CALPUFF/MM5 Study Report

Final Report

June 2001

Prepared by
Earth Tech, Inc.
d.b.a. Earth Tech Consulting, Inc.
196 Baker Avenue
Concord, MA 01742

Prepared for
State of Alaska
Department of Environmental Conservation
410 Willougby Avenue
Juneau, AK 99801-1795

Contract No. 18-4000-00

Table of Contents

Table of Contents (Continued)

APPENDICES

1. INTRODUCTION

The CALPUFF modeling system is capable of predicting the ambient concentration, dry deposition, and wet deposition of pollutants based on non-steady meteorological fields. The CALMET model (Scire et al. 1999) of the system can simulate fine-scale three-dimensional wind flows in complex terrain. It has parameterizations to perform wind field adjustments of terrain, such as slope flows and terrain blocking (Froude number) effects. CALMET first develops an initial guess field, which can be derived from the interpolation of observations or from the output of other model, such as the PSU/NCAR Mesoscale Modeling System (MM5. Grell and Dudhia, 1994). The wind field is then adjusted to make them compatible with the fine-scale CALMET terrain. The next step is for observations to be added back into the flow field, through an objective analysis procedure. In addition, smoothing, divergence minimization, and vertical velocity adjustments can be made to the flow field. CALMET develops fields of other meteorological variables (3-D temperatures) and 2-D fields of mixing heights, surface friction velocities, convective velocity scales, PGT stability classes, mixing heights, and Monin-Obukhov lengths that are consistent with the wind field and spatially-varying surface properties. With this spatially-varying flow field, CALPUFF (Scire et al. 1999) has the ability to simulate the plume transport and dispersion in many important situations, such as terrain-forced flows (e.g., terrain channeled flow, slope flows, terrain blocked flows), flow stagnation, inversion development and breakup, plume fumigation, flow re-circulation, and sea/land breeze circulations and slope/valley circulations.

CALMET/CALPUFF was developed to take whatever observational wind data are available, and adjust the flow fields to be consistent with the fine-scale terrain in CALMET. The adjustments made by CALMET introduce structure to the flow field that is consistent with the terrain, even in areas where observations do not exist. In complex terrain regions, the representativeness of observational data is often quite limited spatially. Often the wind flow just a few hundred meters from an anemometer can be completely different as a result of terrain-induced effects. These terrain effects on the wind flow may have a substantial impact on the design concentrations produced by the dispersion model. Whereas steady-state models such as ISC3 and AERMOD will produce a straight-line plume trajectory based on the wind at a single location, the non-steady-state capabilities in CALPUFF allow the plume trajectory to be deflected or modified by the terrain features.

Often, meteorological observations do not exist in the areas being modeled. The traditional approach has been to require meteorological monitoring in these areas, which involves a considerable expense and delay in schedule for the project. Usually, at least one year of monitoring is necessary in order to meet regulatory requirements. Even with on-site monitoring, the spatial representativeness of the collected meteorological data is often quite limited, especially in areas with complex terrain. In addition, the on-site measurements are usually limited to near-surface observations, and often the measurements are made at a single height in the vertical.

One of the useful features in CALMET is its ability to derive its initial-guess field from an interpolation of coarse-scale prognostic meteorological model output. An interface program (CALMM5) has been developed which processes MM5 model output for this purpose. The use of MM5 data for the initial CALMET field is attractive because it provides dynamically-consistent three-dimension flow as the starting point for the CALMET fine-scale terrain adjustments. The spatial resolution of the MM5 output is usually significantly better than the observational network, often computed at 4-36 km horizontal resolution, and 20-40 levels in the vertical. The MM5 data set has hourly time resolution, whereas upper air observations are often limited to twice-per-day soundings collected at NWS upper air sites. MM5 can be run at much lower costs, with a shorter schedule, and with a much larger number of data points than a meteorological monitoring program. For example, an annual MM5 simulation involving 5,000-10,000 data points may require 3-6 months to develop, whereas monitoring at even only one or two points near the surface would require approximately 18 months to setup and collect a full-year data set. The cost of the development of the entire MM5 data set with 10^3-10^4 data points is typically 1/3 to ½ the cost of the meteorological monitoring program involving a high meteorological tower or remote sensing of winds in the vertical (e.g., with a SODAR system). The MM5 simulations can be done once to cover a large area, and the data used repeatedly for applications within that domain.

It is attractive to use or include MM5 data in the CALMET initial guess wind field relative to the data from typical meteorological observation networks. However, it is common that the coarse-scale MM5 data are not adequate to fully-resolve the fine-scale terrain effects that can dominate the flow field near a particular source and control the design concentrations produced by the model. Increasing MM5 grid resolution would increase costs in cubic, not linear, since the time step of integration needs to be reduced in order to keep the integration stable. On the other hand, CALMET offers a practical, cost-effective solution to this problem, by adjusting the coarse scale flow fields produced by MM5 model so that they represent the fine-scale terrain seen by the CALMET and CALPUFF models. The receptor density in CALPUFF can be (and usually must be for near-field impacts) in the order of every 100 m near the facility, and increasing to every 1-4 km at larger distances from the facility.

The purpose of this study is to investigate whether the CALMET and CALPUFF simulations initialized using various meteorological data sets, including MM5 data set only, can provide adequate results for the near field regulatory analysis in very complex terrain area. The study is conducted in two phases. In the first phase, MM5 generates meteorological fields at grid spacing of 20 km and 4 km for the entire year of 1995. In the second phase, the CALPUFF modeling system is applied to the Alaska modeling domain for five scenarios, each starting from a different initial wind field. ISCST3 and AERMOD are also applied to these five scenarios as a comparison.

The five scenarios, or tasks of the project, are listed in Table 1-1. The initial wind field in Scenario 1 (Task B1) includes on-site observations, remote NWS surface observations, and large scale flow patterns from the prognostic model (20 km MM5 data). This is the base case and represents an ideal data set. This data set is also consistent with the data recommendations made by the U.S. Environmental Protection Agency (EPA) for use in a regulatory near-field analysis.

The remaining scenarios represent non-ideal, but realistic, situations where readily available meteorological data are limited. Scenarios 2 and 3 (Tasks B2 and B3) use MM5 data only to initialize the CALMET wind field. The difference between the two scenarios is the grid spacing of MM5 simulation. These two scenarios would demonstrate whether the use of only MM5 data would be adequate to initialize CALMET in the study domain. Scenario 4 (Task B4) evaluates an even more extreme case, where only remote NWS surface data are available to initialize CALMET. In Scenario 5 (Task B5), 20 km MM5 data are used along with the remote NWS surface data to initialize CALMET.

In Section 2 of this report, the MM5 model simulations are discussed and presented. The CALMET and CALPUFF model set up are described in Section 3. CALMET and CALPUFF model results are given in Section 4 for the near field area and Section 5 for the far field area. Section 6 gives the results from ISCST3 and AERMOD with meteorological data from the five described scenarios. Summary and conclusion are provided in Section 7. An executive summary is given in Section 8. The details of model results are presented in Appendices.

Table 1-1. Five CALPUFF Simulation Scenarios

Scenarios	Project Task #	Initial Wind Field
1	Task B1	20 km MM5, On-site surface station Hawk Inlet, and NWS surface station Juneau
2	Task B2	20 km MM5 only
3	Task B3	4 km MM5 only
4	Task B4	NWS station surface Juneau only
5	Task B5	NWS surface station Juneau and 20 km MM5 data

2. MM5 SIMULATIONS

The MM5 model used in this study is the PSU/NCAR Mesoscale Model System Version II. The MM5 simulations involve three model domains. The coarse domain covers the area of western Canada and the northwest part of the United States. The grid spacing is 60 km. The second domain and third domain are shown in Figure 2-1 together with the MM5 terrain elevations. The second domain covers British Columbia, Alberta, and part of Alaska. The grid spacing is 20 km. The third domain is for Alaska MM5 modeling. The grid size is 4 km. In the vertical direction, there are 18 sigma levels, eight of them below 3000 m above the ground. The model top is at 100 hPa. Domain 3 is located at the northwest corner of the second domain. Its northern and western edges are limited by its mother domain. A sponge area is needed between mother and child domains. The coarse domain is not shown in the figure since it is a sacrifice of two-way nesting. No model output of the coarse domain is used.

