FINAL REPORT

AN ANALYSIS OF THE ATMOSPHERIC DISPERSION OF RADIONUCLIDES RELEASED FROM THE IDAHO CHEMICAL PROCESSING PLANT (ICPP) (1957-1959)

Contract No. 200-2002-00367
Task Order No. 1, Subtask 5

A Report to the
Centers for Disease Control and Prevention
Atlanta, Georgia 30335

SENES Consultants Limited
121 Granton Drive, Unit 12
Richmond Hill, Ontario, L4B 3N4, Canada

SENES Oak Ridge, Inc.
102 Donner Drive
Oak Ridge, Tennessee 37830

SC&A, Inc.
6858 Old Dominion Drive, Suite 301
McLean, Virginia 22101

Authors:

Zivorad Radonjic / SENES Consultants Limited
Ron Stager /SENES Consultants Limited
A. Iulian Apostoaei / *SENES* Oak Ridge, Inc.

July 2005

EXECUTIVE SUMMARY

This report describes the estimation of air concentrations arising from radionuclide emissions during the 1957-1959 period from Idaho Chemical Processing Plant (ICPP) at Idaho National Engineering Laboratory (INEL). The air concentrations are a component in the assessment of radioactive dose arising from these emissions. The air concentrations were estimated using atmospheric dispersion modeling and incorporated uncertainty analyses to provide quantitative confidence intervals on the estimated air concentrations. The distributions of air concentrations developed from the uncertainty analysis were subsequently used in a pathways analysis and dose assessment.

INEL, established in 1949 as the National Reactor Testing Station, started operating the ICPP in 1953. Radionuclides were released from the ICPP during the Radioactive Lanthanum (RaLa) operations at the ICPP that began on Feb. 1, 1957 with the largest amount of radioactivity released between Feb.1, 1957 and Dec. 31, 1959. The emission rates generally decreased over this time period.

The emissions from the RaLa operations included more than 130 radionuclides. A previous screening analysis (Kocher 2005a, b) determined that ^{131}I was by far the most important radionuclide in regard to potential radiation doses to members of the public who resided near INEL during the years 1957-1959. Twelve additional radionuclides of potential concern have also been selected for inclusion in a more detailed dose reconstruction. Air concentrations were estimated using uncertainty analyses for all thirteen radionuclides; however, discussion in this report primarily concerns ^{131}I.

The CALPUFF/CALMET system of computer codes was used to perform the atmospheric transport calculations due to the complex terrain, and meteorology, in the area and the ability to estimate meteorological conditions with limited measurement data during the 1957-1959 period. There was also good agreement between the estimated air concentrations using CALPUF/CALMET and measured concentrations from recent tracer studies.

Discrete receptors were identified for the uncertainty analysis of air concentrations to support the dose assessment. A systematic grid was established for deterministic modeling of air concentrations and creation of contour plots of the concentrations.

Sources of uncertainty included the emission rates, the selection of options when running the air dispersion model, and the effect of uncertainty in the meteorological conditions during the 1957-1959 period on the estimated air concentrations. Meteorological data are only available for three surface air stations during the 1957-1959 period. This uncertainty was quantified by comparing air dispersion modeling conducted in 1999 using these three stations and air dispersion modeling using a more extensive network of 25 stations, not available in 1957-1959. The uncertainty observed in 1999 was used when conducting uncertainty analyses using the air dispersion modeling with three stations during the 1957-1959 period.

The uncertainty analyses comprised 500 simulations of monthly average air concentrations arising from uncertainty analyses on hourly air dispersion modeling. A review of the results indicated the relative contributions to uncertainty depended on the receptor location and time period. The relative contribution from release rates tended to be higher with longer averaging times. The contribution from meteorological uncertainty was generally higher for averages over shorter time periods and for locations that were infrequently downwind from the ICPP. An interesting outcome was that there were shifts from typical concentrations estimated only with three surface meteorological stations to the values adjusted for the differences if 25 stations were available. There was a tendency for concentrations to increase at some receptors but decrease at others as the result of differences in concentrations predicted with 3 and 25 meteorological stations.

TABLE OF CONTENTS

APPENDICES

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

The Idaho National Engineering Laboratory (INEL), established in 1949 as the National Reactor Testing Station, started operating the Idaho Chemical Processing Plant (ICPP) in 1953, for recovering uranium from spent nuclear fuel. The Radioactive Lanthanum (RaLa) operations at the ICPP began on Feb. 1, 1957. The RaLa process was designed to extract lanthanum-140 (^{140}La; half-life of 40.2 hours) from irradiated reactor fuel, an isotope used to evaluate the implosion process of a nuclear weapon. The short half-lives of ^{140}La and its radioactive precursor ^{140}Ba (12.9 days) required a chemical process in which fuel elements irradiated in a nuclear reactor were dissolved shortly after irradiation.

Gases and aerosol particles generated during RaLa dissolution and extraction processes were captured by an off-gas system, and then passed through a series of scrubbers and charcoal beds to a temporary 10,000-ft^3 storage tank. Before gases and aerosols were released to the atmosphere through the 250-ft ICPP stack, they were diluted by mixing with large amounts of the air from the ICPP building ventilation system, which created a total output flow rate of about 100,000 ft^3 per minute.

Due to the short decay time after irradiation of the fuel, the gases and aerosol particles from RaLa operations carried more than 130 radionuclides, which were released into the atmosphere. The largest amount of radioactivity released from the RaLa operations occurred from February 1957 to December 1959. During this period, essentially all releases from the ICPP were due to RaLa process operations.

A screening analysis (Kocher 2005a, b) determined that ^{131}I was by far the most important radionuclide in regard to potential radiation doses to members of the public who resided near INEL during the years 1957-1959. Twelve additional radionuclides of potential concern were also selected for inclusion in a more detailed dose reconstruction.

This report describes the analysis of the atmospheric dispersion of the radionuclides released from the ICPP from 1957 to 1959. This analysis was performed as part of the effort of estimating radiation doses for members of the public living around INEL during the years of release. Due to overwhelming importance of ^{131}I as compared to the other radionuclides released from the ICPP from 1957 to 1959, this analysis focuses on estimation of the concentration of ^{131}I in air at selected locations in the INEL extended region. The modeling of the atmospheric transport for other radionuclides is only described very briefly.

The CALPUFF/CALMET system of computer codes was used to perform the atmospheric transport calculations. The CALPUFF/CALMET systems are described in Chapter 2.0. Site-specific meteorological data was collected from the National Oceanic and Atmospheric Administration (NOAA) for 1957-1959, and also for 1999 (See Chapter 2.2.1). The more abundant data for 1999 was used to demonstrate the capability of CALMET, with a limited number of surface stations as input, to generate three dimensional wind fields. Once the comparison was done, CALMET was applied for the periods of interest as described in Section 2.3.2.

To insure that the CALPUFF/CALMET computer codes are able to accurately predict the air concentration in the INEL environment, a validation exercise was performed using data collected in 1999 during an exercise in which sulfur hexafluoride tracer (SF_6) was released on the INEL site under controlled conditions. The results of the validation exercise indicate a very good performance of the CALPUFF/CALMET system for the time-averaged air concentrations, which are needed for estimation of radiation dose to the members of the public. The SF_6 tracer study and CALPUFF results are described in Chapter 3.0.

2.0 MODELING METHODOLOGY

The U.S. Environmental Protection Agency (U.S. EPA) Guideline on Air Quality Models (40 CFR 51, Appendix W) currently recommends the Industrial Source Complex Short-Term (ISCST3) model for simple terrain settings. Recently, the U.S. EPA has approved the CALPUFF modeling system, for use as a regulatory model for long-range transport and complex wind situations (e.g., complex terrain). The CALPUFF model has been developed using more up-to-date mathematical formulations for atmospheric dispersion and deposition.

Considering the location and the complex terrain around the INEL site, the alternative model (CALMET/CALPUFF) is more suitable in this kind of study than the simple Gaussian Model. The limited input of meteorological data for 1957-1959 period suggested use of the more extensive Meso-West network for 1999 to validate the performance of CALMET wind field creation with limited surface observations as an input. Comparison of these wind fields provides an indication of the uncertainty present in wind fields during 1957-1959 when only 3 surface air stations are available.

2.1 CALPUFF MODELING SYSTEM

CALPUFF is a non-steady-state air quality modeling system developed by Sigma Research Corporation (now part of Earth Tech, Inc.). The CALPUFF modeling system consists of three sub-systems: 1) a meteorological modeling package (CALMET) which includes a diagnostic wind field generator; 2) a Gaussian puff dispersion model (CALPUFF) with chemical removal, wet and dry deposition, complex terrain algorithms, building downwash, plume fumigation, and other effects; and, 3) post-processing programs (CALPOST) for the output of meteorological data, concentration and deposition fluxes.

The original development of the CALMET/CALPUFF models was sponsored by the California Air Resources Board (CARB) and is supported by the U.S. Environmental Protection Agency (U.S. EPA). Both the CALMET and CALPUFF models have been enhanced as part of work conducted for the Interagency Workgroup on Air Quality Modeling (IWAQM), the U.S. EPA, the U.S. Forest Service, the U.S. National Park Service, the U.S. Fish and Wildlife Service, and private industry in the United States and abroad. In June 2000, the U.S. EPA proposed including the CALPUFF modeling system as a *Guideline* model for regulatory applications involving long range transport and on a case-by-case basis for near-field applications where non-steady-state effects (i.e., situations where factors such as spatial variability in meteorological fields, calm winds, fumigation, re-circulation or stagnation, and terrain or coastal effects) may be important.

The CALPUFF modeling system was designed to address the following specifications:

- The capability to treat time-varying point and area sources
- Suitability for modeling domains from tens of meters to hundreds of kilometers from a source

- Predictions for averaging times ranging from one-hour to annual
- Applicability to model inert pollutants and those subject to linear removal and chemical conversion mechanisms
- Applicability to rough or complex terrain

The CALMET model is a meteorological model which includes a diagnostic wind field generator containing objective analysis and parameterized treatments of slope flows, kinematic terrain effects, terrain blocking effects, a divergence minimisation procedure, and a micrometeorological model for over land and over water boundary layers. CALMET develops hourly wind and temperature fields on a three-dimensional gridded modeling domain, which incorporates the effects of terrain on wind, flow. Associated two-dimensional fields such as mixing heights, surface characteristics and dispersion properties are also included in CALMET. The three-dimensional (3-D) wind field can be developed in CALMET using observations from several meteorological monitoring stations in the vicinity of the emission source. Alternatively, if there are no suitable surface-monitoring data available for the area, CALMET has the option to import prognostic wind field data produced by the MM5/MM4 (Penn State/NCAR Mesoscale Model) models.

CALPUFF is a transport and dispersion model that advects a discrete number of packets of pollutant material (i.e., "puffs") emitted from modeled sources to represent the continuous plume, simulating dispersion and transformation processes along the way. Temporal and spatial variations in the meteorological fields derived from CALMET are explicitly incorporated in the resulting distribution of puffs throughout the simulation period. Alternatively, CALPUFF can be run with meteorological data from a single monitoring station as with other commonly available regulatory Gaussian plume dispersion models. In a situation where wind direction would carry a plume from the source towards a receptor on a hill, the 3-D wind field in CALPUFF would determine whether that puff release will be carried over or around the hill, while a standard Gaussian plume model, using wind direction derived from a single meteorological monitoring site, would predict the flow to be over the hill in all cases.

The use of CALPUFF for this application is, according to the proposed U.S. EPA Guideline, an alternative refined model use. The use of the CALPUFF model is considered appropriate because:

- The CALPUFF model has the ability to develop three-dimensional, regional wind fields from the limited surface observation data in a complex terrain setting. CALPUFF has received considerable peer review both in a formalised U.S. EPA process (Allwine et al., 1998) and in statements made at the 7th Modeling Conference (June 2000). Each of the reviews urged the use of CALPUFF for modeling impacts at distances shorter than 50 kilometers.

- On a theoretical basis, CALMET and CALPUFF are applicable to the flat and complex terrain setting in the vicinity of the INEL site, and the model produces results that are comparable to the ISCST3 model, which is currently the regulatory model of choice.

    (1) The relatively few available comparisons between ISCST3 and CALPUFF for short-range applications have shown that CALPUFF often predicts higher concentrations than ISCST3. The higher predicted ambient concentrations result from the CALPUFF model's treatment of calm winds and stagnation conditions, which lead to higher ambient concentrations. Therefore, it can be expected that the CALPUFF model would not underestimate air quality impacts in the current application.

2.2 CALMET MODEL

A major reason for selecting the CALMET/CALPUFF modeling system to model emissions of ^{131}I from the INEL was that CALMET can produce a reasonable wind field based on a limited amount of surface observation data in the modeling domain. The CALMET model uses all available meteorological data within a defined modeling domain to compute gridded wind fields. CALMET requires, at a minimum, one surface station and one upper air (sounding) station with at least two upper air soundings each day. There must also be wind and temperature data at the bottom and top layer of the modeling domain.

For the current analysis, the CALMET model was used to develop a one-year data set - 1999 of hourly wind fields for the comparison of the wind fields with the yearly data sets for 1957, 1958 and 1959 to be used in the CALPUFF dispersion model.

The CALMET model was run in a coarse grid resolution (4km grid spacing) for a 320 x 320 km modeling domain around INEL site. This grid was used for developing contour plots (isopleths) of air concentration. Discrete receptors were identified for the purposes of dose estimation. Table 2.1 shows the hourly surface meteorological stations, the upper air stations and precipitation stations used in analysis of the 1957-1959 data sets. The dispersion modeling domain is depicted in Figure 2.1 along with locations of surface and precipitation data available in 1957-1959.

The input to the CALMET model requires a control file that defines the wind field grid parameters and model option switches, surface and upper air meteorological data, land use data and terrain data.

Table 2.1 Surface, upper air, and precipitation meteorological stations used as input into the CALMET modeling domain for 1957-1959

No.	Station	Station No.	Latitude	Longitude
	Surface Stations			
1	North- LOFT/TAN	10000*	43.859	112.730
2	South – CFA	10055*	43.532	112.948
3	Pocatello	24156	42.917	112.600
	Upper Air Stations			
1	Boise	24131	43.57	116.22
2	Lander	24021	42.82	108.73
3	Salt Lake City	24127	40.77	111.97
	Precipitation Stations			
1	Idaho Falls – 2ESE	n/a	43.483	112.02
2	Idaho Falls – 46W	n/a	43.553	112.950
3	Pocatello Municipal Airport	24156	42.917	112.600

Note: * - assigned
n/a - not assigned

Figure 2.1 Surface stations and precipitation stations used as input into CALMET

Figure 2.1a: Surface Stations

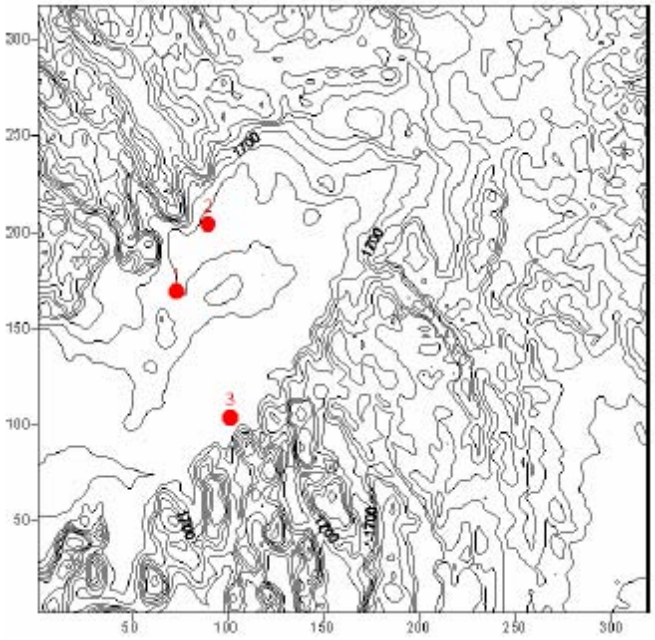
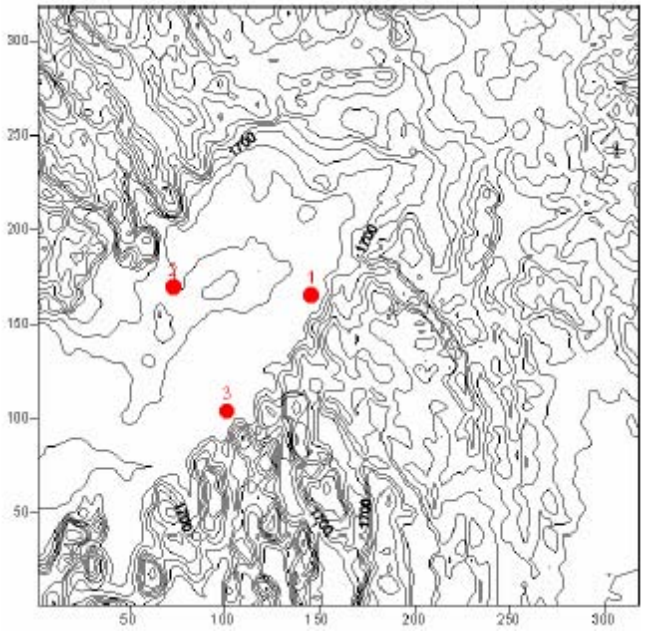


Figure 2.1b: Precipitation Stations



Note: SW Corner of the domain is at (lat=41.96 deg., long=113.89 deg) of UTM Coordinates (Easting = 260,000 km, Northing = 4650,000 km, UTM Zone=12). Axis values are in kilometres.

2.2.1 Meteorology

Meteorological data for 1957-1959 from the two weather stations located within the INEL borders were obtained from the National Oceanic and Atmospheric Administration (NOAA) in Idaho Falls (Clawson 2002). Hourly data are reported for wind speed, wind direction, and temperature. The more complete data are from the weather station at the Central Facilities Area (CFA), which is near the ICPP (labeled the South station). The second (North) station is for the Test Area North (TAN), at the IET site. The data were collected at elevations of 20' and 250' at the South station and at 20' and 150' at the North station. In addition to these two stations, meteorological data for the years of interest were obtained for Pocatello and Idaho Falls, as well as from stations at Boise, Lander and Salt Lake City for upper atmosphere data.

Table 2.1 shows the hourly surface meteorological stations, the upper air stations and precipitation stations used in analysis of the 1957-1959 data sets.

Ten vertical layers were included for the development of the 3-D wind field. The layer heights considered are shown in Table 2.2.

Table 2.2 Vertical layers used in CALMET modeling

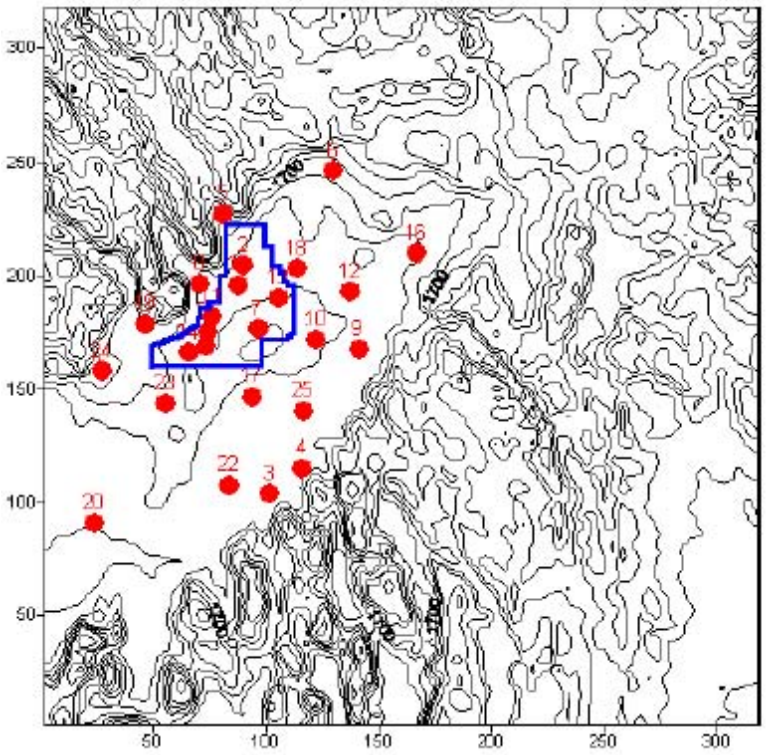
Vertical Height of Layer (metres)	Height at Top of Layer (metres)
20	20
20	40
40	80
60	140
60	200
50	250
500	750
1250	2000
500	2500
500	3000
500	3500

This pattern of rising layers follows the guidance from the CALMET user's manual in terms of gradually increasing layer depth with height. Mixing heights developed by SENES using the CALMET model[1] for upper air monitoring stations at Boise, Lender, and Salt Lake City were reviewed to ensure that the top of the 3-D wind field grid was well above climatological mixing heights.

[1] *A Mixing Height Study for North America (1987-1991)* (SENES 1997)

A complete set of meteorological data for 1999 was obtained from NOAA (Clawson 2002) for 25 stations in and around the INEL site. This data was used for validation of CALPUFF with tracer study data from 1999 and to quantify the uncertainty in air dispersion modeling present if only three stations are available as was the case in 1957-1959. The locations of these stations are shown in Figure 2.2 and include the locations of the three stations with data in 1957-1959 (number 1 to 3 on the figure). The data contains hourly data (when available) of mean wind speed, mean (vector) wind direction, mean temperature, and total precipitation during the year 1999.

Figure 2.2 Surface stations used in 1999



Surface Stations

Names	ID	SENES-No	Map No.
CFA-Building 690	CFA	10000	1
LOFT/TAN	TAN	10080	2
Pocatello	POC	24156	3
Fort Hall	FOR	10010	4
Blue Dome	BLD	10020	5
Dubois	DUB	10030	6
EBR2	EBR2	10040	7
Howe	HOW	10050	8
Idaho Falls	IDF	10060	9
Kettle Butte	KET	10070	10
Naval Reactor Fac.	NRF	10090	11
Roberts	ROB	10100	12
Rover	ROV	10110	13
RWM	RWMC	10120	14
Sand Dunes	NDD	10130	15
Sugar City	SUG	10140	16
Taber	TAB	10150	17
Terreton	TER	10160	18
Arco	ARO	10011	19
Minidoka	INI	10081	20
GRID3	RID	10041	21
Aberdeen	ABD	10012	22
Big Southern Butte	BSB	10013	23
Craters of the Moon	COM	10021	24
Blackfoot	FOO	10014	25

2.2.2 Land Use Data

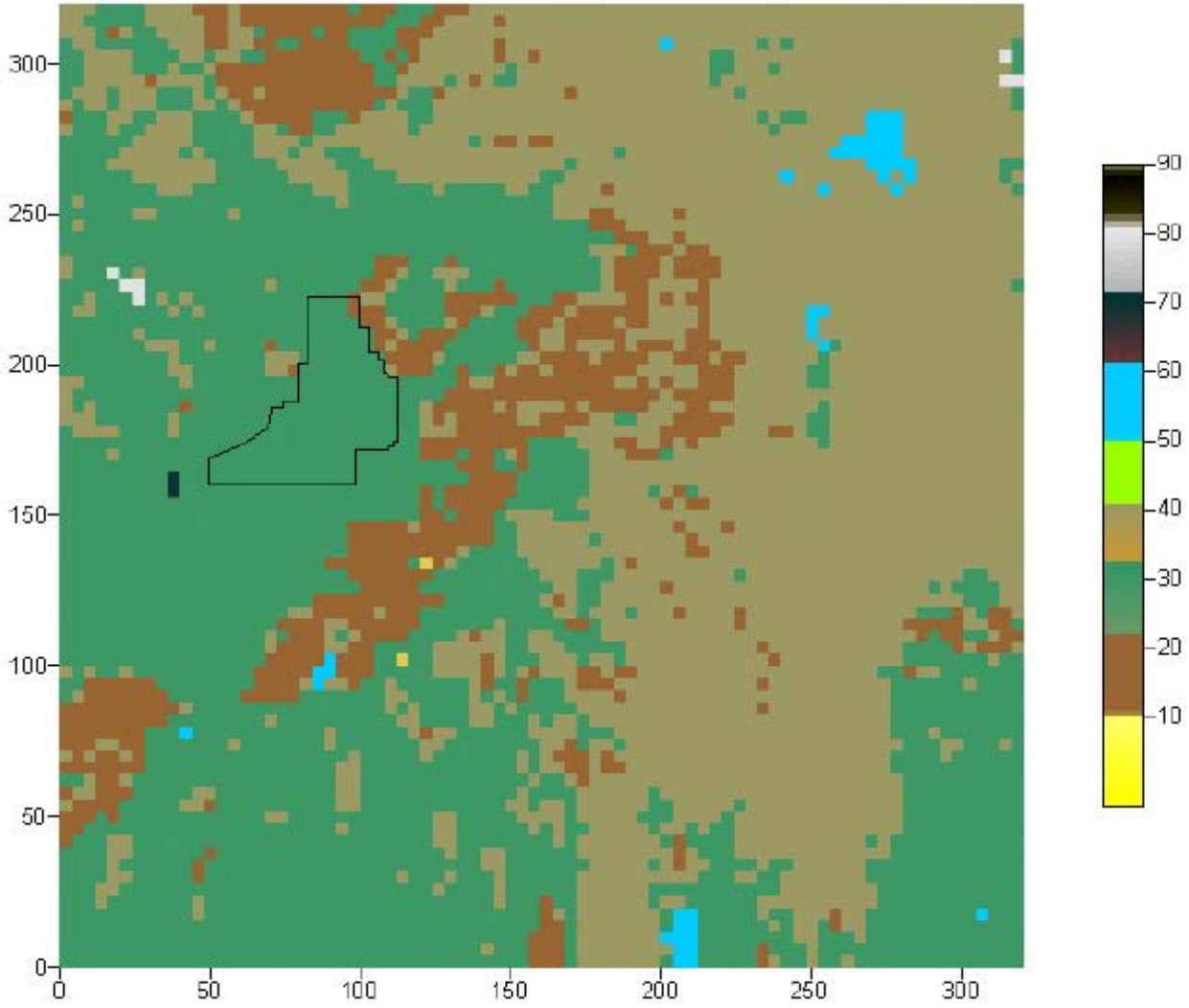
The data for the fine modeling domain were based on the land cover data obtained from USGS based on ~900 m resolution GTOPO data set.

The land use categories for use in CALMET are based on the USGS land use classification system. These categories are listed in Table 2.3, below. The land use data, after processing by CALMET, are presented in Figure 2.3.

Table 2.3 CALMET land use categories based on the U.S. Geological Survey Land Use and Land Cover Classification System (52-category system)

Level I		Level II	
10	Urban or Built-up Land	11	Residential
		12	Commercial and Services
		13	Industrial
		14	Transportation, Communications and
		15	Utilities
		16	Industrial and Commercial Complexes
		17	Mixed Urban or Built-up Land
			Other Urban or Built-up Land
20	Agricultural Land — Unirrigated	21	Cropland and Pasture
		22	Orchards, Groves, Vineyards, Nurseries, and Ornamental Horticultural Areas
		23	Confined Feeding Operations
		24	Other Agricultural Land
!20	Agricultural Land — Irrigated	!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	Non-forested 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

Figure 2.3 Land use data processed through CALMET with approximate outline of Idaho National Engineering Laboratory property line

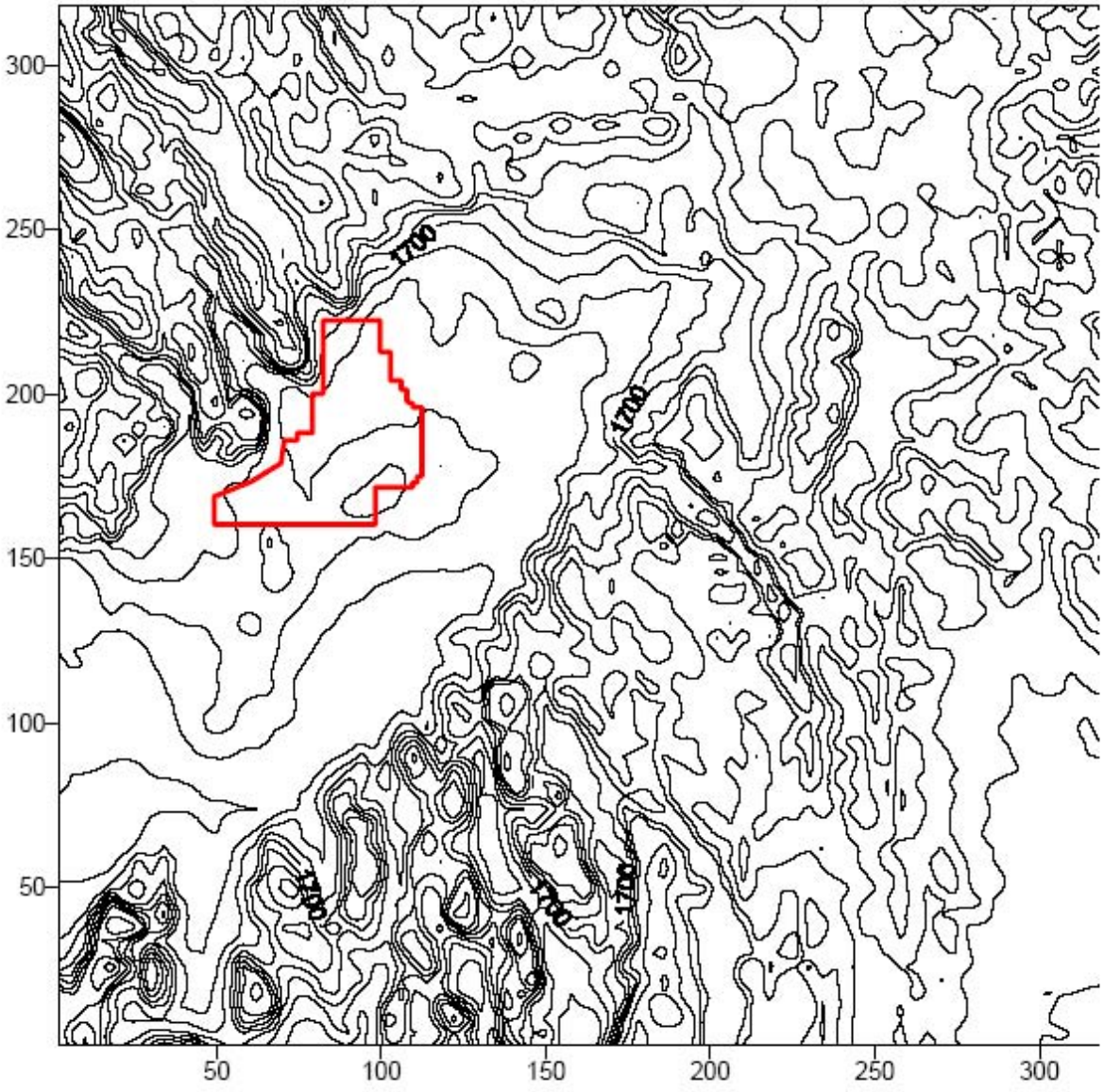


Note: Approximate Coordinates of INEL Property Line
Colours correspond to categories as in Table 2.2

2.2.3 Terrain Data

The GTOP digital elevation maps (DEM's) (~900 m spacing) were downloaded from the USGS Web Site and used for the coarse wind field grid. The digital elevation model (DEM) data were processed to conform to CALMET formats using the terrain-processing program, TERREL that is provided with the CALMET/CALPUFF modeling system. A depiction of terrain data used in this analysis is presented in Figure 2.4.

Figure 2.4 Terrain data with Idaho National Engineering Laboratory property line



2.2.4 CALMET Switches

The CALMET dispersion model has optional algorithms and approaches for meteorological processing that are specified in the control file. Options, or algorithms, are specified as "switches" in the control file. Switch settings for the deterministic run are provided in Section 2.5.1 and switch settings for the probabilistic runs are provided in Section 2.5.2.

A sample CALMET input file with similarity theory for vertical wind extrapolation for January 1957 is presented in Appendix A.

Computer Hardware and Operating System

The operating system is Linux – Mandrake 8.2 installed on the Pentium IV, 1.7 GHz personal computer. The CALMET/CALPUFF model was compiled with Portland Group Fortran Compiler (PGF) with the Optimization Zero. An advantage of the Linux/PGF system is the handling of the large file sizes developed in this project.

Selected results from the Linux model runs were compared against Windows based CALMET/CALPUFF to ensure the same results were produced.

2.3 CALMET RESULTS

2.3.1 CALMET Results for the 1957-1959 Period

CALMET runs were executed for the entire period 1957-59 and the results are presented in this Chapter. As an example, to illustrate the capabilities of the model, 1958 was chosen for more detailed presentation of results.

Actual meteorological observations were compared to CALMET predictions at the closest CALMET grid points. Figure 2.5 presents comparison for the South – CFA meteorological station and grid point (18,42) for 1958. Figure 2.6 shows similar comparison for the North – TAN meteorological station and grid point (22,51) for 1958.

Figures 2.7 and 2.8 show examples of the hourly snap shots of the wind fields predicted by CALMET. Figure 2.7 shows an hour with complex wind patterns where winds “drain” from many directions into the basin with flow generally towards the southwest. Figure 2.8 shows an hour where the wind fields are predicted to be uniformly towards the northeast throughout the modeling domain.

Examples of measured wind flow patterns are presented in Figures 2.9, 2.10 and 2.11. These examples were selected to demonstrate the complexity of the wind flow around the INEL site and to confirm the complexity of wind fields predicted using CALMET.

