb. 15		
REVIEW	SC	27 Feb. 15		

\\bur1-d-filesrv1\Active_2011\1422\11-1422-0046\Phase 4700\06 Data\Modelling\CALMET\Local Domain\prmet\08JAN2012_stable\Fig 17-300m 08JAN2012.srf

Figure 18 shows the wind vectors at 1,400 m in height. The wind vectors at 1,400 m are expected to be uniform, as this altitude is typically expected to be above the mixing layer, as seen in Figure 15. Beyond the mixing layer, the winds are flowing in the layer without turbulence, which results in uniform wind field. This is referred as the free atmosphere. In the free atmosphere, no turbulence is expected. The wind vectors as illustrated in Figure 18 are visibly different than those in the previous two figures. Wind vectors in Figure 18 show a uniform flow, where there is little to no change in wind direction or wind speed in the entire modelling domain.

HOUR 0500 (UTC-800) | HOUR 0600 (UTC-800) | HOUR 0700 (UTC-800)



5 0 5
KILOMETERS

LEGEND

Elevations are shown at 200 m contour intervals.

BURNCO fenceline.

Wind vector range (m/s)

0.0		Minimum
2.5	↑	25%
5.0	↑	50%
7.5	↑	75%
10	↑	Maximum

REFERENCES

DEM provided by GeoBase
Projection: UTM Zone 10 Datum: NAD 83.

PROJECT
BURNCO ROCK PRODUCTS LTD.
BURNCO AGGREGATE PROJECT, HOWE SOUND, B.C.

TITLE
STABLE DAY- WIND VECTOR PLOTS AT 1400 M
JANUARY 8, 2012

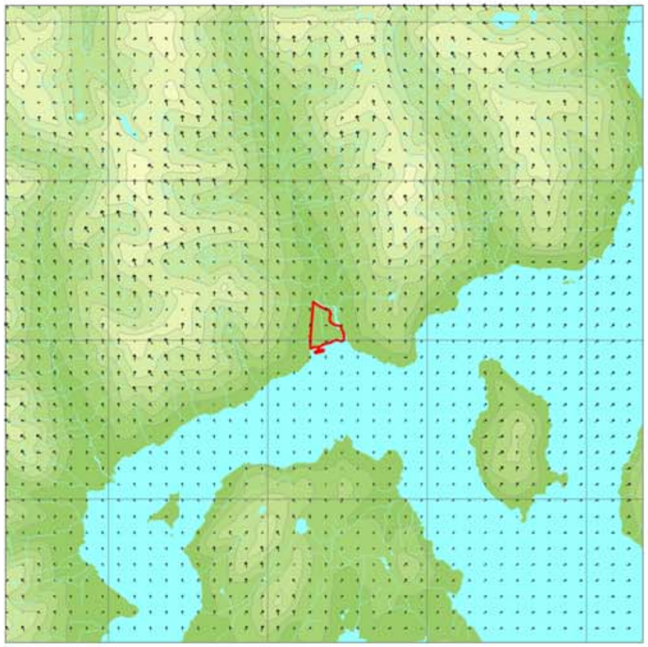
Golder Associates

PROJECT NO. 11-1422-0046			PHASE No. 4700	
DESIGN	TB	02 Aug. 13	SCALE AS SHOWN	REV. 0
AIR	JR	29 Oct. 14	**FIGURE: 18**	
CHECK	JR	23 Feb. 15		
REVIEW	SC	27 Feb. 15		

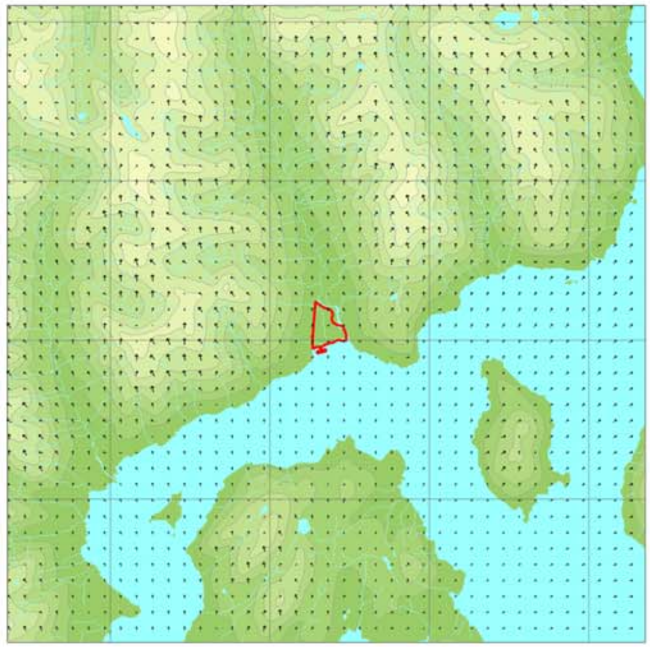
Figure 19, Figure 20 and Figure 21 show wind vector plots for an unstable day for 11:00, 12:00 and 13:00 hours and at the 10, 300, and 1400 m in heights above the ground surface.

Wind flow for an unstable day is expected to move towards the mountains. This phenomenon is caused by the heating of surface, and warm air expands, which reduces the density, resulting in an upward motion along a slope or a mountain side. This trend is well captured in Figure 19, which illustrates wind vectors at 10 m, where the winds are flowing along and up the mountains and valleys. An important aspect of this phenomenon is that wind accelerates as it goes along the slope (Arya 1999).

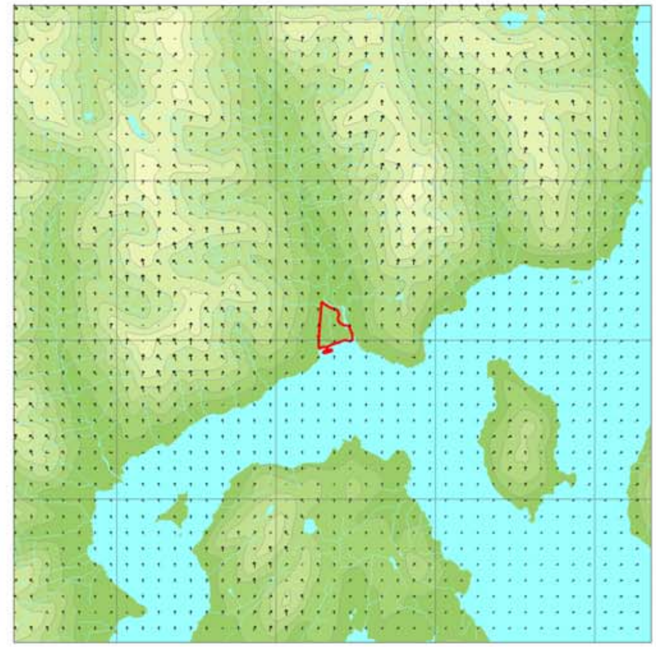
HOUR 1100 (UTC-800)



HOUR 1200 (UTC-800)



HOUR 1300 (UTC-800)



5 0 5

KILOMETERS

LEGEND

Elevations are shown at 200 m contour intervals.

BURNCO fenceline.

Wind vector range (m/s)

0.0		Minimum
2.5	↑	25%
5.0	↑	50%
7.5	↑	75%
10	↑	Maximum

N

REFERENCES

DEM provided by GeoBase
Projection: UTM Zone 10 Datum: NAD 83.

PROJECT

BURNCO ROCK PRODUCTS LTD.
BURNCO AGGREGATE PROJECT, HOWE SOUND, B.C.