Two-way nesting is used for the MM5 Domain 1 and Domain 2. For the Domain 3, one-way nesting is used. The model is run in its non-hydrostatic mode. Initial large scale analysis data are from the NCEP global analyses available at NCAR. The Goddard micro-physics scheme is used for the explicit moisture scheme. This scheme predicts ice number and graupel in addition to cloud and rain water. The Grell cumulus parameterization scheme is used for convection. This scheme uses updraft, downdraft fluxes and compensating flow to determine the heating and moisture vertical profiles. It is suitable for the grid spacing of 10-30 km. The planetary boundary layer module is the high resolution Blackadar planetary boundary layer scheme. The scheme has five layers in the lowest 1 km layer. The Dudhia cloud radiation scheme is used for radiation calculations. The scheme can account for long wave and short wave interactions with cloud and clear air. The five-layer soil model is used to predict soil temperatures at about 1, 2, 4, 8, 16 cm. The vertically resolved soil temperature profile allows rapid response of surface temperature. Analysis nudging is used for the Domains 1 and two, but not for the Domain 3 since it is a small domain and hourly boundary conditions from its mother domain would play similar roles.

The modeled monthly mean wind field from the 4-km grid spacing MM5 domain (Domain 3) is shown in Figure 2-2 for January and Figure 2-3 for July in 1995. The wind field is at the first MM5 level, which is about 36 m above the ground. In January, the wind is dominated by the easterly and southeasterly flows. In July, the southerly flow is strengthened. The wind fields show convergence in valleys and divergence near ridges. It is obvious that the model can only resolve the wind features on the scale of its terrain and land-use type. Although the model grid spacing is 4 km, the resolutions of terrain elevation and land-use category are 9 km and 18 km since they come from the 5-minute geophysical data and 10-minute global land-use data. Therefore, MM5 can only resolve the circulations related to the underlaying surface on the scale of 9 to 18 km. The same terrain and land-use data were used for Domains 1 and 2. Higher resolution data and related modules were not available when the MM5 simulations for Domains 1 and 2 were conducted. It is desirable to use the terrain and land-use data with the resolution same as the MM5 grid size, but there is no harm in using finer terrain and land-use data except additional memory and computer time.

The details of terrain features in Domain 3 can be found in Figures 3-2a to 3-2c in Section 3, which originate from 90 meter resolution USGS data and were averaged over grid size of 250 meters. Comparing these figures, one can find that the terrain in Figures 2-2 and 2-3 misses many detail features. Better terrain and land-use data in MM5 should improve the terrain features and predicted wind fields in Figures 2-2 and 2-3.

Annual MM5 wind roses at the surface are shown in Figures 2-4a-c for the 20 km Domain 2 MM5 wind and Figures 2-5a-c for the 4km Domain 3 MM5 wind at Juneau, the Hawk Inlet, and the Mill Site. The coordinates of these three locations will be given in Section 3. For the 20 km MM5 wind field, the dominant wind is from southeast to northeast. This pattern represents large scale flow in the model area. Due to the warm ocean current along the Alaska coasts, the Aleutian Low pressure is almost a permanent feature on the weather map in this area. The model domain is located to the east of the low pressure center and is under the control of east-easterly flow.

The MM5 20 km wind roses at Yakutat, which is a sounding station used in the CALMET modeling for this study, are shown in Figures 2-6a-b for altitudes of 50 and 1000 meters above the ground. Near the surface, the dominant wind is from ESE-SE. It turns toward SE-SSE when altitude increases. Above 1000 meters, the dominant wind does not change much.

When the grid resolution reduces from 20 km to 4 km, the air flow at the observation sites is shifted toward southeast and south (Figures 2-5a-c). It is more obvious at Juneau. Its dominant wind direction is ENE with frequency about 20% in Domain 2, but it changes to ESE with frequency about 35% in the Domain 3. Comparing the wind roses for Domain 2 and Domain 3, one can find the increase of wind speed in the nested domain, Domain 3. It is known that MM5 tends to over predict its surface wind. Geostrophic wind is used as the first guess of surface wind in the model system. It is the balancing wind of pressure field and is usually higher than actual wind near the surface. The over-prediction can propagate from mother domain to its child domain. More nesting may end up more over prediction due to the accumulation of over prediction.

3. CALMET AND CALPUFF MODEL SETUP

CALMET is a diagnostic meteorological model that produces three-dimensional wind and temperature fields and two-dimensional fields of mixing heights and other meteorological variables. It contains options to parameterize slope flow effects, terrain channeling, and kinematic effects of terrain. The model can start from various initial wind fields. The CALMET model domains for this study are shown in Figure 3-1 along with the 4-km MM5 model domain. The CALMET domain for the near field covers an area of 24 km by 24 km centered at the Hawk Inlet with grid spacing of 250 m. A supplemental CALMET domain with same grid size is added to the area of Juneau in order to generate wind field there. It is too big to include Juneau in the near field CALMET domain at 250 m grid resolution. For the far field, the CALMET domain covers an area of 161 km by 161 km with grid size of 1 km. The Lambert Conformal map projection is used in all CALMET coordinates. The reference center is located at 54.117ºN and 119.854ºW. The standard latitudes are 30ºN and 60ºN. In CALMET, there are 11 vertical cell face heights at 0, 20, 40, 80, 160, 320, 580, 1020, 1480, 2220, and 2980 meters. This corresponds to 10 vertical layers with grid points located midway between each set of cell face heights. The user specified weighting parameter for the initial wind guess to observations at the surface (R1) is set to 3 km. This selection is based on the terrain features near the observation sites. The relative small value can limit the influence of observations to a small area. It is not appropriate to interpolate local observations to a large area in complex terrain areas like the Hawk Inlet. The value of 3 km is also used for the weighting parameter for the layers aloft (R2). R2 does not play any meaningful role in this study since there are no observations aloft in the CALMET domain. The maximum radii of influence of observations (RMAX1, RMAX2, RMX3) are set to 5 km. This setting can prevent the influence of observations at the Hawk Inlet on the wind prediction at the Mill Site since the terrain feature near the Hawk Inlet is very different from that near the Mill Site. The minium radius of influence used in the wind interpolation (RMIN) is set to 0.1 km. Observations are used for a CALMET grid if the distance of the grid to the observation site is within this limit. The radius of influence of terrain is set to 6 km, which is about the distance from the peaks near the Hawk Inlet or the Mill Site to the observation sites. The layer dependent bias weighting factor for surface and upper air observations (BIAS) is used only for Scenario 4, which will be given in Section 4.4. NWS stations are the only data set used to initialize CALMET in this scenario. The bias factor is not needed for other scenarios since these scenarios use prognostic model data sets to initialize CALMET and these data sets include vertical profiles of wind and temperature.

CALPUFF is a non-steady-state puff dispersion model. It was designed to account for the spatial changes in meteorological fields, variability in surface conditions (surface roughness, vegetation type, etc.), and terrain influences on plume interaction with the surface. Chemical transformation, wet removal due to rain and snow, and dry deposition are options within CALPUFF, although they are not considered important for the near field simulations. The configuration of the CALPUFF domain is the same as that of CALMET (Figure 3-1).

3.1 Terrain Data

Gridded terrain elevations needed by CALMET were derived from 3 arc-second Digital Elevation Models (DEM) produced by the USDI-U.S. Geological Survey (USGS). Terrain data are provided in files covering 1 degree by 1 degree block of latitude and longitude. The 1-degree DEM files were produced by the Defense Mapping Agency using cartographic and photographic sources. USGS 1:250,000 topographic maps are the primary source of 1-degree DEM files. One degree DEM data consist of an array of 1201 by 1201 elevations referenced on the geographic (latitude/longitude) coordinate system of the World Geodetic System 1972 Datum. Elevations are in meters relative to mean sea level. The spacing of the elevations along each profile is 3 arc-seconds, which corresponds to a spacing of approximately 90 meters.

The terrain elevation for the near field CALMET is given in Figure 3-2a. This resolution of terrain can resolve most of the fine scale features in the domain. The terrain contours reflect fairly well the north-south channel near the Hawk Inlet and the east-west valley at the Mill Site. The terrain elevation for the far field is shown in Figure 3-2b. In general, this terrain field can resolve major land features in the model domain. The terrain feature of the Juneau supplemental domain is given in Figure 3-2c. NWS station Juneau is located at the foot of a peak more than 1000 m high and at the convergent area of two valleys.

3.2 Land Use Data

USGS global land cover characteristics data have been used to produce dominant land use categories and land-use weighted values of surface and vegetation properties for each CALMET grid cell. This data set has the resolution of 900 meters. The land use data have been processed to produce a 1-km resolution gridded field of fractional land use categories. The Lambert Azimuthal Equal Area Projection is used in the global land cover characteristics data, and it does not always match the Lambert Land Conformal Projection used in CALMET. Therefore there are missing values at some CALMET grids, although the global land characteristics data have the resolution higher than that of CALMET. These missing grids are filled based on the properties of the surrounding grid cells.