Figure 2.5 Wind Rose comparison for CFA Meteorological Station

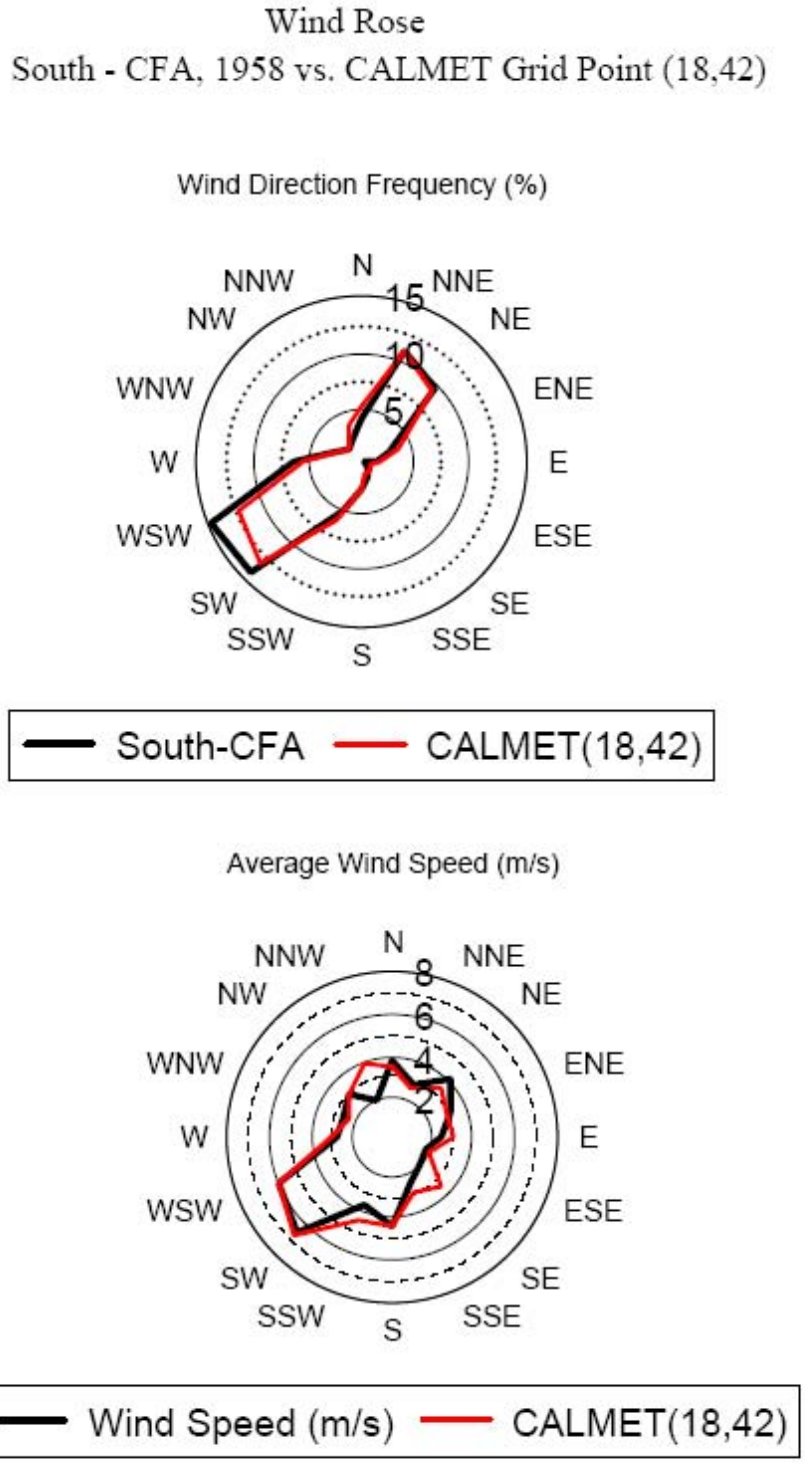


Figure 2.6 Wind Rose comparison for TAN Meteorological Station

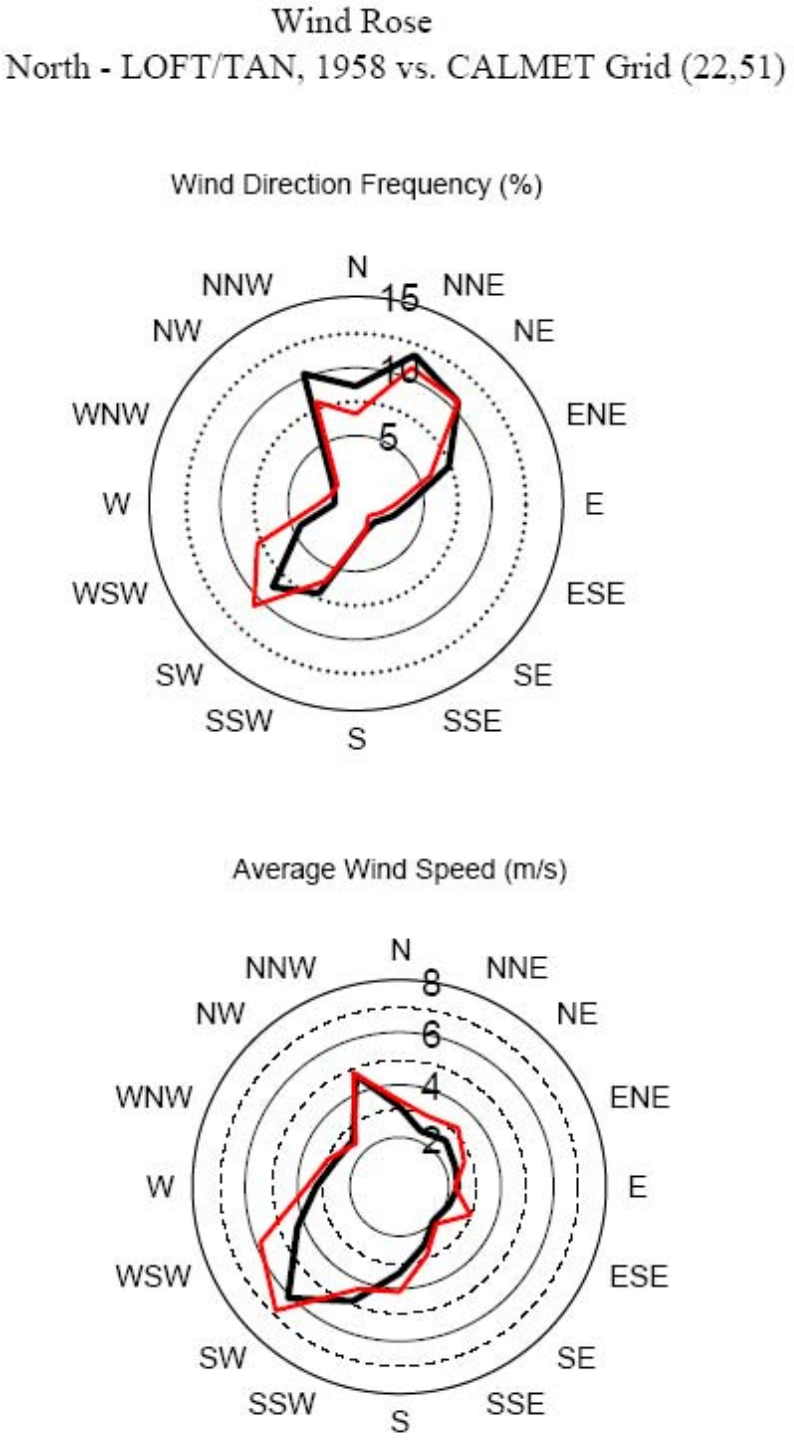


Figure 2.7 Example of wind flow vectors for July 25, 1958 at 00: 00

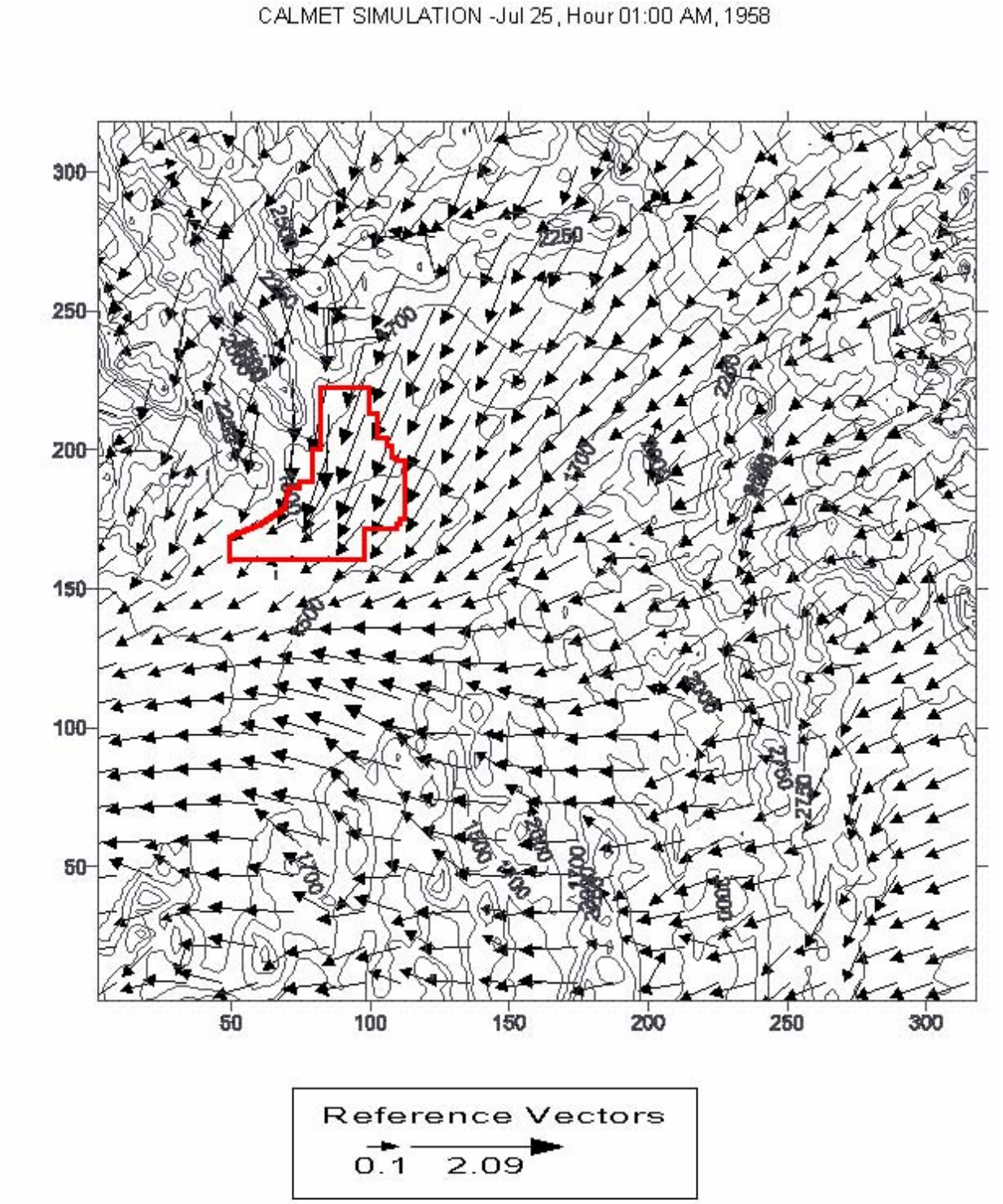


Figure 2.8 Example of wind flow vectors for July 25, 1958 at 13:00

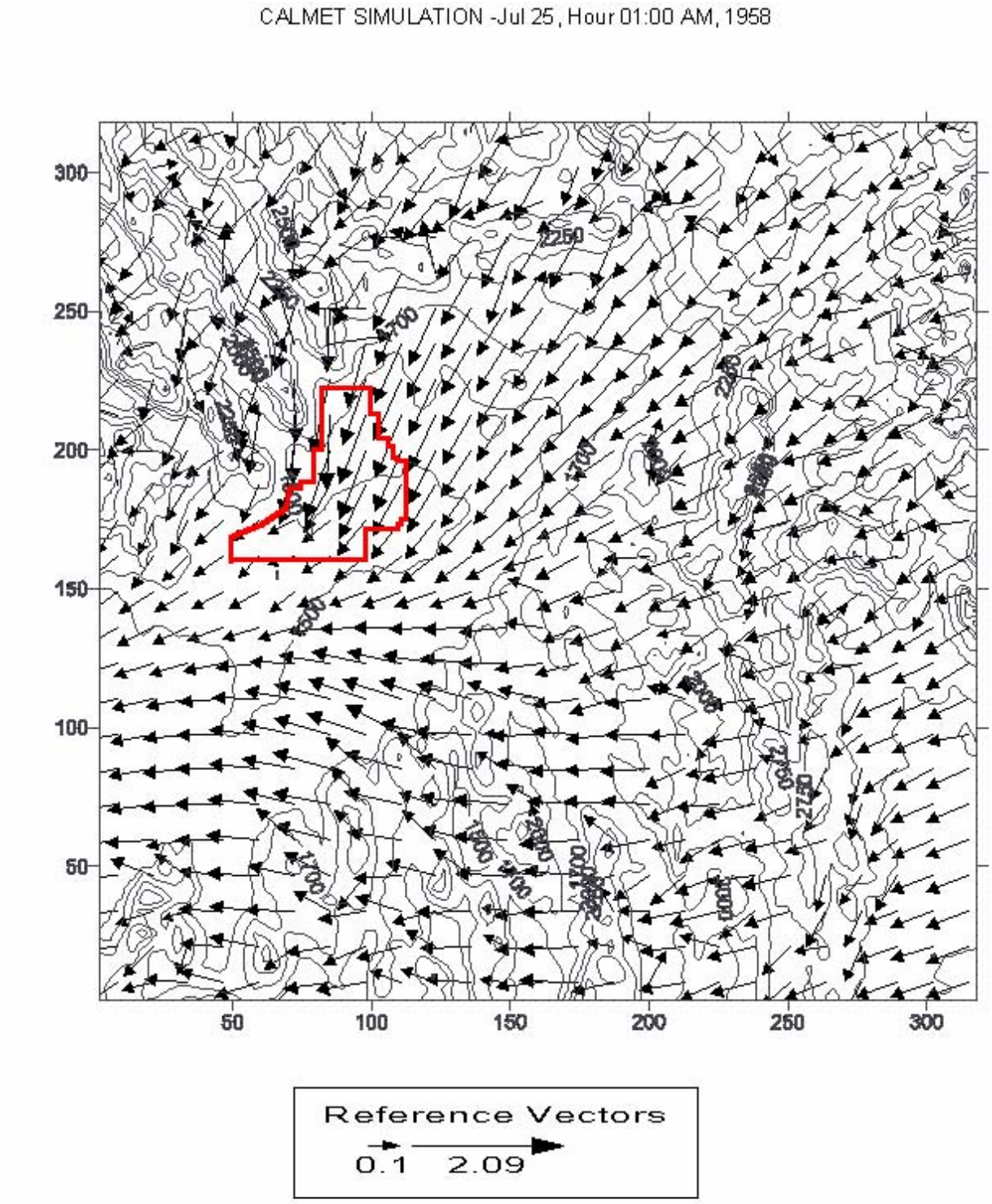


Figure 2.9 Observations at October 21, 2002 at 15:50 MST – 5 minute averages

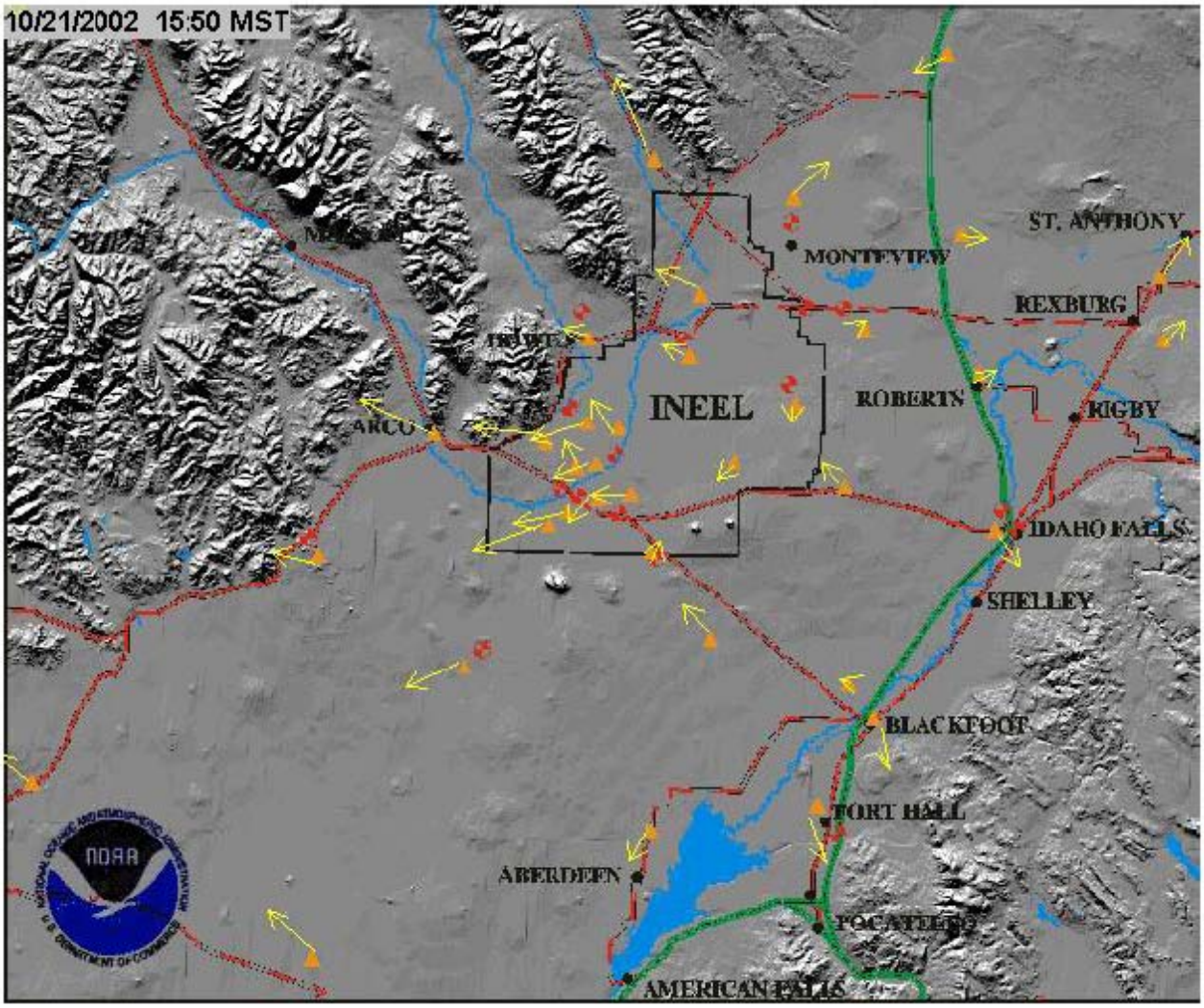


Figure 2.10 Observations at October 21, 2002 at 15:55 MST – 5 minute averages

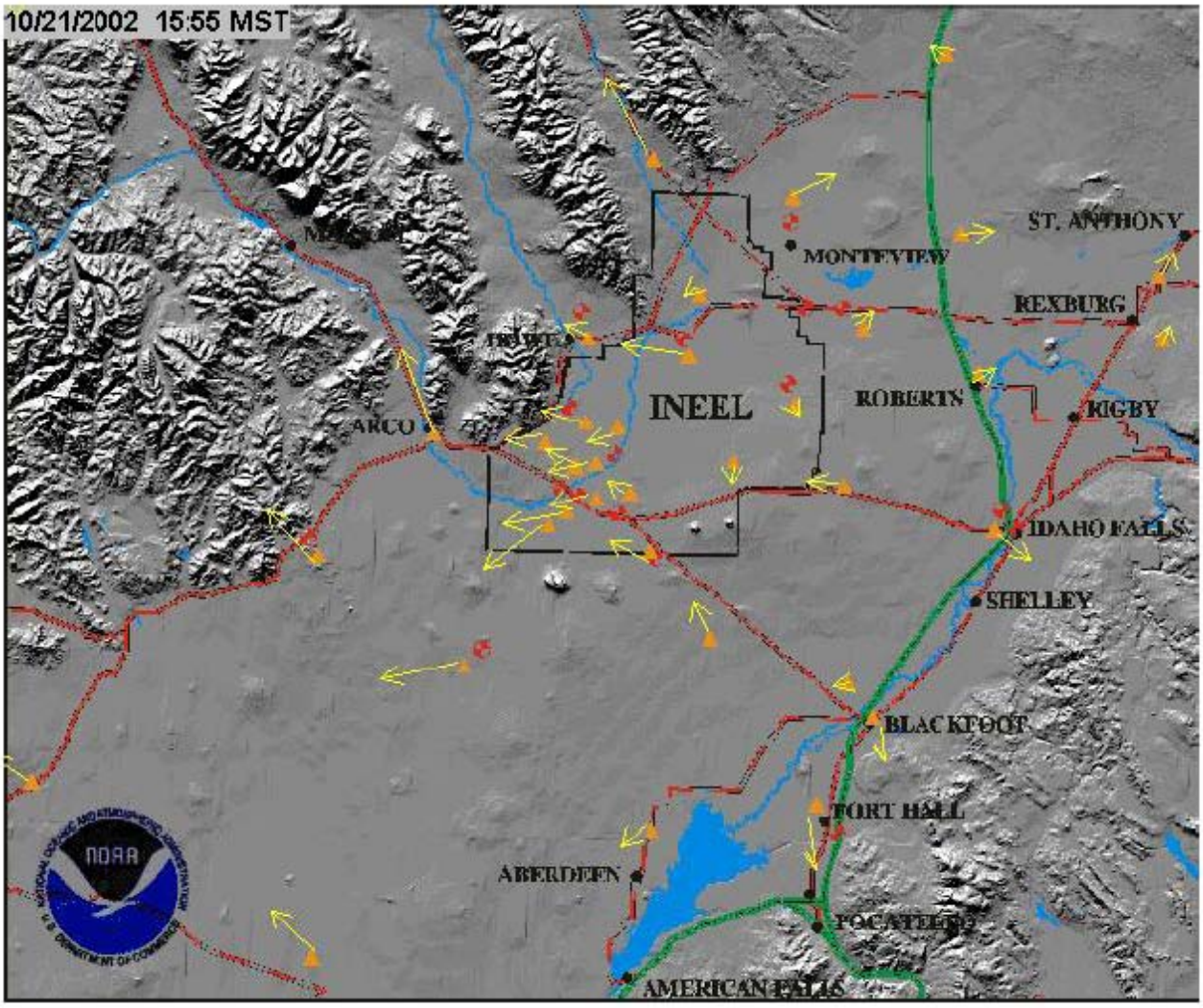
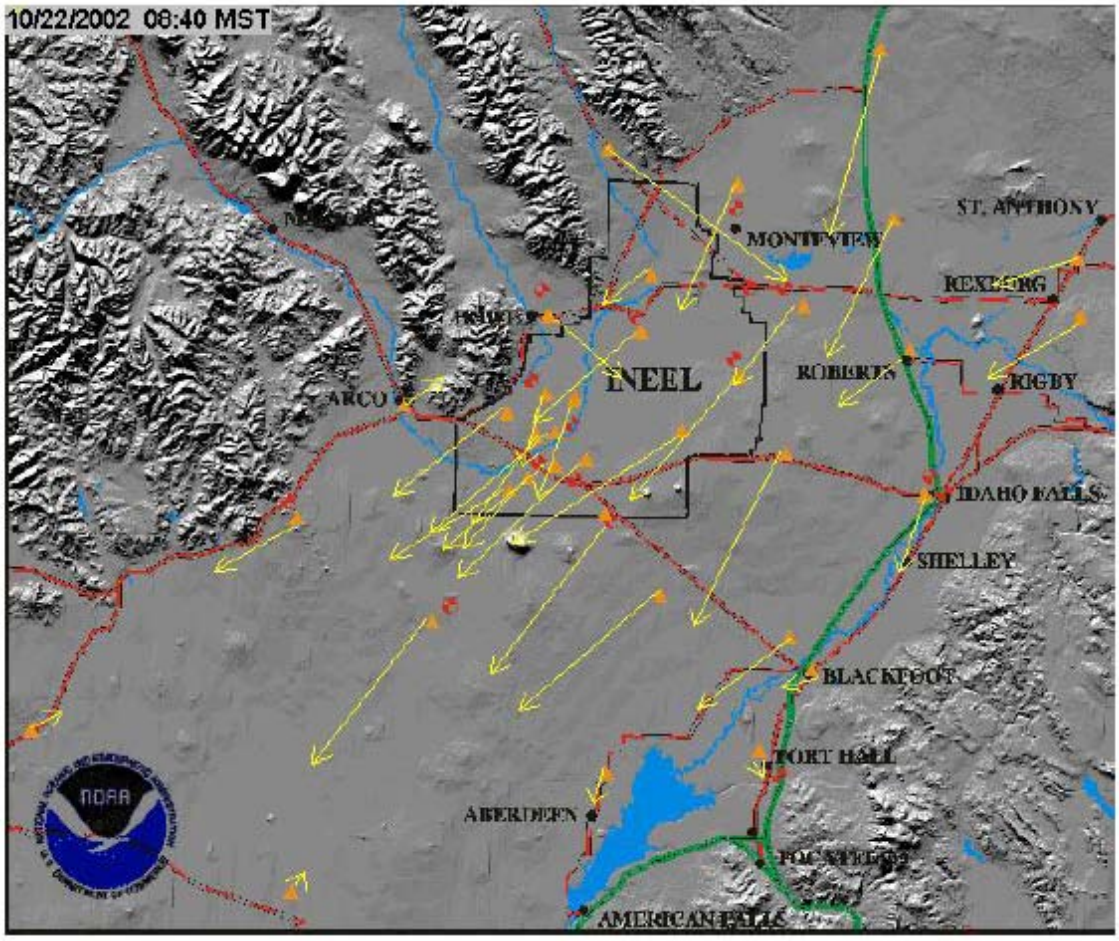


Figure 2.11 Observations at October 22, 2002 at 08:40 MST – 5 minute averages



2.3.2 CALMET Based on 1999 Data

CALMET predictions were made for 1999 in two scenarios; first was using the full network and, second, was using only the three stations that were also available in 1957-1959. The results of the two scenarios can be compared to show the uncertainty present using three stations as compared to the more complete meteorological information. Comparisons of these two scenarios are provided in this chapter.

Wind roses of observations and CALMET predictions at the closest grid point at three stations that were produced for both scenarios (CALMET with 25 stations and CALMET with three surface stations) are presented in Figures 2.12 through 2.17. Figures 2.12 through 2.14 show wind roses based on 25 meteorological stations.

Figure 2.12 Wind Rose South – CFA, 1999 vs. CALMET (18, 42)

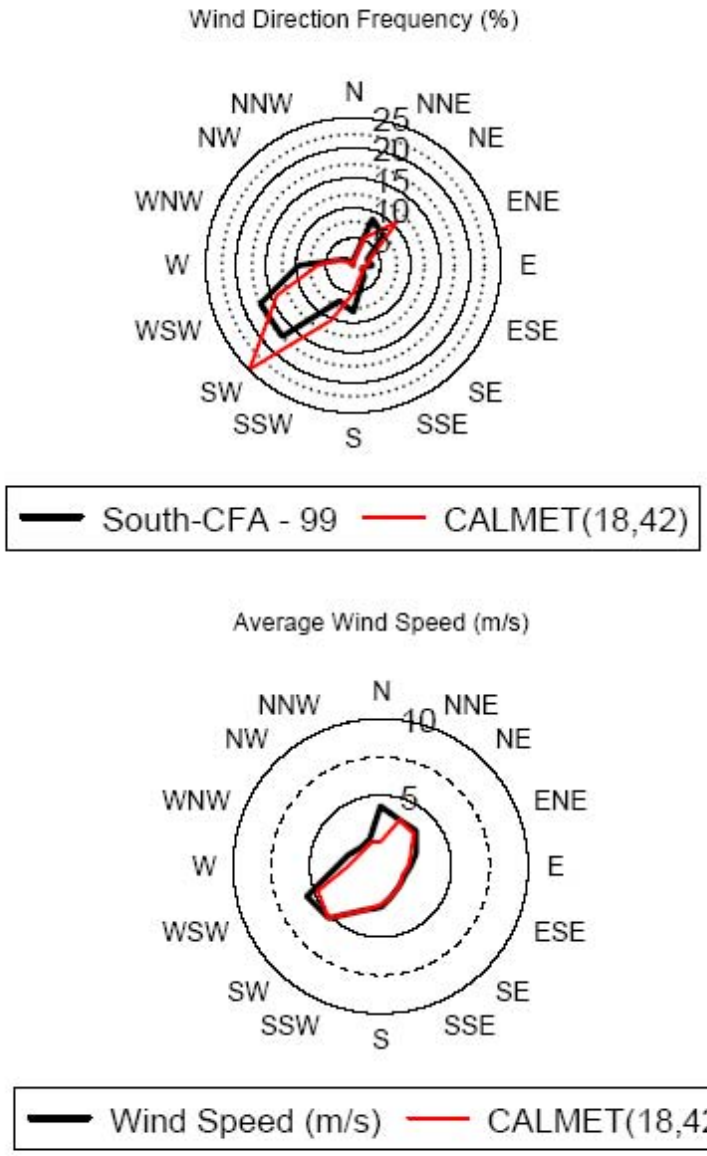


Figure 2.13 Wind Rose North – LOFT/TAN, 1999 vs. CALMET (22,51)

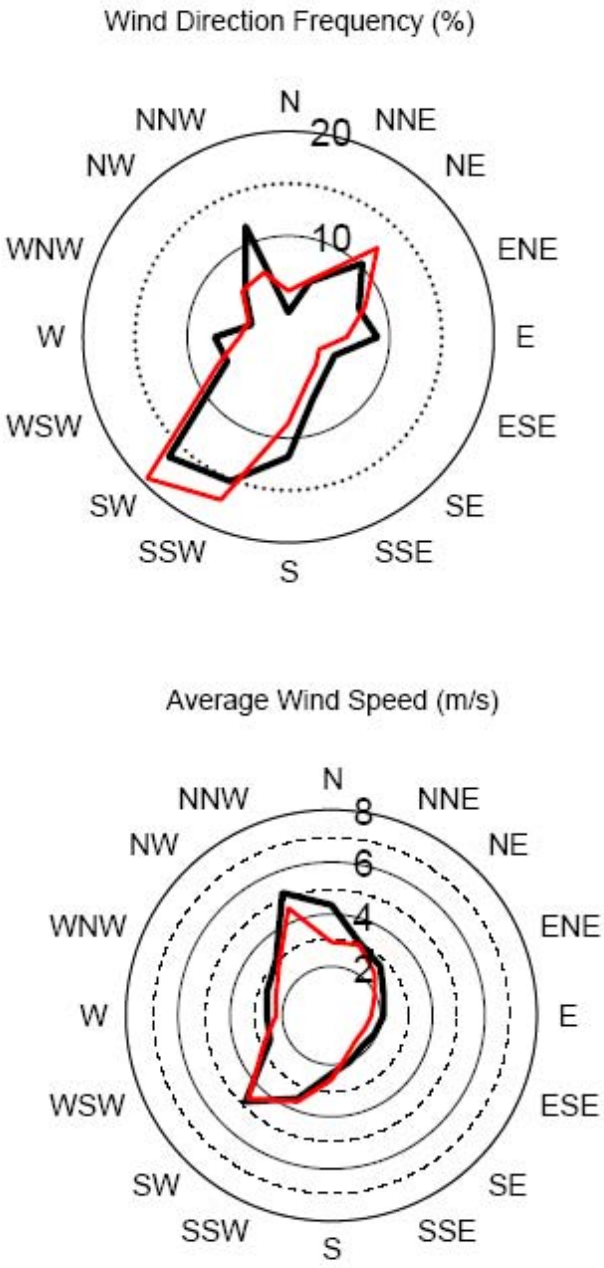
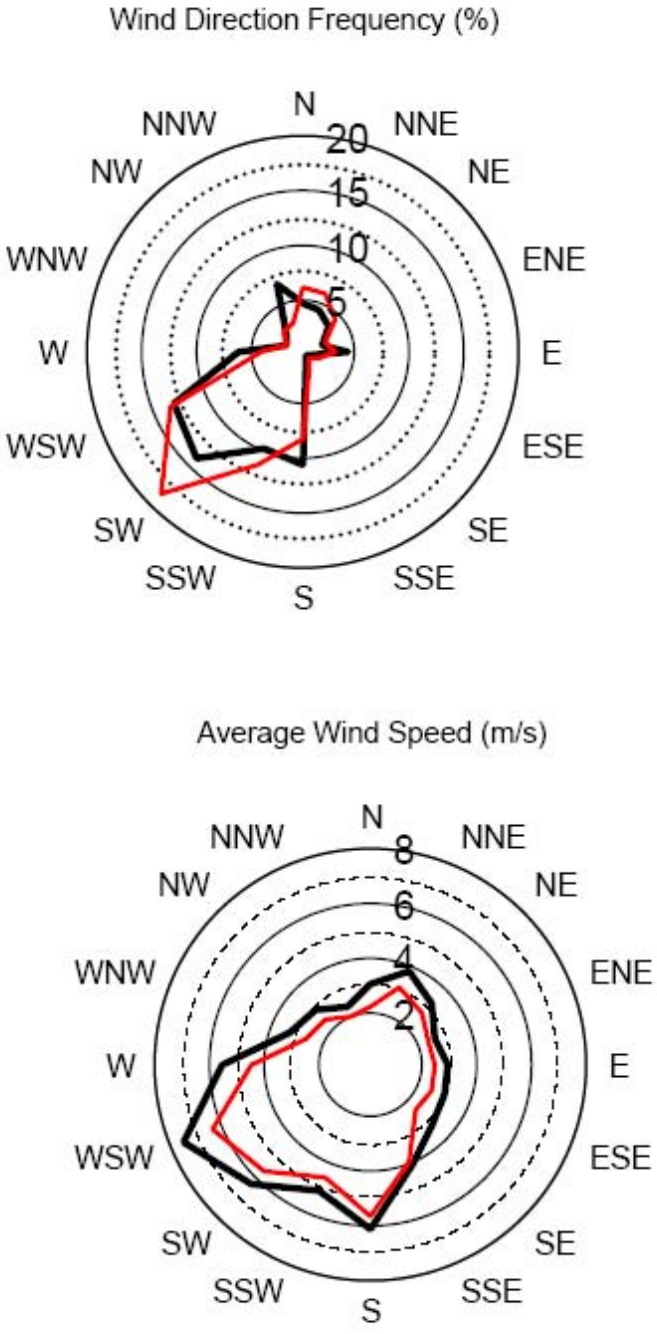
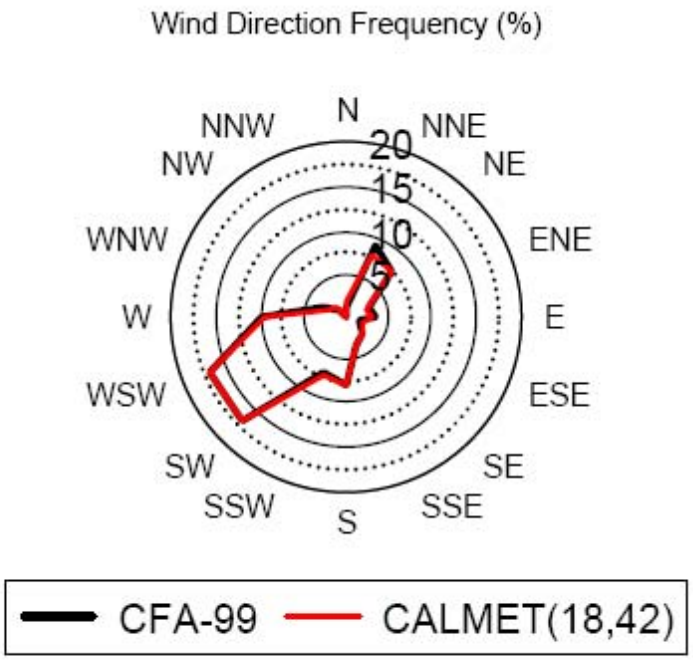


Figure 2.14 Wind Rose Pocatello – POC, 1999 vs. CALMET (25,26)



Figures 2.15 through 2.17 show the wind roses based on 3 meteorological stations.