TITLE

UNSTABLE DAY- WIND VECTOR PLOTS AT 10 M
AUGUST 4, 2012

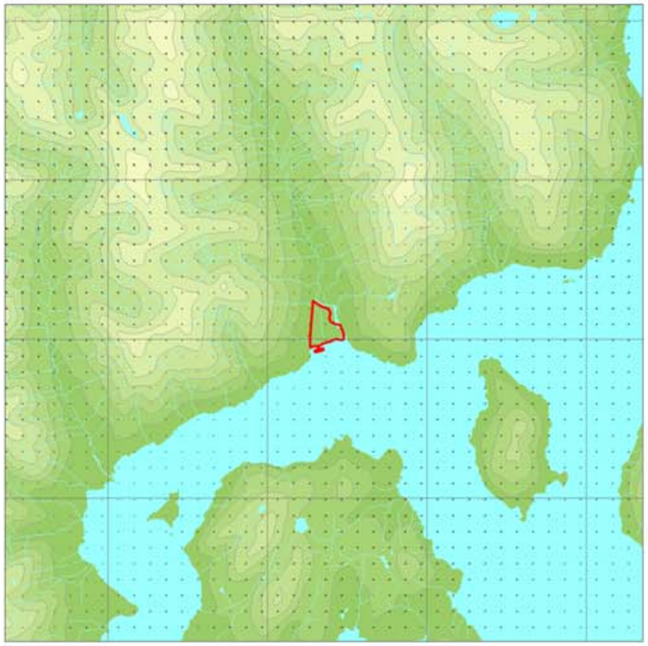
Golder Associates

PROJECT NO. 11-1422-0046			PHASE No. 4700	
DESIGN	TB	02 Aug. 13	SCALE AS SHOWN	REV. 0
AIR	JR	29 Oct. 14	**FIGURE: 19**	
CHECK	JR	23 Feb. 15		
REVIEW	SC	27 Feb. 15		

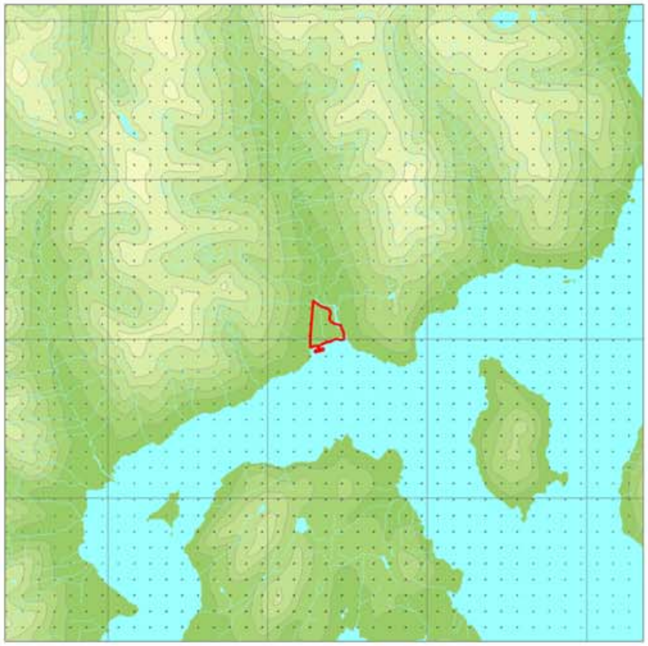
\\bur1-d-filesrv1\Active_2011\1422\11-1422-0046\Phase 4700\06 Data\Modelling\CALMET\Local Domain\prmet\04AUG2012_unstable\Fig 19-10m 04AUG2012.srf

Figure 20 shows wind vectors from an unstable day for three consecutive hours at 300 m. The wind vectors at this height, for an unstable condition, are expected to be similar as the winds from surface (10 m); in an upslope wind, there is less acceleration of wind as the altitude increases (Arya 1999). Figure 20 shows that CALMET is simulating this trend well, as the overland wind directions are similar to that of Figure 19, with lower wind speeds.

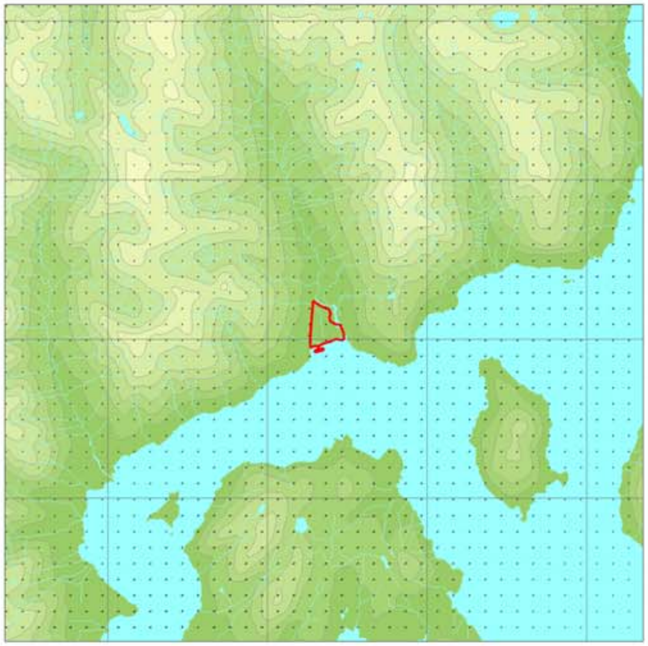
HOUR 1100 (UTC-800)

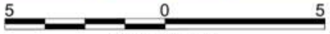


HOUR 1200 (UTC-800)



HOUR 1300 (UTC-800)





LEGEND

Elevations are shown at 200 m contour intervals.

BURNCO fenceline.

Wind vector range (m/s)

(m/s)		
0.0		Minimum
2.5	↑	25%
5.0	↑	50%
7.5	↑	75%
10	↑	Maximum

REFERENCES

DEM provided by GeoBase
Projection: UTM Zone 10 Datum: NAD 83.

PROJECT
BURNCO ROCK PRODUCTS LTD.
BURNCO AGGREGATE PROJECT, HOWE SOUND, B.C.

TITLE
UNSTABLE DAY- WIND VECTOR PLOTS AT 300 M
AUGUST 4, 2012

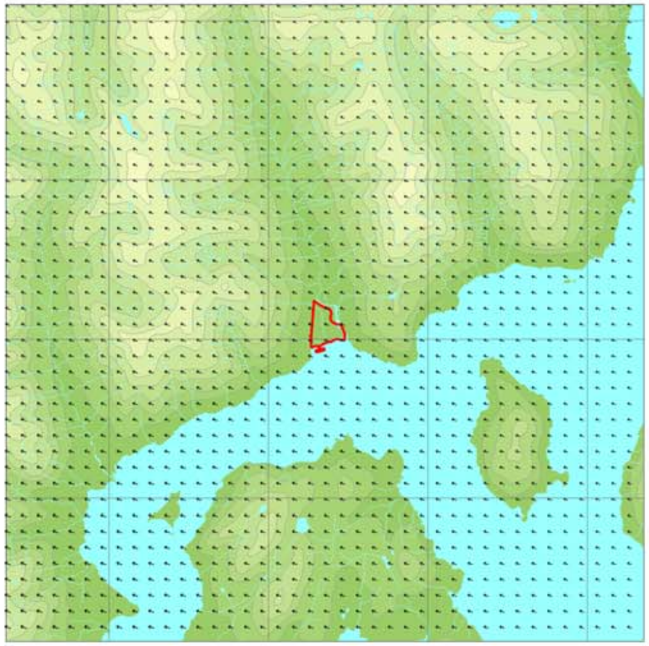
Golder Associates

PROJECT NO. 11-1422-0046			PHASE No. 4700	
DESIGN	TB	02 Aug. 13	SCALE AS SHOWN	REV. 0
AIR	JR	29 Oct. 14	**FIGURE: 20**	
CHECK	JR	23 Feb. 15		
REVIEW	SC	27 Feb. 15		

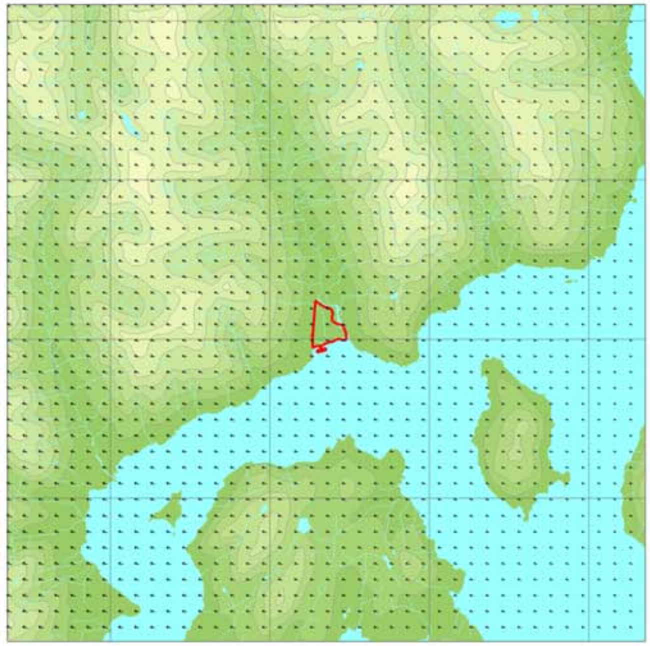
\\bur1-d-filesrv1\Active_2011\1422\11-1422-0046\Phase 4700\06 Data\Modeling\CALMET\Local Domain\prmet\04AUG2012_unstable\Fig 20-300m 04AUG2012.srf

Figure 21 shows the wind vectors for three consecutive hours at 1,400 m. The wind flow at this altitude is expected to be uniform, with little variations in wind direction and wind speed. The figure shows that the change in wind direction and speed.