The 37 Level I USGS land use categories (Table 3-1) are mapped into 14 CALMET land use categories (Table 3-2). Surface properties such as albedo, Bowen ratio, roughness length, and leaf area index are computed proportionally to the fractional land use within each grid cell. The dominant land use categories for each CALMET grid cell are shown in Figure 3-3. The land use data with 250 m resolution are not available, therefore, the land use data used in the near field CALMET are a subset of those shown in Figure 3-3.

3.3 Station Meteorological Data

There are two meteorological towers and one National Weather Service (NWS) surface station in the CALMET domain. The on-site meteorological towers are located at the Hawk Inlet and the Mill Site. The

NWS surface station is Juneau. Precipitation is recorded at the two on-site stations. The nearest upper air station is located in Yakutat, about 320 km northwest of Hawk Inlet. The geographical locations of the two on-site towers and Juneau are shown in Figures 3-2a-c and listed in Table 3-3. The wind observations from January to March 1995 at the Mill Site were deemed by the State of Alaska as not reliable. Therefore, the observations at this site for the period of April to December 1995 are used only for model verification.

The wind roses of upper air sounding at Yakutat are shown in Figure 3-4a for the altitude of 50 meters and in Figure 3-4b for the altitude of 1000 meters above the ground. Yakutat is outside the CALMET and CALPUFF domain, but the wind rose there represents the large scale flow pattern in this area. The

Table 3-1

U.S. Geological Survey Land Use and Land Cover Classification System

	Level I		Level II
10	Urban or Built-up Land	11	Residential
		12	Commercial and Services
		13	Industrial
		14	Transportation, Communications and Utilities
		15	Industrial and Commercial Complexes
		16	Mixed Urban or Built-up Land
		17	Other Urban or Built-up Land
20	Agricultural Land	21	Cropland and Pasture
		22	Orchards, Groves, Vineyards, Nurseries, and Ornamental Horticultural Areas
		23	Confined Feeding Operations
		24	Other Agricultural Land
30	Rangeland	31	Herbaceous Rangeland
		32	Shrub and Brush Rangeland
		33	Mixed Rangeland
40	Forest Land	41	Deciduous Forest Land
		42	Evergreen Forest Land
		43	Mixed Forest Land
50	Water	51	Streams and Canals
		52	Lakes
		53	Reservoirs
		54	Bays and Estuaries
		55	Oceans and Seas
60	Wetland	61	Forested Wetland
		62	Nonforested Wetland
70	Barren Land	71	Dry Salt Flats
		72	Beaches
		73	Sandy Areas Other than Beaches
		74	Bare Exposed Rock
		75	Strip Mines, Quarries, and Gravel Pits
		76	Transitional Areas
		77	Mixed Barren Land
80	Tundra	81	Shrub and Brush Tundra
		82	Herbaceous Tundra
		83	Bare Ground
		84	Wet Tundra
		85	Mixed Tundra
90	Perennial Snow or Ice	91	Perennial Snowfields
		92	Glaciers

Table 3-2
Default CALMET Land Use Categories and Associated Geophysical Parameters
Based on the U.S. Geological Survey Land Use Classification System
(14-Category System)

Land Use Type	Description	Surface Roughness (m)	Albedo	Bowen Ratio	Soil Heat Flux Parameter	Anthropogenic Heat Flux (W/m^2)	Leaf Area Index
10	Urban or Built-up Land	1.0	0.18	1.5	.25	0.0	0.2
20	Agricultural Land - Unirrigated	0.25	0.15	1.0	.15	0.0	3.0
-20*	Agricultural Land - Irrigated	0.25	0.15	0.5	.15	0.0	3.0
30	Rangeland	0.05	0.25	1.0	.15	0.0	0.5
40	Forest Land	1.0	0.10	1.0	.15	0.0	7.0
50	Water	0.001	0.10	0.0	1.0	0.0	0.0
51	Small Water Body	0.001	0.10	0.0	1.0	0.0	0.0
55	Large Water Body	0.001	0.10	0.0	1.0	0.0	0.0
60	Wetland	1.0	0.10	0.5	.25	0.0	2.0
61	Forested Wetland	1.0	0.1	0.5	0.25	0.0	2.0
62	Nonforested Wetland	0.2	0.1	0.1	0.25	0.0	1.0
70	Barren Land	0.05	0.30	1.0	.15	0.0	0.05
80	Tundra	.20	0.30	0.5	.15	0.0	0.0
90	Perennial Snow or Ice	.20	0.70	0.5	.15	0.0	0.0

* Negative values indicate "irrigated" land use

Table 3-3

Meteorological Stations used in the Alaska CALMET Modeling

Station Name	**Station ID**	**Name on Plots**	**X(km)**	**Y(km)**	**Latitude (deg)**	**Longitude (deg)**	**sensor height (m)**
Juneau NWS surface station	25309	JUNE	-847.230	543.001	58.3670	-134.5830	10
Yakutat upper air station	25339	-	-1103.393	729.606	59.5200	-139.6700	-
Hawk Inlet met tower	1	HAWK	-861.672	518.118	58.1210	-134.7488	10*
Mill Site met tower	2	MILL	-856.249	512.842	58.0830	-134.6405	18

* The Hawk Inlet meteorological tower is located on a dock, which extends over tideland. The wind sensor is located 4.6 m above the dock, which provides a total height of approximately 10 m above mean sea level.

dominant wind direction is E-ESE at 50 meters. It shifts about 45 degrees southwards at 1000 meters. The wind roses at Yakutat are typical for a station to the east of the Aleutian Low.

The annual wind roses at the three surface sites are given in Figures 3-5a-c. Their seasonal variations are given in Appendix A. The statistics of observed wind at these three stations are given in Appendix G. The wind rose at the Mill Site is only for the April-December period. The wind rose at Juneau (Figure 3-5a) shows prevailing wind from ESE and E directions. It is consistent with the large scale flow shown by Yakutat upper air soundings (Figures 3-4a). Compared with the wind at Yakutat, the ESE wind at Juneau is enhanced at Juneau, that may result from the channel effect of Gastineau Channel. The frequency of northern wind stands out among the rest of wind directions. It reaches 10%. The wind speed at this direction is very weak, about 1-3 ms^{-1} in most time. Consulting Figures 3-2b and 3-2c, one can find that this northern wind is due to the drainage flow out of the Mendenhall Valley. The down slope flows near Juneau, especially from the Mendenhall Glacier, converge in the Mendenhall Valley north of Juneau, and drain to its south. The calm wind frequency is very high (21.4%) at this station. Winter and spring contribute most to this annual calm peak (Appendix A). This high calm wind frequency may be related to the unique terrain features near Juneau.

The wind rose at Hawk Inlet shows a dipole pattern of prevailing wind. The first dominant wind flow is from NNW to NNE. The maximum frequency is more than 20% in the north. The second one is from S-SSE. In Appendix A, it is shown that this second one is due to the southern flow in spring (Mar-Apr-May) and summer (Jun-Jul-Aug). In winter (Dec-Jan-Feb) and autumn (Sep-Oct-Nov), there is almost no southerly wind at the Hawk Inlet. The dominant wind directions at this site are not consistent with the large scale flow pattern (Figures 3-4a and b) at this area. Figure 3-2a shows that the Hawk Inlet tower is located in a terrain channel oriented almost in the south-north direction. Both easterly and westerly flows can be deflected to the north or south direction at the site. Therefore, it is reasonable to record much more northern and southern winds at the Hawk Inlet.

3.4 Emission Sources used in the CALPUFF Model

Two fictional SO_2 emission sources were used in the CALPUFF modeling. One source is an 800kw Caterpillar D399 IC diesel generator. It burns 406 lb/hr of fuel at full load. The maximum SO_2 emission rate is 4 lb/hr, or 0.51g/s. Another emission source is an oil-fired boiler. The SO_2 emission rate from this boiler is 10 lb/hr, or 1.3 g/s. The parameters for these two sources are listed in Table 3-4. Building down wash is not included in this analysis.

3.5 Receptors used in the CALPUFF Model

Discrete receptors are used in the CALPUFF modeling. In the near-field, the receptor density is 100 m in the area from 300 m to 1000 m around the emission source center, which is set to the location of averaged X and Y coordinates of the sources listed in Table 3-4. From 1000 meters to 10 kilometers, the density is 1 kilometer. There are 856 near-field receptors. A far-field area is selected to the south of the emission sources, considering the fact that the dominant wind at the source is from north. It covers an area of 16 by 16 kilometers. The receptor density is one kilometer. There are 289 receptors in this area. The geographical locations of the receptors are given in Figure 3-6a for the whole CALPUFF domain, and in Figure 3-6b for the near-field receptors for a better view.