Figure 2.15 Wind Rose South – CFA – 1999 vs. CALMET (18, 42) based on 3 stations



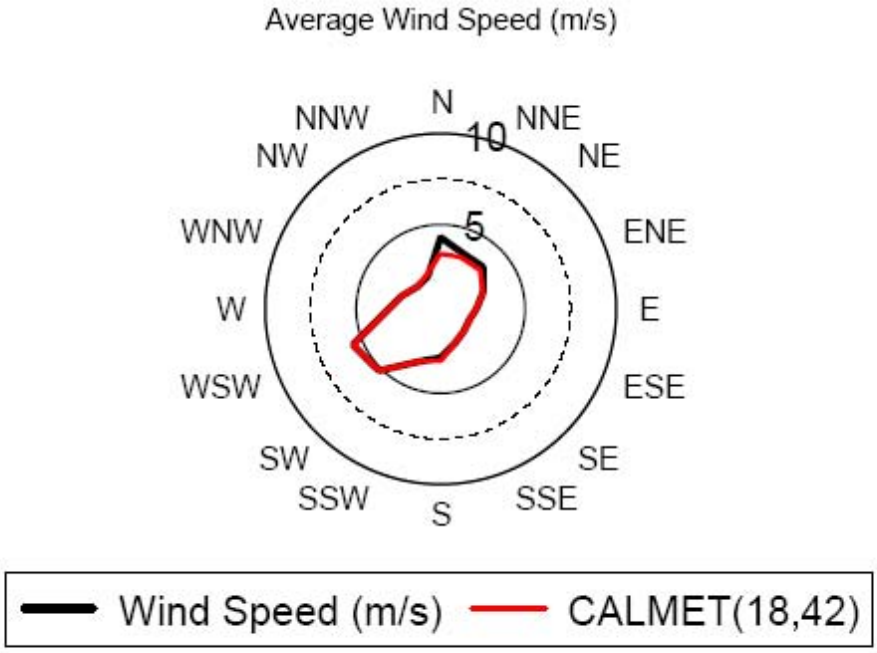


Figure 2.16 Wind Rose North – LOFT/TAN, 1958 vs. LOFT/TAN, 1999 vs. CALMET (22,51) based on 3 stations

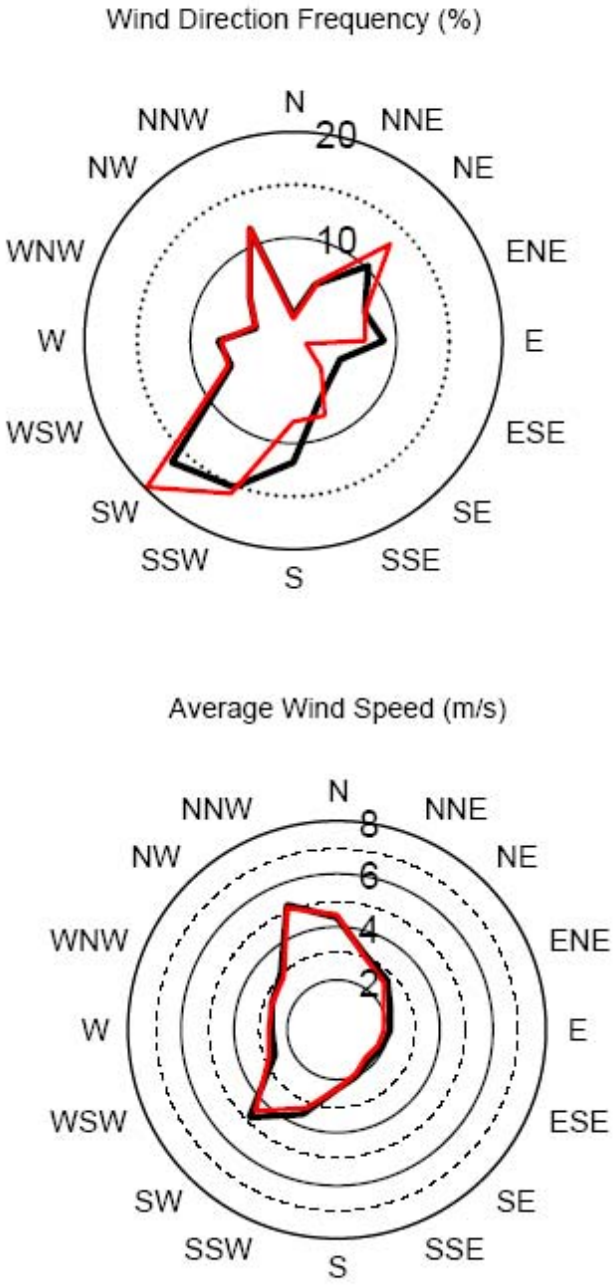
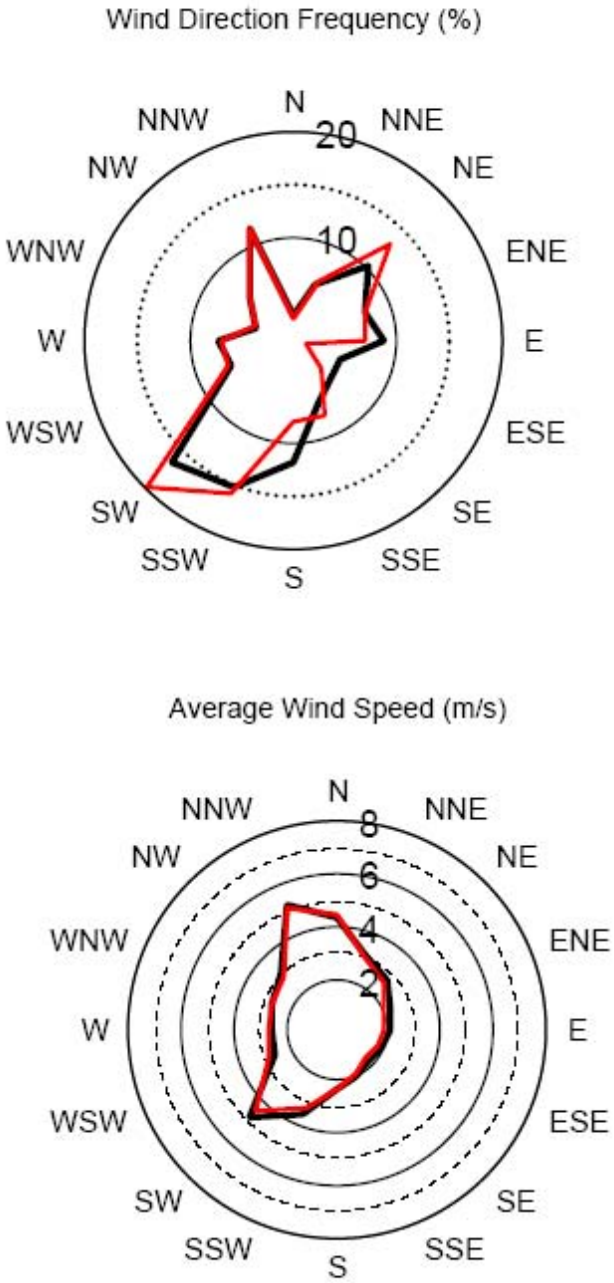


Figure 2.17 Wind Rose Pocatello – POC, 1999 vs. CALMET (25,26) based on 3 stations



Based on these comparisons of the wind roses, it was concluded that CALMET performance with the limited number of stations (3 vs. 25) was reasonable for prediction of meteorological conditions at selected locations.

Table 2.4 summarizes the stability class distribution for CALMET based on 25 stations and 3 stations at the stack location as well as at Idaho Falls using similarity theory. CALMET was performed using similarity theory and power law for vertical profiles as part of the probabilistic assessment. Wind speeds generally increase with height in the atmosphere. To determine the speed at different levels normally the power-law equation is used: $u1/u2=(z1/z2)^p$. The coefficient p varies from 0.4 in urban environment, with scaling down to 0.16 over water surfaces.

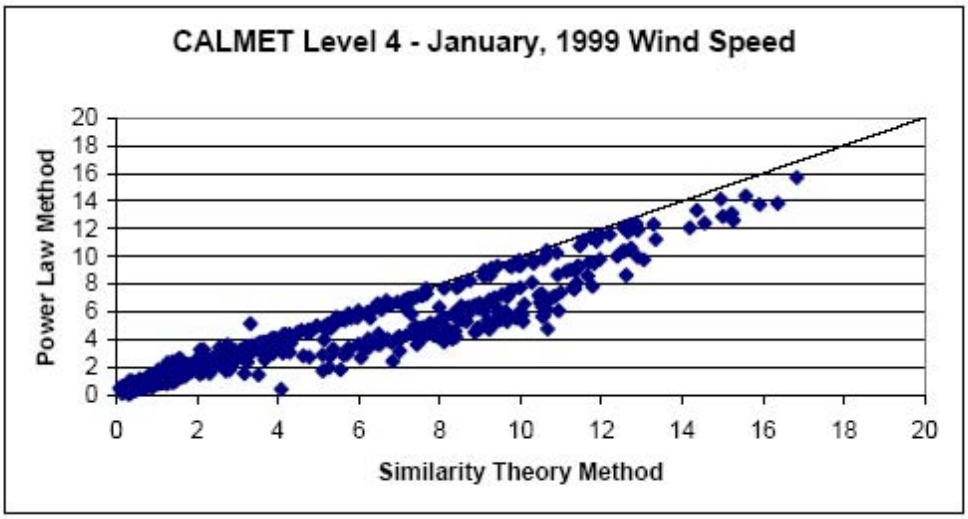
The vertical profile of the wind can also be calculated based on the boundary layer physics and the parameters which represents the layer: surface roughness, surface friction velocities, Monin-Obukhov length, stable and unstable boundary layer heights, sensible heat flux etc. This approach is often called a similarity theory approach in air dispersion modeling. One of the advantages of the CALMET/CALPUFF system is the ability to simulate the atmosphere in both ways. The distribution of stability class did not change substantially between the two methods.

Table 2.4 Stability class comparison based on CALMET runs

Scenario 1 – 25 Stations Similarity Theory Used		**Scenario 2 - 3 Stations Similarity Theory Used**
		At The Stack
Stability	%	%
A	0.8	2.6
B	10.7	13.4
C	14.5	13.2
D	37.8	43.9
E	9.2	11.2
F	26.9	15.8
		Idaho Falls - Location
Stability	%	%
A	1.6	2.7
B	12.6	14.7
C	14.4	14.1
D	33.8	34.1
E	7.0	8.5
F	30.5	26.0

Wind speed and directions at 10 m levels are the same for similarity theory or power law vertical profile. To demonstrate the difference, the wind speeds at level 4 (110m) were processed for January 1999 for scenario 1 (25 stations with similarity theory and power law interpolation). A graph of wind speed differences is presented in Figure 2.18.

Figure 2.18 Level 4 (110 m) wind speed comparison based on similarity theory and power law interpolation



Based on this comparison at higher levels, there were higher wind speeds using the similarity theory than using power law profiles. These differences are expressed through the probabilistic approach, and the speed difference at different levels determines different concentration predictions at different locations. As the speed at ground level (10m) stays the same, it would be difficult to explain the concentration predictions without direct comparisons of concentrations using two different approaches.

Figures B1 through B12 presented in Appendix B demonstrate monthly wind vectors based on 3 and 25 meteorological stations used as an input to generate three-dimensional CALMET wind fields. Visually, differences in wind field difference do no appear large; however, there is a tendency for winds to be shifted slightly counter-clockwise based on the 25 stations compared to the wind fields with three stations.

2.4 CALPUFF MODELING

The CALPUFF model was run for two purposes; first were deterministic runs to develop contour plots (isopleths) over the modeling domain. The second was to provide unit dispersion factors to address the uncertainty in CALPUFF modeling approaches on the air concentrations. This section describes parameter values used in the CALPUFF modeling.

2.4.1 Stack Parameters

For this study, the point source was placed close to the GRID3 meteorological station (lat.: 43.572^0 North and long.: 112.93^0 West). Stack parameters were: height=76.2m, diameter=3.3m, exit velocity=5.5m/s – corresponding to 100,000 ft^3/min and exit temperature=293^0K.

2.4.2 Modeling Locations

A grid was established over the modeling domain for deterministic analysis and description of overall patterns in air concentration described in Chapter 4.

For the purpose of dose reconstruction, discrete receptors were identified at off-site locations and at two sites on the INEL property. Modeling locations were also identified for the calculation of average concentrations over the INEL property and for average concentrations over the area of commercial milk production. Table 2.5 summarizes the locations of discrete receptors and Figure 2.19 presents their locations. Figure 2.20 shows the locations used to calculate average air concentrations for the INEL property and for the commercial milk production area.

Table 2.5 Locations of offsite and onsite receptors used for dose reconstruction calculations

Community or town	Receptor No	Latitude	Longitude
Aberdeen Junction	1	43.223	112.470
Arco*	2	43.637	113.299
Atomic City*	3	43.445	112.812
Basalt	4	43.316	112.168
Blackfoot*	5	43.191	112.344
Butte City*	6	43.610	113.243
Dubois	7	44.176	112.230
Firth	8	43.305	112.182
Fort Hall	9	43.033	112.438
Grandview	10	43.053	112.788
Hamer	11	43.927	112.205
Howe*	12	43.784	113.004
Idaho Falls*	13	43.489	112.034
Lewisville	14	43.696	112.010
Lost River	15	43.689	113.371
Mackay	16	43.915	113.613
Menan	17	43.721	111.989
Moore	18	43.736	113.366
Monteview*	19	43.972	112.536
Mud Lake*	20	43.842	112.475
Roberts*	21	43.720	112.126
Shelley	22	43.381	112.123
Spencer	23	43.361	112.186
Terreton	24	43.842	112.436

ON-SITE LOCATIONS

Location			
CFA @ 250 ft Met Tower location	25	43.533	112.950
Big Lost River sink area - 12 km (8 miles) East-South-East of Howe, about 2-3 miles inside the INEL border.	27	43.775	112.866

Note:
* Previously modeled locations (DOE 1991)
Receptor #26 was not used in dose reconstruction.
Sources: USGS maps and factfinder.census.gov; www.digital-neighbors.com/city/id

Figure 2.19 Discrete receptors used in dose assessment

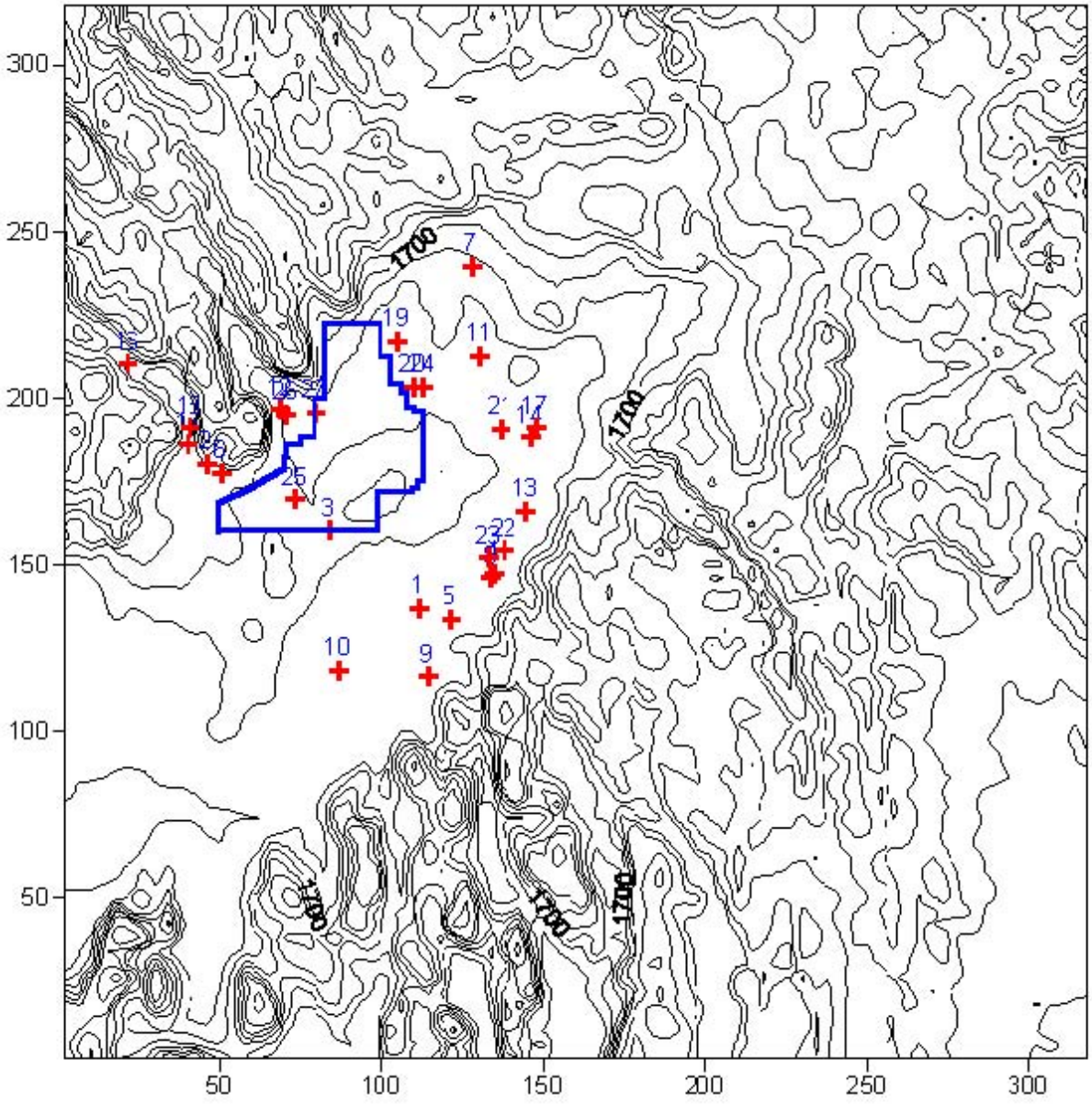
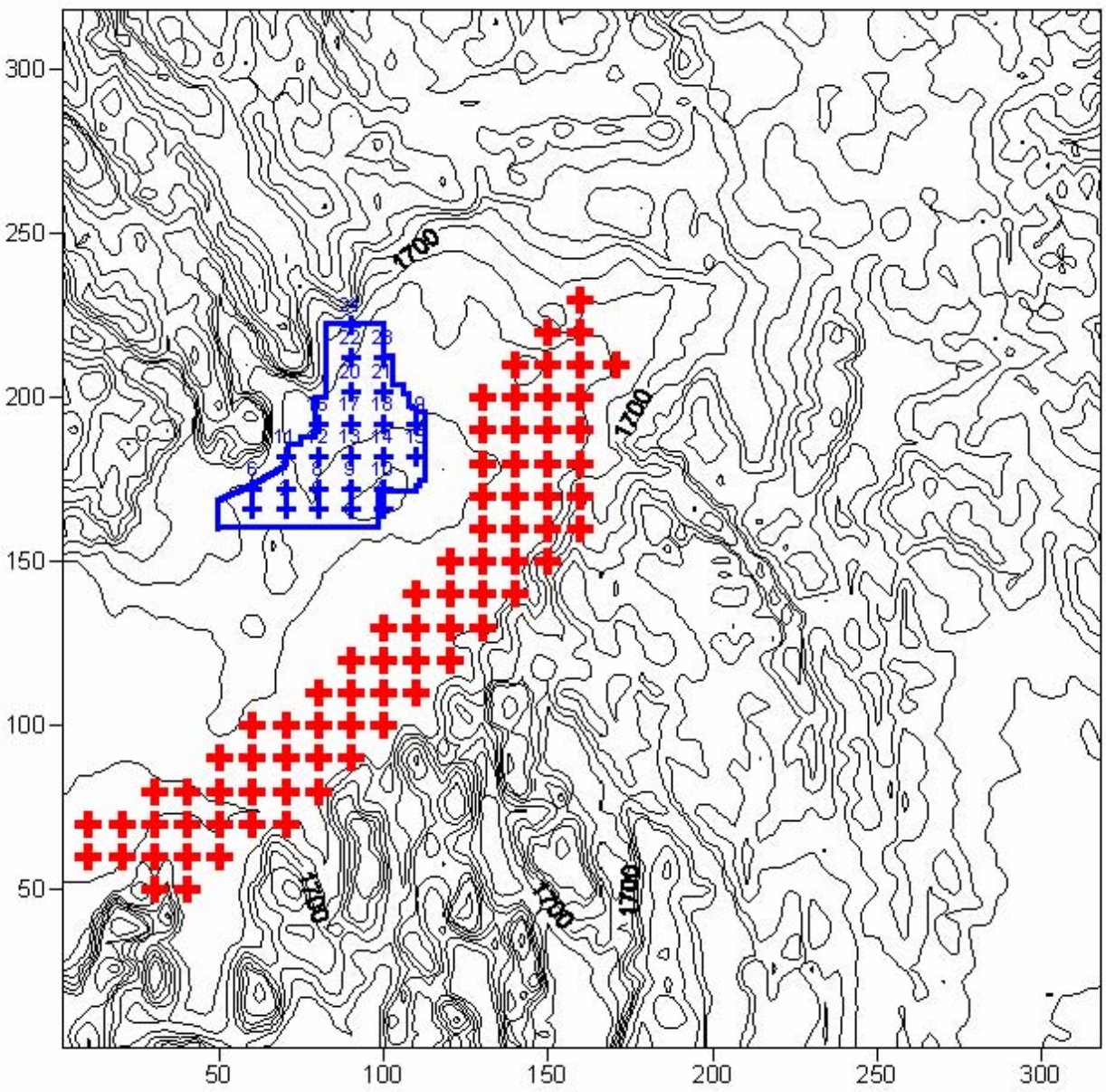


Figure 2.20 Locations used for area average calculations



Blue grid points are used for the area average over the INEL property.
Red points are used for the area average over commercial milk production areas
Spacing between the grid points is 10 km.

2.5 CALPUFF MODEL OPTIONS

Options for algorithms and modeling approaches are specified for the CALPUFF model. This section describes the set-up of these approaches.

2.5.1 Deterministic Run

The CALMET model was run, as described above, using similarity theory to estimate the vertical wind profile. The CALPUFF model provides multiple options for evaluating modeling scenarios. For the deterministic analysis, the model was run using model default settings for most parameters. Pasquill-Gifford stability classes were used in CALPUFF to determine the dispersion coefficients (MDISP=3).

Other important model switches included:

- INPUT Group 1

  (a) NSPEC and NSE were set to run one pollutant at a time to conserve computer resources.

- INPUT Group 2

  (a) MCTADJ = 3 was set to use the CALPUFF type terrain adjustment as the default.
  (b) MSLUG was set to the default (i.e., slug model not used).
  (c) MTRANS was set to 1, the default, because the proximity of the terrain may make transitional plume rise important.
  (d) MTIP is set to the default of 1, although stack tip downwash is not expected at reasonable windspeeds.
  (e) MSHEAR has been selected so that vertical wind shear was not modeled.
  (f) MCHEM=0 (no chemical reactions), MWET and MDRY were all set so that wet and dry removal are considered to reduce plume concentration.
  (g) MDISP was described above, and MTURBV was set accordingly
  (h) MROUGH was set to default (i.e., no surface roughness credit is being taken in calculating diffusion parameters).
  (i) MTINV was set to default so that inversions are computed from gradients only.
  (j) MPDF was set to default, therefore not adding PDF dispersion.
  (k) MSGTIBL was set to default, no shoreline dispersion calculated.

- INPUT Group 3 One Species ^{131}I modeled as a gas

- INPUT Group 4 LSAMP = T Discrete receptors used

- INPUT Group 5 Output Options

- INPUT Group 6 No hills are added as complex terrain inputs
- INPUT Group 7–10 Deposition to be used
- INPUT Group 11 No chemistry used
- INPUT Group 12
- INPUT Group 13 Stack data entry (emissions modeled as daily variable emission (daily numbers are divided on 24 equally distributed hours Ci/s)
- INPUT Group 14 No area sources
- INPUT Group 15 No line sources
- INPUT Group 16 No volume sources
- INPUT Group 17 discrete receptors used in probabilistic run

An example of the CALPUFF input file for the deterministic run of 1957 concentrations is provided in Appendix C.

2.5.2 Probabilistic Run

The sources of uncertainty in the probabilistic runs were:

(a) Uncertainty in emission rates

(b) Model uncertainty related to methods for calculating vertical wind profile (in CALMET), terrain adjustment methods (in CALPUFF) and dispersion coefficients (in CALPUFF)

(c) Meteorological uncertainty due to complex terrain and only 3 stations during the time period of interest (1957-1959)

The uncertainty in unit air dispersion modeling is addressed by considering two methods for calculating the vertical wind profile, two methods for terrain adjustment and two methods for calculating dispersion coefficients. There are therefore eight discrete combinations of dispersion methods identified to reflect the modeling uncertainty. Probabilities for each combination were developed based on experience.

The specific choices for the methods are:

(a) For vertical wind profile within the CALMET processor, the methods are:
1. IEXTRP=4 for use of similarity theory and
2. IEXTRP=2 for use of power law extrapolation

(b) For terrain adjustment with the CALPUFF model, the methods are:
3. MCTADJ=2 for simple CALPUFF type of terrain analysis and
4. MCTADJ=3 for partial plume path adjustment

(c) For dispersion coefficients (i.e. sigma) within the CALPUFF model, the methods are:
5. MDISP2=3 for PG dispersion coefficients and
6. MDISP2=2 for dispersion coefficients from internally calculated sigma v and sigma w using micrometeorological variables (v^*, w^*, L, etc.)

The selection of these methods for consideration is based on expert opinion applicable to this dispersion analysis.

The CALPUFF model was run for each combination for each of the three years during the 1957-1959 period for a total of 24 model runs. The unit dispersion factors were stored in a database with identification by the model uncertainty (i.e. the methods used for CALMET AND CALPUFF).

The uncertainty of using only 3 surface air stations during the 1957-1959 period was quantified from a comparison of unit air dispersion factors calculated for 1999 when 25 air stations are available. The unit dispersion factors determined with 25 air stations were considered the standard (i.e. providing "accurate" meteorological data after CALMET processing).

The CALPUFF unit dispersion factors were calculated for the eight combinations of model uncertainty at the 27 discrete receptor locations. This was done twice; once with the 3 surface air stations and once with the 25 air stations resulting in a total of 16 CALPUFF runs. The difference between the air dispersion factors using 3 stations and the air dispersion factors with the 25 meteorological stations reflect the uncertainty due to uncertainty in meteorological conditions. These distributions were developed for each of the 27 discrete receptor locations and may be further classified according to broad meteorological condition (e.g. stability, wind speed, direction).

This information is stored in a database with identification by model uncertainty (i.e., the methods used for CALMET and CALPUFF).

2.5.3 Atmospheric Releases of Radionuclides from the Idaho Chemical Processing Plant

The Radioactive Lanthanum (RaLa) process was designed to extract ^{140}Ba (half-life of 12.9 days), which decays to ^{140}La (40.2 hours), from irradiated reactor fuel. The latter isotope is an intense source of high-energy gamma rays and was used to evaluate the implosion process of

a nuclear weapon. The short half-lives of ^{140}Ba and ^{140}La required the design of a process in which fuel elements irradiated in a nuclear reactor were dissolved shortly after irradiation.

The RaLa process at the ICPP used fuel elements irradiated in the Material Testing Reactor (MTR) located on-site at INEL. A total of 36 RaLa runs took place at the ICPP between February 1957 and December 1959. Additional releases of radionuclides occurred as a result of a criticality accident on October 16, 1959, when highly enriched uranium solution was inadvertently transferred to a waste tank not designed to hold such a solution.

Essentially all releases from the ICPP during the years 1957-1959 were due to RaLa process operations. Gases and aerosol particles generated during RaLa dissolution and extraction processes were captured by an off-gas system, and then passed through a series of scrubbers and charcoal beds to a temporary 10,000-ft^3 storage tank. The number and type of filters changed with time during the period of operations. Before gases and aerosols were released to the atmosphere through the 250-ft ICPP stack, they were diluted by mixing with large amounts of the air from the ICPP building ventilation system, which created a total output flow rate of about 100,000 ft^3 per minute.

As part of the present study, Wichner et al. (2005a, b) estimated the activity of more than 130 radionuclides that were released to the atmosphere from RaLa process operations at the ICPP during the years 1957-1959, based on information obtained from historical Stack Monitoring Datasheets, from official RaLa project reports, progress reports, operational logs, calculation sheets, and contemporary project letters. On the basis of a screening analysis (Kocher 2005a, b), ^{131}I was determined to be by far the most important radionuclide in regard to potential radiation doses to members of the public who resided near INEL during the years 1957-1959. Twelve additional radionuclides of potential concern were also selected for inclusion in a more detailed dose reconstruction. This section summarizes the estimated releases of radionuclides that were found to be important in regard to potential exposures of the public.

Two isotopes of iodine were released in sufficiently large quantities to be of concern in regard to potential off-site exposures of the public: ^{131}I (half-life of 8.04 days) and ^{133}I (20.8 hours). Releases of radioactive isotopes of iodine were estimated using measurements of ^{131}I in samples of air from the ICPP stack, as reported in Stack Monitoring Datasheets; a method that is considered more reliable than theoretical modeling of the RaLa dissolving, extraction, storage, and off-gas systems. Iodine in stack air was collected during a 24-hour period (midnight to midnight) in a one-liter scrubber liquid sampler, which was later analyzed using a NaI crystal scintillation counter set to record the principal ^{131}I emissions. After removal of iodine from the liquid, a gross beta (i.e., beta minus iodine; β-I) and a gross-alpha (α) reading were taken and recorded.

Since estimated releases of ^{131}I following the criticality accident are similar to releases during a normal RaLa run, and since they occurred over a number of days, the criticality accident can be considered in the same way as a routine RaLa run from the point of view of modeling the transport of ^{131}I into the atmosphere. In this report, the ^{131}I air concentrations were estimated including all normal (routine) releases from the ICPP during the years 1957-1959, and the

releases following the criticality accident. A separate analysis of the criticality accident is not performed. As summarized in Table 2.7, about 3,200 Ci (95% C.I. = 2,400 – 5,100 Ci) of ^{131}I were released from the ICPP as a result of normal RaLa operations during 1957-1959 and the 1959 criticality accident.

Daily records of total beta minus iodine (β-I) activity and α activity provided by ICPP Stack Monitor Datasheets indicate that non-gaseous radionuclides were emitted from ICPP operations. Those radionuclides were attached to very small particles (aerosols), which were transported through the off-gas system and released to the atmosphere. Of the 115 radionuclides attached to aerosols that were assumed to be released to the atmosphere from the ICPP, the screening analysis resulted in selection of ten β/γ-emitting radionuclides (^{89}Sr, ^{90}Sr, ^{91}Y, ^{95}Zr, ^{95}Nb, ^{103}Ru, ^{140}Ba, ^{141}Ce, ^{144}Ce, and ^{143}Pr) and one α-emitting radionuclide (^{238}Pu) for inclusion in a detailed dose reconstruction. Of the ten β/γ-emitting radionuclides of potential concern, ^{140}Ba has the shortest half-life (12.7 days), while ^{90}Sr has the longest half-life (29.2 yrs). The one alpha-emitter of potential concern (^{238}Pu) is long-lived (87.7 years). All the radionuclides of concern for the ICPP releases have a long enough half-lives as compared to the travel time of the plume from the ICPP stack to the location of the receptors, so the loss of activity due to radioactive decay during atmospheric transport has a minimal effect.

Estimated releases of radionuclides attached to aerosols during the years 1957-1959 are presented in Table 2.6. As in the case of releases of iodine discussed above, releases of radionuclides in aerosol form following the criticality accident are similar to releases during a normal RaLa run, and the two types of releases are combined in estimating the air concentrations. The atmospheric dispersion calculations presented in this report are based on the estimated daily releases of radionuclides. As an example, Figure 2.21 shows the estimated activities of ^{131}I, ^{140}Ba and ^{90}Sr released daily during January 1958 (RaLa Run #9).

For the probabilistic runs, the unit emission rate of 1Ci/s was used to estimate unit dispersion factors and these unit dispersion factors were stored in a database. Probabilistic air concentrations were calculated by multiplying probabilistically simulated emission rates by the unit dispersion factors. The emission rates for the uncertainty analyses are described later. Table 2.7 summarizes the central estimate of ^{131}I concentrations used in the deterministic assessment.

Table 2.6 Estimated atmospheric releases of radionuclides from Idaho Chemical Processing Plant during 1957-1959 (Ci)

	Routine Releases [a] (including October 16, 1959 criticality accident) 95% Confidence Interval		
Isotope	**Lower bound**	**Central Estimate**	**Upper Bound**
^{131}I	2,400	3,200	5,100
^{133}I	340	470	730
^{143}Pr	174	344	886
^{141}Ce	171	339	873
^{140}Ba	165	327	841
^{95}Zr	147	292	751
^{91}Y	142	281	723
^{89}Sr	120	237	611
^{95}Nb	98	195	502
^{103}Ru	84	166	428
^{144}Ce	41	81	208
^{90}Sr	1.3	2.6	6.6
^{238}Pu	0.50	0.98	2.5

[a] The reported activities are in Curies (Ci). 1 Ci = 3.7×10^{10} Bq (Becquerel)

Figure 2.21 Activity of iodine-131, barium-149 and strontium-90 released daily into the atmosphere during January 1958

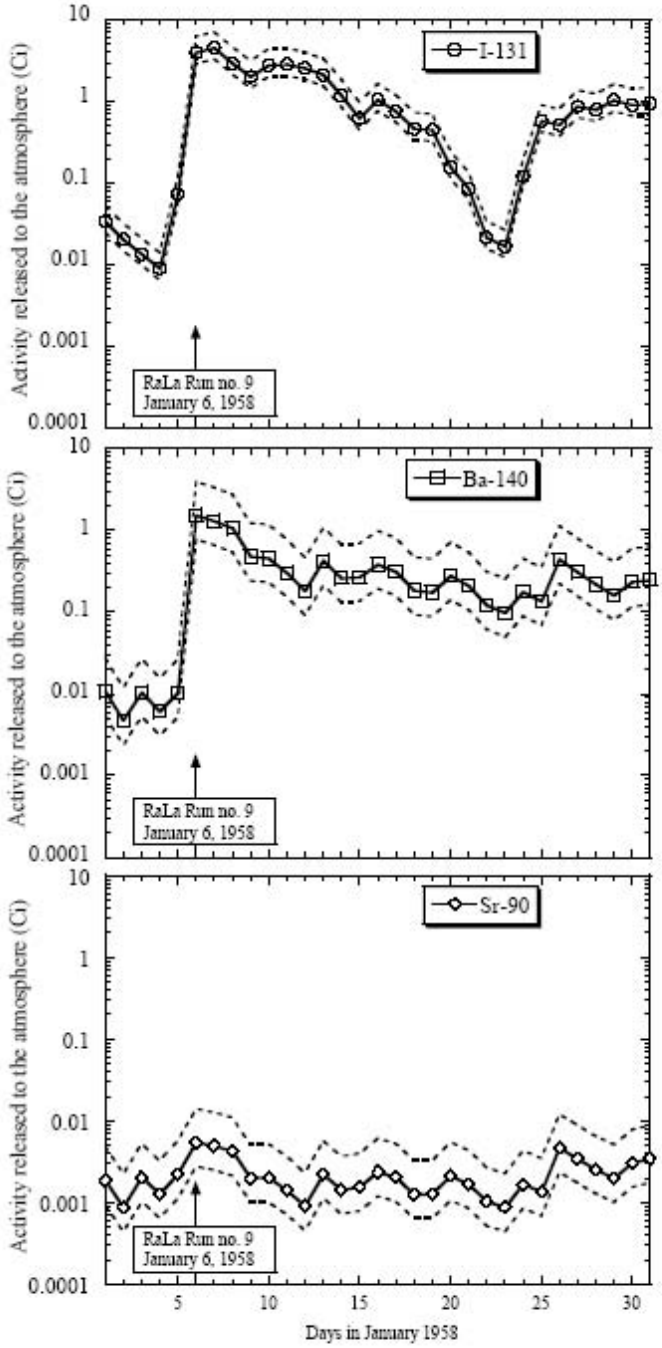


Table 2.7 Deterministic monthly emissions (Ci)

Month	1957	1958	1959
JAN	0	34.8	0.3
FEB	753.9	85.9	127.3
MAR	110.6	147.9	53.8
APR	86.4	56.0	8.9
MAY	50.6	314.3	3.5
JUN	163.1	241.9	2.7
JUL	26.5	1.7	11.5
AUG	0.2	89.5	4.4
SEP	38.4	27.9	9.2
OCT	316.7	125.1	17.1
NOV	257.5	39.9	15.2
DEC	2.9	4.4	2.1
YEAR	1806.7	1169.4	256.1

Note: 50^{th} percentile of the probability distribution function obtained from the uncertainty analysis.

2.5.4 Particle Size Distributions

Iodine-131 and ^{133}I were modeled as gases with plume depletion. When released, the other radionuclides were attached to very small particles, which behave similarly to gases and will also have small depletion from the plume. Therefore, unit air dispersion factors based on dispersion modeling as a gas were used for all radionuclides.