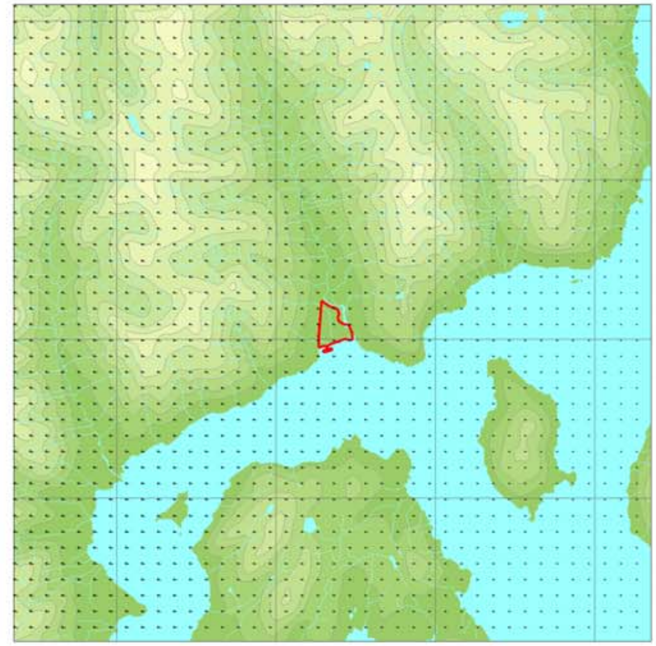
HOUR 1100 (UTC-800)



HOUR 1200 (UTC-800)



HOUR 1300 (UTC-800)



LEGEND

Elevations are shown at 200 m contour intervals.

BURNCO fenceline.

Wind vector range (m/s)

0.0	Minimum
2.5	25%
5.0	50%
7.5	75%
10	Maximum

REFERENCES

DEM provided by GeoBase
Projection: UTM Zone 10 Datum: NAD 83.

PROJECT
BURNCO ROCK PRODUCTS LTD.
BURNCO AGGREGATE PROJECT, HOWE SOUND, B.C.

TITLE
UNSTABLE DAY- WIND VECTOR PLOTS AT 1400 M
AUGUST 4, 2012

PROJECT NO. 11-1422-0046			PHASE No. 4700
DESIGN	TB	02 Aug. 13	SCALE AS SHOWN / REV. 0
AIR	JR	29 Oct. 14	**FIGURE: 21**
CHECK	JR	23 Feb. 15	
REVIEW	SC	27 Feb. 15	

Golder Associates

\\bur1-d-filesrv1\Active_2011\1422\11-1422-0046\Phase 4700\06 Data\Modelling\CALMET\Local Domain\prmet\04AUG2012_unstable\Fig 21-1400m 04AUG2012.srf

The six wind vector figures, Figure 16 to Figure 21, indicate that the winds are in general showing what is expected of the winds for both stable and unstable conditions.

2.2.4.5.2 Land and Sea Breeze

In addition to examining the wind vectors for stable and unstable conditions at different heights and over three consecutive hours, wind vectors during land breeze and sea breeze conditions were examined. As a part of the land breeze and sea breeze analysis, wind vectors at early morning times and wind vectors in the summer afternoon were extracted from nested CALMET domain. Winds at early hours are expected to show land breeze while winds in the summer afternoon are expected to show sea breeze.

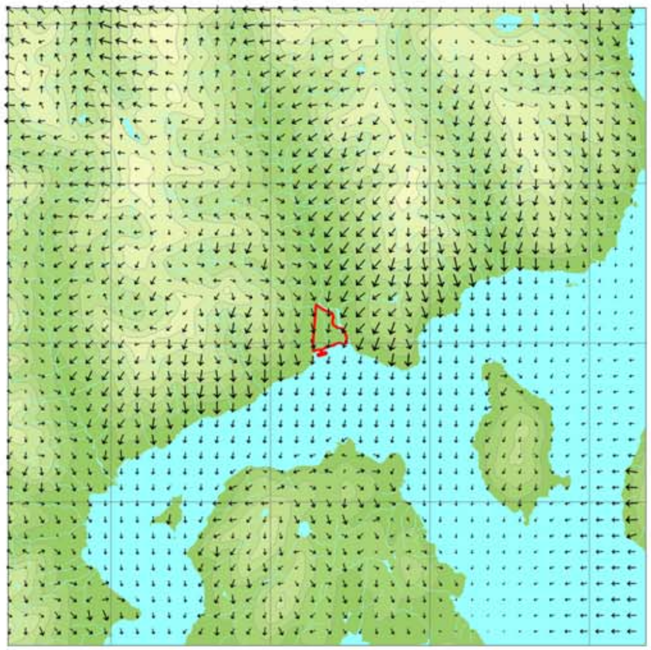
Land breeze is a phenomenon where the wind flows from land to sea. This is caused by the difference in heat conductivity in soil and water. Soil requires less energy to warm up than water, similarly, when the incoming solar radiation is not present, soil cools down faster than water. Therefore, during the day, land is warmer than water, and during at night, land is cooler than water. In land breeze, because air is warmer over water, there’s an upward air movement over water. Air lifted over water eventually cools, then flows away and sinks on land. Because air is being removed due to heating, the atmosphere tries to balance itself and wind flows from land to sea.

Sea breeze is the opposite of land breeze, where the wind flows from sea to land. Sea breeze occurs when radiative heating is present. When strong radiative heating is present, air over land is warmed, and warm air rises. As air is lifted, it starts to cool down and starts to move away and starts to sink. Because the air over land is being removed, the atmosphere tries to balance itself and the wind flows from sea to land.

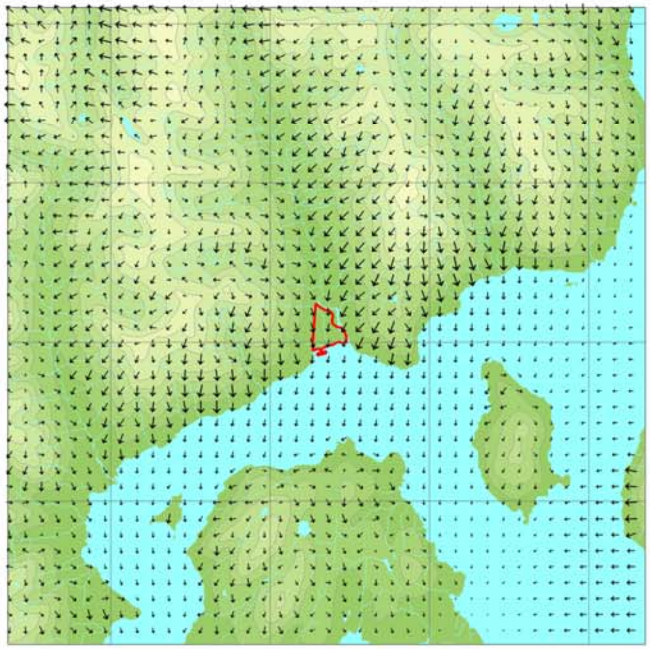
Figure 22 shows the wind vectors at surface during land breeze. The winds were extracted from CALMET model in the morning during the winter time for three consecutive hours. During land breeze, the winds are expected to flow from land to water. As seen in the figure, the winds are behaving as expected during this period.