Table 3.4

SO_2 Emission Rate used in the CALPUFF Modeling

Source Name	X	Y	Stack	Base	Stack	Exit	Exit	Bldg.	SO_2 Emission
			Height	Elevation	Diameter	Vel.	Temp.	Dwash	Rates
	(km)	(km)	(m)	(m)	(m)	(m/s)	(deg. K)		g/s
Generator	-861.795	518.729	14	8.5	0.31	40	790	0	0.51
Boiler	-861.852	518.703	49	8.5	1.2	10	330	0	1.3

4. CALMET AND CALPUFF MODEL SIMULATIONS FOR THE NEAR FIELD

CALMET and CALPUFF modeling system has been applied to the five scenarios listed in Table 1-1. Each scenario corresponds to a different initial meteorological data set. For Scenario 1, the initial data set is the combination of model data (20 km MM5) and the observations from on-site and remote NWS stations (Hawk Inlet and Juneau). For Scenarios 2 and 3, model data only are used to initialize CALMET: 20 km MM5 data for Scenario 2 and 4 km MM5 data for Scenario 3. For Scenario 4, observations from remote NWS stations only (Juneau and Yakutat) are used to initialize CALMET. For Scenario 5, the initial data set includes model data (20 km MM5) and observations from remote NWS station (Juneau). The results of CALMET and CALPUFF simulations for the near field area are presented in this section.

4.1 Scenario 1 - 20 km MM5, On-Site Station Hawk Inlet, and NWS Station Juneau

4.1.1 CALMET Modeling

This scenario is the Task B1 in the RFP. In this case, the 20 km MM5 data from Domain 2 and the observations at the on-site station Hawk Inlet and the NWS station Juneau are used to initialize CALMET. An example of the CALMET wind field is given in Figure 4-1.1a. The wind field in the figure shows high variability. The convergent flow in valleys and divergent flow over high peaks are dominant features of this wind field. Near the Mill Site, the wind direction is from northeast to its north, but from southeast to its south. This wind convergence happens for all other four scenarios, which are discussed later. The terrain elevation in Figure 3-2a shows a deep valley at the Mill Site. The peaks to its north and south rise more than 700 meters within 2-3 kilometers. The wind vectors along the western coast of the bay near the Hawk Inlet are almost parallel to terrain contours. A stagnant area exists near the convergent region of three valley flows at the low right part of the domain. The stagnant area near Juneau is much larger than this one (not shown). The flows coming from its north, east, and south converge there. It may explain why the calm wind frequency in Juneau reaches as high as 21% (Figure 3-5a).

The CALMET output is large, about 42 GB for one year for one case. It is very difficult to examine the properties of wind field over the entire model domain. Therefore, annual and seasonal wind roses are calculated and plotted for the three observation sites of Juneau, the Hawk Inlet, and the Mill Site.
The wind rose plots for the Mill Site are only for the period of April to December. The three observation sites are not located at any CALMET grid. The wind sensor height at these sites may not be at one of the CALMET levels. To obtained CALMET wind at the sites and at the wind sensor height, gridded CALMET wind has been interpolated vertically and horizontally to the location and the sensor height of observations at each site. In the vertical direction, exponential interpolation is used to get the wind speed at wind sensor height at four closest grids. The surface roughness length needed for the interpolation is from the land use category at the grid. Linear interpolation is then used in both X and Y directions to obtain the U and V components of CALMET wind at the observation site. The final wind speed and direction at the observation

site are calculated using interpolated U and V components.

The annual wind rose at Juneau is given in Figure 4-1.1b. The wind roses for winter, spring, summer and autumn are given in Appendix B. The statistics of CALMET wind at this site for Scenario 1 is given in Appendix G together with other four scenarios as well as observations. Comparing with the observations in Figure 3-5a, one can find that the predicted wind rose is very close to the observed. The predicted dominant wind direction is ESE, same as the observed. The frequency is about 1% higher in the CALMET prediction. The frequency peak of northern wind is well predicted too. The notable difference between the predicted and observed is the calm wind frequency. In the observations, 21% of the time in 1995 is calm. In the CALMET prediction, this calm wind is replaced by the weak wind from SE to NNE, which reflects the terrain effect near Juneau. The seasonal wind roses given in Appendix B show that the weak NE-ENE flow occurs mainly in winter and spring. The frequency of these directions reaches about 30% in winter. Figure 3-2b shows that the weak NE-ENE is the down slope flow from the terrain peak northeast of Juneau, which is more than 1000 m higher than Juneau. During the winter, the air near the ground cools much faster than that in the free atmosphere due to the long wave radiation of the ground. The near surface cold flow drains down along the hill to Juneau and forms the NE-ENE weak wind there.

The predicted annual wind rose at the Hawk Inlet is shown in Figure 4-1.1c. The observed wind rose in Figure 3-5b is well simulated. No major difference can be found between observation and prediction. The dipole flow pattern is predicted. The dominant wind directions are from north and south. The seasonal variations are also well predicted. The northern flow occurs mainly in winter and autumn, and the southern flow dominates in summer and spring (Appendices A and B).

The CALMET annual wind roses at the Mill Site are given in Figure 4-1.1d. Note that the Mill Site has never been used in any of the CALMET simulations. The predicted wind is mainly from east. Comparing with the observations given in Figure 3-5c, the predicted wind speed is higher than observed. The predicted dominant wind direction is biased toward south about 45 degrees. The second frequency peak of southwestern wind is much weaker in the prediction. The prediction is close to the wind speed and dominant wind direction in 20 km MM5 field at this location (Figure 2-4c).

4.1.2 CALPUFF Modeling

The predicted annual mean SO_2 ambient concentration is plotted in Figure 4-1.2a. Plots of second maximum concentrations for 24-hour, 3-hour, and 1-hour averages are given in Appendix C. The tables in Appendix D list the concentrations at each receptor for the four averaging time period and the coordinates of receptors. A zoom-in plot for Figure 4-1.2a is given in Appendix H, which is for a better view of concentration distributions near the sources for annual, 24-hour, 3-hour, and 1-hour averaging periods. Note that the concentration contour lines within 300 m around the emission sources in the report and its appendices should not be considered since there are no receptors within this area. A summary of the peaks of annual means, 24-hour, 3-hour, and 1-hour second maximums are given in Table 4-1 along with their receptor numbers and locations. The peak concentrations and their locations for the five scenarios are plotted in Figure 4-1.2b for the annual means and in Figure 4-1.2c for the 24-hour second maximums.

The large impact area of annual mean SO_2 concentrations (the area enclosed by 0.2 μg/m^3 contour line) in Figure 4-1.2a expands more in the south-north direction along the bay near the Hawk Inlet. The concentration reduces to below 0.2 μg/m^3 about 5 km away from the SO_2 sources in the north-south direction. The concentration drops quickly to below 0.2 μg/m^3 within 1-2 km to the east of the sources. The peak value is 5.8 μg/m^3 , occurring about 300 m south of the emission sources. The zoom-in plot of Figure 4-1.2a in Appendix H shows that the concentration gradient is larger in the west-east direction that in the north-south direction near the maximum.

The second maximum concentrations of 24-hour, 3-hour, and 1-hour in the near field also show impact larger in the south-north direction (Appendix C for the entire near field area and Appendix H for the zoom-in area). In general, their contour patterns follow that of annual means. The maximum concentration is 29.5, 73.1, and 150.0 μg/m^3, respectively. The area enclosed by 0.2 μg/m^3 contour line for annual means in Figure 4-1.2a is roughly equal to the area enclosed by 2.0 μg/m^3 contour line for 24-hour average, by 10 μg/m^3 contour line for 3-hour average, and by 15 μg/m^3 contour line for 1-hour average. The gradients near their maximums are in general also larger in the west-east direction than that in the north-south direction. The second 24-hour peak concentrations and their locations are given in Figure 4-1.2c.

4.2 Scenario 2 - 20 km MM5 only

4.2.1 CALMET Modeling

This scenario is the Task B2 in the RFP. In this case, the 20 km resolution wind field from MM5 domain 2 is the only source used to initialize the CALMET wind field. This case examines whether an MM5 data set alone is adequate to initialize the CALMET model in complex terrain areas.