3.0 COMPARISON OF CALPUFF WITH REAL TIME SF_6 MEASUREMENTS FROM THE IDAHO NATIONAL ENGINEERING LABORATORY

This chapter provides a description of the validation of CALPUFF predictions compared to the results of a tracer study done by the Air Resources Laboratory Field Research Division (ARLFRD) for the emergency response at INEL. Based on these comparisons, CALPUFF was considered appropriate for air dispersion modeling of radionuclides.

3.1 TRACER TEST DATA

To test the validity of estimates of airborne concentrations of radionuclides, CALPUFF was evaluated using data collected in 1999 as part of an atmospheric tracer experiment. In that experiment, sulfur hexafluoride (SF6) was released from a 21-m stack in the INEL site in April and May 1999 during six 4-hour and one 2-hour tests. Two mobile real-time SF6 detectors were placed in vans and deployed during each test. The SF6 air concentrations were measured using detectors in the vans and detectors at fixed locations along three sampling arcs located 15 to 50 km northeast of the release (i.e., downwind). The number of sampling points per test varied from 520 to 12,478, and 54 sets of measurements were generated. The complete set of data, including release information, meteorological information, and measured air concentrations, was provided by Dr. Kirk Clawson of NOAA, one of the organizers of the experiment (Clawson 2003). The details of the experiment and measurements are described in a paper, "Comparison of a Puff Trajectory Model with Real Time Tracer Measurements" by Kirk L. Clawson et al. (2002).

Figure 3.1 adapted from Kirk L. Clawson et al. shows the location of the tracer release stack and plume sampling arcs on the INEL site. The distances to the arcs are: Arc A – about 15 km; Arc B – about 30 km; Arc C – about 50 km; and Arc D – about 15 – 20 km. Table 3.1 summarizes the tracer test results.

Figure 3.1 Location of the tracer release stack and plume sampling arcs on the Idaho National Engineering Laboratory site

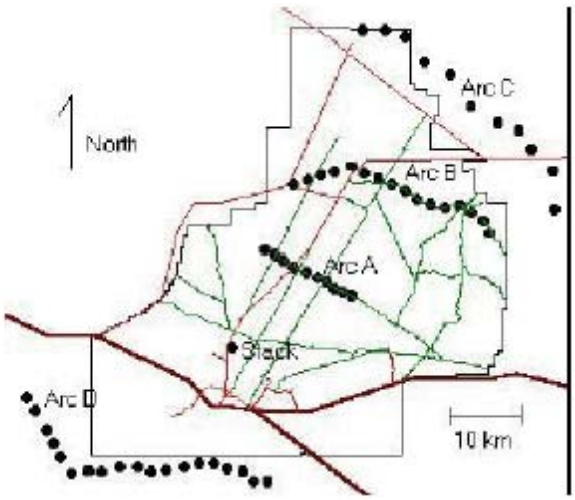


Table 3.1 Tracer test summary (Ref. 1)

Test #	Date	Release		Plume Tracking	Meteorology			
		Start Time (MDT)	End Time (MDT)	End Time (MDT)	Wind Direction (degrees)	Wind Speed (m/s)	Air Temp (C)	P-G Stability
1	19-Apr	1400	1600	1700	205 to 245	11 to 13	19.2 to 17.2	B to D
2	23-Apr	1300	1700	1745	036 to 052	13 to 12	10.6 to 11.6	D
3	26-Apr	1245	1645	1745	221 to 246	10 to 12	17.8 to 16.1	C to D
4	27-Apr	1300	1650	1740	223 to 150	7 to 6	13.6 to 9.6	C
5	02-May	1230	1623	1730	219 to 230	9 to 12	7.8 to 7.3	B to D
6	07-May	1300	1700	1800	231 to 241	12 to 12	16.8 to 16.3	C to D
7	07-May 08-May	2215	0215	0345	216 to 257	7 to 4	8.5 to 0.8	F

SENES Consultants Ltd. has attempted validation for all seven tracer tests. Each tracer test had a set of measurements and all measurements are included in the validation for all but Tracer test 5 and Tracer test 7, which each had 22 sets of measurements. For these tracer tests, we validated 6 of the 22 sets of measurements.

3.2 METHODOLOGY OF VALIDATION

Tracer measurements were done by instrumenting two vans. The time and location of each van were recorded, as well as the measured SF_6 concentrations. The number of sampling points per test varied from 520 to 12,478. All of the points in a particular test are taken into account during the validation. All lat-long coordinates for the measurements were converted to Lambert-Conformal coordinates and incorporated into the CALPUFF input files. Thus, wherever the measurements were taken there is a corresponding model prediction.

Excel spreadsheets were developed for each test and set of measurements and predictions. Based on these results the model performance statistics were developed. The summary of all the measurements and predictions is presented in Table 3.2.

Due to the characteristics of the model, all predictions are made on an hourly basis. Thus, the model results represent the hourly estimates. The maximum hourly results referred to in Table 3.2 are selected from all locations. The sample results represent the plume concentrations at the moment (few seconds) of the van passing through the plume at a specific location.

After the first round of validation, it was discovered that the measured averaged values were far below the predicted averages. This led to a review of NOAA's original work (K.L. Clawson, 1999). From this, it was discovered that the values between limit of detection (LOD) and the limit of quantification (LOQ) were (very much) less certain than measurements reported as above the LOQ. NOAA defines the LOQ as 10 times the baseline noise and it is the level above which quantification may be performed with "reasonable" certainty.

After revising the measurement data and considering the exclusion of data below LOD and LOQ the model performance has improved. Nonetheless, the best agreement between the modeling and observation was still achieved with the maximum observed numbers. This is perhaps not surprising considering, the variety of factors that affect confidence in measuring and predicting concentrations over short times.

Table 3.2 SF_6 - CALPUFF model validation

TEST 1 - April 19, 1999 (14:00-16:00 MDT)

Test Number	Duration (s) of Sampling	Number of Sampling Points	Maximum Peak of Observ.(µg/m^3)	Average Peak of Observ(µg/m^3)	1 Hour Obs. (µg/m^3)	Model Prediction(µg/m^3)	
						Average	Maximum
001-4-01	617.7	2472	0.616	0.157	**0.088**	**0.342**	0.702
001-4-02	152.0	609	0.437	0.058	**0.020**	**0.997**	1.045
001-7-01	309.7	1240	0.343	0.130	**0.058**	**0.107**	0.112
001-7-02	2759.5	11039	2.010	0.184	**0.169**	**0.483**	1.844

TEST 2 - April 23, 1999 (13:00-17:00 MDT)

Test Number	Duration (s) of Sampling	Number of Sampling Points	Maximum Peak of Observ.(µg/m^3)	Average Peak of Observ. (µg/m^3)	1 Hour Obs. (µg/m^3)	Model Prediction(µg/m^3)	
						Average	Maximum
002-4-01	250.3	1002	0.975	0.139	**0.081**	**0.234**	0.296
002-4-02	239.7	960	0.191	0.044	**0.025**	**0.036**	0.068
002-4-03	129.8	520	0.209	0.047	**0.024**	**0.213**	0.249
002-4-04	2044.8	8180	0.649	0.233	**0.208**	**0.475**	1.031
001-7-01	1487.5	5951	0.677	0.143	**0.120**	**0.151**	0.257
001-7-02	1169.8	4680	0.663	0.141	**0.113**	**0.306**	0.354
001-7-03	2061.8	8248	0.822	0.106	**0.095**	**0.999**	1.283
001-7-04	384.7	1540	0.764	0.198	**0.126**	**1.181**	1.282

TEST 3 - April 26, 1999 (12:45-16:45 MDT)

Test Number	Duration (s) of Sampling	Number of Sampling Points	Maximum Peak of Observ. (µg/m^3)	Average Peak of Observ.(µg/m^3)	1 Hour Obs. (µg/m^3)	Model Prediction (µg/m^3)	
						Average	Maximum
003-4-01	1004.7	4020	0.334	0.133	**0.103**	**0.761**	0.854
003-4-02	2014.7	8060	0.513	0.203	**0.181**	**0.563**	0.852
003-4-03	2270.0	9081	0.491	0.166	**0.152**	**0.456**	0.851
003-4-04	1017.3	4070	0.318	0.059	**0.046**	**0.759**	0.804
003-7-01	3119.3	12478	1.369	0.213	**0.207**	**2.571**	2.571
003-7-02	171.0	685	1.054	0.188	**0.102**	**2.708**	2.755
003-7-03	2906.5	11627	2.583	0.253	**0.242**	**1.185**	2.956

Table 3.2 SF_6 - CALPUFF model validation (continued)

TEST 4 - April 27, 1999 (13:00-16:50 MDT)

Test Number	Duration (s) of Sampling	Number of Sampling Points	Maximum Peak of Observ.(µg/m^3)	Average Peak of Observ. (µg/m^3)	1 Hour Obs. (µg/m^3)	Model Prediction (µg/m^3)	
						Average	Maximum
004-4-01	1052.0	4209	0.434	0.123	**0.069**	**0.096**	0.121
004-4-02	1487.0	5949	0.323	0.065	**0.036**	**0.140**	0.273
004-4-03	299.8	1200	0.439	0.151	**0.085**	**0.339**	0.371
004-4-04	1360.7	5444	0.278	0.046	**0.026**	**0.394**	0.703
004-4-05	294.8	1180	1.448	0.403	**0.225**	**0.640**	1.117
004-4-06	214.7	860	1.073	0.248	**0.139**	**0.801**	1.118
004-7-01	1508.8	6036	1.485	0.216	**0.120**	**3.227**	5.443
004-7-02	1373.3	5494	3.684	0.313	**0.175**	**2.326**	4.817
004-7-03	1519.3	6078	3.498	0.586	**0.327**	**2.331**	4.808
004-7-04	1704.5	6819	1.123	0.168	**0.094**	**1.708**	2.814
004-7-05	396.5	1587	1.397	0.507	**0.283**	**2.413**	2.739

TEST 5 - May 02, 1999 (12:30-16:23 MDT)

Test Number	Duration (s) of Sampling	Number of Sampling Points	Maximum Peak of Observ. (µg/m^3)	Average Peak of Observ. (µg/m^3)	1 Hour Obs. (µg/m^3)	Model Prediction (µg/m^3)	
						Average	Maximum
005-4-01	1034.8	4140	0.504	0.169	**0.131**	**0.048**	0.265
005-4-04	324.7	1300	0.449	0.155	**0.096**	**0.000**	0.000
005-4-08	650.0	2601	0.536	0.163	**0.116**	**0.237**	0.499
005-7-04	744.8	2980	0.891	0.307	**0.224**	**0.225**	0.644
005-7-08	329.7	1320	0.930	0.348	**0.216**	**0.979**	1.160
005-7-12	869.7	3480	0.930	0.248	**0.186**	**0.703**	1.163

TEST 6 - May 07, 1999 (13:00-17:00 MDT)

Test Number	Duration (s) of Sampling	Number of Sampling Points	Maximum Peak of Observ. (µg/m^3)	Average Peak of Observ. (µg/m^3)	1 Hour Obs. (µg/m^3)	Model Prediction (µg/m^3)	
						Average	Maximum
006-4-01	284.8	1240	0.087	0.090	**0.054**	**0.457**	0.593
006-4-02	400.2	1860	0.363	0.066	**0.042**	**0.392**	0.593
006-4-03	1511.8	1460	0.434	0.090	**0.076**	**0.214**	0.559
006-4-04	1169.8	1560	0.281	0.036	**0.029**	**0.158**	0.426
006-7-01	284.8	1240	0.087	0.090	**0.054**	**0.468**	0.515
006-7-02	400.2	1860	0.363	0.066	**0.042**	**0.343**	0.593
006-7-03	1511.8	1460	0.434	0.090	**0.076**	**0.395**	0.749
006-7-04	1169.8	1560	0.281	0.036	**0.029**	**0.674**	0.888
006-7-05	1265.0	5061	3.917	1.144	**0.928**	**0.672**	1.699
006-7-06	1002.3	4010	0.394	0.071	**0.055**	**0.563**	0.802
006-7-07	1363.0	5453	0.301	0.078	**0.064**	**0.314**	0.633
006-7-08	389.8	1560	0.320	0.123	**0.079**	**0.533**	0.888

Table 3.2 SF_6 - CALPUFF model validation (continued)

TEST 7 - May 07/08, 1999 (22:15-02:15 MDT)

Test Number	Duration (s) of Sampling	Number of Sampling Points	Maximum Peak of Observ. (µg/m^3)	Average Peak of Observ. (µg/m^3)	1 Hour Obs. (µg/m^3)	Model Prediction (µg/m^3)	
						Average	Maximum
007-4-01	244.7	980	0.220	0.059	**0.037**	**0.186**	0.376
007-4-04	1059.2	4238	3.265	1.473	**1.201**	**0.370**	1.036
007-4-08	2040.5	8163	19.723	6.339	**5.766**	**3.433**	5.410
005-4-12	299.8	1200	0.440	0.087	**0.057**	**0.370**	1.036
007-7-03	2497.8	9992	16.373	4.448	**4.184**	**2.739**	4.609
007-7-07	1184.7	4740	20.326	9.762	**8.109**	**2.242**	4.042

Table 3.3 SF_6 - CALPUFF model validation > LOD, and >LOQ

TEST 1 - April 19, 1999 (14:00-16:00 MDT)

Test Number	Duration (s) of Sampling	Number of Sampling Points	Maximum Peak of Observ. (µg/m^3)	Avg>LOD of Observ. (µg/m^3)	Avg>LOQ Obs. (µg/m^3)	Model Prediction (µg/m^3)	
						Average	Maximum
001-4-01	617.7	2472	0.616	0.286	**0.579**	**0.342**	0.702
001-4-02	152.0	609	0.437	0.268	**N/A**	**0.997**	1.045
001-7-01	309.7	1240	0.343	0.211	**N/A**	**0.107**	0.112
001-7-02	2759.5	11039	2.010	0.543	**0.881**	**0.483**	1.844

TEST 2 - April 23, 1999 (13:00-17:00 MDT)

Test Number	Duration (s) of Sampling	Number of Sampling Points	Maximum Peak of Observ. (µg/m^3)	Avg>LOD of Observ. (µg/m^3)	Avg>LOQ Obs. (µg/m^3)	Model Prediction (µg/m^3)	
						Average	Maximum
002-4-01	250.3	1002	0.975	0.375	**0.975**	**0.234**	0.296
002-4-02	239.7	960	0.191	0.183	**N/A**	**0.036**	0.068
002-4-03	129.8	520	0.209	0.181	**N/A**	**0.213**	0.249
002-4-04	2044.8	8180	0.649	0.351	**0.583**	**0.475**	1.031
001-7-01	1487.5	5951	0.677	0.347	**0.587**	**0.151**	0.257
001-7-02	1169.8	4680	0.663	0.308	**0.588**	**0.306**	0.354
001-7-03	2061.8	8248	0.822	0.362	**0.636**	**0.999**	1.283
001-7-04	384.7	1540	0.764	0.363	**0.602**	**1.181**	1.282

Table 3.3 SF_6 - CALPUFF model validation > LOD, and >LOQ (continued)

TEST 3 - April 26, 1999 (12:45-16:45 MDT)

Test Number	Duration (s) of Sampling	Number of Sampling Points	Maximum Peak of Observ. (µg/m^3)	Avg>LOD of Observ. (µg/m^3)	Avg>LOQ Obs. (µg/m^3))	Model Prediction (µg/m^3)	
						Average	Maximum
003-4-01	1004.7	4020	0.334	0.210	**N/A**	**0.761**	0.854
003-4-02	2014.7	8060	0.513	0.283	**N/A**	**0.563**	0.852
003-4-03	2270.0	9081	0.491	0.248	**N/A**	**0.456**	0.851
003-4-04	1017.3	4070	0.318	0.209	**N/A**	**0.759**	0.804
003-7-01	3119.3	12478	1.369	0.526	**0.798**	**2.571**	2.571
003-7-02	171.0	685	1.054	0.411	**0.837**	**2.708**	2.755
003-7-03	2906.5	11627	2.583	0.586	**0.907**	**1.185**	2.956

TEST 4 - April 27, 1999 (13:00-16:50 MDT)

Test Number	Duration (s) of Sampling	Number of Sampling Points	Maximum Peak of Observ. (µg/m^3)	Avg>LOD of Observ. (µg/m^3)	Avg>LOQ Obs. (µg/m^3))	Model Prediction (µg/m^3)	
						Average	Maximum
004-4-01	1052.0	4209	0.434	0.267	**N/A**	**0.096**	0.121
004-4-02	1487.0	5949	0.323	0.201	**N/A**	**0.140**	0.273
004-4-03	299.8	1200	0.439	0.295	**N/A**	**0.339**	0.371
004-4-04	1360.7	5444	0.278	0.190	**N/A**	**0.394**	0.703
004-4-05	294.8	1180	1.448	0.684	**1.046**	**0.640**	1.117
004-4-06	214.7	860	1.073	0.444	**0.807**	**0.801**	1.118
004-7-01	1508.8	6036	1.485	0.359	**0.703**	**3.227**	5.443
004-7-02	1373.3	5494	3.684	0.572	**1.137**	**2.326**	4.817
004-7-03	1519.3	6078	3.498	0.813	**1.185**	**2.331**	4.808
004-7-04	1704.5	6819	1.123	0.375	**0.732**	**1.708**	2.814
004-7-05	396.5	1587	1.397	0.757	**0.846**	**2.413**	2.739

TEST 5 - May 02, 1999 (12:30-16:23 MDT)

Test Number	Duration (s) of Sampling	Number of Sampling Points	Maximum Peak of Observ. (µg/m^3)	Avg>LOD of Observ. (µg/m^3)	Avg>LOQ Obs. (µg/m^3)	Model Prediction (µg/m^3)	
						Average	Maximum
005-4-01	1034.8	4140	0.504	0.236	**N/A**	**0.048**	0.265
005-4-04	324.7	1300	0.449	0.262	**N/A**	**0.000**	0.000
005-4-08	650.0	2601	0.536	0.266	**N/A**	**0.237**	0.499
005-7-04	744.8	2980	0.891	0.418	**0.655**	**0.225**	0.644
005-7-08	329.7	1320	0.930	0.442	**0.643**	**0.979**	1.160
005-7-12	869.7	3480	0.930	0.372	**0.636**	**0.703**	1.163

Table 3.3 SF_6 - CALPUFF model validation > LOD, and >LOQ (continued)

TEST 6 – May 07, 1999 (13:00-17:00 MDT)

Test Number	Duration (s) of Sampling	Number of Sampling Points	Maximum Peak of Observ. (µg/m^3)	Avg>LOD of Observ. (µg/m^3)	Avg>LOQ Obs. (µg/m^3)	Model Prediction (µg/m^3)	
						Average	Maximum
006-4-01	284.8	1240	0.264	0.189	**N/A**	**0.457**	0.593
006-4-02	400.2	1860	0.322	0.217	**N/A**	**0.392**	0.593
006-4-03	1511.8	1460	0.246	0.184	**N/A**	**0.214**	0.559
006-4-04	1169.8	1560	0.264	0.197	**N/A**	**0.158**	0.426
006-7-01	284.8	1240	0.382	0.210	**N/A**	**0.468**	0.515
006-7-02	400.2	1860	0.363	0.218	**N/A**	**0.343**	0.593
006-7-03	1511.8	1460	0.434	0.231	**N/A**	**0.395**	0.749
006-7-04	1169.8	1560	0.281	0.200	**N/A**	**0.674**	0.888
006-7-05	1265.0	5061	3.917	1.422	**1.448**	**0.672**	1.699
006-7-06	1002.3	4010	0.394	0.241	**N/A**	**0.563**	0.802
006-7-07	1363.0	5453	0.301	0.195	**N/A**	**0.314**	0.633
006-7-08	389.8	1560	0.320	0.212	**N/A**	**0.533**	0.888

TEST 7 - May 07/08, 1999 (22:15-02:15 MDT)

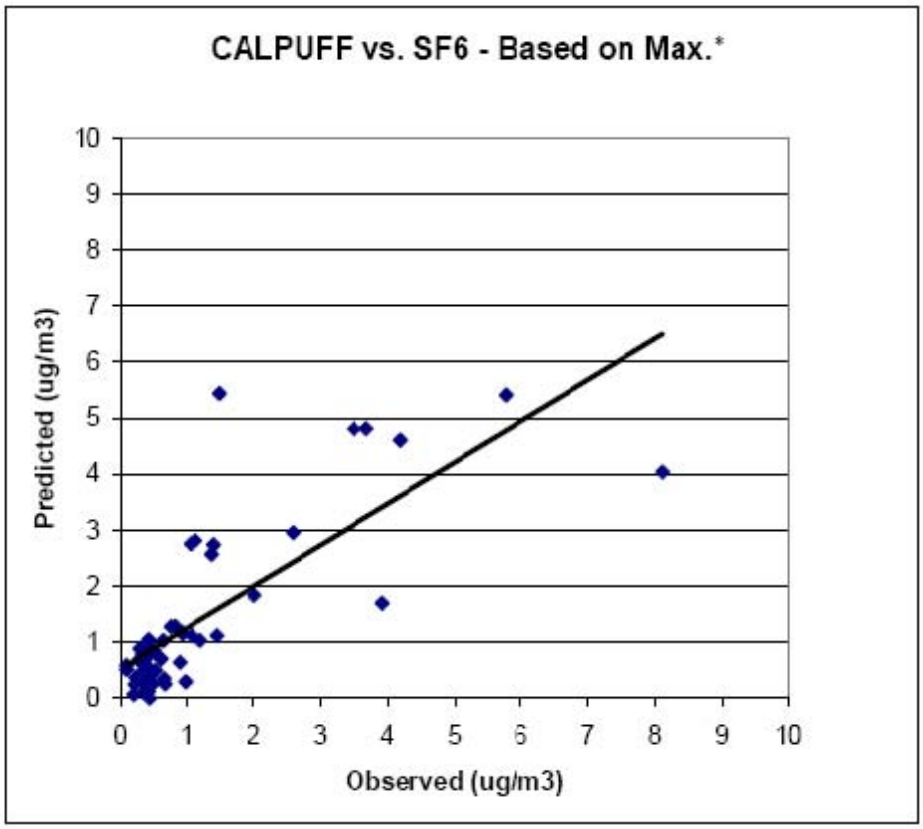
Test Number	Duration (s) of Sampling	Number of Sampling Points	Maximum Peak of Observ. (µg/m^3)	Avg>LOD of Observ. (µg/m^3)	Avg>LOQ Obs. (µg/m^3)	Model Prediction (µg/m^3)	
						Average	Maximum
007-4-01	244.7	980	0.220	0.220	**N/A**	**0.186**	0.376
007-4-04	1059.2	4238	3.265	1.824	**1.846**	**0.370**	1.036
007-4-08	2040.5	8163	19.723	6.940	**7.324**	**3.433**	5.410
005-4-12	299.8	1200	0.440	0.281	**N/A**	**0.370**	1.036
007-7-03	2497.8	9992	16.373	4.742	**5.038**	**2.739**	4.609
007-7-07	1184.7	4740	20.326	11.036	**11.292**	**2.242**	4.042

Based on the maximum predicted and maximum observed numbers and following the EPA's Protocol for the best performing model, the summary statistics for the model performance are as presented in Table 3.4. Figure 3.2 presents the scattergram of measured and predicted concentrations based on 54 sets of measurements with thousands of different locations and indicates a correlation between predicted and measured values.

Table 3.4 Maximum hourly model vs. observation results

Statistics	All Tests 54 Sets of Measurements
Mean of prediction	1.4
Mean of observations	1.1
Fractional bias of the average	0.17
Standard deviation of prediction	1.4
Standard deviation of observations	1.5
Fractional bias of standard deviation	-0.05
For paired data	
Within a factor of two (%)	59.3
Correlation coefficient	0.77

Figure 3.2 Scattergram of model performance



Note: * For TEST 7, with stable atmospheric conditions, the predicted maximum concentrations were lower than those observed (overall average ratio of pred/obs of about 0.85). However, when the observed peaks were converted to hourly average values the comparison to maximum hourly predictions improved.

Figures 3.3, 3.4, and 3.5 represent the ratio of modeled results with the observation as a function of sampling time. These graphs demonstrate two things:

(a) As sampling time increases, there is a tendency for the ratio between model predictions and observations to converge (become less variable) as the averaging time for measurement approaches the averaging time for the predicted concentrations.

(b) When observed values are limited to those above the LOQ, the general agreement between the observations and model predictions improves.

Figure 3.3 Ratios of maximums as a function of sampling time

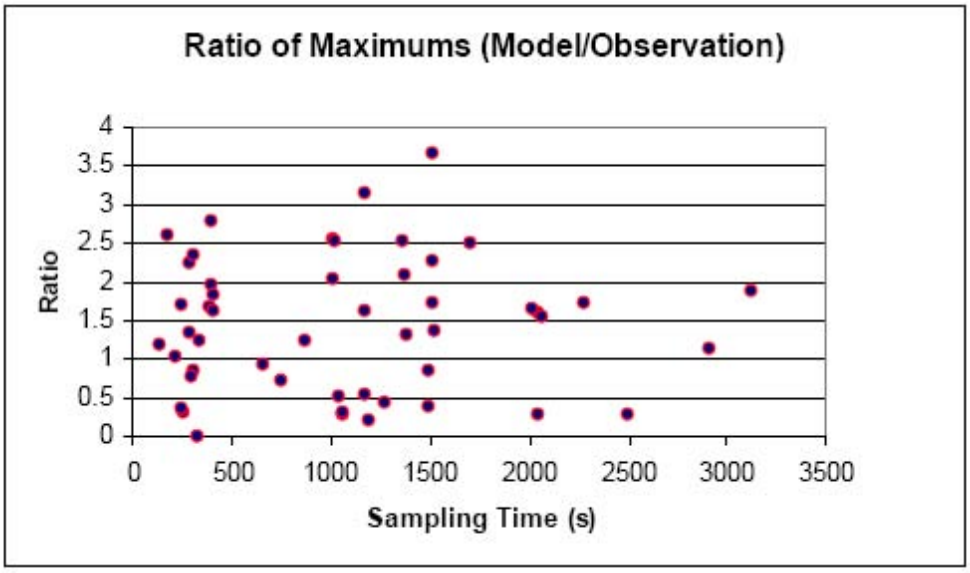


Figure 3.4 Ratios of averages > LOD as a function of sampling time

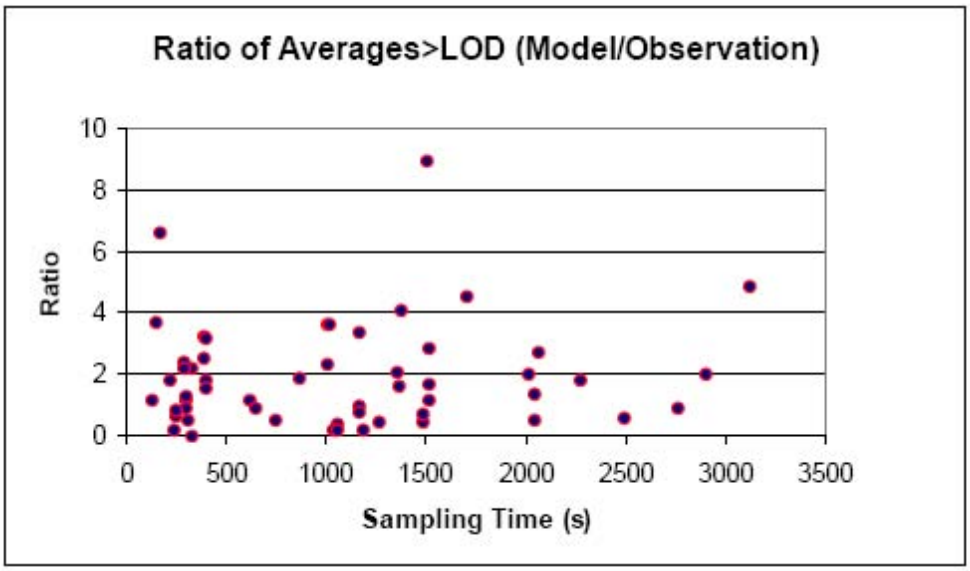


Figure 3.5 Ratios of averages > LOQ as a function of sampling time

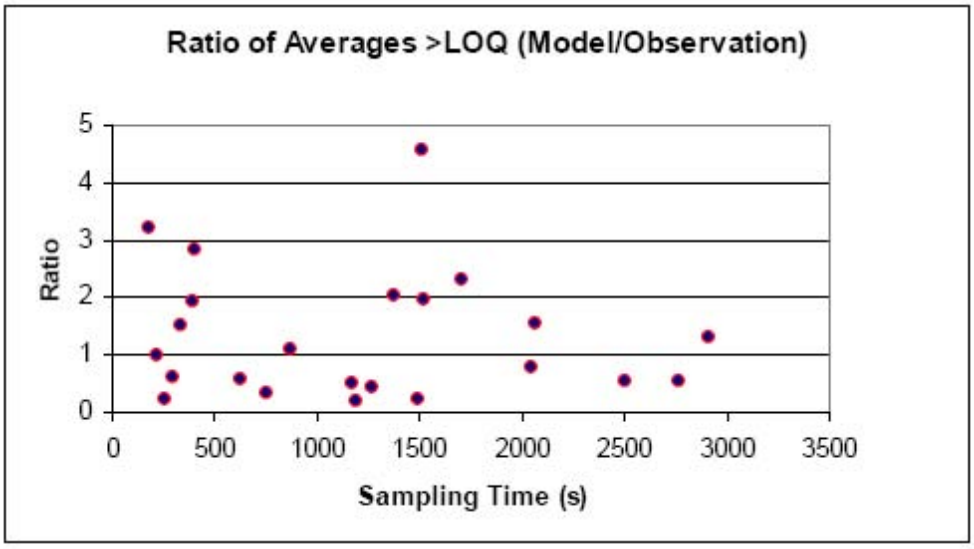


Figure 3.6 presents CALPUFF results of 5-hour average concentrations for test 1 (April 19, 1999). This pattern compared quite well with the MDIFF output for the same time period shown in Figure 21 (Clawson, 1999).

Figure 3.6 CALPUFF results

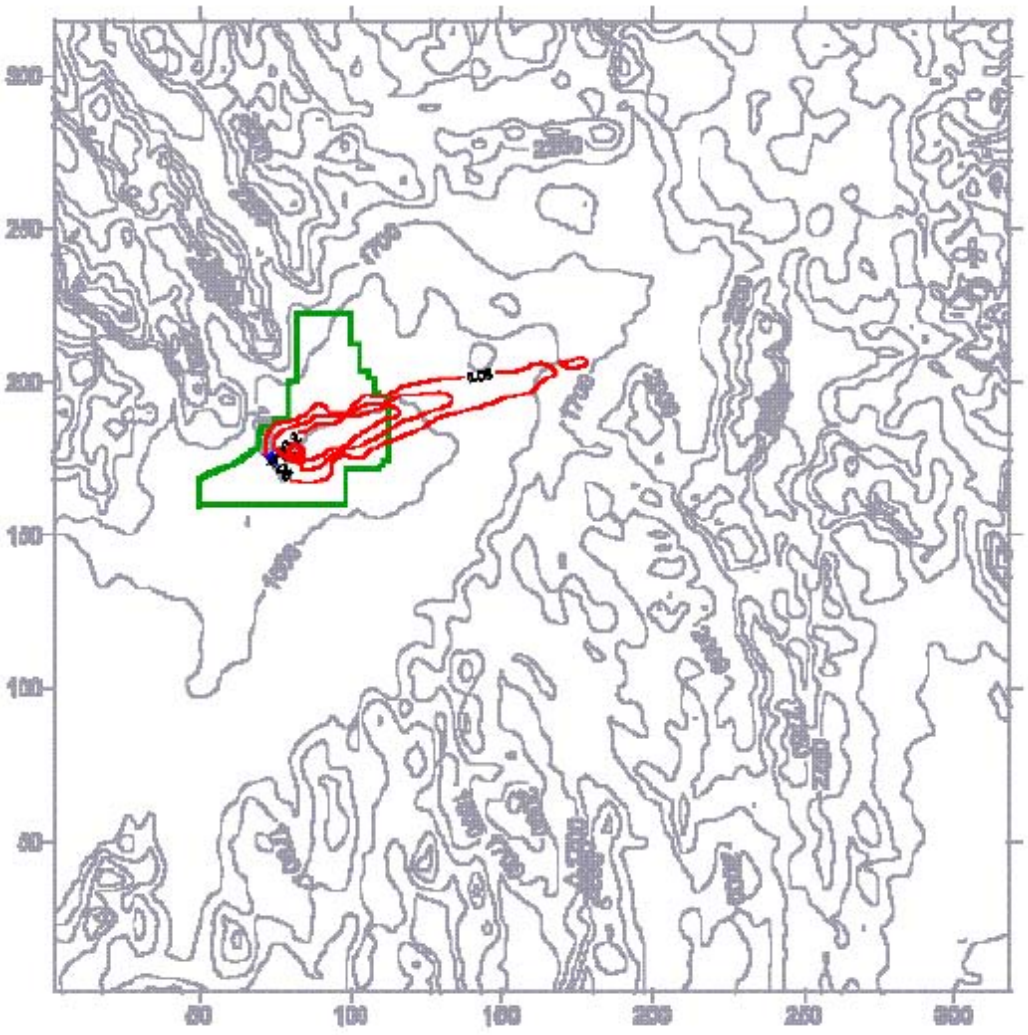


Figure 21 is an example "footprint" output of MDIFF showing trajectories (black lines) and total Integrated SF_6 concentration isopleths for Test 1 (19 April) from Clawson 1999.