//bur1-d-filesrv1/Active/_2011/1422/11-1422-0046/Phase 4700/06 Data/Modelling/CALMET/Local Domain/prmet/land_breeze_4FEB12/Fig 22-10 m land breeze 4FEB12.srf

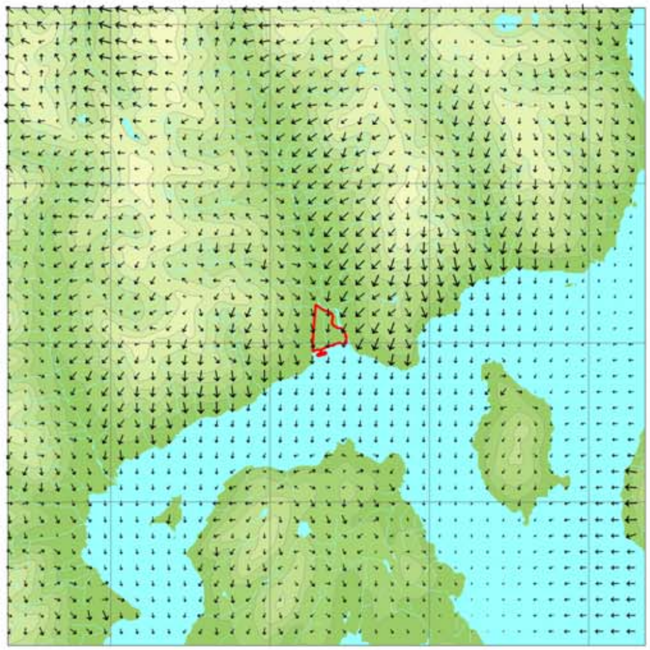
HOUR 0400 (UTC-800)



HOUR 0500 (UTC-800)



HOUR 0600 (UTC-800)



5 0 5
KILOMETERS

LEGEND

Elevations are shown at 200 m contour intervals.

BURNCO fenceline.

Wind vector range (m/s)

0.0		Minimum
2.5	↑	25%
5.0	↑	50%
7.5	↑	75%
10	↑	Maximum

REFERENCES

DEM provided by GeoBase
Projection: UTM Zone 10 Datum: NAD 83.

PROJECT

BURNCO ROCK PRODUCTS LTD.
BURNCO AGGREGATE PROJECT, HOWE SOUND, B.C.

TITLE

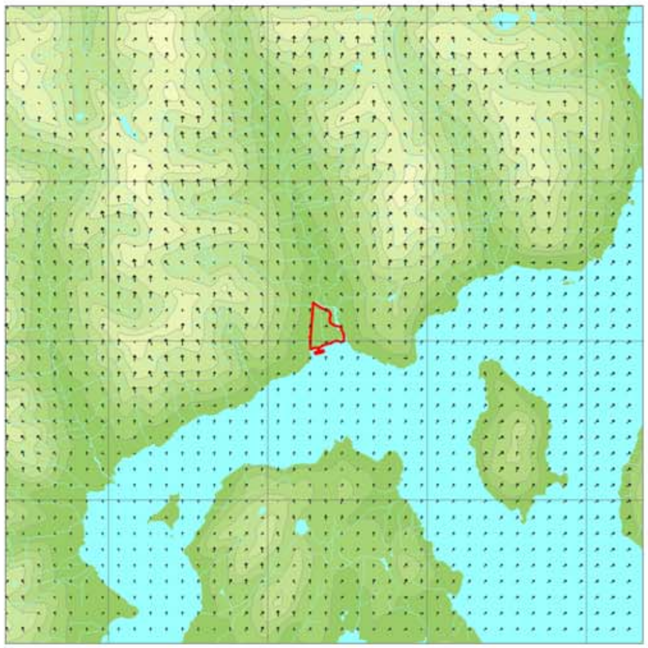
LAND BREEZE- WIND VECTOR PLOTS AT 10 M
FEBRUARY 4, 2012

Golder Associates

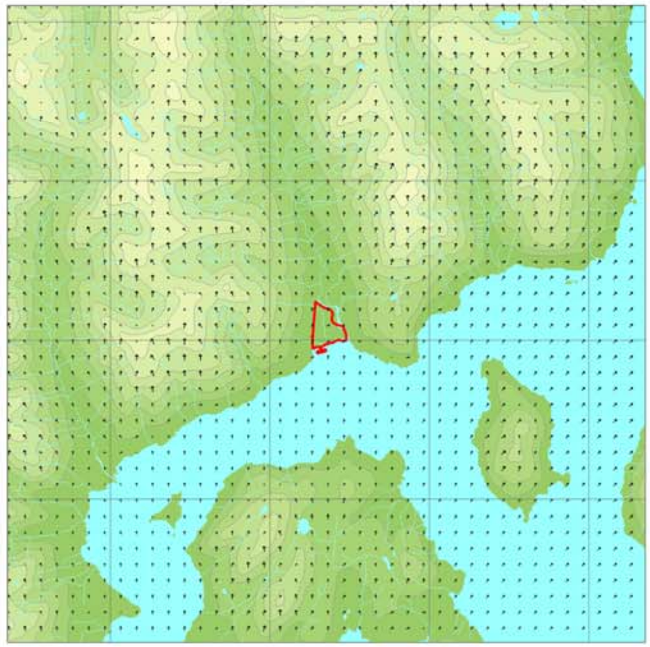
PROJECT NO.11-1422-0046			PHASE No.4700	
DESIGN	TB	02 Aug. 13	SCALE AS SHOWN	REV. 0
AIR	JR	29 Oct. 14	**FIGURE: 22**	
CHECK	JR	23 Feb. 15		
REVIEW	SC	27 Feb. 15		

Figure 23 shows wind vectors at surface during sea breeze. Wind vectors were extracted from the nested CALMT domain. Figure 23 shows wind vectors over three consecutive hours for a summer day. The figure shows that the winds are flowing from over water to land during these hours; this is consistent with what is expected. Therefore, Figure 23 indicates that the CALMET is able to simulate this phenomenon correctly.

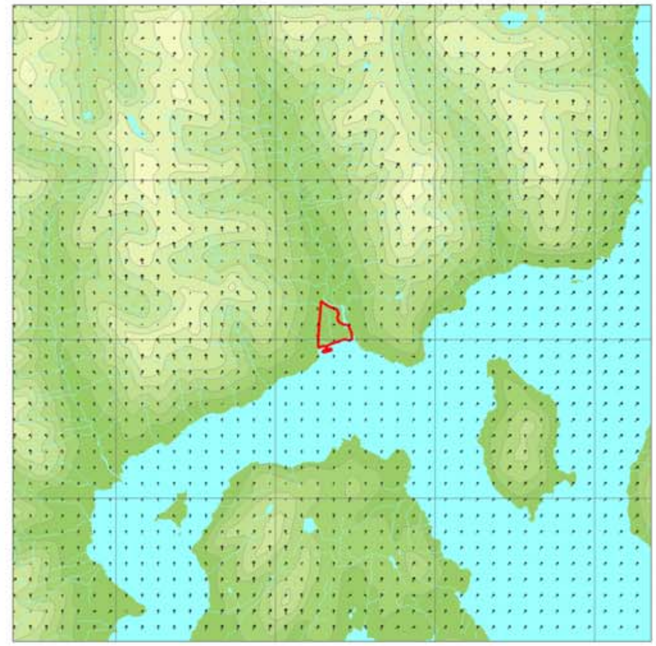
HOUR 1500 (UTC-800)



HOUR 1600 (UTC-800)



HOUR 1700 (UTC-800)



5 0 5
KILOMETERS

LEGEND

Elevations are shown at 200 m contour intervals.

BURNCO fenceline.

Wind vector range (m/s)

0.0	Minimum
2.5	25%
5.0	50%
7.5	75%
10	Maximum

REFERENCES

DEM provided by GeoBase
Projection: UTM Zone 10 Datum: NAD 83.

PROJECT

BURNCO ROCK PRODUCTS LTD.
BURNCO AGGREGATE PROJECT, HOWE SOUND, B.C.