An example of CALMET wind field is shown in Figure 4-2.1a for the same time as in Figure 4-1.1a. No noticeable differences can be found away from Hawk Inlet between the figures. Near the Hawk Inlet, the wind is stronger in Scenario 2 than in Scenario 1. The wind direction turns easterly in this case, but it is northeasterly in the previous case. The annual wind roses for the three sites are given in Figures 4-2.1b-d. The annual wind frequency distributions at these sites reflect the distributions of 20 km MM5 wind field at these locations. At Juneau, the CALMET dominant wind is ranging from east-northeast to southeast, which is similar to that of 20 km MM5 wind. The observed dominant wind at the site is from east-southeast to east. The secondly dominant wind in the observation is from north, which is under predicted by about 7% in CALMET. The 21% of calm wind and large part of westerly wind in the observations are replaced by easterly wind in the CALMET. At the Mill Site, the CALMET dominant wind from April to December is also easterly, which is about 45º toward south of its observed dominant wind direction of northeast. The secondly dominant wind in the southwestern direction in the observation is not captured in CALMET. The predicted wind speed is too strong compared with observations. At the Hawk Inlet, the CALMET predicted dominant wind is more than 90º different from the observed. The observed dominant wind is from north, but the CALMET prediction is from east-northeast to southeast. These wind roses show that the CALMET wind roses in this scenario are determined mainly by 20 km MM5 wind. At Juneau, the MM5 dominant wind can roughly represent the observed dominant wind there (easterly wind), therefore the CALMET wind rose at this site is relatively close to the observation compared with other two sites.

CALMET does not predict the northern dominant wind at the Hawk Inlet. This dominant wind is almost opposite to the large scale flow direction in this area. The sounding observations at Yakutat and the surface observations at the NWS station Juneau all show dominant wind from east to southeast. The MM5 wind also shows the same dominant wind direction. However the observed dominant wind at the Hawk Inlet is from north, which is the local terrain effect of the strait near the site.

Although the CALMET prediction in this scenario does not provide the adequate wind field for the regulatory purpose in this study, but it is too early to reach the conclusion that the on-site station is a must. There are still possibilities to improve the CALMET prediction for the purpose of this study. One possibility is the improvement of drainage flow in CALMET, especially for an area in high latitudes where an ice field exists in the model domain. The convergence of down slopes flow in a valley or a basin in such areas may result in the much stronger drainage flow along a valley or a channel. Another possibility is the improvement of large scale flow from MM5. It is possible to apply MM5 to a smaller area near emission sources, using finer grid spacing and improved terrain and land use data. The current MM5 terrain and land use do not reflect the fine features near the Hawk Inlet. It is possible to generate our own terrain and land use input for MM5 from the best available data. Another improvement to MM5 field is the adjustment of surface wind speed. The over prediction of surface MM5 wind can overwhelm the terrain adjustment of CALMET wind, which is about on the order of 1 m/s. Reducing MM5 surface wind can improve the CALMET prediction, especially at locations of weak wind like the Mill Site.

4.2.2 CALPUFF Modeling

The predicted annual mean SO_2 concentration is shown in Figures 4-2.2a. The actual values are listed in the tables in Appendix D. The shape and area enclosed by 0.2 μg/m^3 contour line are similar to that in Scenario 1, but the impact along the coast to the south of Hawk Inlet is reduced. The maximum centers to the north and to the south of the emission sources are also significantly reduced in this case. The maximum annual concentration is 1.7 μg/m^3 (Table 4-1), occurring to northwest of the sources (Figure 4-1.2b). The second peak concentration of 24-hour average is 17.9 μg/m^3, occurring to the southeast of emission sources. The large impact area (enclosed by 2.0 μg/m^3 contour line) expands more in the west-east direction in this scenario than in Scenario 1 (Appendix C). The second maximums for 3-hour and 1-hour averages are 49.7 and 117.5 $\mu g/m^3$. The peak values in this scenario are less than those in Scenario 1. The gradients near the peaks are also reduced (Appendix H).

Table 4-1

CALPUFF predicted SO_2 ambient concentration for second maximum of 1-hour, 3-hour and 24-hour averages, and for annual mean in the near field area (Grid size in CALMET: 250 m)

SUBTASK	X Coord	Y Coord	CON.	JDay
	(km)	(km)	(µg/m³)	
	Annual Mean			
Subtask-B1	-861.824	518.416	5.8	
Subtask-B2	-862.524	519.616	1.7	
Subtask-B3	-861.824	519.416	3.7	
Subtask-B4	-861.524	518.816	3.9	
Subtask-B5	-862.624	519.716	1.9	
	24-Hour 2nd Maximum			
Subtask-B1	-861.724	519.016	29.5	143
Subtask-B2	-861.524	518.516	17.9	141
Subtask-B3	-861.624	519.016	28.1	164
Subtask-B4	-861.524	518.816	23.0	248
Subtask-B5	-861.824	518.316	27.1	23
	3-Hour 2nd Maximum			
Subtask-B1	-861.624	519.316	73.1	269
Subtask-B2	-861.724	518.416	49.7	203
Subtask-B3	-861.824	518.416	80.5	61
Subtask-B4	-861.824	518.416	74.4	67
Subtask-B5	-861.824	518.416	106.8	258
	1-Hour 2nd Maximum			
Subtask-B1	-861.624	519.316	150.0	269
Subtask-B2	-861.524	518.816	117.5	133
Subtask-B3	-861.524	518.616	185.6	22
Subtask-B4	-861.824	518.416	187.2	259
Subtask-B5	-861.824	518.416	150.5	258

4.3 Scenario 3 - 4 km MM5 only

4.3.1 CALMET Modeling

This scenario is the Task B3. CALMET is initialized using the 4 km MM5 meteorological data set only. This case is used to examine whether a finer MM5 grid spacing can improve modeled results.

An example of CALMET wind field at the same time as the previous two cases is given in Figure 4-3.1a. The wind field shows more spatial variation than that in Scenario 2. The wind direction in the eastern part of domain is almost opposite to that in the western part of domain. The number of 4 km MM5 grids used in the initialization in this scenario is 25 times more than that in Scenario 2. This spatial variability originates from the spatial variation of 4 km MM5 wind.

The annual wind roses at the three sites are shown in Figures 4-3.1b-d. Again the frequency distribution is dominated by the 4 km MM5 wind at these locations. Both Scenarios 2 and 3 indicate that the influence of MM5 wind overwhelms the terrain effect. Among the three sites in the two scenarios, CALMET predicts better wind field at Juneau than at the Hawk Inlet and the Mill Site. The initial MM5 wind at Juneau is closer to the observations than at the other two sites. The results in Scenarios 2 and 3 suggest that without on-site observations in a complex terrain area like the Hawk Inlet and the Mill Site, a good MM5 initial field is crucial to a successful CALMET simulation. A better MM5 field may be achieved by using improved terrain and land use input, and the adjustment of surface layer wind as discussed in Section 4.2.1.

4.3.2 CALPUFF Modeling

The CALPUFF predicted annual mean concentrations are given in Figures 4-3.2a for the near field receptors. The large impact area expands more to the north and northeast in this case. The coverage of 0.2 μg/m^3 contour line is similar to the previous two scenarios. The maximum annual mean concentration is 3.7 μg/m^3, located about 1 km to the north of the emission sources. The peaks of short term second maximums are 28.1, 80.5, and 185.6 μg/m^3 for 24-hour, 3-hour, and 1-hour averaging periods respectively. The peak of second maximum 24-hour average occurs to the northeast of emission sources (Figure 4-1.2c). Its location and magnitude are fairly close to those in Scenario 1. But the pattern of second maximum 24-hour averages near the emission sources is quite different between two scenarios due to the difference between their wind fields (Figures 4-1.1b-d and Figures 4-3.1b-d).

4.4 Scenario 4 - NWS Station Juneau Only

4.4.1 CALMET Modeling

This scenario is the Task B4 in the RFP. The initial meteorological data set is based on the remote NWS station Juneau, which is about 30 km northeast to the emission sources. The purpose of this scenario is to examine whether a data set of remote, non-representative NWS observations would be adequate to initialize CALMET for a regulatory near-field analysis in complex terrain. The bias weighting factor of surface and upper air observations for 10 CALMET layers is set to 0, 0, 0, 0, 0, 0.5, 0.8, 1, 1, 1 for the main domain, and -1, -1, -1, -1, -1, 0.5, 0.8, 1, 1, 1 for the supplemental Juneau domain. Positive bias reduces the weight of surface observation in the initialization of wind at the layer, while the negative bias reduces the weight of upper air observations in the same way. An example of CALMET wind field at the same time as previous cases is given in Figure 4-4.1a. The wind field in this scenario is a good example of terrain adjustment in CALMET. The wind is dominated by the terrain induced down slope flow and valley flow over the land. It is calm over the water. The initial wind at Juneau is calm at this time.

The annual wind roses at Juneau, the Hawk Inlet, and the Mill Site are shown in Figures 4-4.1b-d. At Juneau, the observed wind is well reproduced by CALMET except the calm wind in the observations (21%), which is replaced by weak westerly or easterly flows in CALMET. At the Hawk Inlet and the Mill Site the calm wind in the initial wind is replaced by the corresponding terrain induced wind, mainly in the west-east and the north northeast directions. CALMET wind roses at the Hawk Inlet and at the Mill site show similar characteristics to those at Juneau in this scenario, but these similarities do not exist in their observations. The observations at Juneau NWS station are the only meteorological data source for the first guess of CALMET wind in the entire CALMET domain. CALMET adjusts this first guess wind to reflect the terrain effect. The results of this case indicate that the terrain adjustment is not strong enough to overcome the effect of remote, non-representative station. The possible improvement is to modify the drainage flow in the CALMET for areas in high latitudes, as discussed in Section 4.2.1.