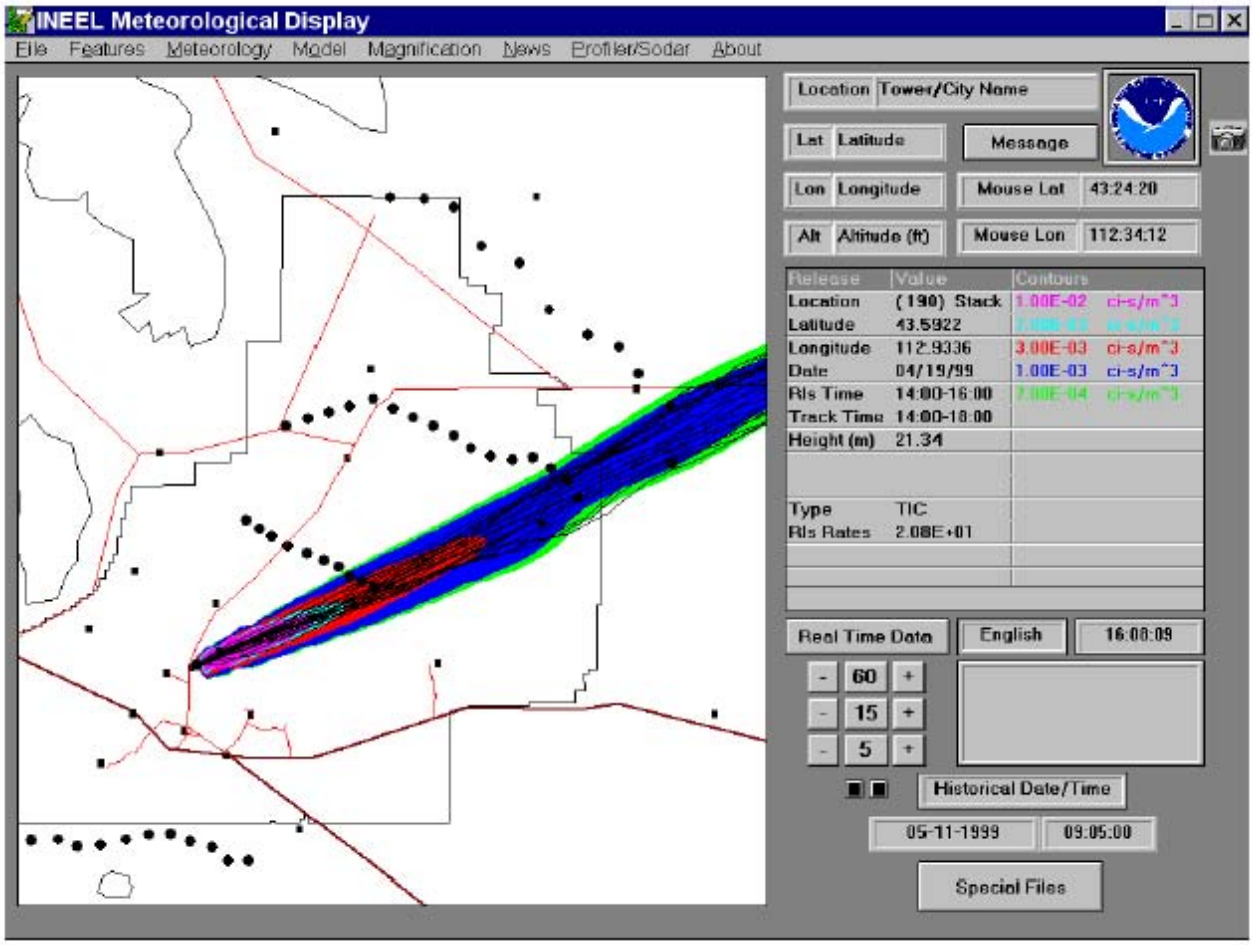
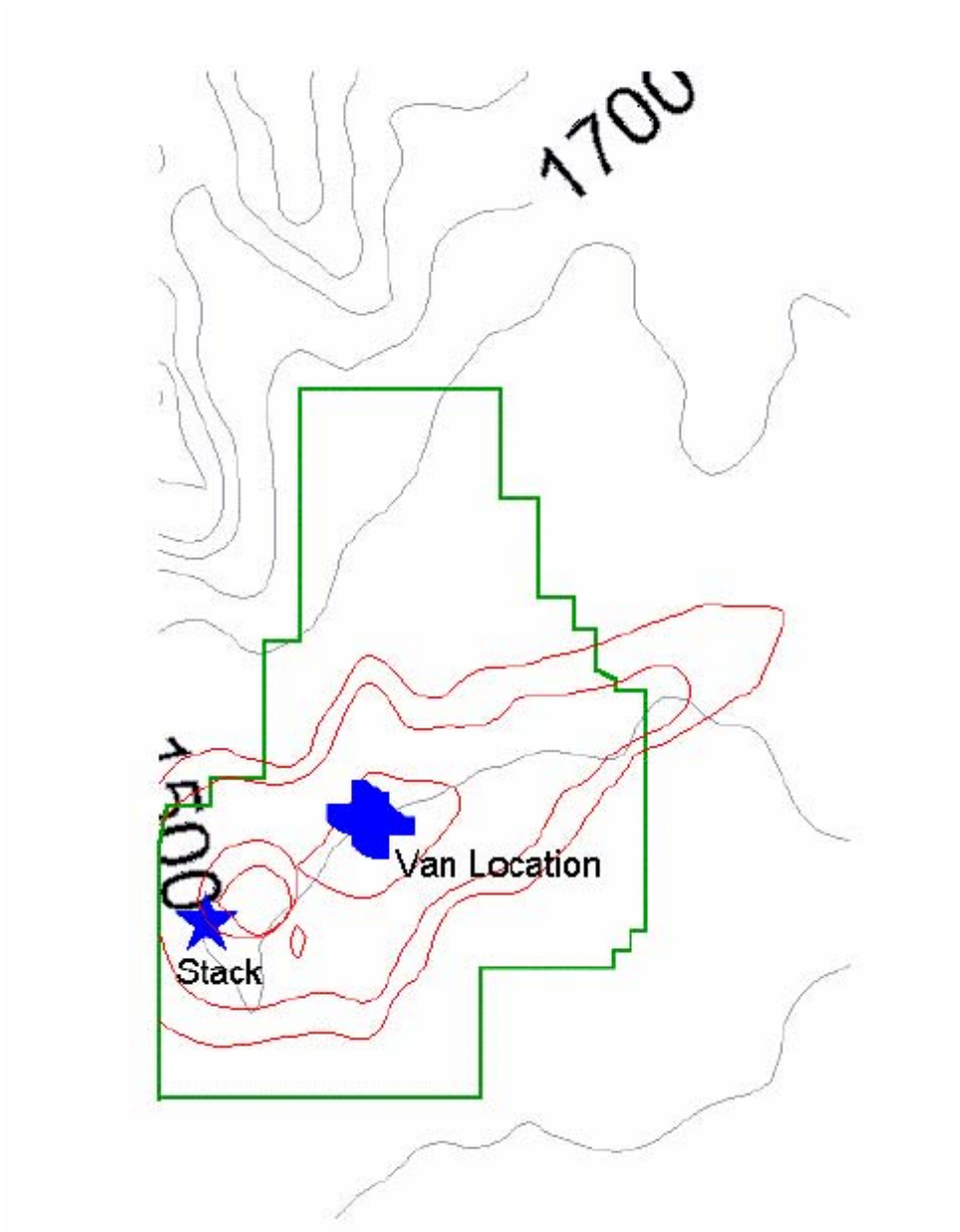


Figure 3.7 shows one example of the sampling points and plume lines during the TEST 3 between 14:00 and 15:00 MDT. This figure demonstrates that sampling locations during this experiment were in the plume.

Figure 3.7 003701 max hour ground level concentration in ug/m^3 of SF_6 based on emissions of 20.8 g/s
April 26, 1999 (14:00 – 15:00 MDT)



3.3 CALMET PERFORMANCE

Figure 2 (Clawson, 2000) and Figure 3.3 for TEST 4 (April 27, 1999 at 14:00 MST) are suggesting good agreement between the observations and CALMET predictions (Figure 3.8).

Figures D.1 through D.18 in Appendix D are the wind fields for selected hours during different tests. Note: the hours on the Figures are in MST time. Wind flow presented in Figure D.18 agrees with the description in the cited paper about the northwest cold air drainage from Birch Creek Canyon (a canyon located to the north-west of the INEL property). This is a good illustration of CALMET's capabilities to capture the up-slope and down-slope winds.

Figure 2 (Clawson, 2000)

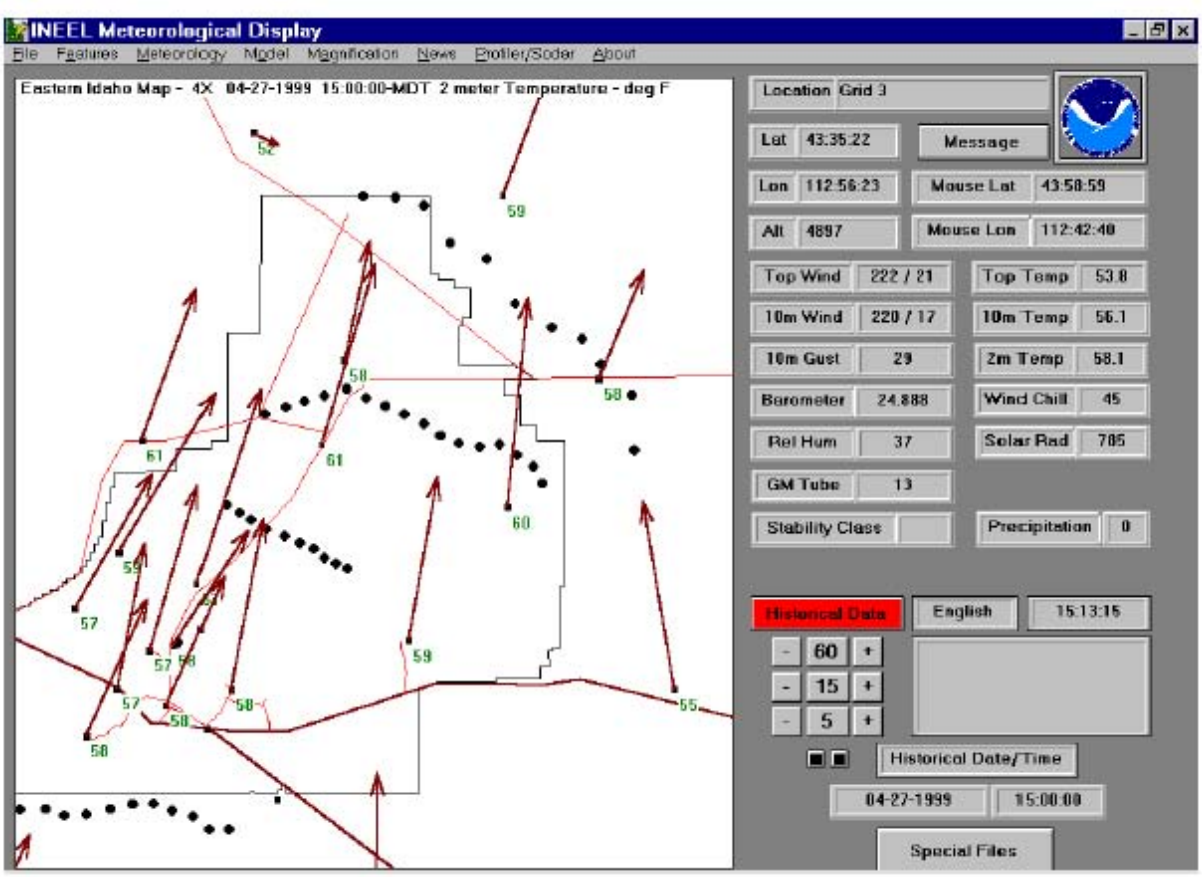
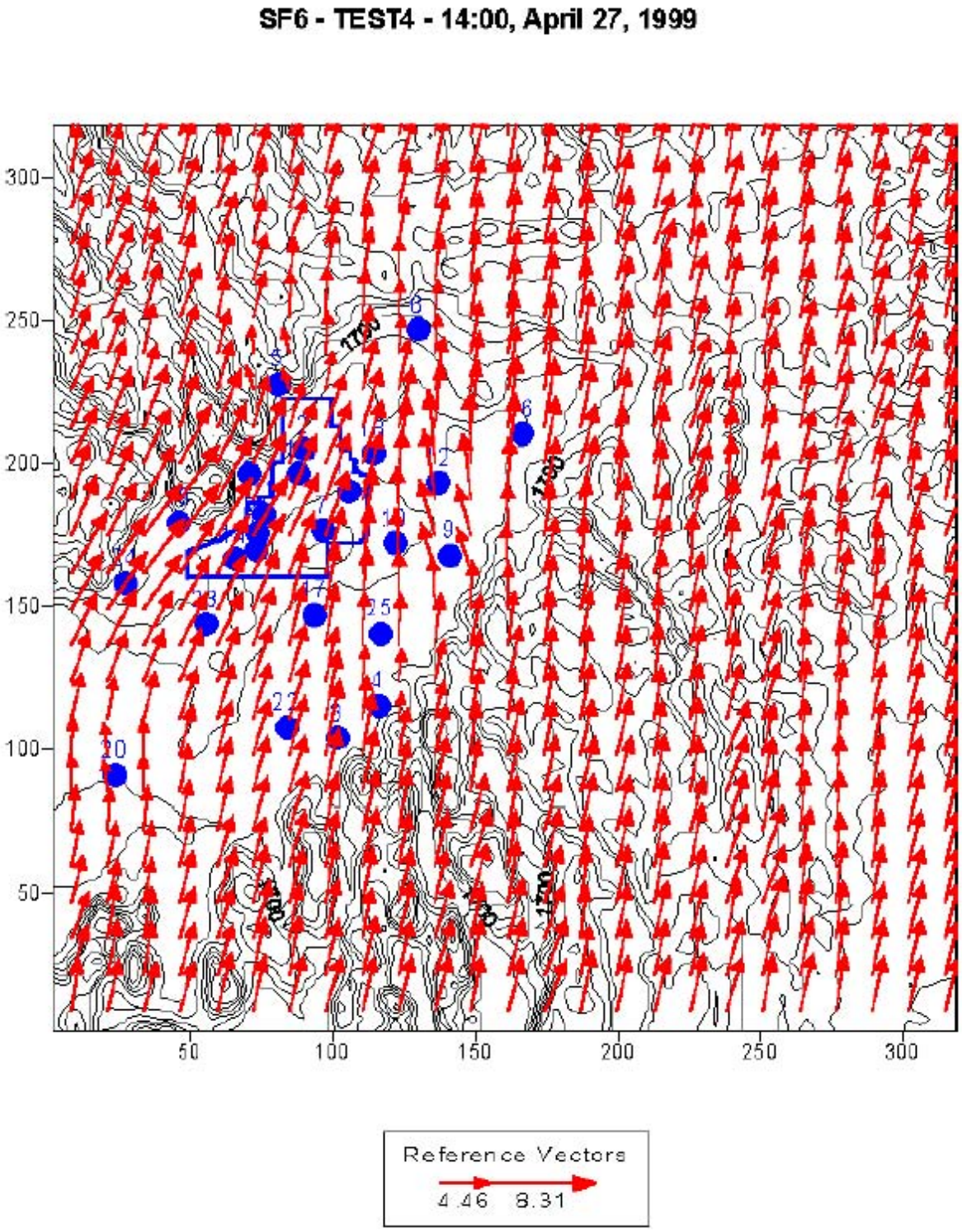


Figure 2 is an example INEL mesonet wind field over the test grid for Test 4 (27 April) at 1500 hours MDT.

Figure 3.8 Wind fields over Idaho National Engineering Laboratory property and CALPUFF modeling domain



3.4 CONCLUSIONS AND RECOMMENDATIONS

Based on this validation, it is evident that the CALMET/CALPUFF modeling system is quite applicable for the INEL site. The model validations demonstrate quite good agreement with the maximum measured values. Agreement with the average values is satisfactory but not as good, in our view, because of the LOD problem of the measurements.

Based on past experience, in view of this problem, validation through direct comparison of hourly predicted and observed values is likely to result in even further confidence concerning the reasonableness of the CALPUFF predicted concentrations, and subsequent dose calculations. Availability of hourly data for a year would allow model validation for longer averaging periods (1 hr, 24 hr and annual); time periods of greater importance for dose calculations.

4.0 CALPUFF PREDICTED IODINE-131 CONCENTRATIONS FOR DETERMINISTIC RUN

The concentrations of ^{131}I predicted using the CALMET/CALPUFF options, as described previously, are summarized in this chapter. The deterministic modeling is based on daily emission factors and the CALMET meteorological predictions based on the three stations available in the 1957-1959 period. The annual ^{131}I air concentrations predicted using daily emission factors for 1957, 1958 and 1959 are presented in Figures 4.1, 4.2 and 4.3 respectively. All presented concentrations are in Bq/m^3.

The variability in annual average concentrations, based on the deterministic runs, includes the effects of meteorological and emission variability. If the SE corner of the property is taken as a point of comparison it can be seen that in 1957 and 1958 predicted concentrations are approximately 0.01 Bq/m^3, while in 1959 the predicted concentration at the same location is 0.0015 Bq/m^3. A comparison of total emissions, given in Table 2.5, indicates that there is a 7 to 1 reduction in emissions between 1957-1958 and 1959. The temporal pattern in predicted concentrations follows this temporal pattern in emissions.

The patterns generally align along a southwest to northeast axis that is consistent with the predominant wind directions in the area. There is some variation in the pattern of annual average concentrations arising from, in part, differences in meteorology between the years. It is of note that the concentrations at Atomic City (location 3 on the figures) are greater that the concentrations measured at Mud Lake (location 20 on the figures). This arises because the uncertainty analyses include adjustments based on differences between dispersion with three stations and with 25 meteorological stations. These adjustments were not included in the deterministic modeling. The relative magnitude of air concentrations changes after the uncertainty analysis as described in Section 5.4.4.

Figure 4.1 Predicted annual iodine-131 CALPUFF concentrations for 1957

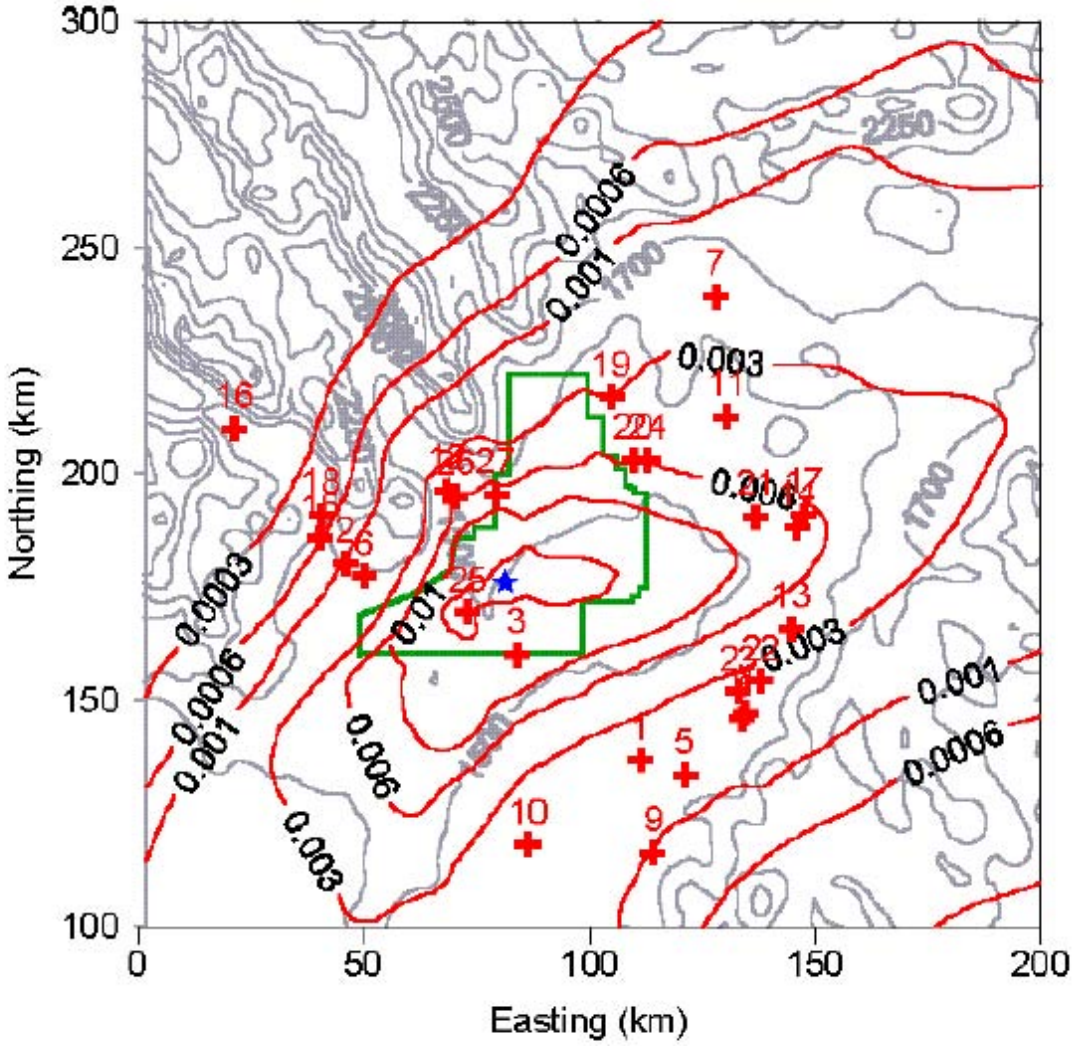


Figure 4.2 Predicted annual iodine-131 CALPUFF concentrations for 1958

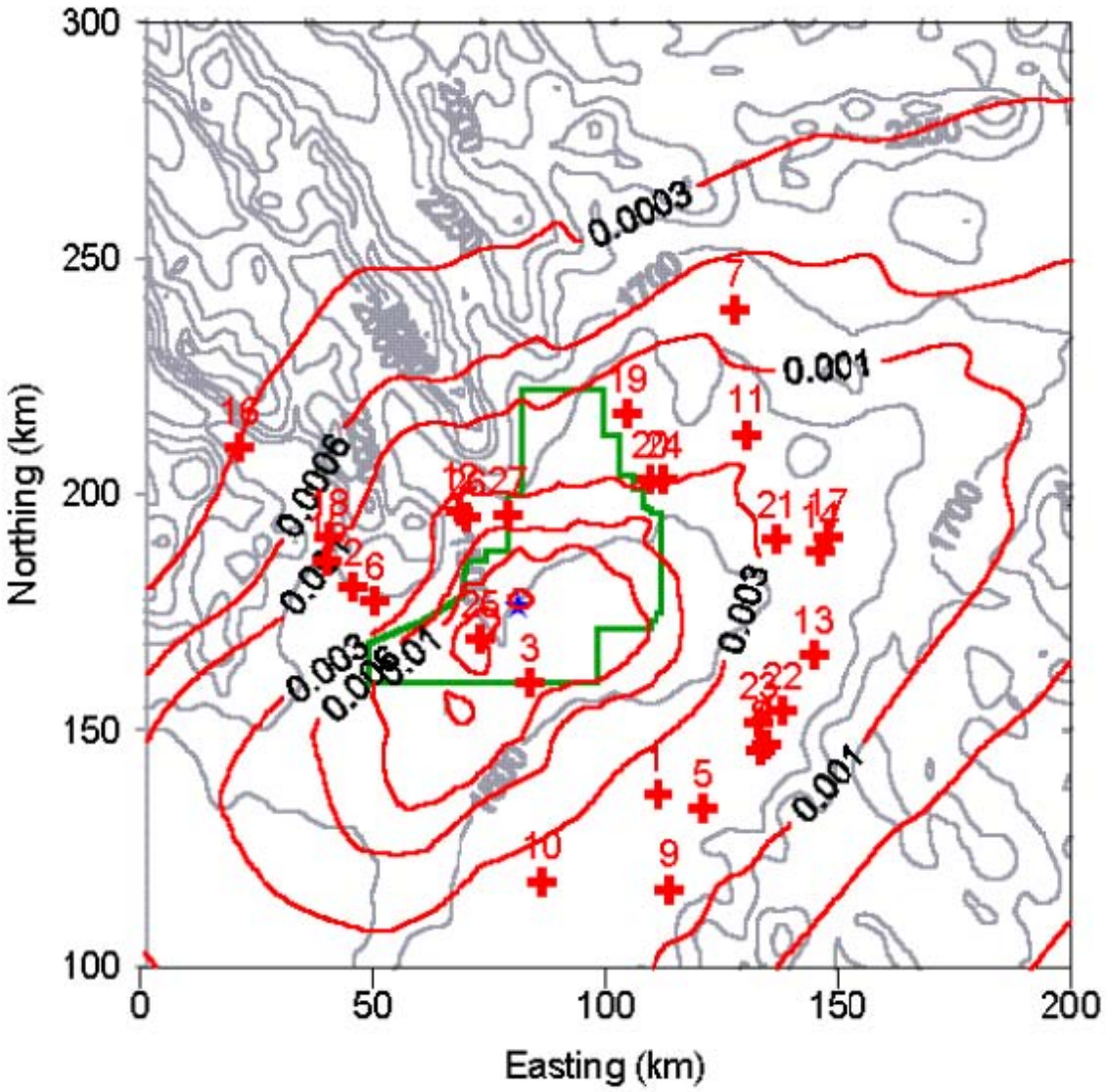
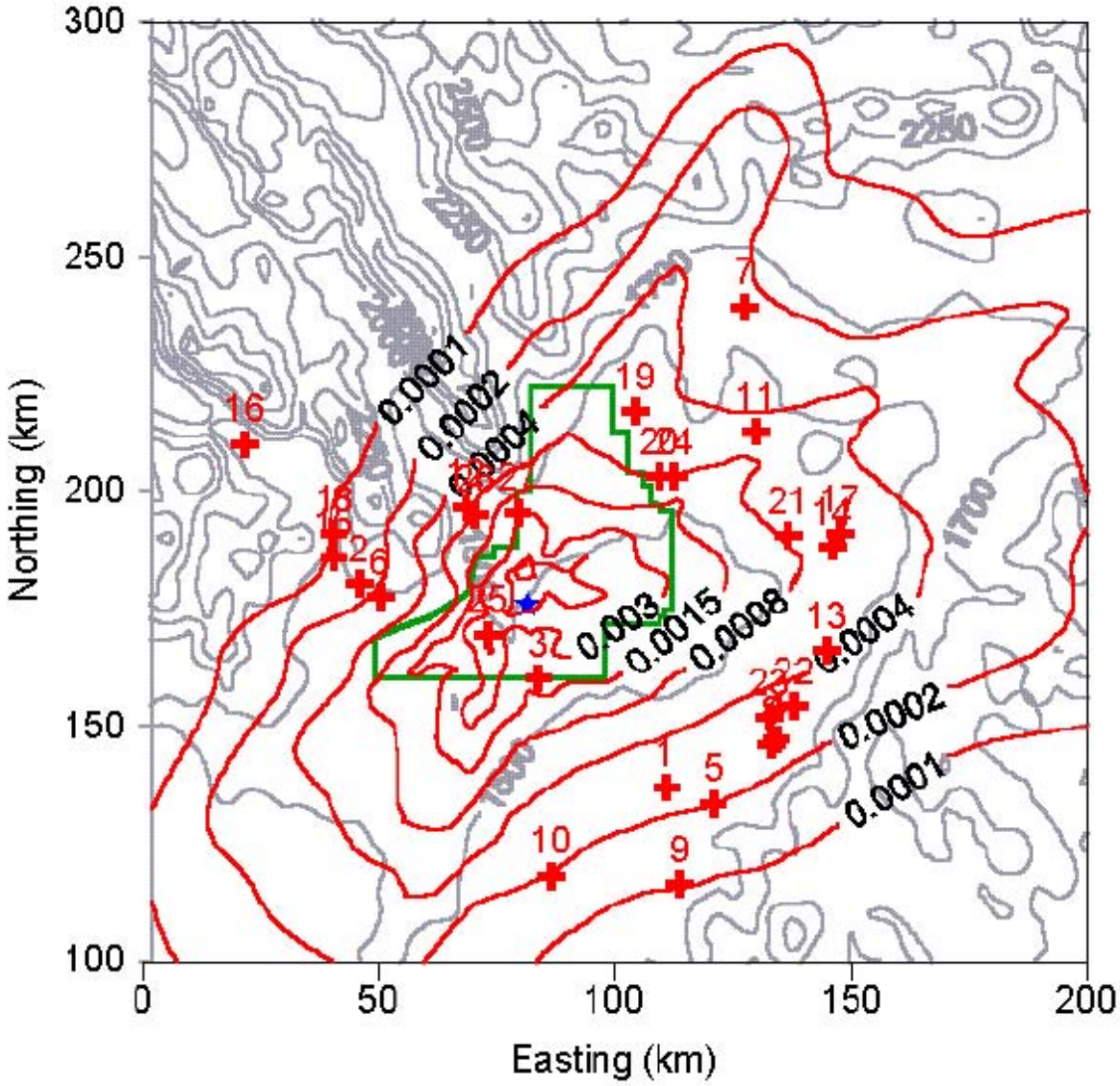


Figure 4.3 Predicted annual Iodine-131 CALPUFF concentrations for 1959



From the summary of emission rates shown in Table 2.5, the three highest months from 1957 and 1958 are presented in Figures 4.4 through 4.9. Figures 4.4, 4.5 and 4.6 represent monthly concentrations for February, October and November in 1957 respectively. Figures 4.7, 4.8 and 4.9 show the three months (March, May and June) with the highest emissions in 1958. These figures represent the variability in monthly (daily) emissions as well as variability (seasonality) in meteorology.

On a monthly basis, the variability in concentrations at the SE corner of the property is in the range of 0.1 to 0.03 Bq/m^3 (factor of 3) for these months with high emissions. It is important to note that the predicted monthly concentration levels can be higher than annual averages by about factor of 10 as a result of variability in both emissions and meteorology. Another characteristic of the monthly concentration prediction is the shape of contour lines, which represents, in part, the monthly (seasonal) meteorological variability. The month-to-month variations in shape are larger then the variation in shape of annual average concentrations shown in Figures 4.1 to 4.3.