TITLE

SEA BREEZE- WIND VECTOR PLOTS AT 10 M
JULY 19, 2012

Golder Associates

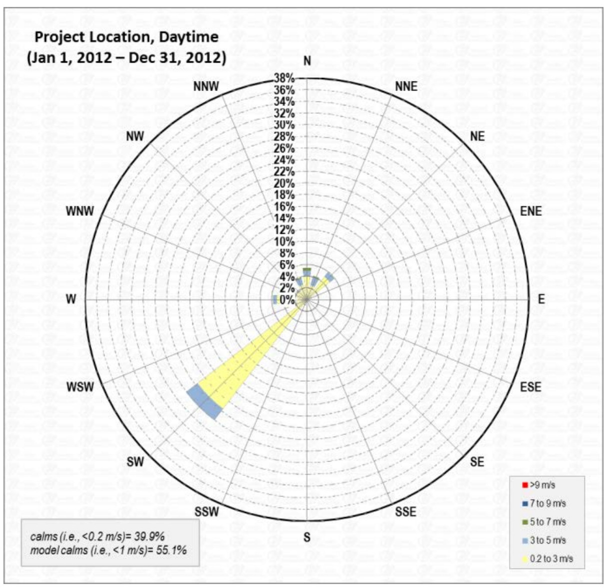
PROJECT NO. 11-1422-0046			PHASE No. 4700	
DESIGN	TB	02 Aug. 13	SCALE AS SHOWN	REV. 0
AIR	JR	29 Oct. 14	**FIGURE: 23**	
CHECK	JR	23 Feb. 15		
REVIEW	SC	27 Feb. 15		

As illustrated in Figure 22 and Figure 23 the CALMET is predicting the land breeze and sea breeze as expected.

2.2.4.6 Diurnal Wind Patterns at Project Site

The Project is located at the mouth of a valley bordered by the Howe Sound to the south; therefore, it is expected that the Project would be affected by land and sea breeze and subsequently have a diurnal variation in wind patterns. This section outlines the diurnal wind analysis undertaken on CALMET predictions on an annual and seasonal basis.

Figure 24 illustrates the daytime and the nighttime wind roses, on an annual basis for the Project location. As discussed in Section 2.2.4.5.1, the winds are generally expected to flow from land to sea at night and sea to land during the day. As seen from the Figure 24 (night time), there is strong northerly wind, which is expected of wind pattern at this location. The daily wind dominance of south-west winds is most likely a product of the terrain feature to the west of the Project. During the day northerly winds are less frequent which is consistent with typical sea breeze. The south-westerly winds during the day are likely the result of sea breeze. At night, land breeze becomes more apparent, and is shown as the northerly wind in Figure 24.



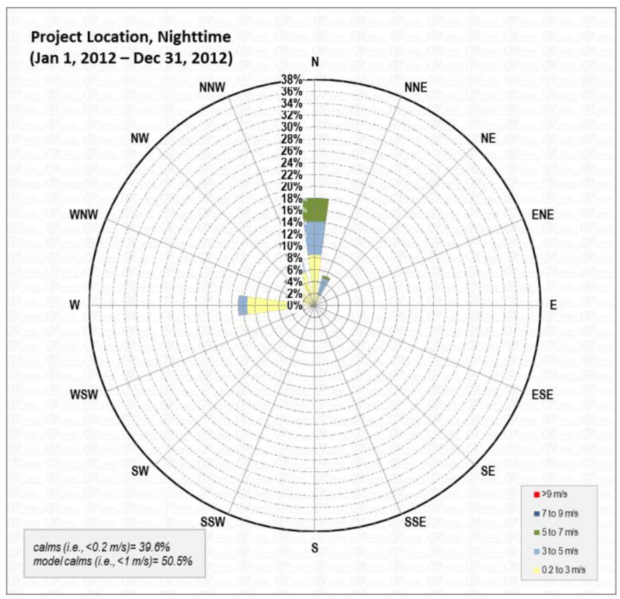


Figure 24: Diurnal Windrose Annual

Figure 25 illustrates CALMET's hourly daytime and nighttime wind roses during the foliage season (May to September) for the Project location. Figure 25 shows a similar diurnal trend as observed in Figure 24. The differences between Figure 24 and Figure 25 include that for daytime winds there are more south-westerly flow and for nighttime winds there is a greater dominance of westerly winds and north-north westerly flows.

From May to September, during the day, it is expected that there would be more unstable days as a result of radiative heating. The resulting wind flow is expected to be dominated by sea breeze, as well as the wind patterns bound by the terrain features surrounding the Project.

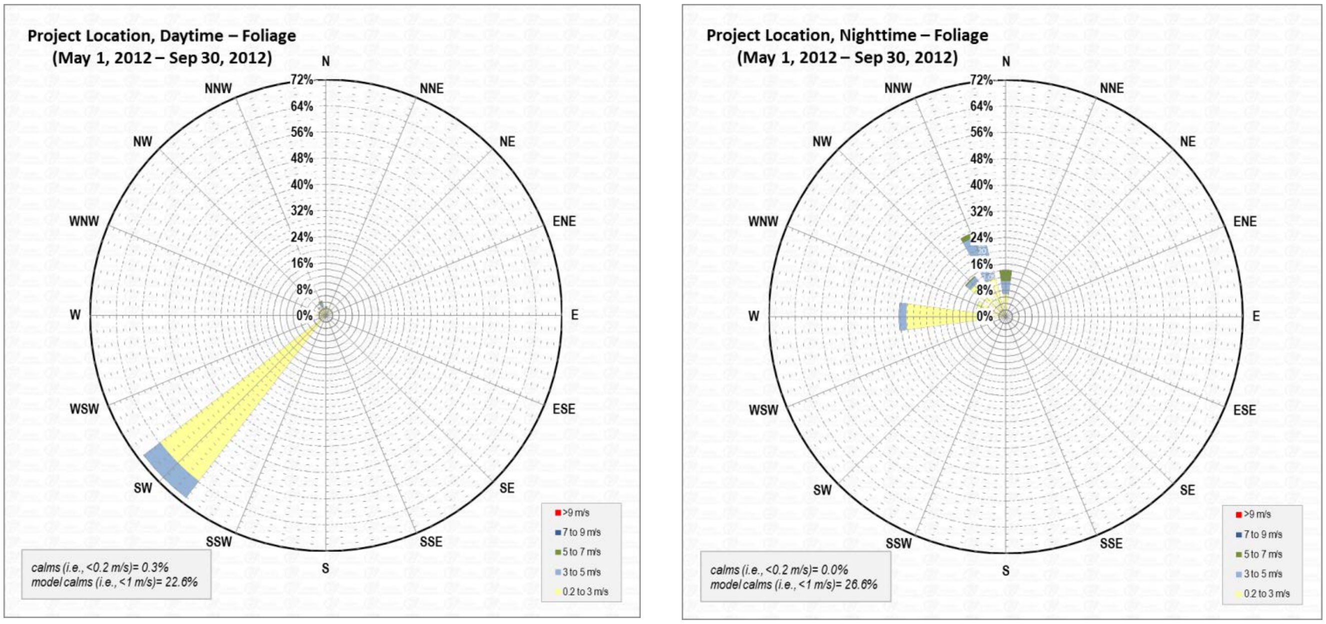


Figure 25: Diurnal Windrose – Foliage Season

Figure 26 illustrates the day and nighttime wind roses during the non-foliage season (January to April and October to December). Compared to the foliage season, the non-foliage season experiences less radiative heating; overall, it is expected that stable days occur more often in the non-foliage season than the foliage season. In stable conditions, drainage flow is expected to occur. Figure 26 shows that northerly winds are present in both day and nighttime wind roses, but is more dominant at night. Also note that the northerly wind in Figure 26 at night is more dominant compared to the foliage season in Figure 25 at night. It is expected that more stable nights occur during the non-foliage season than in the foliage season. Therefore, more land breeze is expected to occur during the non-foliage season and the difference in the night time wind pattern in Figure 25 and Figure 26 suggest that this is the case.