4.4.2 CALPUFF Modeling

The distribution of predicted annual SO_2 concentration in the near field is shown in Figure 4-4.2a. The large impact area is much larger than other scenarios. The impacted area expands more to the south and west of the emission sources. The maximum annual mean concentration is 3.9 $\mu g/m^3$, located to the east of the sources. The peaks of second maximum of 24-hour, 3-hour, and 1-hour averages are 23.0, 74.4, and 187.2 $\mu g/m^3$. The impact in the area to the north of emission sources is much less than the previous three scenarios for these averaging time periods.

4.5 Scenario 5 - 20 km MM5 and NWS Station Juneau

4.5.1 CALMET Modeling

This scenario is the Task B5 in the RFP. In this case, 20 km MM5 data and the observations of NWS station Juneau are used to initialize the CALMET wind field. This scenario was developed as the refinement to

Scenarios 2 and 4. The purpose is to examine whether the use of remote, non-representative NWS station data in conjunction with MM5 data would be adequate to initialize CALMET for a regulatory near-field analysis in complex terrain. An example of CALMET wind field same as the previous cases is given in Figure 4-5.1a. The flow pattern is almost identical to Scenario 2, which is initialized by 20 km MM5 only. Including remote NWS station Juneau in the initialization has little influence on the wind field far away from the station.

The annual wind roses at Juneau, the Hawk Inlet, and the Mill Site are given in Figures 4-5.1b-d. The wind roses at Juneau and the Mill site are almost identical to those in Scenario 1, which is initialized using 20 km MM5 and observations at Juneau and the Hawk Inlet. At the Hawk Inlet, the wind rose is very close to that in Scenario 2, which is initialized using 20 km MM5 data only. Comparing with observations, one can find that the prediction at Juneau is very close to the observed. But at the Hawk Inlet, CALMET fails to predict the northern dominant wind. At the Mill Site, the prediction also misses the dominant northeasterly wind, and the predicted wind speed is too high. The results of this case indicate that the improved MM5 large scale flow and the enhanced drainage flow in CALMET are needed in order to provide adequate wind field for a regulatory purpose, as discussed in Section 4.2.1.

The Mill Site is not included in any scenarios. CALMET predicts dominant easterly wind at the Mill Site in Scenarios 1, 2 and 5 (e.g. Figure 4-1.1d), about 45º clockwise to its observations (Figure 3-5c). The initial wind at this site is from the 20 km MM5 data. The dominant wind of 20 km MM5 data is from southeast with other high frequencies ranging from northeast to south-southeast (Figure 2-4c). Comparing the 20 km MM5 wind rose with CALMET wind rose at this site, one can find that CALMET has significantly adjusted MM5 wind to the direction of the valley in the Mill Site. It squeezes the initial wind into the east-west direction. The valley at the Mill Site in the 250 m grid spacing terrain is almost in the west-east direction, but in the RFP the valley is in the WSW-ENE direction. The CALMET prediction would be improved if the valley direction in the current terrain data can be manually modified to reflect the valley direction in the RFP. The over prediction of wind speed at this site originates from the MM5 initial guess fields. MM5 suffers from the over prediction of wind speed at the surface. Specific processing is needed to resolve this issue. At the Hawk Inlet, CALMET fails to predict the local northern dominant wind in the background flow from southeast. Stronger drainage flow along a valley or a channel is needed to simulate the flow pattern near the Hawk Inlet. In the high latitude areas with ice field nearby, the down slope flow and related drainage flow can be much stronger than those in the low and middle latitudes.

4.5.2 CALPUFF Modeling

The distribution of predicted annual SO_2 concentration is shown in Figures 4-5.2a. The pattern of impact is similar to Scenario 2. The coverage expands more in the south-north direction and contracts in the east-west direction near the emission sources. The maximum annual mean concentration is 1.9 μg/m^3, occurring to the northwest of the sources and very close to the peak location in Scenario 2. The peaks of second maximum of 24-hour, 3-hour, 1-hour averages are 27.1, 106.8, and 150.5 μg/m^3. Their patterns of distribution are similar to those in Scenario 2.

5. CALMET AND CALPUFF SIMULATIONS FOR THE FAR FIELD

The purpose of Section 4 is to search for alternative initial meteorological data sets for the CALMET and CALPUFF model system in complex terrain for the near-field when on-site observations are not available. The far-field regulatory analysis also faces the difficulties of lack of routinely observed meteorological data set in complex terrain areas. It is useful if the CALPUFF modeling system can use the data from other numerical models or from remote NWS stations to provide adequate prediction for the air quality assessment in the far-field. For this purpose, CALMET and CALPUFF have been also applied to a far field area about 50 km south of emission sources for the same five scenarios as in Section 4.

The CALMET domain for the far field region is shown in Figure 3-1. The grid size is 1 km. The locations of 289 CALPUFF discrete receptors are given in Figure 3-6a. The far field receptors are about 60 km south southwest to the emission sources. The CALMET settings are the same as those for the near field areas except grid spacing. But the CALPUFF settings for the far field include the chemical transformation and dry and wet depositions.

The maximum annual SO_2 concentrations for the five scenarios are given in Table 5-1. All maximum concentrations occur at the northeast corner of the far field area. Scenarios 1, 2, and 5 produce similar maximum concentration, about 0.0013 $\mu g/m^3$. Scenario 3 gives the lowest, 0.00097 $\mu g/m^3$, while Scenario 4 gives the highest, 0.004 $\mu g/m^3$. In Scenario 3, the 4 km MM5 wind is used to initialize the CALMET wind. The CALMET wind in this scenario shows more spatial variability and higher wind speed than in Scenario 2. Both spatial variability and high wind speed are favorable to the dissipation of pollutant. The highest prediction in Scenario 4 is caused by the weak wind speed and frequent calm weather condition at Juneau.

The geographical distributions of annual mean concentration are given in Figures 5-1-5.5 for the five scenarios. Similar to maximum concentrations, the distributions for Scenarios 1, 2, and 5 are similar. The concentration decreases from northeast to southwest. The contours line from southeast to northwest in the eastern part of area, turn to almost east-west direction in the western part of area. For Scenario 3, the contours line almost in the north-south direction. For Scenario 4, the contours line in the southeast-northwest direction in the entire far field area. If Scenario 1 represents the base case, Scenario 5 provides the prediction closest to the base case. Predicted annual peak concentration is only about 0.2% less the base case. The on-site station (Hawk Inlet) does not have significant influence on the impact to the far-field area. The prediction of Scenario 2 is also close to the base case, but it over predicts the peak by about 10%. The surface observations at Juneau are used in Scenarios 1 and 5, but not used in Scenario 2. The information provided by the surface observations at Juneau contributes to the close resemblance between the predictions of Scenarios 1 and 5. The results suggest that the combination of model data and remote NWS observations is an adequate initial meteorological data set for the CALMET and CALPUFF modeling system for the far-field regulatory purpose in complex terrain area if on-site observations are not available.

Table 5-1

Maximum Annual Mean SO2 Concentrations in Far Field Domain

Subtask	Receptor	X(km)	Y(km)	Con($\mu g/m^3$)
Subtask B1	289	-880	468	0.001319
Subtask B2	289	-880	468	0.001468
Subtask B3	289	-880	468	0.000968
Subtask B4	289	-880	468	0.004105
Subtask B5	289	-880	468	0.001316

6. ISCST3 AND AERMOD RUNS

In addition to CALPUFF, two other dispersion models have been applied to the near field in this study as a comparison: Industrial Source Complex Short Term dispersion model (ISCST3, Version 99155), and AMS/EPA Regulatory Model (AERMOD, Version 99351). Both AERMOD and ISC are steady-state plume models. The ISCST3 model is based on a steady-state Gaussian plume algorithm. AERMOD accounts for a non-Gaussian vertical distribution in case of convective conditions.

ISCST3 and AERMOD only require the meteorological data at one location. The meteorological input for ISCST3 is a single file with the surface records of wind speed and wind direction, temperature and stability class, as well as mixing height. The meteorological input for AERMOD consists of two files. The surface data file contains observed and calculated surface variables, such as wind speed and wind direction, temperature, surface friction velocity, convective velocity scale, vertical potential temperature gradient in the 500 m layer above the planetary boundary layer (PBL), height of convectively and mechanically generated boundary layer, Monin-Obukhov length, and surface roughness length. The profile data file contains wind speed, wind direction, temperature, $?_?$, and $?_w$, and height at each level. The meteorological data for ISCST3 and AERMOD can be obtained from other models or from observations. In this study, the meteorological data are extracted from the CALMET three dimensional output at a grid nearest to the center of emission sources. Most variables already exist in the CALMET output, such as wind, temperature, Monin-Obukov length. A few variables can be derived for existing variables in CALMET, such as the convective or mechanical boundary layer.