Figure 4.4 Monthly iodine-131 CALPUFF concentrations – February 1957

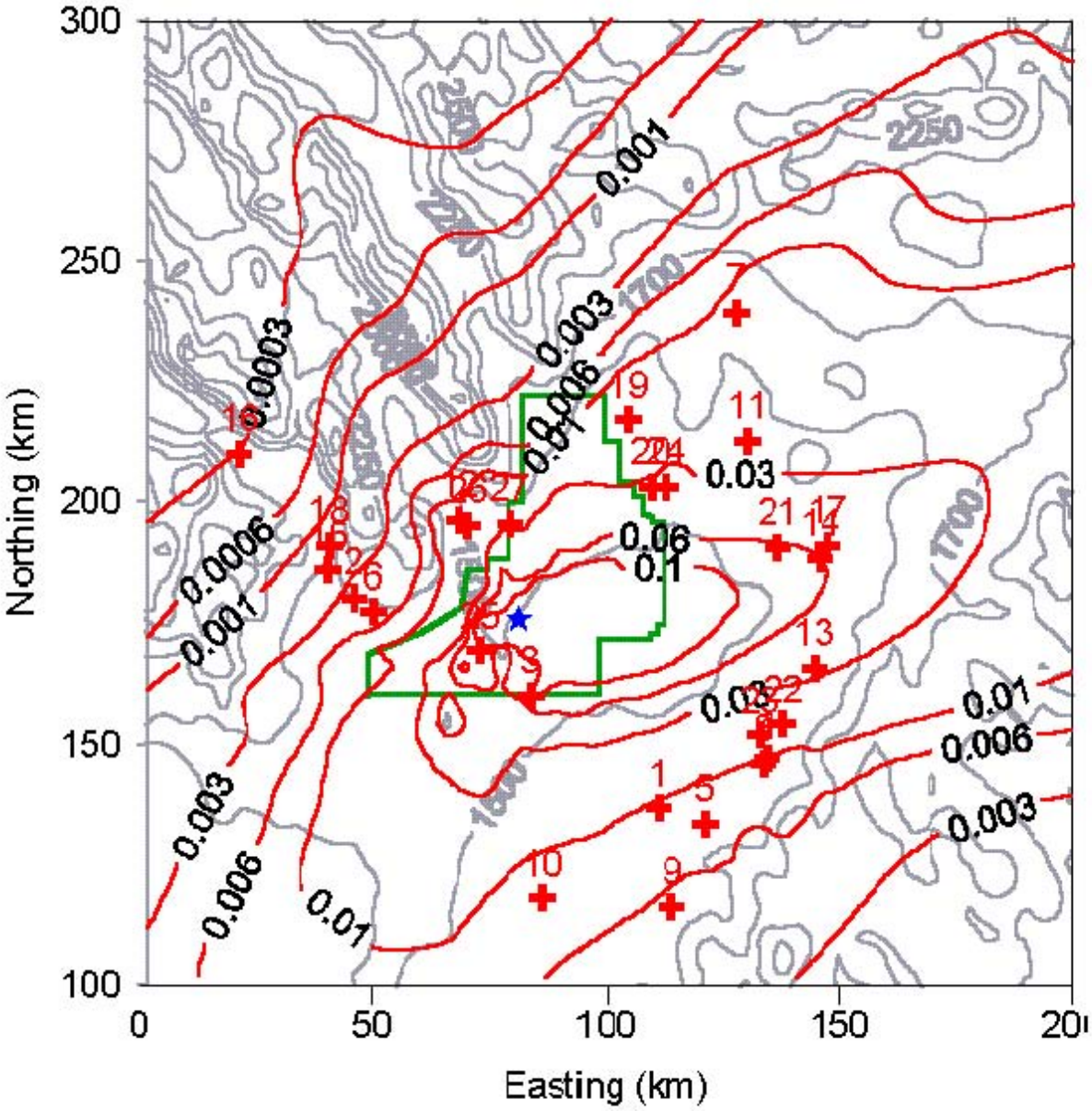


Figure 4.5 Monthly iodine-131 CALPUFF concentrations – October 1957

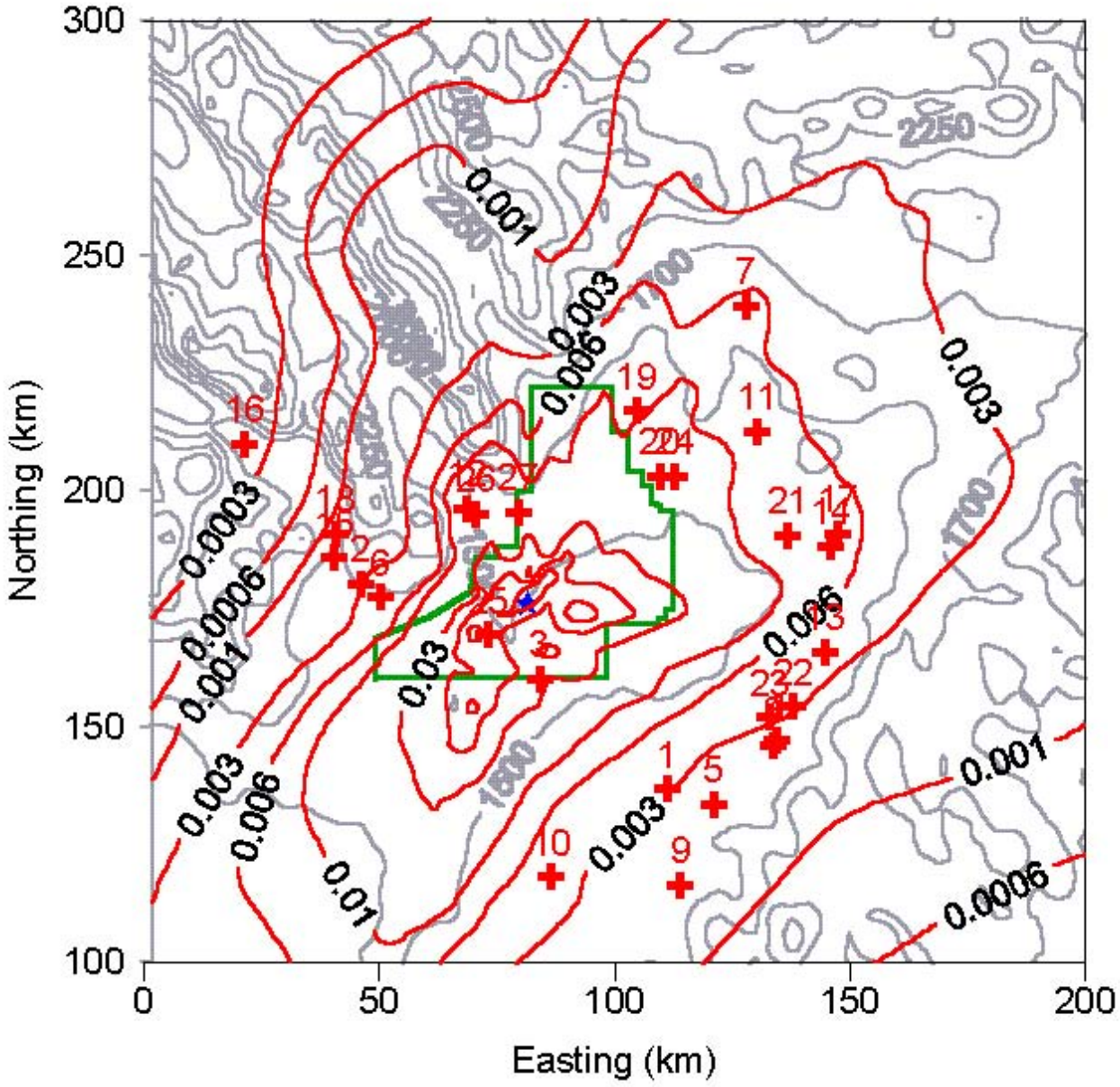


Figure 4.6 Monthly iodine-131 CALPUFF concentrations – November 1957

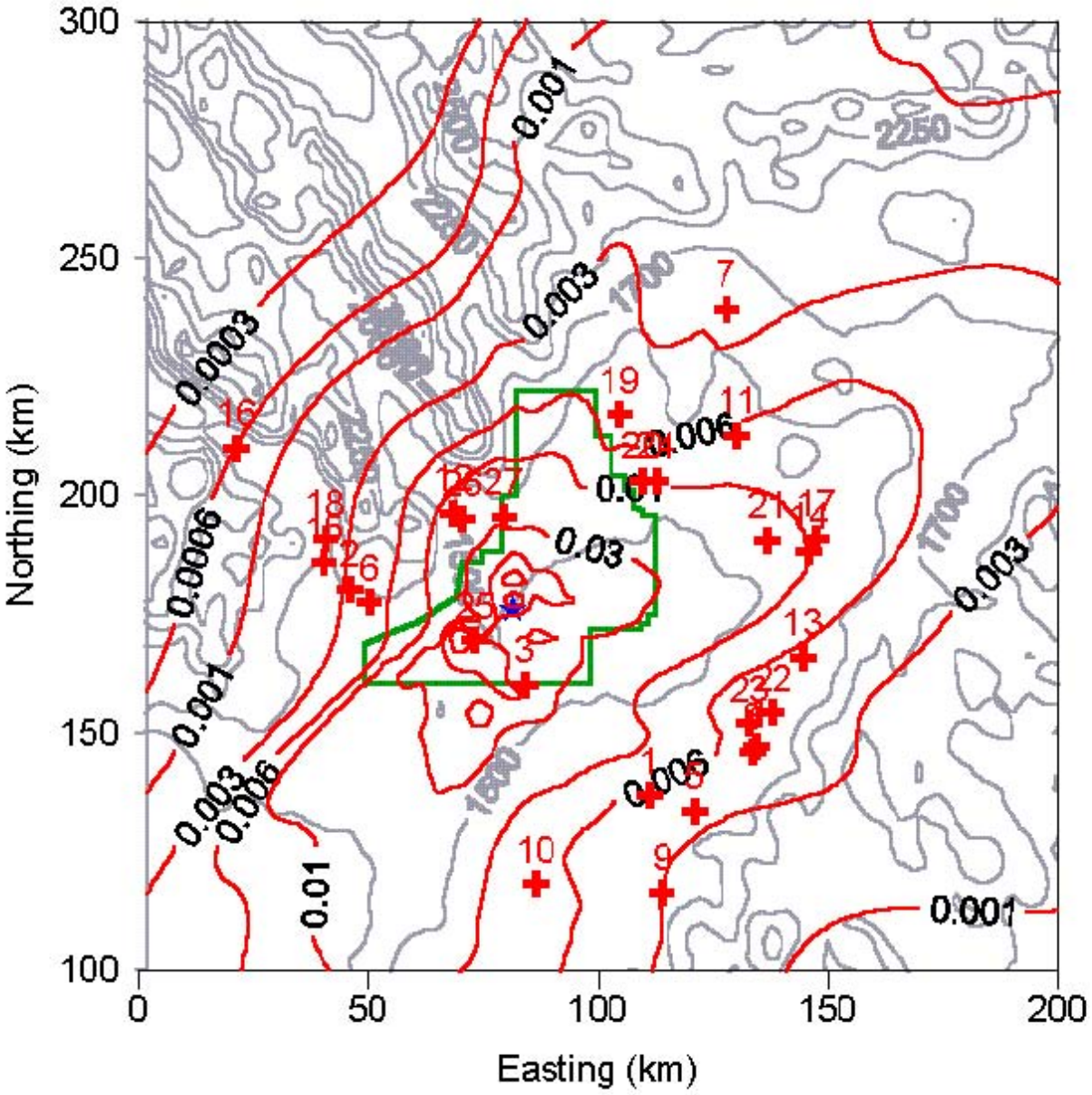


Figure 4.7 Monthly iodine-131 CALPUFF concentrations – March 1958

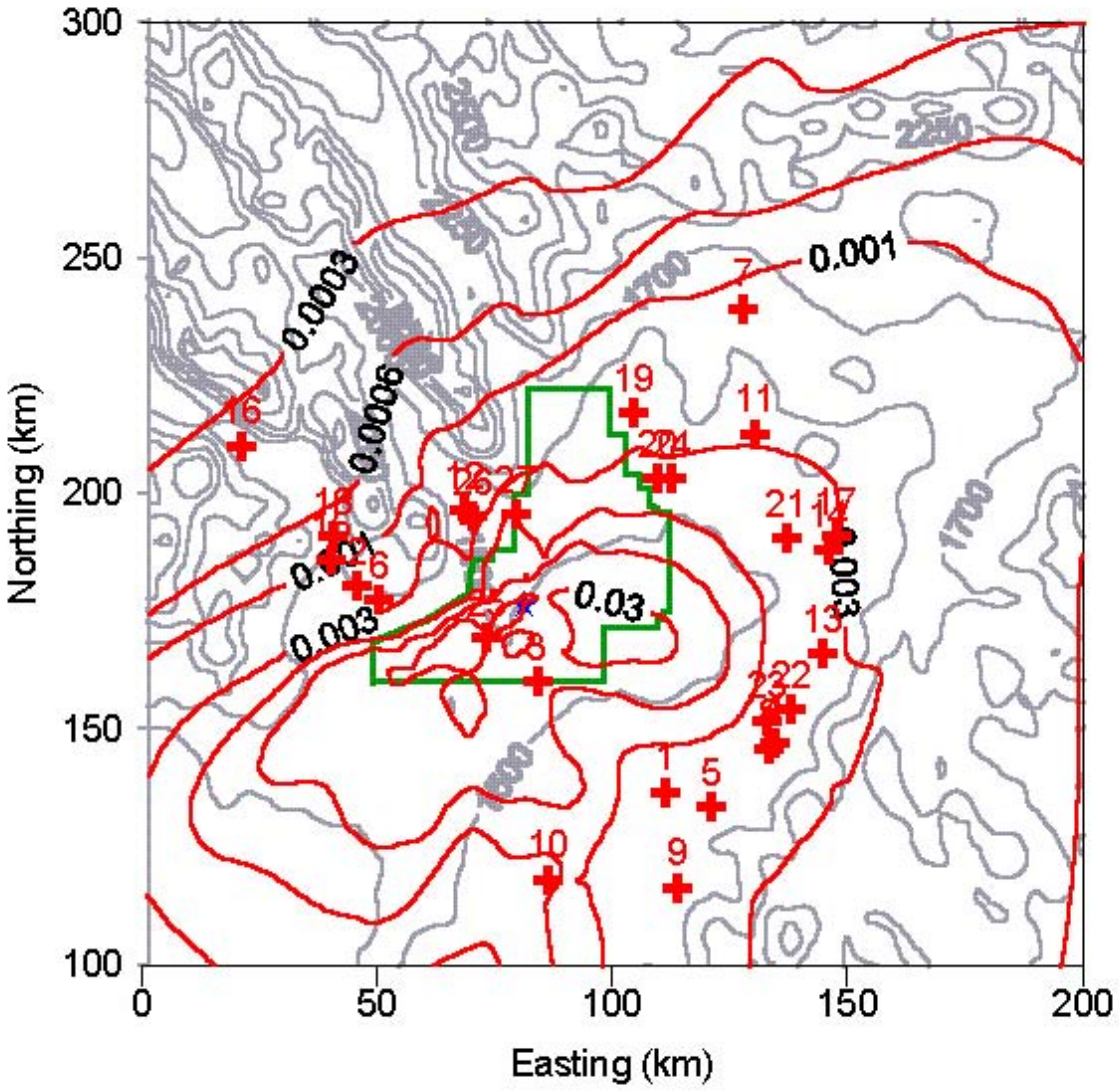


Figure 4.8 Monthly iodine-131 CALPUFF concentrations – May 1958

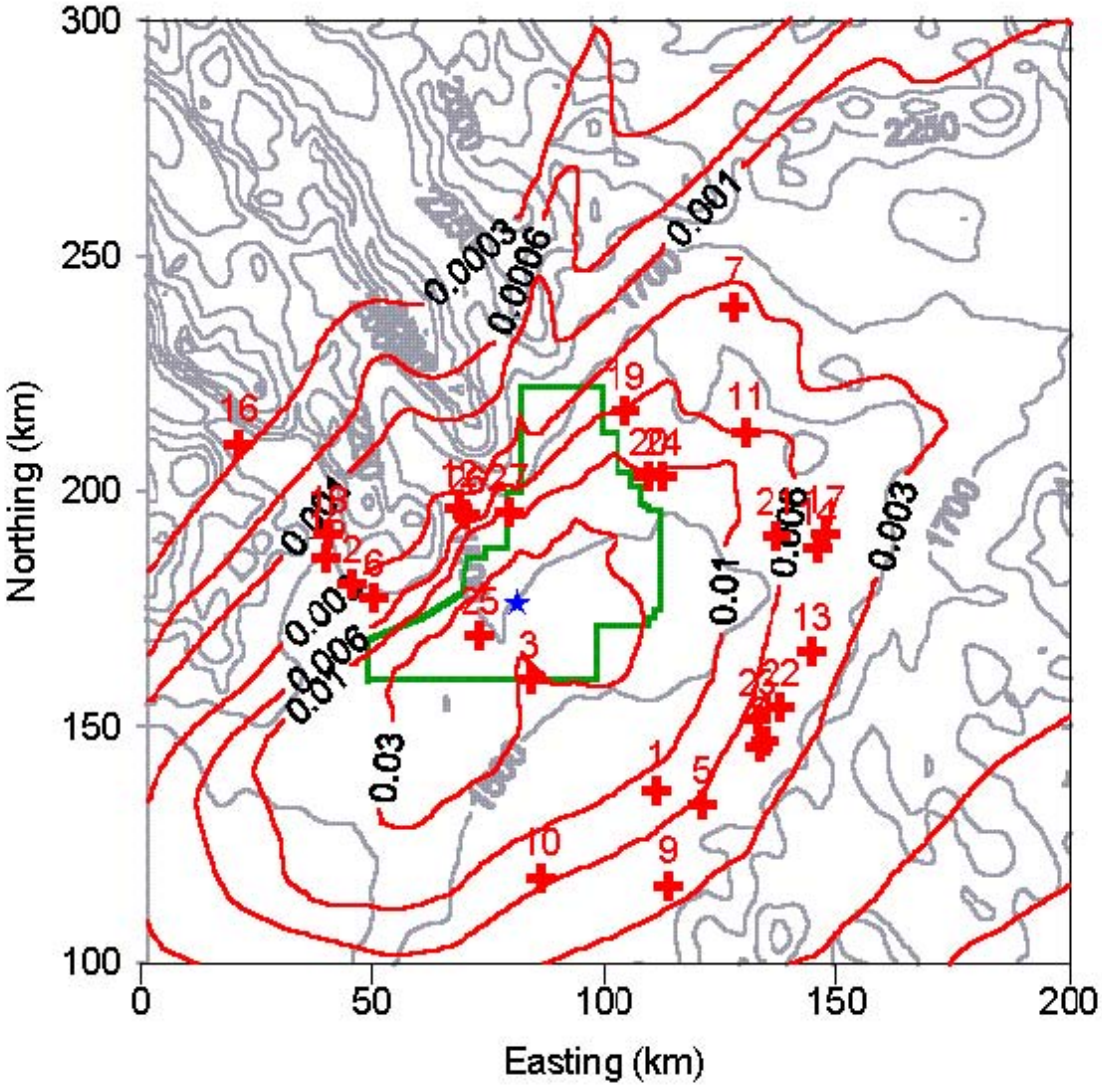
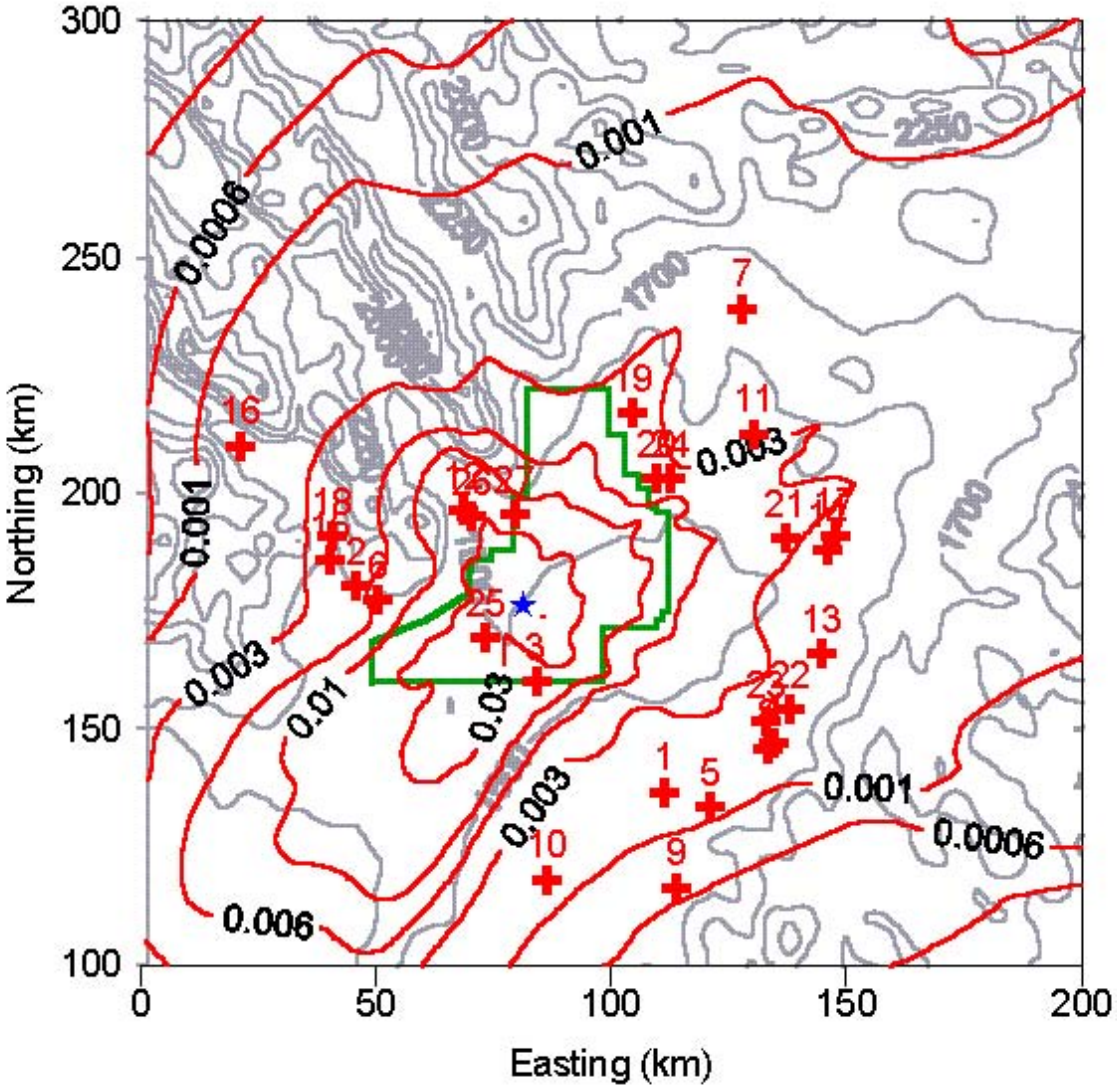


Figure 4.9 Monthly iodine-131 CALPUFF concentrations – June 1958



5.0 PROBABILISTIC APPROACH

The objective of the probabilistic simulation was to estimate monthly average air concentrations and the uncertainty in these average concentrations. Three major sources of uncertainty in the air concentrations were considered: first, was the emission rate from the facility, second was the approach for air dispersion modeling and, third, was the uncertainty in air dispersion modeling introduced by uncertainty in the meteorological conditions.

Monte Carlo sampling techniques were used to formally quantify the uncertainty in the estimated air concentrations.

5.1 APPROACH

Variability in air concentrations and receptor locations will be present due to variations in release rates, air dispersion processes and meteorological conditions which can change substantially on time-scales of less than a month. Information is available on meteorological conditions on an hourly basis and for emissions on a daily basis. In order to account for variability in hourly meteorological conditions, air dispersion characteristics have been calculated on an hourly basis and summarized on a daily basis. These daily dispersion factors are combined with daily emission rates to estimate daily average concentrations. The daily average concentrations are then summarized on a monthly basis. In this way, the variability in meteorology, air dispersion and emission rates are addressed in the calculation of monthly average concentrations. The probabilistic approach addresses the uncertainty present in the daily emission rates and the hourly meteorological and air dispersion characteristics.

The overall approach was to use CALPUFF to calculate unit dispersion factors (concentration per unit emission) on an hourly basis for each receptor location in order to reflect the hourly variability in dispersion due to meteorology and location relative to the facility. Uncertainty is present in the air dispersion modeling even if meteorological conditions were known exactly due to the choice of algorithms within the mathematical model. Eight choices of algorithms within the CALPUFF dispersion model and the CALMET processor were identified and unit dispersion factors with these choices were stored in a database for access during the probabilistic assessment rather than re-running the CALPUFF model for each simulation.

Due to the complex local topography and meteorological characteristics present in the physical setting, there is uncertainty in the hourly meteorological characteristics using the three surface air stations available for the 1957-1959 period. An estimate of the uncertainty in meteorological conditions has been quantified using a recent and more intensive network of 25 surface air stations. This larger network is considered to provide “precise” characterization of meteorological conditions in the area. The uncertainty in air dispersion attributable to uncertainty in meteorological conditions can be quantified by comparing hourly unit dispersion factors calculated using the 25 surface air stations to the unit dispersion factors calculated using three surface air stations. This was completed for 1999 using each of the eight dispersion-modeling approaches. The uncertainty in unit air dispersion factors quantified for 1999 was considered applicable for 1957-1959. The uncertainty was applied to the 1957-1959 unit air dispersion

factors (estimated with three surface air stations) on an hourly basis and then summarized on a daily basis. This step provided a probabilistic assessment of average daily dispersion factor.

The probabilistically generated daily dispersion factors were multiplied by the probabilistically sampled emission rates to calculate the average concentration on a daily basis. For each simulation, a monthly average was calculated.

For each radionuclide and receptor location, there were 500 simulations of average monthly air concentrations for the 1957-1959 period.

5.2 SAMPLING DISTRIBUTIONS

5.2.1 Emission Rates

Five hundred (500) probabilistic simulations of daily emissions for each of the 13 radionuclides were used (Wichner et al. 2005a,b). These values are summarized in a previous chapter.

5.2.2 Air Dispersion Modeling Scenarios

The options considered during air dispersion modeling include: i) the methods for calculation of vertical wind profile by the CALMET processor; ii) the method for terrain adjustment within CALPUFF; and, the method for estimating dispersion coefficients within CALPUFF. The choice of a particular method was considered the major source of uncertainty in atmospheric dispersion modeling given that meteorology and release characteristics are well known.

Overall, there are eight dispersion-modeling scenarios (i.e. two options for wind profile times two options for terrain adjustment times two options for dispersion coefficients). Table 5.1 shows the probabilities for the dispersion modeling scenarios. The assigned subjective probabilities were based on the experience of the authors. The scenario using similarity theory for vertical wind profile in CALMET, partial plume for terrain adjustment in CALPUFF and PG dispersion coefficients in CALPUFF was considered the most likely scenario for air dispersion modeling.

During the probabilistic analyses, the same air dispersion modeling approach was used for all receptors for the entire 1957-1959 period rather than changing the air dispersion modeling approach from hour-to-hour or day-to-day.

Table 5.1 Probability for dispersion modeling scenarios

Modeling Scenario	Scenario Code	Probability (%)
Similarity, partial plume, PG coefficients	s1	30
Similarity, partial plume, internal	s2	10
Similarity, simple CALPUFF, PG coefficients	s3	10
Similarity, simple CALPUFF, internal	s4	10
Power law, partial plume, PG coefficients	sa1	10
Power law, partial plume, internal	sa2	10
Power law, simple CALPUFF, PG coefficients	sa3	10
Power law, simple CALPUFF, internal	sa4	10

Notes:
Dispersion modeling scenario described by vertical wind profile method, terrain adjustment and dispersion coefficients.

5.2.3 Meteorological Uncertainty

Dispersion modeling was conducted for 1999 using each modeling scenario with either only the surface 3 stations also available in 1957-1959 or all 25 surface stations available in 1999. The 25 surface stations are assumed to provide "accurate" meteorological data for air dispersion modeling; therefore, the uncertainty in unit dispersion factors was defined as the difference between unit dispersion factors modeled with 25 surface stations and the unit dispersion factors modeled with 3 surface air stations.

Table 5.2 presents a matrix that shows how the approach to simulation of unit dispersion factors in 1957-1959 based on unit dispersion factors calculated using 3 stations related to the unit dispersion factors calculated for the same location using the meteorological data for 25 stations. This is potentially important, as there are situations where, for example, the concentrations predicted at a specific location using the meteorological data for 3 stations may be zero while the concentrations predicted using the meteorological data developed for 25 stations is non-zero and vice-versa. The modeled unit dispersion factor using three surface stations will either be zero or a value >0. When the modeled unit dispersion factor is zero, the sampled unit dispersion factor will be zero with probability $P(0,0)^*$. For the remaining percentage, the uncertainty in the modeled unit dispersion factor will be sampled from the distribution of modeled unit dispersion factors observed in 1999 using 25 stations when the modeled unit dispersion factor using three stations was zero and the modeled unit dispersion factor using 25 stations was non-zero.
For the case when the unit dispersion factor for three stations is >0, the adjustment to the unit dispersion factor will be zero with probability P(0,>0). For the remaining percentage, a ratio between 25 and 3 station unit dispersion factors will be sampled from the distribution observed in 1999. The adjusted unit dispersion factor will be calculated by multiplying the unit dispersion factor, using three stations, by the sampled ratio.

Table 5.2 Approach to modeling effect of meteorological uncertainty for different categories

	Zero with 25 stations	Positive with 25 stations
Zero with 3 stations	P(0,0) *probability of zero for 25 stations when 3 stations also had a zero* Outcome: Sample a value of zero	1 - P(0,0) Outcome: sample from distribution of unit dispersion factors with 25 stations.
Positive with 3 stations	P(0,>0) *probability of zero for 25 stations when 3 stations had a positive factor* Outcome: Sample a value of zero	1-P(0,>0) Outcome: sample from distribution of ratio between unit dispersion factors with 25 stations and unit dispersion factor

* Where the concentrations predicted with both data set is zero [P (25 stations, 3 stations)]

The probability of zero with 25 stations and the uncertainty in unit dispersion factors are likely related to meteorological conditions. A more precise characterization of the uncertainty attributable to meteorological uncertainty has been pursued by subdividing the sampling probabilities by meteorological category relative to wind speed, direction and stability class, since these are important factors in air dispersion. The four categories for wind direction are N (315^o – 45^o), E (45^o - 135^o), S (135^o - 225^o), and W (225^o - 315^o). Three stability categories have been created by grouping AB, CD, and EF. Wind speeds were categorized by 0-2 m/s, 2-3 m/s, 3-5 m/s, 5-6 m/s and >6 m/s for CD stability class. Since higher wind speeds are infrequent for AB and EF stability classes, the wind speeds were categorized as 0-2 m/s, 2-3 m/s and >3 m/s for these stability categories. The meteorological categories are based on selected CALMET grid points.

Each hour in 1999 was categorized by the meteorological categories described above. The average unit dispersion factors for 3 and 25 surface air stations were calculated for each hour and the sampling distributions were developed for that meteorological category. The uncertainty estimated in 1999 was assumed to be the same that would be present in the 1957 to 1959 period between unit dispersion factors that were calculated with 3 surface stations and the unit dispersion factors that would have been calculated if 25 surface stations were available.

Adjustment to Reflect Uncertainty when the Unit Dispersion Factor with Three Stations is Zero

An example of P(0,0), the probability that the dispersion factor with 25 stations would be zero when the dispersion factor with 3 surface air stations is zero is provided in Table 5.3. There is some dependency between this probability and the meteorological characteristics developed with 3 surface air stations. The probability is highest for winds from the east and for higher wind speeds. This is consistent with the receptor location being located to the east of the facility and with less variable wind direction when wind speeds are generally high.

Table 5.3 Probability (%) zero dispersion factor with 25 surface stations when zero dispersion factor with 3 surface stations

Stability	Speed (m/s)	North	East	West	South
AB	0-2	40	60	20	20
	2-3	41	64	16	33
	3+	38	60	26	33
CD	0-2	22	33	15	23
	2-3	41	48	18	28
	3-5	51	94	40	38
	5-6	70	100	50	59
	6+	86	100	65	43
EF	0-2	50	54	29	29
	2-3	65	65	34	8
	3+	67	65	54	48

Note:

i) Table is for Mud Lake Receptor with Scenario S1

For some hours, the dispersion factor with 25 surface air stations is greater than zero when the air dispersion factor calculated with 3 surface air stations is zero. This occurs with the complementary probability of above. Table 5.4 shows the average dispersion factor during these hours by meteorological category. For the particular example, the average dispersion factors for west and south wind directions tend to be higher than for winds from the north or east. This would be consistent with the location being downwind from the facility for westerly and southerly winds.

Table 5.4 Average unit dispersion factor (s/m^3) for 25 surface stations when zero dispersion factor with 3 surface stations

Stability	Speed (m/s)	North	East	West	South
AB	0-2	37E-10	67E-11	63E-10	62E-10
	2-3	29E-10	62E-10	39E-10	11E-9
	3+	3E-9	6E-9	5E-9	38E-10
CD	0-2	26E-10	38E-10	62E-10	7E-9
	2-3	87E-10	22E-10	85E-10	48E-10
	3-5	33E-10	14E-10	95E-10	44E-10
	5-6	25E-10		1E-8	18E-9
	6+	8E-11		8E-9	11E-9
EF	0-2	18E-10	12E-10	4E-9	26E-10
	2-3	18E-10	28E-11	11E-9	71E-10
	3+	58E-11	51E-11	58E-10	5E-9

Note:

i) Table is for Mud Lake Receptor with Scenario S1

Adjustment to Unit Dispersion Factor when Unit Dispersion Factor with Three Stations is Greater than Zero

An example of P(0,>0), the probability that the dispersion factor with 25 stations would be zero when the dispersion factor with 3 surface air stations is greater than zero is provided in Table 5.5. There is some dependency between this probability and the meteorological characteristics developed with 3 surface air stations. The probability is higher with higher wind speeds.

The probability of adjusting with unit dispersion factor of zero is also related to the magnitude of the unit dispersion factor based on the 3 stations. Hence, the sampling distribution has been made conditional on the magnitude of the unit dispersion factor from 3 stations by assigning the probability based on 10 categories of the unit dispersion factor. Table 5.6 shows a specific example for CD stability and winds 2-3 m/s from the N. The probability of adjusting with a zero unit dispersion factor is higher when the unit dispersion factor from 3 stations is lower.

Table 5.5 Probability (%) zero dispersion factor with 25 surface stations when dispersion factor with 3 surface stations greater than zero

Stability	Speed (m/s)	North	East	West	South
AB	0-2	12	11	7	9
	2-3	23	34	4	10
	3+	33	25	15	35
CD	0-2	7	8	4	8
	2-3	20	22	10	16
	3-5	33	30	23	36
	5-6	40	50	40	43
	6+	30	100	61	47
EF	0-2	8	11	7	9
	2-3	16	26	13	17
	3+	7	29	11	30

Note:
1) At Mud Lake receptor location with scenario S1.

Table 5.6 Specific example of dependency of adjusting with a zero unit dispersion factor when unit dispersion factor from three stations is greater than zero

Range of unit dispersion factor (s/m^3) with three stations	Probability of adjusting zero dispersion factor (%)
0+ to 2E-12	55
2E-12 to 21E-12	45
21E-12 to 77E-12	27
77E-12 to 15E-11	45
15E-11 to 28E-11	9
28E-11 to 76E-11	17
76E-11 to 13E-10	0
13E-10 to 29E-10	0
29E-10 to 58E-10	0
58E-10 +	0

Notes:
1) At Mud Lake Receptor with Scenario S1
2) North winds CD stability Speed 2-3 m/s

The approach for adjusting with non-zero unit dispersion factors is more complex. Since the sampled unit dispersion factor will be positively correlated with the unit dispersion factor with 3 stations, the unit dispersion factors from 3 stations have been classified to categories based on their magnitude. For each of these categories, the unit dispersion factors were classified

according to the unit dispersion factor calculated with 25 stations. A ratio was determined by dividing the average unit dispersion factor with 25 stations by the average unit dispersion factor with 3 stations. Table 5.7 shows the range of ratios and the probability for the case of CD stability, 2-3 m/s winds from the south and unit dispersion factors for 3 stations ranging from 1.9E-9 to 2.9E-9 s/m^3. The table shows that the uncertainty in hourly unit dispersion factors using 3 stations can range by orders of magnitude.

Table 5.7 Specific example of sampled ratio of unit dispersion factors

Probability (%)	Ratio
8	0.0072
12	0.0174
8	0.0553
12	0.2823
8	0.5453
12	0.6794
12	1.342
8	3.0878
12	9.6409
8	18.607

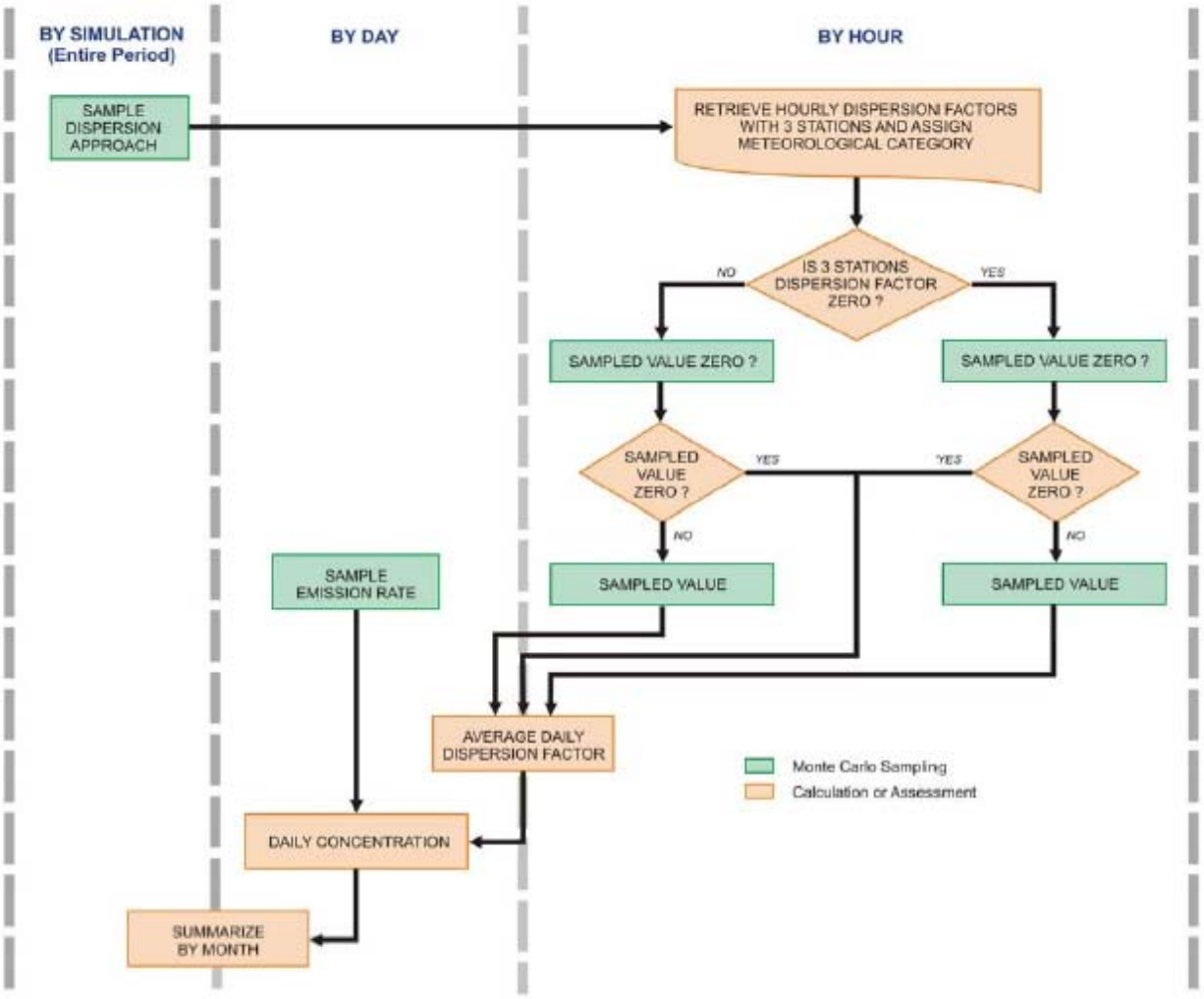
Notes:
At Mud Lake Receptor with Scenario S1
South Winds CD stability Speed 2-3 m/s
For Unit Dispersion Factors Ranging from 1.9E-9 to 2.9E-9 s/m^3

5.3 IMPLEMENTATION

Figure 5.1 shows the probabilistic approach to estimating air concentrations.

For each simulation, one of the dispersion modeling approaches is randomly selected. This approach is used for all receptor locations the entire 1957-1959 period and for all radionuclides. The hourly unit dispersion factors for this modeling scenario are retrieved from a database of unit dispersion factors to remove the necessity of running the CALPUFF model for each simulation.

Figure 5.1 Summary of probabilistic sampling of air concentrations



For each calendar day, the unit air dispersion factor using the three surface meteorological stations is averaged for the wind speed, direction and stability category. There are two general cases: first, the unit dispersion factor with 3 stations is zero. In this case, a probabilistic sampling is conducted to see if the adjusted unit dispersion factor is zero or a value greater than zero. If the sampling indicates that a value greater than zero is applicable, the value is probabilistically sampled from the range of unit dispersion factors in 1999 using the 25 surface stations. In the second case where the unit dispersion factor from three stations is non-zero, the probabilistic sampling selects whether the adjusted unit dispersion factor will be zero or a non-zero value. If this sampling indicates the adjusted unit dispersion factor is non-zero, an uncertainty factor is selected from the range of ratios (in 1999) when unit dispersion factors with both 3 and 25 stations are non-zero. A daily average unit dispersion factor is calculated, with weighting by the number of hours, from the adjusted unit dispersion factors for each meteorological condition.

The approach assumes independence from day-to-day in the uncertainty in unit dispersion factor for the same meteorological category. For example, the sampled uncertainty for speeds 2-3 m/s with AB stability class and directions from the north could be a factor of two higher on one day than on the following day. Within a day, the uncertainty is also uncorrelated between separate meteorological categories: the sampled dispersion factor may be higher than the modeled factor for one meteorological category and lower for another meteorological category. The sampling is also independent between locations. The uncertainty is however the same for all radionuclides considered in the simulation.

The daily unit dispersion factors are then multiplied by the probabilistically sampled emission rates for the day. Within a simulation, all receptor locations use the same emission rate when calculating air concentration.

For each simulation, the probabilistically generated air concentrations are summarized by calendar month.