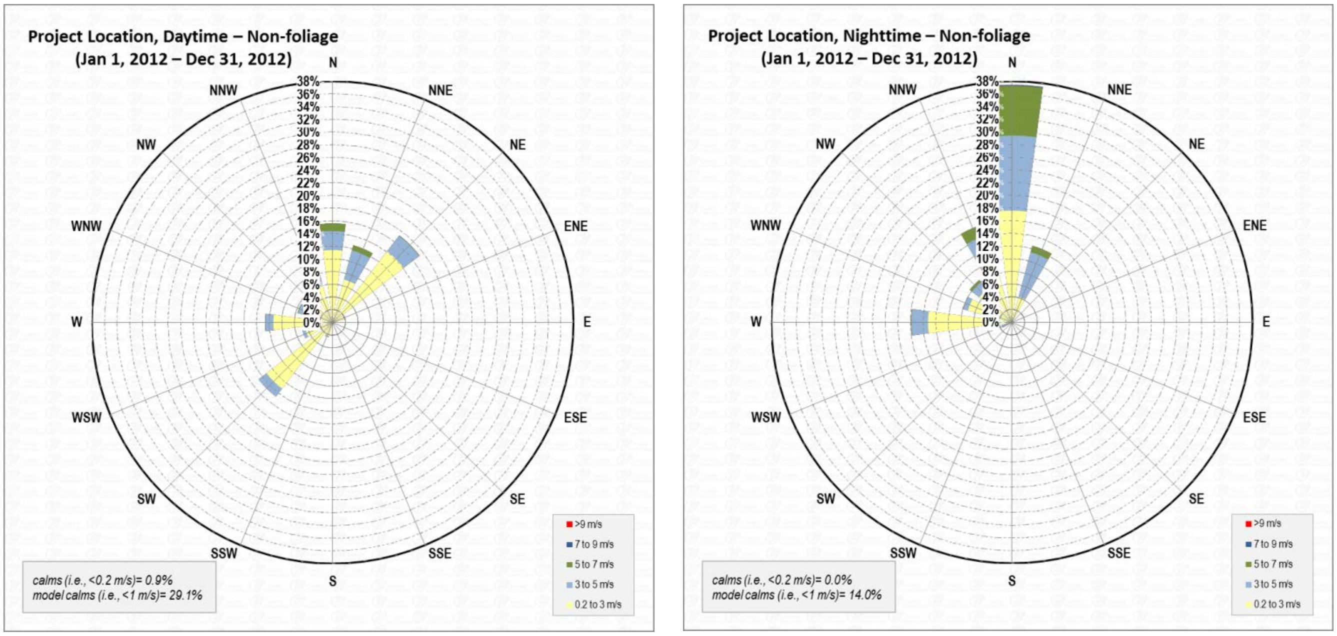


Figure 26: Diurnal Windrose – Non-foliage Season

2.2.5 Seasonal Temperature Patterns at Project Site

The Project is located at the mouth of a valley bordered by the Howe Sound to the south; therefore it is expected that the Project ambient temperature would be reflective of heating and cooling of the land water interface which drives land and sea breeze. This section outlines the hourly temperature analysis undertaken on CALMET predictions on an annual and seasonal basis.

Figure 27 illustrates hourly plots of temperature an annual basis for the Project location. As expected the daytime temperatures are generally higher due to heating from the sun.

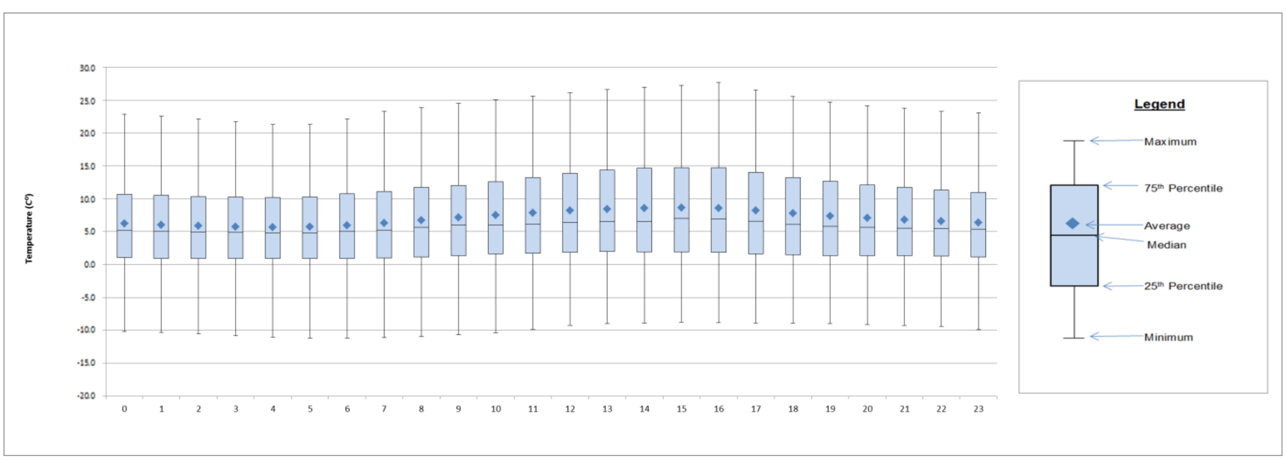


Figure 27: Hourly Temperature Annually

Figure 28 illustrates CALMET's hourly temperatures during the foliage season (May to September) for the Project location. Figure 28 shows a similar but more predominant diurnal trend as observed in Figure 27. The differences between Figure 27 and Figure 28 include higher daytime temperature observations.

From May to September, during the day, it is expected that there would be warmer days as a result of radiative heating; this is observed in Figure 28.

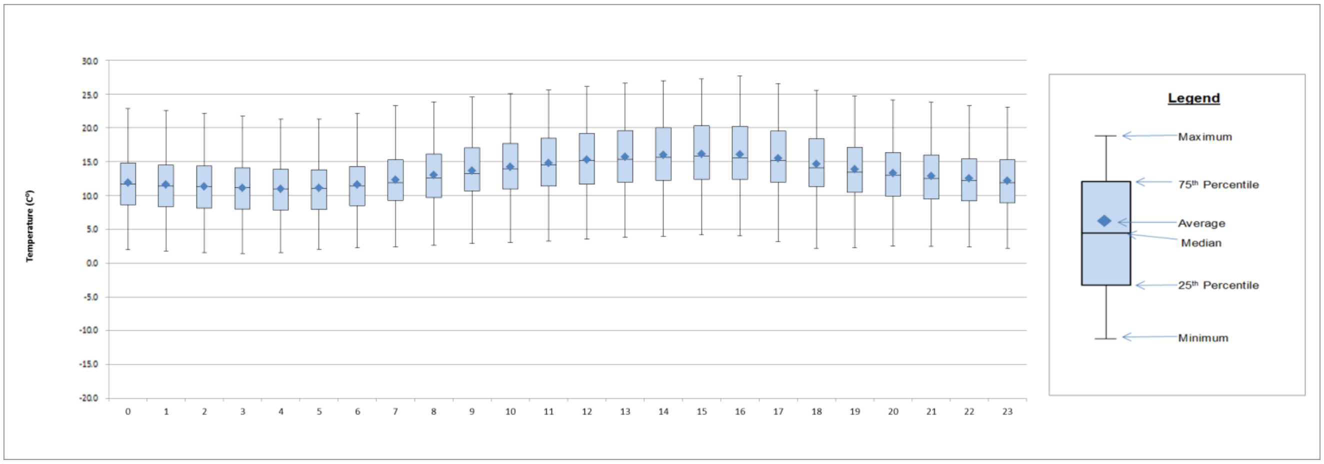


Figure 28: Hourly Temperature- Foliage Season

Figure 29 illustrates CALMET's hourly temperatures during the non-foliage season (January to April and October to December). Compared to the foliage season, the non-foliage season will experience less radiative heating. Overall, it is expected that hourly temperatures would be lower during the daytime; this is observed in the generally flat temperature distribution in Figure 29.