Emission sources used in the ISCST3 and AERMOD simulations are the same as those used in the CALPUFF (Table 3-4). Annual mean SO2 concentrations predicted by ISCST3 for five scenarios are plotted in Figures 6.1a-e. The similar predictions by AERMOD are given in Figures 6.2a-e. The 24-hour, 3-hour, and 1-hour second maximum concentrations are given in Appendices E and F for the entire near-field domain, and in Appendix H for the zoom-in area. The large impact area of annual mean (enclosed by 0.2 µg/m^3) predicted by ISC varies significantly from scenario to scenario. The variability of ISC prediction is much larger than that of CALPUFF. In Scenario 1, the large impact area stretches further south in ISC prediction. In Scenarios 3, it expands north out of domain. In Scenario 4, it becomes a butterfly shape. The patterns of large impact area predicted by AERMOD in the five scenarios show little resemblance to their corresponding predictions in CALPUFF and ISC. The impact area predicted by AERMOD is much smaller than that of CALPUFF or ISC, especially in Scenarios 2, 3, and 5.

The peaks and their locations of annual mean and the second maximums of 24-hour, 3-hour, and 1-hour averages are listed in Table 6-1 for the ISC simulation and in the Table 6-2 for the AERMOD simulation. The peak of annual mean varies from 2.7 to 13.9 µg/m^3 for ISC and from 3.3 to 5.4 µg/m^3. In general, the predicted peak values of ISC and AERMOD are higher that the predictions of CALPUFF. The predictions of ISC are always higher than those of CALPUFF, more than doubled in Scenario 1. For AERMOD, fifteen out of twenty predictions in Table 6-2 are higher than the predictions of CALPUFF.

Table 6-1

ISC predicted SO2 ambient concentration for second maximum of 1-hour, 3-hour and 24-hour averages, and for annual mean in the near field area (Grid size in CALMET: 250 m)

SUBTASK	X Coord	Y Coord	CON.	JDay
	(km)	(km)	($\mu g/m^3$)	
	Annual Mean			
Subtask-B1	-861.824	518.416	13.9	
Subtask-B2	-861.924	519.016	2.7	
Subtask-B3	-861.824	519.316	4.8	
Subtask-B4	-861.924	518.316	5.4	
Subtask-B5	-861.824	518.316	3.7	
	24-Hour 2nd Maximum			
Subtask-B1	-861.824	518.416	85.0	331
Subtask-B2	-861.824	518.416	40.1	61
Subtask-B3	-861.724	519.016	42.9	165
Subtask-B4	-861.824	518.416	70.0	200
Subtask-B5	-861.824	518.416	54.2	141
	3-Hour 2nd Maximum			
Subtask-B1	-861.724	519.016	155.3	128
Subtask-B2	-861.824	518.416	130.4	201
Subtask-B3	-861.724	519.016	126.0	132
Subtask-B4	-861.824	518.416	192.8	191
Subtask-B5	-861.824	518.416	172.5	201
	1-Hour 2nd Maximum			
Subtask-B1	-861.824	518.416	203.0	262
Subtask-B2	-861.824	518.416	158.3	203
Subtask-B3	-861.724	519.016	150.8	162
Subtask-B4	-861.824	518.416	206.1	132
Subtask-B5	-861.824	518.416	189.3	203

Table 6-2

AERMOD predicted SO2 ambient concentration for second maximum of 1-hour, 3-hour and 24-hour averages, and for annual mean in the near field area

(Grid size in CALMET: 250 m)

SUBTASK	X Coord	Y Coord	CON.	JDay
	(km)	(km)	(µg/m³)	
	Annual Mean			
Subtask-B1	-861.624	519.016	5.4	
Subtask-B2	-861.624	518.416	3.3	
Subtask-B3	-861.824	518.416	3.4	
Subtask-B4	-861.524	518.416	5.4	
Subtask-B5	-861.624	518.416	3.6	
	24-Hour 2nd Maximum			
Subtask-B1	-861.524	518.516	35.4	222
Subtask-B2	-861.724	518.416	35.5	149
Subtask-B3	-861.824	518.416	36.9	251
Subtask-B4	-861.524	518.616	27.9	2
Subtask-B5	-861.724	518.416	37.9	281
	3-Hour 2nd Maximum			
Subtask-B1	-861.524	518.516	134.5	185
Subtask-B2	-861.524	518.516	106.7	146
Subtask-B3	-861.524	518.516	84.7	256
Subtask-B4	-861.524	518.516	63.0	90
Subtask-B5	-861.524	518.516	105.9	15
	1-Hour 2nd Maximum			
Subtask-B1	-861.524	518.516	163.8	262
Subtask-B2	-861.524	518.516	125.8	261
Subtask-B3	-861.524	518.516	128.1	256
Subtask-B4	-861.524	518.516	129.2	2
Subtask-B5	-861.524	518.516	148.2	302

7. SUMMARY AND CONCLUSION

The main objective of this study was to evaluate various potential meteorological data sets for a hypothetical regulatory, near-field application in a complex terrain area in Southeastern Alaska. The complexity and magnitude of the terrain features in this study are somewhat extreme, but as such serve as a severe (although a site-specific or at least situation-specific) test of the meteorological models. The meteorological part of the CALPUFF modeling system, CALMET, is initialized using five different meteorological data sets. The Penn State/NCAR MM5 model is used in 4 of the 5 scenarios to initialize CALMET. In Scenario 1, the model is initialized by 20 km MM5 data and one on-site station and one remote NWS station. In the second scenario, only 20 km MM5 data are used to initialize the model. The third scenario uses finer-scale 4 km MM5 data instead of 20 km MM5 data. In Scenario 4, the remote NWS station alone is used in the initialization. In the fifth scenario, the 20 km MM5 data set is added to Scenario 4. CALPUFF is driven by the CALMET meteorological fields to predict pollutant concentrations from two fictitious emission sources in the five scenarios. As a comparison, two different models, ISC and AERMOD, are also used to predict pollutant concentrations for the same scenarios. The meteorological fields driving ISC and AERMOD are point values or profiles extracted from the three dimensional CALMET output in each scenario.

CALMET reproduces well the wind fields at Hawk Inlet and Juneau in Scenario 1 and at Juneau in Scenarios 4 and 5. When the on-site meteorological data at Hawk Inlet are excluded in Scenarios 2 to 5, the predicted wind field at Hawk Inlet show significant differences with observations and with the base scenario (Scenario 1). The predicted maximum impact area and locations also show significant variability among the five scenarios. These results suggest the importance of on-site meteorological observations in the extreme Southeastern Alaska terrain near Juneau. It is possible that finer scale MM5 simulations with highly resolved terrain, may improve the quality of the initial guess field, although additional MM5 simulations could not be performed within the scope of this study. Also, it is expected that MM5 model performance would be improved with the latest version of MM5 (Version 3) that has become available after the start of this study, because of its associated higher resolution terrain dataset and detailed land-surface module.

The results indicate that the CALMET predictions are significantly improved by the presence of the observations in the complex terrain areas. One important factor in the quality of the CALMET final wind fields when the onsite observations are excluded is the first guess field used initialize the model. Due primarily to the inability of MM5 with 20 km and 4 km grid cells to resolve the detailed terrain in the Juneau area, the near-surface MM5 fields showed significant differences with the observations, which were carried through to the CALMET fields. CALMET did adjust the winds to reflect the fine scale terrain it resolved, but there may be an underestimation of the magnitude of the slope flows due to some special factors in the Alaskan domain (i.e., the presence of glaciers).

Initializing CALMET with the MM5 data set only (Scenarios 2 and 4) generally did not produce surface wind fields that matched the onsite measurements. This in turn, led to differences in the predicted concentration patterns produced by the dispersion models. The wind field model results in Scenarios 1-3 and 5 depend on how well MM5 can resolve the terrain and land use properties. Significant difference between observed and predicted winds can occur when MM5 cannot resolve corresponding complex terrain features. In Scenario 4, the wind field results depend on reasonably representative NWS station data to initialize CALMET. In this case, the observed wind rose from the Juneau NWS site showed large differences with the observed onsite data. Although initializing CALMET with the MM5 data set only led to mixed results, this may be more an indication that better resolution of the terrain is needed for predicting the near-surface wind flow properly in the complex terrain in the Juneau area, than any fundamental limitation of the prognostic model. Also, the MM5 results shows a tendency for the MM5 surface wind speeds to be overpredicted. This suggests an adjustment in CALMET of the vertical MM5 wind profile may improve the quality of the final CALMET winds when MM5 data are used as the initial guess field. The Juneau results also suggest that the drainage flow algorithm in CALMET could be improved to reflect high latitude conditions (e.g., the presence of glaciers and icefields).