5.4 RESULTS

5.4.1 Predicted Air Concentrations

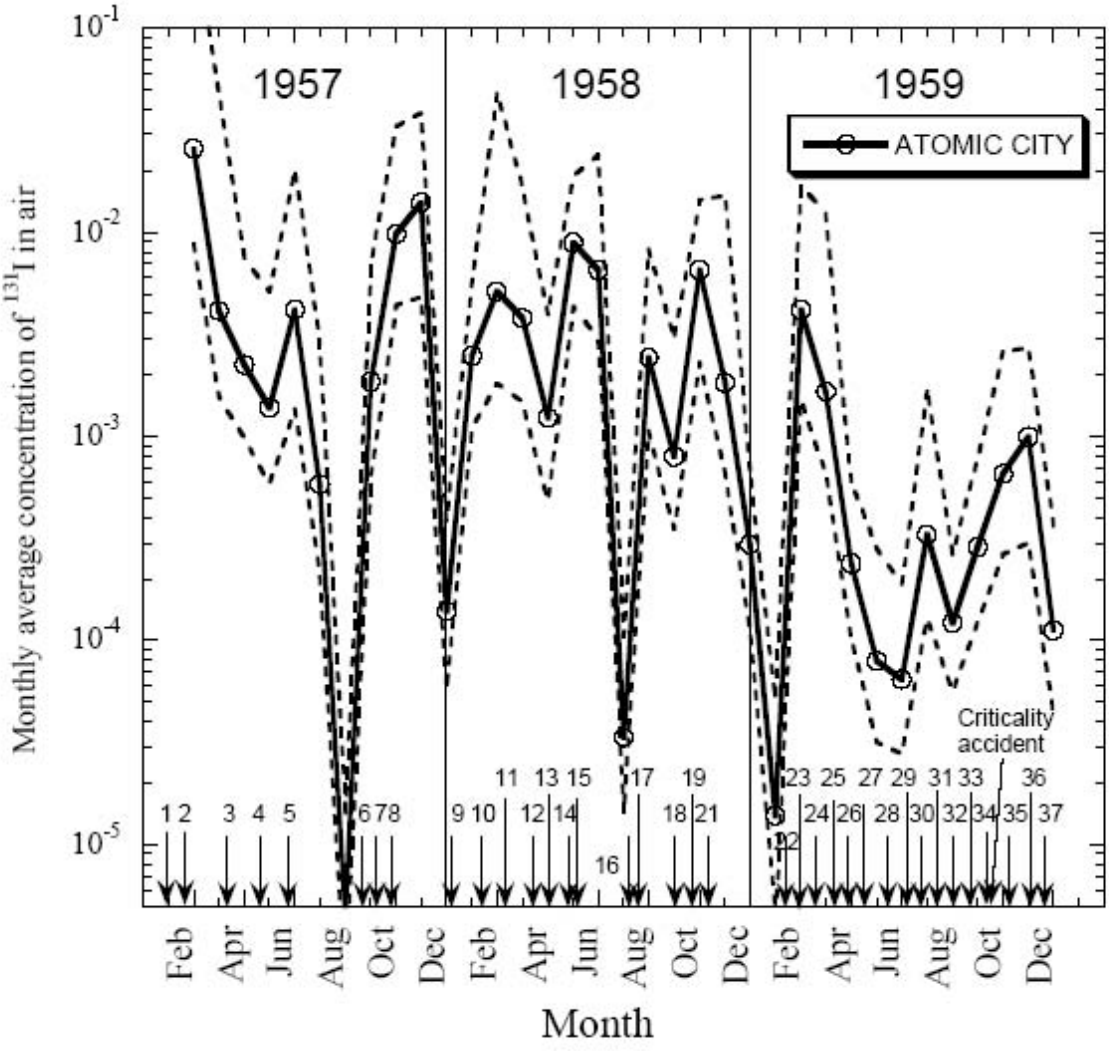
Air concentrations were predicted on a monthly basis and these results and the range of these concentrations are shown in Table 5.8. The central estimate in the table is the median, or 50th percentile, of the probabilistically sampled concentrations with the lower and upper bounds given by the 95th percentiles of the simulated concentrations. The table also shows the distribution for period average concentrations (February 1957 through December 1959). It is of note that February 1957 concentrations are about 10 times higher than average concentrations, due mostly to higher releases, and therefore this month accounts for about 30% of the period average.

Table 5.8 Summary of iodine-131 air concentrations (Bq/m^3)

	February 1957			Period Average		
Off-site Location	Lower Bound	Central Estimate	Upper Bound	Lower Bound	Central Estimate	Upper Bound
Aberdeen Junction	2.0E-03	4.5E-03	8.5E-03	4.0E-04	6.2E-04	1.0E-03
Arco	4.2E-03	1.1E-02	4.2E-02	1.0E-03	1.8E-03	4.3E-03
Atomic City	8.7E-03	2.6E-02	3.4E-01	1.5E-03	3.8E-03	1.1E-02
Basalt	1.9E-03	3.6E-03	7.0E-03	3.1E-04	4.8E-04	8.0E-04
Blackfoot	1.4E-03	3.0E-03	6.2E-03	2.9E-04	4.4E-04	7.5E-04
Butte City	5.9E-03	1.5E-02	5.8E-02	1.5E-03	2.6E-03	6.3E-03
Dubois	1.5E-02	2.8E-02	4.9E-02	1.7E-03	2.5E-03	4.1E-03
Firth	1.8E-03	3.6E-03	9.6E-03	3.1E-04	4.7E-04	8.0E-04
Fort Hall	9.7E-04	2.9E-03	5.8E-03	2.4E-04	3.6E-04	6.4E-04
Grandview	1.4E-03	3.5E-03	1.8E-02	3.8E-04	6.5E-04	1.2E-03
Hamer	2.2E-02	3.3E-02	5.8E-02	2.3E-03	3.1E-03	5.1E-03
Howe	1.3E-02	3.1E-02	8.2E-02	2.6E-03	4.2E-03	9.6E-03
Idaho Falls	4.1E-03	7.6E-03	1.9E-02	4.1E-04	6.8E-04	1.2E-03
Lewisville	1.2E-02	1.8E-02	3.2E-02	9.4E-04	1.3E-03	2.2E-03
Lost River	2.5E-03	6.5E-03	2.0E-02	6.8E-04	1.1E-03	2.3E-03
Mackay	6.2E-04	1.9E-03	5.0E-03	2.0E-04	3.4E-04	6.3E-04
Menan	1.0E-02	1.6E-02	3.0E-02	8.8E-04	1.3E-03	2.1E-03
Moore	2.2E-03	6.0E-03	2.2E-02	5.8E-04	1.0E-03	2.3E-03
Monteview	2.2E-02	4.1E-02	8.2E-02	2.8E-03	4.3E-03	7.4E-03
Mud Lake	2.8E-02	5.1E-02	8.9E-02	3.2E-03	5.0E-03	8.4E-03
Roberts	1.3E-02	2.1E-02	4.1E-02	1.2E-03	1.8E-03	2.9E-03
Shelley	2.5E-03	4.5E-03	9.6E-03	3.5E-04	5.3E-04	8.6E-04
Spencer	2.5E-03	4.7E-03	8.9E-03	3.7E-04	5.5E-04	9.2E-04
Terreton	2.6E-02	4.8E-02	8.4E-02	2.8E-03	4.7E-03	7.8E-03
Average milk prod area	4.8E-03	7.3E-03	1.2E-02	4.6E-04	6.7E-04	1.1E-03
On Site Location	Lower Bound	Central Estimate	Upper Bound	Lower Bound	Central Estimate	Upper Bound
CFA @ 250ft Met Tower	4.8E-02	1.5E-01	4.7E-01	1.6E-02	2.6E-02	4.9E-02
BLR sink area	2.9E-02	5.9E-02	1.3E-01	4.3E-03	7.1E-03	1.5E-02
Average INEL area	2.9E-02	6.5E-02	1.2E-01	3.7E-03	7.5E-03	1.3E-02

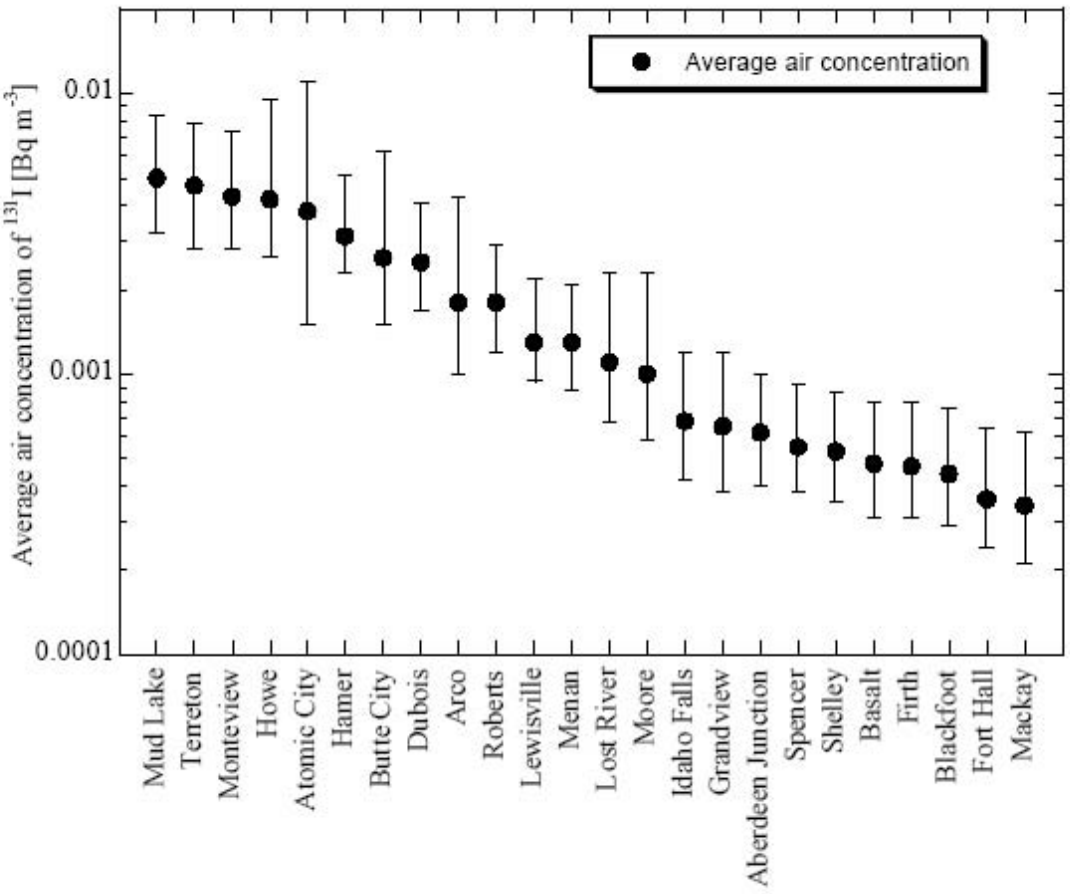
Figure 5.2 shows the range of monthly average concentrations at the Atomic City receptor location. The figure shows an overall pattern of decreasing concentrations with time and, within this pattern, variation between months due to the pattern of releases over the period. Figure 5.3 summarizes the overall period average concentrations at the off-site discrete receptors. Mud Lake was the receptor with highest central estimate of air concentration; however, it is apparent the relative variation in air concentrations differs between receptor locations. Both Howe and Atomic City locations had upper bounds on the concentration that were higher than the upper bound at Mud Lake.

Figure 5.2 Estimated concentration of iodine-131 in air in Atomic City, Idaho, due to releases from the Idaho Chemical Processing Plant operations



Note:
The numbers represent each of the 37 RaLa runs, and the arrows indicate the approximate date of each run. The dotted lines represent the 95% confidence interval.

Figure 5.3 Concentration of iodine-131 in air averaged over the period of release (February 1958 – December 1959)



Note:
The vertical lines represent the 95% confidence interval

5.4.2 Contributions to Uncertainty

The contribution from the three sources of uncertainty has been assessed by calculating the sum of squared deviations explained by each source. Table 5.9 shows the relative contributions for February 1957, which is the month with the highest concentrations. Typically, the largest source of uncertainty (or variability in the estimated concentrations) is meteorological uncertainty with variation in release rates being the next largest source. The relative contribution to uncertainty from release rate tends to be higher for those receptor locations located northeast of the facility and this is consistent with being in a downwind direction from the facility. Meteorological uncertainty is lowest for the INEL area as would be expected since this is an average air concentration in several directions from the facility therefore the meteorological uncertainty has been "averaged out" spatially.

Table 5.9 Sources of uncertainty in iodine-131 air concentrations during February 1957

	Percent of Variation (%) Explained by Uncertainty Source		
Off-site Locations	**Release**	**Dispersion Approach**	**Meteorological**
Aberdeen Junction	30	16	54
Arco	8	41	51
Atomic City	2	9	89
Basalt	28	9	63
Blackfoot	34	10	57
Butte City	8	42	50
Dubois	42	18	40
Firth	21	16	63
Fort Hall	31	48	20
Grandview	5	9	86
Hamer	62	7	31
Howe	17	55	28
Idaho Falls	29	24	48
Lewisville	46	13	41
Lost River	10	30	60
Mackay	17	24	60
Menan	49	17	34
Moore	14	42	44
Monteview	35	42	23
Mud Lake	44	28	27
Roberts	48	19	33
Shelley	40	11	49
Spencer	40	13	47
Terreton	43	30	27
Average milk prod area	76	10	15
On-Site Locations	**Release**	**Dispersion Approach**	**Meteorological**
CFA @ 250ft Met Tower	13	14	73
BLR sink area	21	52	27
Average INEL area	41	52	7

Table 5.10 summarizes the contribution to the distribution of overall period average concentrations (i.e. the sum-of-squares) for the sources of uncertainty. Typically, uncertainty in average release rate is the largest source of variation in the estimate period average concentrations, followed by dispersion scenario and then by meteorological uncertainty. The short-term uncertainty in meteorological conditions has typically been “averaged out” when period averages are determined, compared to the uncertainty in release rates and dispersion approach that are correlated over longer time periods.

Regardless of this typical pattern, some locations have relatively large contributions from the meteorological uncertainty. For example, meteorological uncertainty contributes substantially to the overall uncertainty at Atomic City, the CFA and at Grandview. These receptors are located to the south of facility where winds from the direction of the facility are infrequent.

Table 5.10 Sources of uncertainty in period average iodine-131 air concentrations

	Percent of Variation (%) Explained by Uncertainty Source		
Off-site Locations	**Release**	**Dispersion Approach**	**Meteorological**
Aberdeen Junction	62	27	11
Arco	24	64	12
Atomic City	10	30	61
Basalt	69	16	15
Blackfoot	68	19	13
Butte City	27	62	11
Dubois	74	18	8
Firth	63	22	15
Fort Hall	66	23	12
Grandview	46	20	34
Hamer	87	6	7
Howe	28	66	6
Idaho Falls	55	28	17
Lewisville	78	10	12
Lost River	34	54	13
Mackay	49	39	12
Menan	79	11	9
Moore	31	59	11
Monteview	57	37	7
Mud Lake	64	30	6
Roberts	81	10	9
Shelley	73	15	12
Spencer	74	15	12
Terreton	63	31	6
Average milk prod area	86	11	2
Off-site Location	**Release**	**Dispersion Approach**	**Meteorological**
CFA @ 250ft Met Tower	40	24	36
BLR sink area	32	62	6
Average INEL area	42	55	3

5.4.3 Differences by Air Dispersion Modeling Scenario

Some uncertainty arises due the differences in dispersion modeling approach. Table 5.11 shows the range of the central estimates of period average concentration. The table includes the central estimate for the S1 dispersion approach, which was considered the most likely scenario. The central estimates range by a factor of two or three between the lowest and highest values with the S1 scenario estimate typically between the highest and lowest estimates; however, the S1 dispersion modeling provides the lowest central estimate for the Moore receptor location.

Table 5.11 Comparison of central estimates of period average iodine-131 air concentrations by dispersion modeling scenario

Off-site Receptor	Lowest Scenario	S1 Dispersion Scenario	Highest Scenario
Aberdeen Junction	4.6E-04 (s2)	5.7E-04	7.7E-04 (sa4)
Arco	1.3E-03 (s3)	1.4E-03	3.6E-03 (sa4)
Atomic City	1.9E-03 (s2)	4.8E-03	5.9E-03 (s3)
Basalt	4.2E-04 (sa2)	4.4E-04	5.7E-04 (s4)
Blackfoot	3.7E-04 (s2)	4.1E-04	5.3E-04 (sa4)
Butte City	2.0E-03 (s3)	2.1E-03	4.9E-03 (sa4)
Dubois	2.3E-03 (s3)	2.3E-03	3.1E-03 (sa4)
Firth	4.2E-04 (sa2)	4.5E-04	6.1E-04 (s4)
Fort Hall	3.0E-04 (s2)	3.3E-04	4.8E-04 (sa4)
Grandview	5.2E-04 (s2)	6.0E-04	7.6E-04 (s3)
Hamer	2.7E-03 (sa2)	3.2E-03	3.3E-03 (s4)
Howe	3.4E-03 (s2)	3.5E-03	8.0E-03 (sa4)
Idaho Falls	5.2E-04 (sa1)	7.4E-04	8.8E-04 (s4)
Lewisville	1.2E-03 (sa2)	1.3E-03	1.5E-03 (sa4)
Lost River	8.8E-04 (s3)	9.1E-04	1.9E-03 (sa4)
Mackay	2.8E-04 (s3)	2.8E-04	4.7E-04 (sa4)
Menan	1.1E-03 (sa3)	1.3E-03	1.5E-03 (sa4)
Moore	7.9E-04 (s1)	7.9E-04	1.8E-03 (sa4)
Monteview	3.5E-03 (s2)	3.8E-03	6.0E-03 (sa4)
Mud Lake	3.5E-03 (s2)	4.9E-03	6.5E-03 (sa1)
Roberts	1.5E-03 (s2)	1.8E-03	2.1E-03 (sa4)
Shelley	4.5E-04 (sa1)	5.3E-04	6.4E-04 (s4)
Spencer	4.8E-04 (sa2)	5.5E-04	6.5E-04 (s4)
Terreton	3.2E-03 (s2)	4.7E-03	6.2E-03 (sa3)
Average milk prod area	5.8E-04 (sa2)	6.6E-04	7.8E-04 (s4)
On-site Receptor	**Lowest Scenario**	**S1 Dispersion Scenario**	**Highest Scenario**
CFA @ 250ft Met Tower	2.1E-02 (sa2)	2.5E-02	3.6E-02 (s3)
BLR sink area	5.0E-03 (s2)	6.6E-03	1.3E-02 (sa3)
Average INEL area	4.4E-03 (s2)	8.3E-03	1.0E-02 (sa3)

The lowest concentrations tend to be with s2 and s3 dispersion modeling approaches while the highest concentrations tend be to be with s3, s4 and sa4 modeling approaches. There is some direction dependency present: the s3 provides the highest concentrations at locations to the south of the facility.

5.4.4 Bias Introduced by Meteorology

The uncertainty introduced by meteorology includes not only variation about the estimated unit dispersion factors with 3 stations but also a shift, or bias, in the concentrations. The magnitude of this shift depends not only on the receptor location but also on the air dispersion modeling approach. Furthermore, the shift may lead to lower or higher unit dispersion factors than estimated with 3 surface stations. Table 5.12 compares an estimate of the monthly concentrations using the unit dispersion factor from 3 stations and the deterministic estimate of release rates with the 50th percentile of the simulated concentrations of the s1 scenario. Mud Lake is the receptor location with highest central estimate of air concentration and Atomic City is the receptor location with the highest upper bound of air concentrations

Table 5.12 Example of shift in monthly concentrations in 1957 due to meteorological uncertainty with S1 scenario

Month	Mud Lake			Atomic City		
	With 3 Stations	Central Estimate	Change (%)	With 3 Stations	Central Estimate	Change (%)
2	2.8E-02	5.0E-02	79	3.7E-02	3.4E-02	-8
3	3.1E-03	4.4E-03	44	1.4E-02	6.0E-03	-56
4	1.6E-03	3.8E-03	147	4.7E-03	2.8E-03	-41
5	7.8E-04	2.4E-03	204	4.6E-03	1.7E-03	-63
6	7.2E-03	8.1E-03	13	1.5E-02	4.1E-03	-73
7	1.3E-03	1.3E-03	1	1.9E-03	6.9E-04	-64
8	6.5E-06	8.1E-06	23	1.1E-05	6.4E-06	-44
9	8.3E-04	1.6E-03	93	5.7E-03	2.5E-03	-56
10	1.1E-02	1.7E-02	56	2.2E-02	1.3E-02	-42
11	8.4E-03	1.4E-02	65	3.2E-02	1.8E-02	-46
12	7.9E-05	1.6E-04	103	1.8E-04	1.5E-04	-13

The monthly concentrations calculated with unit dispersion factors based on 3 stations are lower at Mud Lake compared to Atomic City. The shifts for this scenario and year act to increase concentrations at the Mud Lake and decrease concentrations at Atomic City relative to the calculation based on 3 stations. Mud Lake concentrations increase by up to a factor of 3 (i.e. 204%) while Atomic City concentrations decrease by up to a factor of about 3 (i.e. -73%). As a result, the probabilistically concentrations at Mud Lake tend to be lower than the probabilistically simulated concentrations at Atomic City.

This shift is consistent with differences in wind direction determined by the CALMET processor for 3 and 25 stations as shown on a monthly basis in Appendix D. There is a tendency for the wind directions with 25 stations to shift towards the north relative to the wind directions based on three stations. This would tend to increase the wind frequency, and concentrations, at the Mud Lake receptor location compared to the Atomic City location.

6.0 CONCLUSIONS

CALPUFF air dispersion modeling was used to estimate air concentrations, Comparisons with concentrations measured as part of SF_6 tracer studies showed good model agreement; however, additional validation data would have been useful.

Three sources of uncertainty were considered: i) emission rates; ii) dispersion modeling approach, and the effect of meteorological uncertainty due to only three surface air stations with date during the 1957-1959 period. An uncertainty analyses was conducted to estimate monthly average concentrations and confidence intervals on these estimates. Rather than run CALPUFF for each trial, a database of unit dispersion factors and empirical estimates of uncertainty were developed.

Uncertainty in release rates was typically the major source of uncertainty in period average concentrations while uncertainty in the dispersion modeling approach contributed a factor of two or three. The uncertainty in air concentrations arising from uncertainty in meteorological conditions included both shift, or bias, and variability. High variability was present on an hourly basis but this tended to "average out" over monthly and period average durations. There was however a shift in concentrations with some receptor locations tending to have higher concentrations than would be predicted with the uncertain wind field based on 3 stations with other locations having lower concentrations. This shift was on the order of a factor of 2 or 3 and is comparable, for period averages, to the uncertainty in air dispersion modeling approach.

The uncertainty was found to be complex and dependent on location, meteorology and air dispersion modeling approach. The use of empirical estimates removed the necessity of parameterization of the uncertainties but required extensive database manipulations.

REFERENCES

Allwine, K.J., Dabbert, W.F. and L.L. Simmons 1998. *Peer Review of the CALMET/CALPUFF*.

Clawson, K.L. 2002. *Meteorological data from the TAN/IET (North) station and CFA (South)station North from 1954 to 1970.* Dr. Kirk L. Clawson, Ph.D. Deputy Director & Research Meteorologist Air Resources Laboratory Field Research Division U.S. Department of Commerce National Oceanic & Atmospheric Administration 1750 Foote Drive Idaho Falls, Idaho 83402.

Clawson, K.L., J.F. Sagendorf and R.G. Carter 2000. *Comparisons of a Puff Trajectory Model with Real Time Tracer Measurements.* Air Resource Laboratory Field Research Division, National Oceanic and Atmospheric Administration, Idaho Falls, Idaho. 11th Conference on Air Pollution Meteorology, American Meteorological Society. Long Beach, California. January.

Clawson, K.F. 1999. *Field Research Division – Field Test Range Support.* Final Report. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Research Laboratories, Air Resources Laboratory Field Research Division, Idaho Falls, Idaho 83402. July.

Kocher, D.C. *Method of Screening of Radionuclides Released to the Atmosphere from Facilities at INEL, Final report*. S. Cohen and Associates, McLean, Virginia and *SENES* Oak Ridge, Inc., Oak Ridge, Tennessee. July 2005a.

Kocher, D.C. *Selection of Radionuclides for Inclusion in Dose Reconstructions at INEL, Final report*. S. Cohen and Associates, McLean, Virginia, and *SENES* Oak Ridge, Inc., Oak Ridge, Tennessee. July 2005b.

Modeling System. Report compiled by V.A. Hanzel, The KEVRIC Company Inc., Durham, NC, under EPA Contract No. 68-D-98-092.

Scire, J.; Robe, M. Ferunau, M.; Yamartino R. *A User's Guide for the CALMET Meteorological Model (Version 5).* Earth Tech, Inc, Concord, MA. 2000.

Scire, J.; Strimaitis, D.; Yamartino R. *A User's Guide for the CALPUFF Dispersion Model (Version 5* Earth Tech, Inc, Concord, MA. 2000.

Wichner, R.P., Renier, J.-P., and Apostoaei, A.I. *Atmospheric Source Terms for the Idaho Chemical Processing Plant, 1957-1959, Final report*. S. Cohen and Associates, McLean, Virginia and *SENES* Oak Ridge, Inc., Oak Ridge, Tennessee. July 2005a.

Wichner, R.P., Renier, J.-P., and Apostoaei, A.I. *Aerosol Releases from the Idaho Chemical Processing Plant, 1957-1959, Final report.* S. Cohen and Associates, McLean, Virginia and *SENES* Oak Ridge, Inc., Oak Ridge, Tennessee. July 2005b.

APPENDIX A: SAMPLE CALMET CONTROL FILE

APPENDIX A: SAMPLE CALMET CONTROL FILE

The CALMET dispersion model has optional algorithms and approaches for meteorological processing that are specified in the control file. Options, or algorithms, are specified as "switches" in the control file.

The switches in Input Groups 1 - 4 are set as required for the nature of the run, the grid sizes, and the outputs desired. Input Group 5 contains the wind field model options. Those switches that do not follow the default recommendations are as follows:

- INPUT Group 1 Defaults + Data Entry
- INPUT Group 2 Defaults + Data Entry
- INPUT Group 3 Defaults + Output Options
- INPUT Group 4 Defaults
- INPUT Group 5
  - ◊ IKINE = 0 which is the correct default (model output of default value in error) and kinematic effects are not computed.
  - ◊ RMIN2 set to -1 default value.
  - ◊ RMAX1 was set to 20 kilometers, RMAX2 was set to 20 km.
  - ◊ TERRAD was set at 20 kilometers, the terrain influence in this application.
  - ◊ R1 and R2 are set at 10 and 10.
  - ◊ NINTR2 was set at 5 to limit number of stations used in each layer of the interpolation to a grid point (not applicable here, only three surface stations).
- INPUT Group 6
  - ◊ ZIMIN and ZIMINW were set to 50 meters the default value.
  - ◊ SIGMAP was set to 50 kilometers although precipitation is not being used.
- INPUT Group 7 Station Variables
- INPUT Group 8 Upper Air Stations
- INPUT Group 9 Precipitation Stations