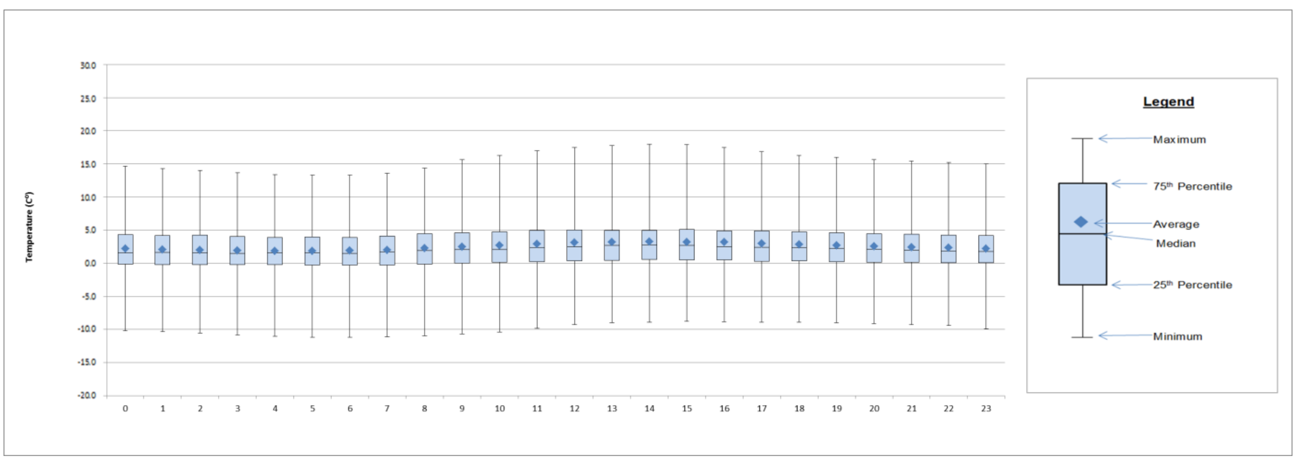


Figure 29: Hourly Temperature- Non-foliage Season

3.0 CONCLUSIONS

The air quality effects associated with the Project were assessed using CALPUFF an air dispersion model. The Project is surrounded by rugged and varied topography, and is bordered by a large water body to the south which also occupies much of the study area. Furthermore, no meteorological stations were located in the same valley of the Project and because of the complex terrain the meteorological conditions between neighbouring valleys are expected to be different. Due to the complex terrain and the land water interface and due to the lack of representative monitored meteorological data CALPUFF was executed in 3D mode with no-observations.

A CALMET meteorological data set for the 2012 calendar year was developed for the air quality assessment. The mesoscale meteorological data that was input into CALMET was generated by MM5. The prognostic MM5 data was validated using observed meteorological data at Squamish Airport to assess if it was representative of the region. The resulting CALMET meteorological dataset has been demonstrated to be reasonable compared to the meteorological monitoring station records at Port Mellon. These data (MM5 and CALMET) are therefore well-suited for the dispersion modelling assessment of the mine site area.

REFERENCES

Arya, S.P. 1999. Air Pollution Meteorology and Dispersion. New York, Oxford. Oxford University Press.

BC MoE (British Columbia Ministry of Environment). 2008. Guidelines for Air Quality Dispersion Modelling in British Columbia. Environmental Protection Division Environmental Quality Branch Air Protection Section.

Canada Centre for Remote Sensing (CCRS), Earth Sciences Sector, Natural Resources Canada (NRC), ESS Program: Understanding Canada from Space (UCS). 2008. Land Cover Map of Canada 2005. Available at: ftp://ftp.ccrs.nrcan.gc.ca/ad/NLCCLandCover/LandcoverCanada2005_250m/. Accessed April 24, 2014.

Environment Canada. 2014. Environment Canada Historical Climate Data Website. Available at: http://climate.weather.gc.ca/index_e.html#access. Accessed June 18, 2014.

Government of Canada, NRC, Earth Sciences Sector, Mapping Information Branch, Centre for Topographic Information – Ottawa 1999. Canadian Digital Elevation Data – 092G, VANCOUVER. Available at: http://www.geobase.ca/geobase/en/browse.do?produit=cded&decoupage=250k&map=092. Accessed April 24, 2014.

NRC (Natural Resources Canada), Earth Sciences Sector, Canada Centre for Remote Sensing. 2004. Canada Wide Leaf Area Index from SPOT-VEGETATION. Available at: http://ftp2.cits.rncan.gc.ca/pub/geott/eo_imagery/collections/SPOTVGT_LAI/. Accessed April 24, 2014.

Scire, J., F. Robe, M. Fernau, and R. Yamartino. 2000. A User's Guide for the CALMET Meteorological Model, Version 5. Concord, MA. USA.

\\golder.gds\gal\burnaby\final\2011\1422\11-1422-0046\1114220046-566-r-rev0-4700\1114220046-566-r-rev0-4700-appendix 5.7-b-dispersion meteorology 09mar_15.docx

APPENDIX A

CALMET Options and Flags

Input Group	Parameter	Default	Project	Description
Input Ground 1: General Run Control Parameters	IBYR	-	2012	Starting year
	IBMO	-	1	Starting month
	IBDY	-	1	Starting day
	IBHR	-	1	Starting hour
	IBSEC	-	0	Starting second
	IEYR	-	2013	Ending year
	IEMO	-	1	Ending month
	IEDY	-	1	Ending day
	IEHR	-	23	Ending hour
	IESEC	-	3600	Ending second
	ABTZ	-	UTC-0800	UTC time zone (Pacific Standard Time)
	NSECDT	3600	3600	Length of modelling time step (seconds)
	IRTYPE	1	1	Run type – computes wind fields and micrometeorological variables
	LCALGRD	T	T	Compute special data fields required by CALGRID
	ITEST	2	2	Continues with execution of computational phase after setup
	MREG	-	0	No checks for conformance with US EPA guidance
Input Group 2: Map Projection and Grid Control Parameters	PMAP	UTM	UTM	Map projection = Universal Transverse Mercator
	FEAST	0.0	N/A	Not used if PMAP = UTM
	FNORTH	0.0	N/A	Not used if PMAP = UTM
	IUTMZN	-	10	UTM zone
	UTMHEM	N	N	Northern hemisphere projection
	RLAT0	-	N/A	Not used if PMAP = UTM
	RLON0	-	N/A	Not used if PMAP = UTM
	XLAT1	-	N/A	Not used if PMAP = UTM
	XLAT2	-	N/A	Not used if PMAP = UTM
	DATUM	WGS-84	NAR-C	Datum region for output coordinates = NAR-C Canada 1983 GRS 80 Spheroid
	NX	-	220	Number of X grid cells
	NY	-	220	Number of Y grid cells
	DGRIDKM	-	0.100	Grid spacing (km)
	XORIGKM	-	460.771	X coordinate of southwest corner of domain (km)
	YORIGKM	-	5479.514	Y coordinate of southwest corner of domain (km)
	NZ	-	10	Number of vertical layers
	ZFACE	-	0, 20, 50, 100, 200, 400, 800, 1200, 1600, 2200, 3000	Cell face heights in vertical grid (m)
Input Group 3: Output Options	LSAVE	T	T	Save meteorological fields in an unformatted output file
	IFORMO	1	1	CALPUFF/CALGRID type of unformatted output file
	LPRINT	F	F	Do not print meteorological fields
	IPRINF	1	N/A	Not applicable since LPRINT = F
	IUVOUT	NZ*0	N/A	Not applicable since LPRINT = F
	IWOUT	NZ*0	N/A	Not applicable since LPRINT = F
	ITOUT	NZ*0	N/A	Not applicable since LPRINT = F
	STABILITY	0	0	Do not print PGT stability class
	USTAR	0	0	Do not print friction velocity
	MONIN	0	0	Do not print Monin-Obukhov length
	MIXHT	0	0	Do not print mixing height
	WSTAR	0	0	Do not print convective velocity scale
	PRECIP	0	0	Do not print precipitation rate
	SENSHEAT	0	0	Do not print sensible heat flux
	CONVZI	0	0	Do not print convective mixing height
	LDB	F	F	Do not print input meteorological data and internal variables
	NN1	1	1	First time step for which debug data are printed
	NN2	1	1	Last time step for which debug data are printed (QA option only)
	LDBCST	F	F	Do not print distance to land internal variables
	IOUTD	0	0	Control variable for writing the test/debug wind fields to disk files
	NZPRN2	1	1	Number of levels to print
	IPR0 to IPR8	0	0	Do not print wind field components after each adjustment
Input Group 4: Meteorological Data Options	NOOBS	0	2	No surface, overwater or upper air observations (used MM5 data only)
	NSSTA	-	N/A	Not applicable since CALMET in no-obs mode
	NPSTA	-	N/A	Not applicable since CALMET in no-obs mode
	ICLOUD	0	4	Gridded cloud cover from Prognostic Rel. Humidity at all levels
	IFORMS	2	N/A	Not applicable since NOOBS=2
	IFORMP	2	N/A	No precipitation file used
	IFORMC	2	N/A	Cloud output data format not applicable
Input Group 5: Wind Field Options and Parameters	IWFCOD	1	1	Diagnostic wind module
	IFRADJ	1	1	Compute Froude number adjustment effects
	IKINE	0	0	Do not compute kinematic effects
	IOBR	0	0	Do not use O'Brien procedure for adjustment of the vertical velocity
	ISLOPE	1	1	Compute slope flows
	IEXTRP	-4	-1	No extrapolation is done, use data directly from prognostic data
	ICALM	0	0	Do not extrapolate surface winds if calm
	BIAS	NZ*0	N/A	Not applicable since CALMET in no-obs mode