In Scenario 4, CALMET predicts the winds at the Hawk Inlet similar to be similar to those at Juneau, but the observations at these two sites are different. This suggests that when a remote station is used for the initialization, it needs to be at least somewhat representative of the region of interest within the modeling domain.

CALPUFF predicted impact areas in the near field are similar in general for the five scenarios, but the peaks and their locations of annual mean, the second maximum 24-hour, 3-hour, and 1-hour averages vary from scenario to scenario. The predictions range from 1.7 (Scenario 2) to 5.8 μg/m^3 (Scenario 1) for the annual means. For the short term averages, the predictions vary about 1-2 times. Compared with ISC and AERMOD predictions, CALPUFF predictions are more stable with different meteorological fields. The high impact area in ISC and AERMOD can change significantly from scenario to scenario. This suggests the ISC and AERMOD models may be more sensitive to onsite data, which is reasonable given that these are both steady-state models that do not allow for horizontal variations in the wind fields. The peak values predicted by ISC and AERMOD are usually higher than those predicted by CALPUFF.

The results of this study suggest that for the complex terrain environment in the Juneau area, the ideal initial meteorological data set should include on-site observations and a large scale model dataset on a resolution of around 20 km or less. When the data set from a remote station or prognostic model data alone are the only choices, verification is needed to determine whether the selected datasets adequately represent the flow in the region of interest.

8. EXECUTIVE SUMMARY

This study evaluated the use of various meteorological data sets in a regulatory-type, near-field air quality modeling application in areas of extreme complex terrain in Southeastern Alaska, using the CALPUFF, AERMOD and ISCST3 dispersion models. A particular focus of the study was whether adequate modeling results could be obtained using only large-scale, regional meteorological data (MM5 data). The study also looked at the use of only remote data obtained from a single National Weather Service (NWS) station, and a combination of MM5 and remote NWS data. In addition to evaluating near-field applications (ambient impacts within areas fairly near the emission sources), the study also compared the far-field (distant) ambient impacts using the CALPUFF modeling system. The following discussion summarizes the reasons for conducting the study, the basic components of the study, and the results.

The study was conducted in an effort to evaluate alternative approaches to modeling emission sources located in areas with no or inadequate local meteorological data. Regulatory modeling applications within Alaska are frequently hampered by the lack of routinely available, adequately representative meteorological data. This is due in part to the limited number of both NWS and other meteorological observation stations within the State. In addition to the limited number of observation sites, Alaska has extensive areas with extremely complex terrain. Therefore, the meteorological data collected at stations located within these complex terrain areas only represent the meteorological conditions within a very limited range. This lack of representative meteorological data has forced New Source Review (NSR) permit applicants to either use conservative screening data in their air quality modeling analysis, or to take the time and expense to collect at least one year of site-specific meteorological data.

Modeling air quality impacts in areas with extensive complex terrain can also provide unrealistic results when using the standard NSR dispersion model, ISCST3. To address this problem, the U.S. Environmental Protection Agency (EPA) has proposed case-by-case use of the more advanced CALPUFF modeling system for modeling near-field impacts in "areas with complex wind flows" (i.e., complex terrain). However, the use of the CALPUFF modeling system may still require the use of local (site-specific) meteorological data. In this case, a network of meteorological towers would be required to provide adequate data for widespread regulatory modeling in Alaska. This need for site-specific data would place a significant resource burden (time and money) either on permit applicants or on the State.

Recent modifications to the CALPUFF modeling system have opened the possibility of using only regional, three-dimensional meteorological fields developed from the fifth generation of the Mesoscale Meteorological Model (MM5) for near-field modeling applications. The CALPUFF modeling system includes a diagnostic meteorological model, CALMET, which could then be used to estimate localized wind-fields from the regional MM5 data, terrain data, and land-use data. The CALPUFF modeling system provides the potential to solely rely on modeled wind-fields instead of site-specific meteorological data for near-field regulatory applications.

This study was conducted to evaluate the adequacy of several potential meteorological data sets that could be produced by CALMET. To provide a worst-case test, the study focused on an area within Southeast Alaska. This area has extremely complex terrain due to numerous mountains and fjords. Southeast Alaska was also selected since an existing MM5 data set with 20 km grid spacing covering this region was available from a previous study conducted on behalf of British Columbia and Alberta. Site-specific and NWS data are also available.

The study centered around Hawk Inlet, which is located on the Chatham Strait side of Admiralty Island. Kennecott Greens Creek Mining Company (KGCMC) operates a loadout facility there and provided data from a meteorological tower located at the inlet. KGCMC also provided meteorological data from their mine/mill site, which is located in a steep, enclosed valley, approximately 8 km from the Hawk Inlet site. Remote NWS surface data was available from the Juneau airport, which is located approximately 30 kilometers from the Hawk Inlet Site. The Juneau airport (NWS site) is located on the continental mainland at the confluence of Gastineau Channel and the Mendenhall Valley.

The study compared the modeled wind-fields using CALMET to the actual observed wind-fields. The study also assumed that two fictitious emission sources were operating at Hawk Inlet. This allowed for a comparison of the dispersion modeling results using the various meteorological data sets. The meteorological data sets included: Hawk Inlet, Juneau NWS and 20 km MM5 data (Scenario 1 - base case); 20 km MM5 data (Scenario 2); 4 km MM5 data (Scenario 3); Juneau NWS data (Scenario 4); and Juneau NWS data and 20 km MM5 data (Scenario 5)

The study found that representative, site-specific meteorological data are needed for the complex terrain situation found in the Juneau area. The use of just 20 km or 4 km MM5 data (Scenarios 2 and 3), remote NWS data (Scenario 4), and remote NWS data along with 20 km MM5 data (Scenario 5) all produced wind characteristics that did not match the observed winds at Hawk Inlet. The same is true when comparing the modeled wind characteristics with the winds observed at the Mill Site. The generality of these conclusions, however are limited to the conditions and grid resolutions tested, as the model performance is highly sensitive to the ability of the grid resolution of the MM5 model to capture the specific terrain features in the application and/or the representativeness of the offsite station in representing the local flow conditions.

A comparison of the magnitude and location of the predicted maximum impacts also shows that the alternative meteorological data sets (Scenarios 2-5) produce significant variability from the base case in the predicted regulatory concentrations. For this study, the base case (Scenario 1) results are used as the reference concentrations when comparing the maximum concentrations obtained with a given dispersion model (i.e., CALPUFF, ISCST3 or AERMOD). Looking at the annual average concentrations obtained when modeling with CALPUFF, all of the maximum impacts for the alternative scenarios are less than 70% of the base case maximum. The location of these impacts ranged from 500 to 1500 meters from the location of the base case maximum. Most of the short-term impacts also have significant differences with the base case, although some of the maximum 3-hour and 1-hour impacts using CALPUFF overpredict rather than underpredict the base case maximum.

This study does not excluded the possibility in the general case of using prognostic model data in observation-sparse areas or remote offsite data to initialize the diagnostic model. It does indicate the need for a detailed examination of the representativeness of the available datasets to characterize the specific features of the flow field considered important in the local area of interest. Further study should concentrate on finer scale MM5 simulations (grid spacing of 1-2 km) in a small area around sources (with 50 km), better characterization of the land surface characteristics (e.g., glaciers in the Juneau area) and on the improvement of drainage flow at high latitudes in CALMET. Also, a more representative offsite station, even in the absence of fine-scale MM5 data, is likely to improve the initial guess field, and the final wind fields.

9. REFERENCES

Scire, J.S., F.R. Robe, M.E. Fernau and R.J. Yamartino, 1999: A User's Guide for the CALMET Meteorological Model (Version 5). Earth Tech, Inc., Concord, MA.

Scire, J.S., D.G. Strimaitis and R.J. Yarmartino, 1999. A User's Guide for the CALPUFF Dispersion Model (Version 5.0). Earth Tech, Inc., Concord, MA.

Grell, G.A., 1993: Prognostic Evaluation of Assumptions used by Cumulus Parameterizations Mon. Wea. Rev., **121**, 764-787. J. Dudhia and D.R. Stauffer, 1994: A Description of the Fifth Generation Penn State/NCAR Mesoscale Model (MM5). NCAR Tech. Note, NCAR/TN 398+STR, 138 pp.