Input Group	Parameter	Default	Project	Description
Input Group 5: Wind Field Options and Parameters	RMIN2	4	N/A	Not applicable since CALMET in no-obs mode
	IPROG	0	14	Winds from MM5/M3D.dat used as initial guess field
	ISTEPPGS	3600	3600	Timestep of the prognostic model input data (seconds)
	IGFMET	0	0	Do not use coarse CALMET fields as initial guess fields
	LVARY	F	F	Do not use varying radius of influence
	RMAX1	-	N/A	Not applicable since CALMET in no-obs mode
	RMAX2	-	N/A	Not applicable since CALMET in no-obs mode
	RMAX3	-	N/A	Not applicable since CALMET in no-obs mode
	RMIN	0.1	N/A	Not applicable since CALMET in no-obs mode
	TERRAD	-	5	Radius of influence of terrain features
	R1	-	N/A	Not applicable since CALMET in no-obs mode
	R2	-	N/A	Not applicable since CALMET in no-obs mode
	RPROG	-	N/A	Not applicable since CALMET in no-obs mode
	DIVLIM	0.000005	0.000005	Maximum acceptable divergence in the divergence minimization procedure
	NITER	50	50	Maximum number of iterations in the divergence minimization procedure
	NSMTH	2, (mxnz-1)*4	2, 4, 4, 4, 4, 4, 4, 4, 4	Number of passes in the smoothing procedure
	NINTR2	NZ*99	NZ*99	Maximum number of stations used in each layer for the interpolation of data to a grid point
	CRITFN	1	1	Critical Froude number
	ALPHA	0.1	0.1	Empirical factor controlling the influence of kinematic effects
	FEXTR2	NZ*0	NZ*0	Multiplicative scaling factor for extrapolation of surface observations to upper layers. Used only if IEXTRP = 3 or -3.
	NBAR	0	0	Number of barriers to interpolation of the wind fields
	KBAR	NZ	N/A	Not applicable since NBAR = 0
	XBBAR	-	N/A	Not applicable since NBAR = 0
	YBBAR	-	N/A	Not applicable since NBAR = 0
	XEBAR	-	N/A	Not applicable since NBAR = 0
	YEBAR	-	N/A	Not applicable since NBAR = 0
	IDIOPT1	0	0	Compute surface temperature internally from hourly surface observations
	ISURFT	-1	-1	2-D spatially varying surface temperatures
	IDIOPT2	0	0	Compute domain-averaged temperature lapse rate internally from prognostic fields
	IUPT	-1	-1	2-D spatially varying lapse rate
	ZUPT	200	200	Depth through which the domain-scale lapse rate is computed
	IDIOPT3	0	0	Compute domain-averaged wind components internally from prognostic wind fields
	IUPWIND	-1	-1	3-D initial guess fields
	ZUPWND	1, 1000	1, 1000	Bottom and top of layer through which the domain-scale winds are computed
	IDIOPT4	0	N/A	Not applicable since CALMET in no-obs mode
	IDIOPT5	0	N/A	Not applicable since CALMET in no-obs mode
	LLBREZE	F	F	Do not use lake breeze module
	NBOX	-	N/A	Not applicable since LLBREZE = F
	XG1	-	N/A	Not applicable since LLBREZE = F
	XG2	-	N/A	Not applicable since LLBREZE = F
	YG1	-	N/A	Not applicable since LLBREZE = F
	YG2	-	N/A	Not applicable since LLBREZE = F
	XBCST	-	N/A	Not applicable since LLBREZE = F
	YBCST	-	N/A	Not applicable since LLBREZE = F
	XECST	-	N/A	Not applicable since LLBREZE = F
	YECST	-	N/A	Not applicable since LLBREZE = F
	NLB	-	N/A	Not applicable since CALMET in no-obs mode
	METBXID	-	N/A	Not applicable since CALMET in no-obs mode
Input Group 6: Mixing Height, Temperature, and Precipitation Parameters	CONSTB	1.41	1.41	Constant for neutral mechanical equation
	CONSTE	0.15	0.15	Constant for convective mixing height equation
	CONSTN	2400	2400	Constant for stable mixing height equation
	CONSTW	0.16	0.16	Constant for overwater mixing height equation
	FCORIOL	0.0001	0.00012	Absolute value of Coriolis parameter
	IAVEZI	1	1	Conduct spatial averaging of mixing heights
	MNMDAV	1	10	Maximum search radius in averaging process (grid cells)
	HAFANG	30	30	Half-angle of upwind looking cone for averaging
	ILEVZI	1	1	Layer of winds used in upwind averaging
	IMIXH	1	1	Convective mixing height option = Maul-Carson for land and water cells
	THRESHL	0	0	Threshold buoyancy flux required to sustain convective mixing height growth overland (expressed as a heat flux per metre of boundary layer W/m^3)
	THRESHW	0.05	0.05	Threshold buoyancy flux required to sustain convective mixing height growth overwater (expressed as a heat flux per metre of boundary layer W/m^3)
	ITWPROG	0	2	Use prognostic lapse rates and prognostic delta T
	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 mixing height (K/m)

Input Group	Parameter	Default	Project	Description
Input Group 6: Mixing Height, Temperature, and Precipitation Parameters	DZZI	200	200	Depth of layer above current convective mixing height through which lapse rate is computed
	ZIMIN	50	50	Minimum overland mixing height (m)
	ZIMAX	3000	3000	Maximum overland mixing height (m)
	ZIMINW	50	50	Minimum overwater mixing height (m)
	ZIMAXW	3000	3000	Maximum overwater mixing height (m)
	ICOARE	10	10	Use COARE with no wave parameterization for overwater surface fluxes
	DSHELF	0	0	Coastal/shallow water length scale (km) (COARE fluxes only)
	IWARM	0	0	COARE warm layer computation off
	ICOOL	0	0	COARE cool skin layer computation off
	IRHPROG	0	1	Use prognostic RH
	ITPROG	0	2	No surface or upper air observations. Use MM5/3D.DAT for surface and upper air data
	IRAD	1	1	Use 1/R for temperature interpolation
	TRADKM	500	500	Radius of influence for temperature interpolation (km)
	NUMTS	5	5	Maximum number of stations to include in temperature interpolation
	IAVET	1	1	Conduct spatial averaging of temperatures
	TGDEFB	-0.0098	-0.0098	Default temperature gradient below the mixing height over water (K/m)
	TGDEFA	-0.0045	-0.0045	Default temperature gradient above the mixing height over water (K/m)
	JWAT1, JWAT2	-	50, 55	Beginning and ending land use categories for temperature interpolation over water
	NFLAGP	2	2	Use 1/R2 for precipitation interpolation
	SIGMAP	100	100	Radius of influence (km)
	CUTP	0.01	0.01	Minimum precipitation rate cut off (mm/h)

As a global, employee-owned organisation with over 50 years of experience, Golder Associates is driven by our purpose to engineer earth's development while preserving earth's integrity. We deliver solutions that help our clients achieve their sustainable development goals by providing a wide range of independent consulting, design and construction services in our specialist areas of earth, environment and energy.

For more information, visit golder.com

Africa	+ 27 11 254 4800
Asia	+ 86 21 6258 5522
Australasia	+ 61 3 8862 3500
Europe	+ 356 21 42 30 20
North America	+ 1 800 275 3281
South America	+ 56 2 2616 2000

solutions@golder.com
www.golder.com

Golder Associates Ltd.
Suite 200 - 2920 Virtual Way
Vancouver, BC, V5M 0C4
Canada
T: +1 (604) 296 4200