Examples of switches

```
INEL - 1957 CALMET Run
Using 3 Surface Stations +  2 Upper Air
---------------- Run title (3 lines) ------------------------------------------

                    CALMET MODEL CONTROL FILE
                    -------------------------

--------------------------------------------------------------------------------

INPUT GROUP: 0 -- Input and Output File Names


Subgroup (a)
------------
Default Name  Type          File Name
------------  ----          ---------
GEO.DAT       input    ! GEODAT=geo4km.DAT       !
SURF.DAT      input    ! SRFDAT=surf57.DAT      !
CLOUD.DAT     input    * CLDDAT=             *
PRECIP.DAT    input    ! PRCDAT=precip57.dat    !
MM4.DAT       input    * MM4DAT=             *
WT.DAT        input    * WTDAT=              *

CALMET.LST    output   ! METLST=jan57.LST     !
CALMET.DAT    output   ! METDAT=jan57.DAT    !
PACOUT.DAT    output   * PACDAT=             *

All file names will be converted to lower case if LCFILES = T
Otherwise, if LCFILES = F, file names will be converted to UPPER CASE
         T = lower case      ! LCFILES = T !
         F = UPPER CASE

NUMBER OF UPPER AIR & OVERWATER STATIONS:

    Number of upper air stations (NUSTA)  No default     ! NUSTA =  1  !
    Number of overwater met stations
                                (NOWSTA) No default     ! NOWSTA =  0  !

                      !END!
--------------------------------------------------------------------------------
Subgroup (b)
--------------------------------
Upper air files (one per station)
--------------------------------
Default Name  Type       File Name
------------  ----       ---------
UP1.DAT       input     1  ! UPDAT=2413157.DAT!    !END!
--------------------------------------------------------------------------------
Subgroup (c)
----------------------------------------
Overwater station files (one per station)
----------------------------------------
Default Name  Type       File Name
------------  ----       ---------
--------------------------------------------------------------------------------
Subgroup (d)
----------------
Other file names
----------------

Default Name  Type       File Name
------------  ----       ---------
DIAG.DAT      input      * DIADAT=                 *
PROG.DAT      input      * PRGDAT=                 *

TEST.PRT      output     * TSTPRT=                 *
TEST.OUT      output     * TSTOUT=                 *
TEST.KIN      output     * TSTKIN=                 *
TEST.FRD      output     * TSTFRD=                 *
```

```
TEST.SLP      output     * TSTSLP=                  *

------------------------------------------------------------------------------
NOTES: (1) File/path names can be up to 70 characters in length
       (2) Subgroups (a) and (d) must have ONE 'END' (surround by
           delimiters) at the end of the group
       (3) Subgroups (b) and (c) must have an 'END' (surround by
           delimiters) at the end of EACH LINE

                        !END!


------------------------------------------------------------------------------

INPUT GROUP: 1 -- General run control parameters
--------------

     Starting date:   Year (IBYR) -- No default       ! IBYR=  1957  !
                     Month (IBMO) -- No default       ! IBMO=  1  !
                       Day (IBDY) -- No default       ! IBDY=  1  !
                      Hour (IBHR) -- No default       ! IBHR=  0  !

     Base time zone        (IBTZ) -- No default       ! IBTZ=  7  !
        PST = 08, MST = 07
        CST = 06, EST = 05

     Length of run (hours) (IRLG) -- No default       ! IRLG=   744 !

     Run type            (IRTYPE) -- Default: 1       ! IRTYPE=  1  !

        0 = Computes wind fields only
        1 = Computes wind fields and micrometeorological variables
            (u*, w*, L, zi, etc.)
        (IRTYPE must be 1 to run CALPUFF or CALGRID)

     Compute special data fields required
     by CALGRID (i.e., 3-D fields of W wind
     components and temperature)
     in additional to regular            Default: T    ! LCALGRD = T !
     fields ? (LCALGRD)
     (LCALGRD must be T to run CALGRID)

      Flag to stop run after
      SETUP phase (ITEST)             Default: 2       ! ITEST=  2   !
      (Used to allow checking
      of the model inputs, files, etc.)
      ITEST = 1 - STOPS program after SETUP phase
      ITEST = 2 - Continues with execution of
                  COMPUTATIONAL phase after SETUP

!END!

------------------------------------------------------------------------------

INPUT GROUP: 2 -- Grid control parameters
--------------

     HORIZONTAL GRID DEFINITION:

            No. X grid cells (NX)      No default     ! NX =   80  !
            No. Y grid cells (NY)      No default     ! NY =   80  !

     GRID SPACING (DGRIDKM)            No default     ! DGRIDKM = 4. !
                                       Units: km

     REFERENCE COORDINATES
     of SOUTHWEST corner of grid cell (1,1)

        X coordinate (XORIGKM)         No default     ! XORIGKM =   0.000 !
        Y coordinate (YORIGKM)         No default     ! YORIGKM =    0.000 !
                                       Units: km
        Latitude  (XLAT0)              No default     ! XLAT0 = 41.960 !
```

```
        Longitude (XLON0)              No default     ! XLON0 = 113.890 !

     UTM ZONE (IUTMZN)                 Default: 0     ! IUTMZN =   0  !

     LAMBERT CONFORMAL PARAMETERS

     Rotate input winds from true north to
     map north using a Lambert conformal
     projection? (LLCONF)              Default: F     ! LLCONF = T !

     Latitude of 1st standard parallel   Default: 30.   ! XLAT1 = 30.000 !
     Latitude of 2nd standard parallel   Default: 60.   ! XLAT2 = 60.000 !
     (XLAT1 and XLAT2; + in NH, - in SH)

        Longitude (RLON0)                Default = 90.  ! RLON0 = 113.89 !
        (used only if LLCONF = T)
        (Positive = W. Hemisphere;
         Negative = E. Hemisphere)
        Origin Latitude (RLAT0)          Default = 40.  ! RLAT0 = 41.960 !
        (used only if IPROG > 2)
        (Positive = N. Hemisphere;
         Negative = S. Hemisphere)

     Vertical grid definition:

        No. of vertical layers (NZ)    No default     ! NZ =  11  !

        Cell face heights in arbitrary
        vertical grid (ZFACE(NZ+1))    No defaults
                                       Units: m
        ! ZFACE = 0.,20.,40.,80.,140.,200.,500.,750.,2000.,2500.,3000.,3500. !

!END!


--------------------------------------------------------------------------------

INPUT GROUP: 3 -- Output Options
--------------


    DISK OUTPUT OPTION

       Save met. fields in an unformatted
       output file ?              (LSAVE)  Default: T     ! LSAVE = T !
       (F = Do not save, T = Save)

       Type of unformatted output file:
       (IFORMO)                            Default: 1    ! IFORMO =  1  !

            1 = CALPUFF/CALGRID type file (CALMET.DAT)
            2 = MESOPUFF-II type file     (PACOUT.DAT)


    LINE PRINTER OUTPUT OPTIONS:

       Print met. fields ?  (LPRINT)       Default: F     ! LPRINT = T !
       (F = Do not print, T = Print)
       (NOTE: parameters below control which
              met. variables are printed)

       Print interval
       (IPRINF) in hours                   Default: 1     ! IPRINF =  1  !
       (Meteorological fields are printed
        every  1  hours)


       Specify which layers of U, V wind component
       to print (IUVOUT(NZ)) -- NOTE: NZ values must be entered
       (0=Do not print, 1=Print)
       (used only if LPRINT=T)        Defaults: NZ*0
       ! IUVOUT =  0 ,  0 ,  0 ,  0 ,  0 ,  0 ,  0 ,  0 ,  0  !
```

```
----------------------


Specify which levels of the W wind component to print
(NOTE: W defined at TOP cell face --  9  values)
(IWOUT(NZ)) -- NOTE: NZ values must be entered
(0=Do not print, 1=Print)
(used only if LPRINT=T & LCALGRD=T)
-----------------------------------
                                    Defaults: NZ*0
 ! IWOUT =  0 ,  0 ,  0 ,  0 ,  0 ,  0 ,  0 ,  0 ,  0  !


Specify which levels of the 3-D temperature field to print
(ITOUT(NZ)) -- NOTE: NZ values must be entered
(0=Do not print, 1=Print)
(used only if LPRINT=T & LCALGRD=T)
-----------------------------------
                                    Defaults: NZ*0
 ! ITOUT =  0 ,  0 ,  0 ,  0 ,  0 ,  0 ,  0 ,  0 ,  0  !

Specify which meteorological fields
to print
(used only if LPRINT=T)             Defaults: 0 (all variables)
----------------------


  Variable            Print ?
                  (0 = do not print,
                   1 = print)
  --------        ------------------

!  STABILITY  =           0           ! - PGT stability class
!  USTAR      =           0           ! - Friction velocity
!  MONIN      =           0           ! - Monin-Obukhov length
!  MIXHT      =           0           ! - Mixing height
!  WSTAR      =           0           ! - Convective velocity scale
!  PRECIP     =           0           ! - Precipitation rate
!  SENSHEAT   =           0           ! - Sensible heat flux
!  CONVZI     =           0           ! - Convective mixing ht.


Testing and debug print options for micrometeorological module

   Print input meteorological data and
   internal variables (LDB)         Default: F       ! LDB = F !
   (F = Do not print, T = print)
   (NOTE: this option produces large amounts of output)

   First time step for which debug data
   are printed (NN1)                Default: 1       ! NN1 =  1  !

   Last time step for which debug data
   are printed (NN2)                Default: 1       ! NN2 =  2  !


Testing and debug print options for wind field module
(all of the following print options control output to
 wind field module's output files: TEST.PRT, TEST.OUT,
 TEST.KIN, TEST.FRD, and TEST.SLP)

   Control variable for writing the test/debug
   wind fields to disk files (IOUTD)
   (0=Do not write, 1=write)        Default: 0       ! IOUTD =  0  !

   Number of levels, starting at the surface,
   to print (NZPRN2)                Default: 1       ! NZPRN2 =  1  !

   Print the INTERPOLATED wind components ?
   (IPR0) (0=no, 1=yes)             Default: 0       !  IPR0 =  0  !
   Print the TERRAIN ADJUSTED surface wind
   components ?
```

```
          (IPR1) (0=no, 1=yes)             Default: 0       !  IPR1 =  0  !

          Print the SMOOTHED wind components and
          the INITIAL DIVERGENCE fields ?
          (IPR2) (0=no, 1=yes)             Default: 0       !  IPR2 =  0  !

          Print the FINAL wind speed and direction
          fields ?
          (IPR3) (0=no, 1=yes)             Default: 0       !  IPR3 =  0  !

          Print the FINAL DIVERGENCE fields ?
          (IPR4) (0=no, 1=yes)             Default: 0       !  IPR4 =  0  !

          Print the winds after KINEMATIC effects
          are added ?
          (IPR5) (0=no, 1=yes)             Default: 0       !  IPR5 =  0  !

          Print the winds after the FROUDE NUMBER
          adjustment is made ?
          (IPR6) (0=no, 1=yes)             Default: 0       !  IPR6 =  0  !

          Print the winds after SLOPE FLOWS
          are added ?
          (IPR7) (0=no, 1=yes)             Default: 0       !  IPR7 =  0  !

          Print the FINAL wind field components ?
          (IPR8) (0=no, 1=yes)             Default: 0       !  IPR8 =  0  !

!END!

------------------------------------------------------------------------------

INPUT GROUP: 4 -- Meteorological data options
--------------

    NUMBER OF SURFACE & PRECIP. METEOROLOGICAL STATIONS

       Number of surface stations   (NSSTA)  No default     ! NSSTA =  3  !
       Number of precipitation stations
                                    (NPSTA)  No default     ! NPSTA =  3  !

    CLOUD DATA OPTIONS
       Griddid cloud fields:
                                   (ICLOUD)  Default: 0     ! ICLOUD =  0  !
       ICLOUD = 0 - Gridded clouds not used
       ICLOUD = 1 - Gridded CLOUD.DAT generated as OUTPUT
       ICLOUD = 2 - Gridded CLOUD.DAT read as INPUT

    FILE FORMATS

       Surface meteorological data file format
                                   (IFORMS)  Default: 2     ! IFORMS =  2  !
       (1 = unformatted (e.g., SMERGE output))
       (2 = formatted   (free-formatted user input))

       Precipitation data file format
                                   (IFORMP)  Default: 2     ! IFORMP =  2  !
       (1 = unformatted (e.g., PMERGE output))
       (2 = formatted   (free-formatted user input))

       Cloud data file format
                                   (IFORMC)  Default: 2     ! IFORMC =  2  !
       (1 = unformatted - CALMET unformatted output)
       (2 = formatted   - free-formatted CALMET output or user input)

!END!

------------------------------------------------------------------------------


INPUT GROUP: 5 -- Wind Field Options and Parameters
--------------
```

```
WIND FIELD MODEL OPTIONS
   Model selection variable (IWFCOD)     Default: 1      ! IWFCOD =  1  !
      0 = Objective analysis only
      1 = Diagnostic wind module

   Compute Froude number adjustment
   effects ? (IFRADJ)                    Default: 1      ! IFRADJ =  1  !
   (0 = NO, 1 = YES)

   Compute kinematic effects ? (IKINE)   Default: 0      ! IKINE  =  0  !
   (0 = NO, 1 = YES)

   Use O'Brien procedure for adjustment
   of the vertical velocity ? (IOBR)     Default: 0      ! IOBR =  0  !
   (0 = NO, 1 = YES)

   Compute slope flow effects ? (ISLOPE) Default: 1      ! ISLOPE  =  1  !
   (0 = NO, 1 = YES)

   Extrapolate surface wind observations
   to upper layers ? (IEXTRP)            Default: -4     ! IEXTRP =  4  !
   (1 = no extrapolation is done,
    2 = power law extrapolation used,
    3 = user input multiplicative factors
        for layers 2 - NZ used (see FEXTRP array)
    4 = similarity theory used
    -1, -2, -3, -4 = same as above except layer 1 data
        at upper air stations are ignored

   Extrapolate surface winds even
   if calm? (ICALM)                      Default: 0      ! ICALM  =  0  !
   (0 = NO, 1 = YES)

   Layer-dependent biases modifying the weights of
   surface and upper air stations (BIAS(NZ))
     -1<=BIAS<=1
   Negative BIAS reduces the weight of upper air stations
     (e.g. BIAS=-0.1 reduces the weight of upper air stations
   by 10%; BIAS= -1, reduces their weight by 100 %)
   Positive BIAS reduces the weight of surface stations
     (e.g. BIAS= 0.2 reduces the weight of surface stations
   by 20%; BIAS=1 reduces their weight by 100%)
   Zero BIAS leaves weights unchanged (1/R**2 interpolation)
   Default: NZ*0
                           ! BIAS = -1 , -1 , -1 , -1 , -1 , -1 ,  0 ,  0 ,  0 , 0, 0,  0!

   Minimum distance from nearest upper air station
   to surface station for which extrapolation
   of surface winds at surface station will be allowed
   (RMIN2: Set to -1 for IEXTRP = 4 or other situations
    where all surface stations should be extrapolated)
                                          Default: 4.    ! RMIN2 = -1 !

   Use gridded prognostic wind field model
   output fields as input to the diagnostic
   wind field model (IPROG)              Default: 0      ! IPROG =   0  !
   (0 = No, [IWFCOD = 0 or 1]
    1 = Yes, use CSUMM prog. winds as Step 1 field, [IWFCOD = 0]
    2 = Yes, use CSUMM prog. winds as initial guess field [IWFCOD = 1]
    3 = Yes, use winds from MM4.DAT file as Step 1 field [IWFCOD = 0]
    4 = Yes, use winds from MM4.DAT file as initial guess field [IWFCOD = 1]
    5 = Yes, use winds from MM4.DAT file as observations [IWFCOD = 1]
    13 = Yes, use winds from MM5.DAT file as Step 1 field [IWFCOD = 0]
    14 = Yes, use winds from MM5.DAT file as initial guess field [IWFCOD = 1]
    15 = Yes, use winds from MM5.DAT file as observations [IWFCOD = 1]

RADIUS OF INFLUENCE PARAMETERS

   Use varying radius of influence       Default: F      ! LVARY =  F!
   (if no stations are found within RMAX1,RMAX2,
```

```
       or RMAX3, then the closest station will be used)

      Maximum radius of influence over land
      in the surface layer (RMAX1)          No default      ! RMAX1 = 20. !
                                            Units: km
      Maximum radius of influence over land
      aloft (RMAX2)                         No default      ! RMAX2 = 20. !
                                            Units: km
      Maximum radius of influence over water
      (RMAX3)                               No default      ! RMAX3 =  0. !
                                            Units: km


   OTHER WIND FIELD INPUT PARAMETERS

      Minimum radius of influence used in
      the wind field interpolation (RMIN)   Default: 0.1    ! RMIN = 0.1 !
                                            Units: km
      Radius of influence of terrain
      features (TERRAD)                     No default      ! TERRAD = 20. !

                                            Units: km
      Relative weighting of the first
      guess field and observations in the
      SURFACE layer (R1)                    No default      ! R1 = 10. !
      (R1 is the distance from an           Units: km
      observational station at which the
      observation and first guess field are
      equally weighted)

      Relative weighting of the first
      guess field and observations in the
      layers ALOFT (R2)                     No default      ! R2 = 10. !
      (R2 is applied in the upper layers    Units: km
      in the same manner as R1 is used in
      the surface layer).

      Relative weighting parameter of the
      prognostic wind field data (RPROG)    No default      ! RPROG = 0. !
      (Used only if IPROG = 1)              Units: km
      ------------------------

      Maximum acceptable divergence in the
      divergence minimization procedure
      (DIVLIM)                              Default: 5.E-6  ! DIVLIM= 5.0E-06 !

      Maximum number of iterations in the
      divergence min. procedure (NITER)     Default: 50     ! NITER =  50  !

      Number of passes in the smoothing
      procedure (NSMTH(NZ))
      NOTE: NZ values must be entered
           Default: 2,(mxnz-1)*4 ! NSMTH =
2 ,  4 ,  4 ,  4 ,  4 ,  4 ,  4 ,  4 ,  4, 4, 4, 4  !

      Maximum number of stations used in
      each layer for the interpolation of
      data to a grid point (NINTR2(NZ))
      NOTE: NZ values must be entered       Default: 99.    ! NINTR2 =
99 ,  99 ,  99 ,  99 ,  99 ,  99 ,  99 ,  99 ,  99, 99, 99, 99  !

      Critical Froude number (CRITFN)       Default: 1.0    ! CRITFN = 1. !

      Empirical factor controlling the
      influence of kinematic effects
      (ALPHA)                               Default: 0.1    ! ALPHA = 0.1 !

      Multiplicative scaling factor for
      extrapolation of surface observations
      to upper layers (FEXTR2(NZ))          Default: NZ*0.0
      ! FEXTR2 = 0., 0., 0., 0., 0., 0., 0., 0., 0., 0. !
      (Used only if IEXTRP = 3 or -3)
```

```
BARRIER INFORMATION

   Number of barriers to interpolation
   of the wind fields (NBAR)             Default: 0      ! NBAR =  0  !

   THE FOLLOWING 4 VARIABLES ARE INCLUDED
   ONLY IF NBAR > 0
   NOTE: NBAR values must be entered     No defaults
         for each variable               Units: km

      X coordinate of BEGINNING
      of each barrier (XBBAR(NBAR))      ! XBBAR = 0. !
      Y coordinate of BEGINNING
      of each barrier (YBBAR(NBAR))      ! YBBAR = 0. !

      X coordinate of ENDING
      of each barrier (XEBAR(NBAR))      ! XEBAR = 0. !
      Y coordinate of ENDING
      of each barrier (YEBAR(NBAR))      ! YEBAR = 0. !


DIAGNOSTIC MODULE DATA INPUT OPTIONS

   Surface temperature (IDIOPT1)         Default: 0      ! IDIOPT1 =  0  !
      0 = Compute internally from
          hourly surface observations
      1 = Read preprocessed values from
          a data file (DIAG.DAT)

      Surface met. station to use for
      the surface temperature (ISURFT)   No default     ! ISURFT =  1  !
      (Must be a value from 1 to NSSTA)
      (Used only if IDIOPT1 = 0)
      --------------------------

   Domain-averaged temperature lapse
   rate (IDIOPT2)                        Default: 0     ! IDIOPT2 =  0  !
      0 = Compute internally from
          twice-daily upper air observations
      1 = Read hourly preprocessed values
          from a data file (DIAG.DAT)

      Upper air station to use for
      the domain-scale lapse rate (IUPT) No default     ! IUPT   =  1  !
      (Must be a value from 1 to NUSTA)
      (Used only if IDIOPT2 = 0)
      --------------------------

      Depth through which the domain-scale
      lapse rate is computed (ZUPT)      Default: 200.  ! ZUPT = 200. !
      (Used only if IDIOPT2 = 0)         Units: meters
      --------------------------

   Domain-averaged wind components
   (IDIOPT3)                             Default: 0     ! IDIOPT3 =  0  !
      0 = Compute internally from
          twice-daily upper air observations
      1 = Read hourly preprocessed values
          a data file (DIAG.DAT)

      Upper air station to use for
      the domain-scale winds (IUPWND)    Default: -1    ! IUPWND = -1  !
      (Must be a value from -1 to NUSTA)
      (Used only if IDIOPT3 = 0)
      --------------------------

      Bottom and top of layer through
      which the domain-scale winds
      are computed
      (ZUPWND(1), ZUPWND(2))        Defaults: 1., 1000. ! ZUPWND= 1., 1000. !
```

```
          (Used only if IDIOPT3 = 0)    Units: meters
          -------------------------

       Observed surface wind components
       for wind field module (IDIOPT4)  Default: 0     ! IDIOPT4 =  0  !
          0 = Read WS, WD from a surface
              data file (SURF.DAT)
          1 = Read hourly preprocessed U, V from
              a data file (DIAG.DAT)

       Observed upper air wind components
       for wind field module (IDIOPT5)  Default: 0     ! IDIOPT5 =  0  !
          0 = Read WS, WD from an upper
              air data file (UP1.DAT, UP2.DAT, etc.)
          1 = Read hourly preprocessed U, V from
              a data file (DIAG.DAT)

       LAKE BREEZE INFORMATION

          Use Lake Breeze Module  (LLBREZE)
                                          Default: F      ! LLBREZE = F !

           Number of lake breeze regions (NBOX)            ! NBOX =  0  !

        X Grid line 1 defining the region of interest
                                                          ! XG1 = 0. !
        X Grid line 2 defining the region of interest
                                                          ! XG2 = 0. !
        Y Grid line 1 defining the region of interest
                                                          ! YG1 = 0. !
        Y Grid line 2 defining the region of interest
                                                          ! YG2 = 0. !

         X Point defining the coastline (Straight line)
                   (XBCST)   (KM)   Default: none    ! XBCST = 0. !

         Y Point defining the coastline (Straight line)
                   (YBCST)   (KM)   Default: none    ! YBCST = 0. !

         X Point defining the coastline (Straight line)
                   (XECST)   (KM)   Default: none    ! XECST = 0. !

         Y Point defining the coastline (Straight line)
                   (YECST)   (KM)   Default: none    ! YECST = 0. !


       Number of stations in the region     Default: none ! NLB = *1 !*
       (Surface stations + upper air stations)

       Station ID's  in the region   (METBXID(NLB))
       (Surface stations first, then upper air stations)
         ! METBXID = *0 !*

!END!


--------------------------------------------------------------------------------

INPUT GROUP: 6 -- Mixing Height, Temperature and Precipitation Parameters
--------------

    EMPIRICAL MIXING HEIGHT CONSTANTS

       Neutral, mechanical equation
       (CONSTB)                            Default: 1.41   ! CONSTB = 1.41 !
       Convective mixing ht. equation
       (CONSTE)                            Default: 0.15   ! CONSTE = 0.15 !
       Stable mixing ht. equation
       (CONSTN)                            Default: 2400.  ! CONSTN = 2400.!
       Overwater mixing ht. equation
       (CONSTW)                            Default: 0.16   ! CONSTW = 0.16 !
       Absolute value of Coriolis
```

```
   parameter (FCORIOL)                  Default: 1.E-4  ! FCORIOL = 1.0E-04!
                                        Units: (1/s)

SPATIAL AVERAGING OF MIXING HEIGHTS

   Conduct spatial averaging
   (IAVEZI)  (0=no, 1=yes)              Default: 1      ! IAVEZI =  1  !

   Max. search radius in averaging
   process (MNMDAV)                     Default: 1      ! MNMDAV =  1  !
                                        Units: Grid
                                               cells
   Half-angle of upwind looking cone
   for averaging (HAFANG)               Default: 30.    ! HAFANG = 30. !
                                        Units: deg.
   Layer of winds used in upwind
   averaging (ILEVZI)                   Default: 1      ! ILEVZI =  1  !
   (must be between 1 and NZ)

OTHER MIXING HEIGHT VARIABLES

   Minimum potential temperature lapse
   rate in the stable layer above the
   current convective mixing ht.        Default: 0.001  ! DPTMIN = 0.001 !
   (DPTMIN)                             Units: deg. K/m
   Depth of layer above current conv.
   mixing height through which lapse    Default: 200.   ! DZZI = 200. !
   rate is computed (DZZI)              Units: meters

   Minimum overland mixing height       Default:  50.   ! ZIMIN = 50. !
   (ZIMIN)                              Units: meters
   Maximum overland mixing height       Default: 3000.  ! ZIMAX = 3000. !
   (ZIMAX)                              Units: meters
   Minimum overwater mixing height      Default:   50.  ! ZIMINW = 50. !
   (ZIMINW) -- (Not used if observed    Units: meters
   overwater mixing hts. are used)
   Maximum overwater mixing height      Default: 3000.  ! ZIMAXW = 3000. !
   (ZIMAXW) -- (Not used if observed    Units: meters
   overwater mixing hts. are used)


TEMPERATURE PARAMETERS

   Interpolation type
   (1 = 1/R ; 2 = 1/R**2)               Default:1         ! IRAD =  1  !

   Radius of influence for temperature
   interpolation (TRADKM)               Default: 500.     ! TRADKM = 500. !
                                        Units: km

   Maximum Number of stations to include
   in temperature interpolation (NUMTS) Default: 5        ! NUMTS = 5  !

   Conduct spatial averaging of temp-
   eratures (IAVET)  (0=no, 1=yes)        Default: 1     ! IAVET =  1  !
   (will use mixing ht MNMDAV,HAFANG
    so make sure they are correct)

   Default temperature gradient        Default: -.0098 ! TGDEFB = -0.0098 !
   below the mixing height over
   water (K/m) (TGDEFB)

   Default temperature gradient        Default: -.0045 ! TGDEFA = -0.0045 !
   above the mixing height over
   water (K/m) (TGDEFA)

   Beginning (JWAT1) and ending (JWAT2)
   land use categories for temperature                  ! JWAT1 =  99  !
   interpolation over water -- Make                     ! JWAT2 =  99  !
   bigger than largest land use to disable
PRECIP INTERPOLATION PARAMETERS
```

```
       Method of interpolation (NFLAGP)      Default = 2    ! NFLAGP =  2  !
        (1=1/R,2=1/R**2,3=EXP/R**2)
       Radius of Influence (km) (SIGMAP)     Default = 100.0  ! SIGMAP = 100. !
        (0.0 => use half dist. btwn
         nearest stns w & w/out
         precip when NFLAGP = 3)
       Minimum Precip. Rate Cutoff (mm/hr)   Default = 0.01  ! CUTP = 0.01 !
        (values < CUTP = 0.0 mm/hr)
!END!


--------------------------------------------------------------------------------

INPUT GROUP: 7 -- Surface meteorological station parameters
--------------

     SURFACE STATION VARIABLES
     (One record per station --  4  records in all)


             1     2
         Name   ID            X coord.   Y coord.   Time   Anem.
                               (km)       (km)      zone   Ht.(m)
       ------------------------------------------------------------
! SS1  ='POCA'    24156      101.536      103.724    7     6  !
! SS2  ='NORT'    10000       89.818      204.848    7     6  !
! SS3  ='SOUT'    10055       73.394      169.497    7     6  !
-------------------
      1
        Four character string for station name
        (MUST START IN COLUMN 9)

      2
        Five digit integer for station ID

!END!


--------------------------------------------------------------------------------

INPUT GROUP: 8 -- Upper air meteorological station parameters
--------------

     UPPER AIR STATION VARIABLES
     (One record per station --  2  records in all)

             1     2
         Name    ID      X coord.   Y coord.  Time zone
                           (km)       (km)
       ------------------------------------------------
! US1  ='BOIS'   24131   -181.335    175.713    7  !
-------------------
      1
        Four character string for station name
        (MUST START IN COLUMN 9)

      2
        Five digit integer for station ID

!END!


--------------------------------------------------------------------------------

INPUT GROUP: 9 -- Precipitation station parameters
--------------

     PRECIPITATION STATION VARIABLES
     (One record per station --  0  records in all)
     (NOT INCLUDED IF NPSTA = 0)

            1          2
```

```
          Name   Station    X coord.  Y coord.
                   Code       (km)      (km)
          ------------------------------------
! PS1  ='2ESE'   14455     145.994    165.435      !
! PS2  ='49WI'   14460      73.212    169.529      !
! PS3  ='POCA'   17211     101.536    103.724      !


-------------------
      1
        Four character string for station name
        (MUST START IN COLUMN 9)

      2
        Six digit station code composed of state
        code (first 2 digits) and station ID (last
        4 digits)

!END!
```

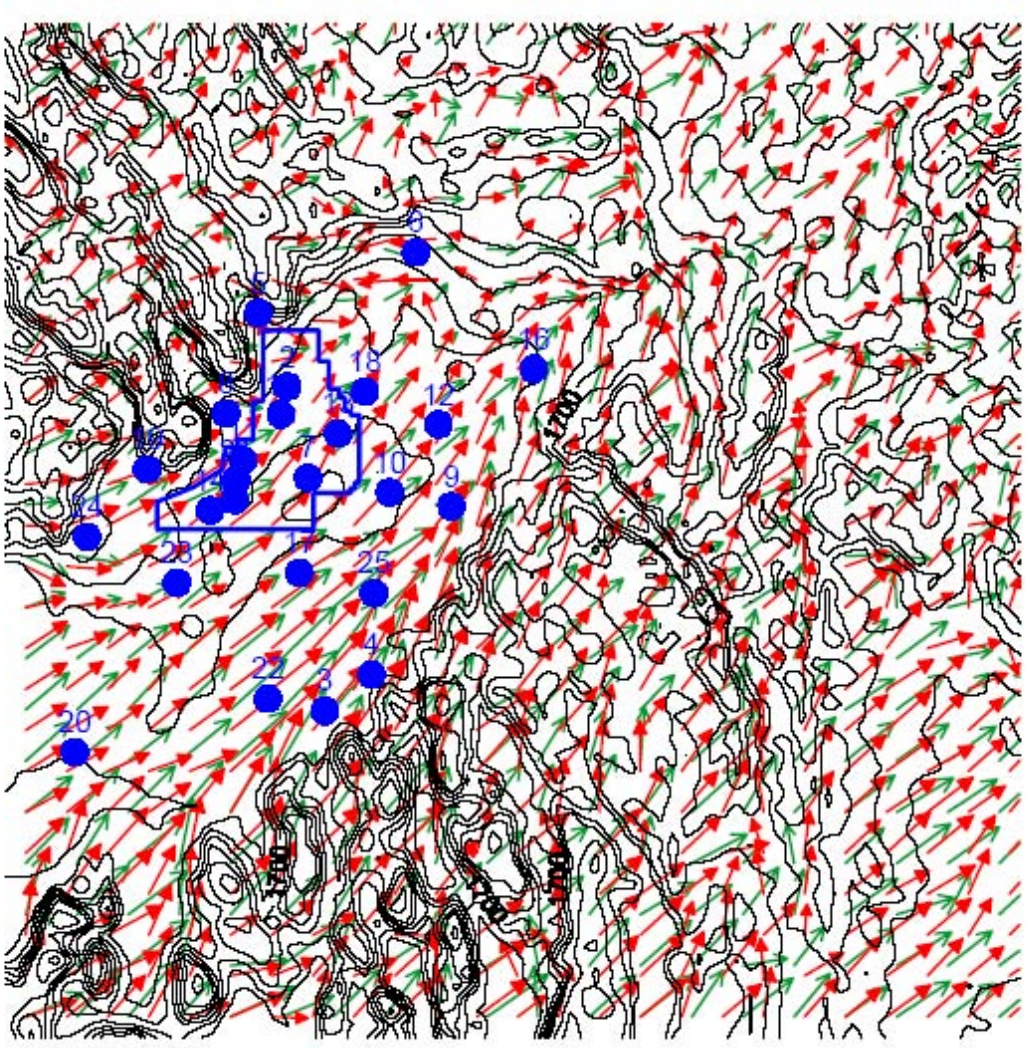
APPENDIX B: CALMET RESULTS BASED ON 3 AND 25 SURFACE STATIONS

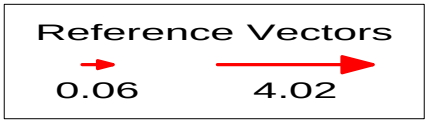
LIST OF FIGURES

Page No.

APPENDIX B: CALMET RESULTS BASED ON 3 AND 25 SURFACE STATIONS

Figure B.1 CALMET simulation – average for January 1999
3 STATIONS - BLUE
25 STATIONS – RED





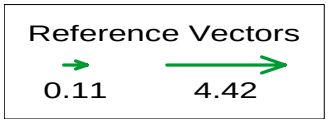


Figure B.2 CALMET simulation – average for February 1999
3 STATIONS - GREEN
25 STATIONS – RED

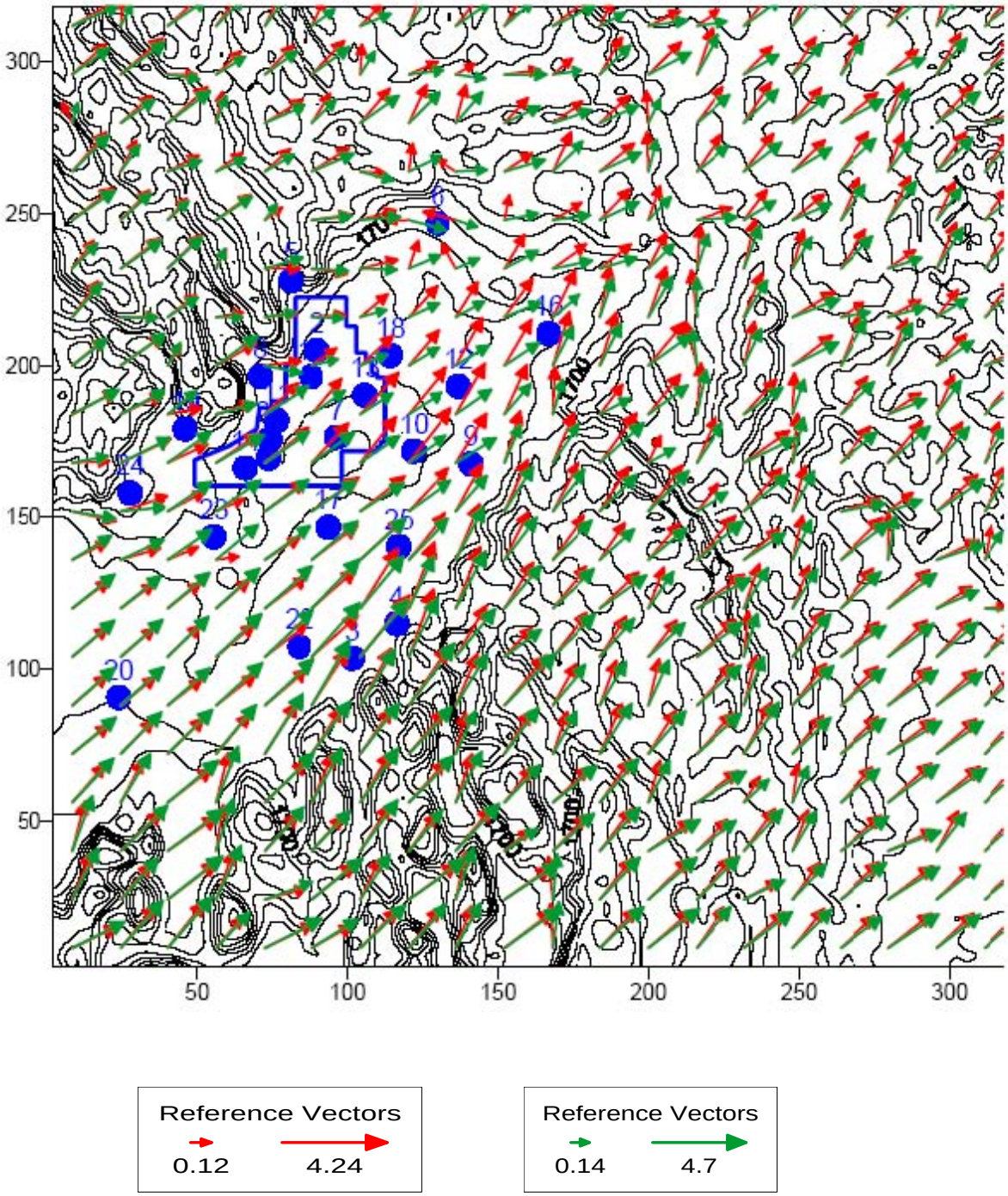


Figure B.3 CALMET simulation – average for March 1999
3 STATIONS - GREEN
25 STATIONS – RED

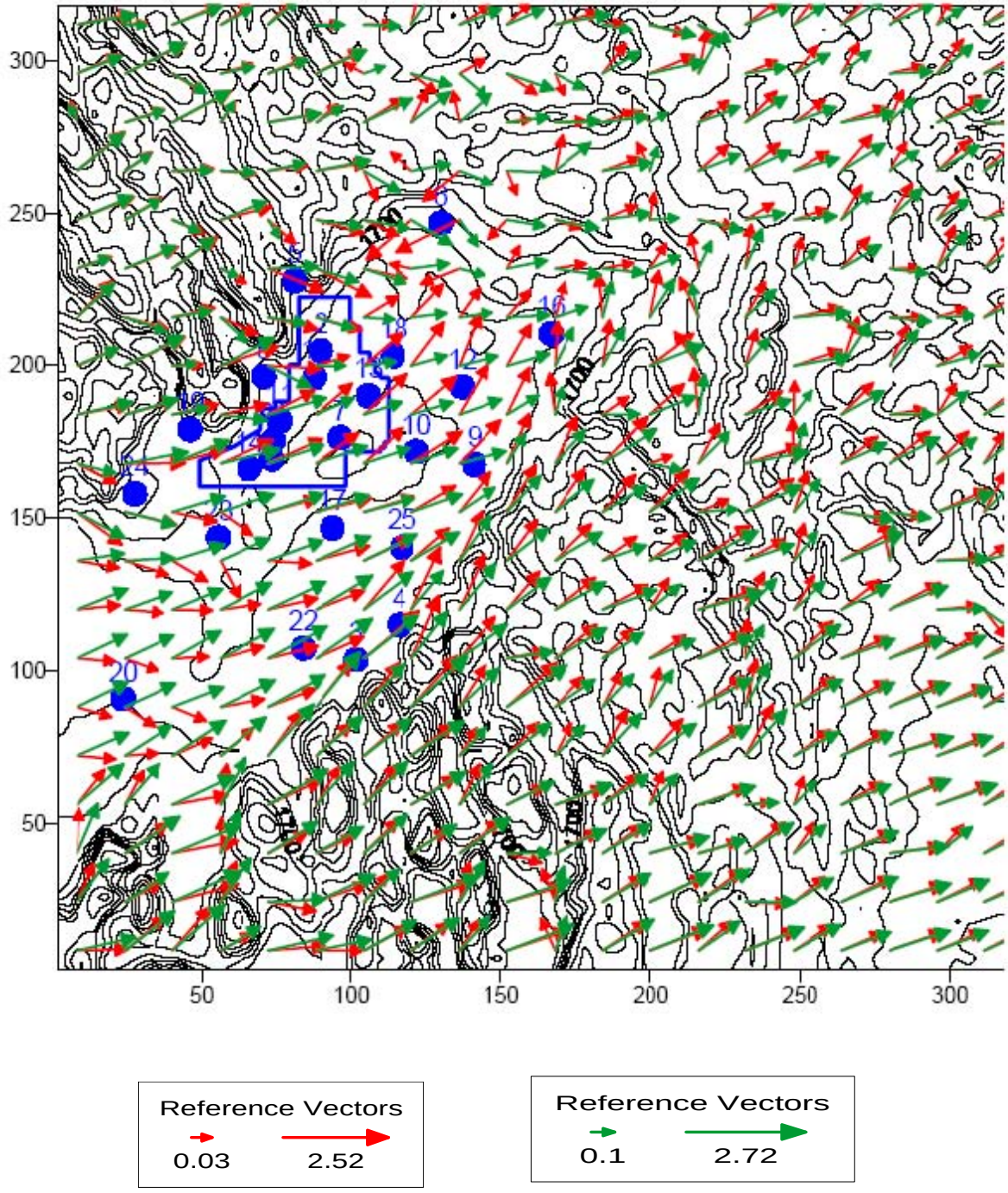
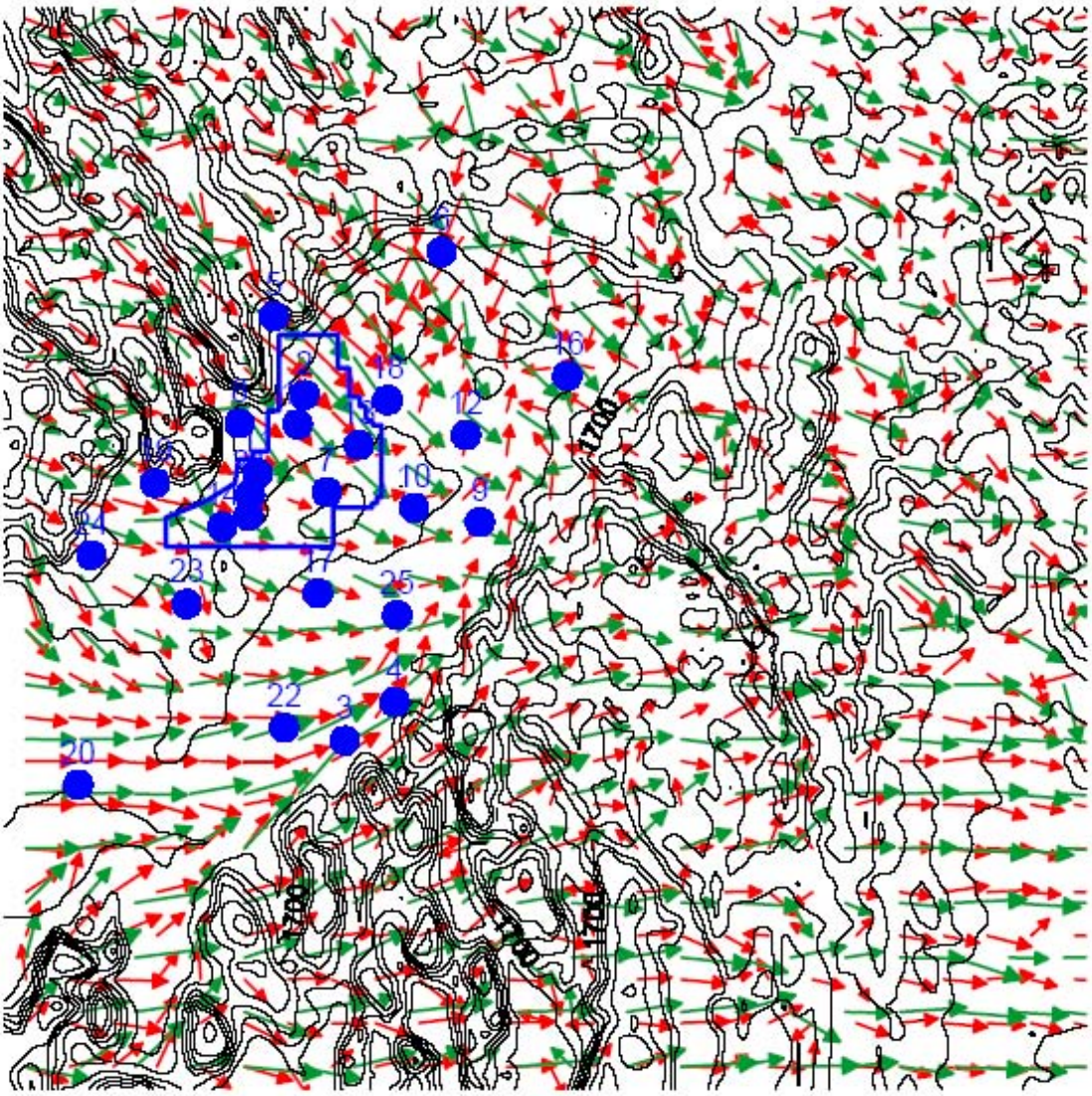
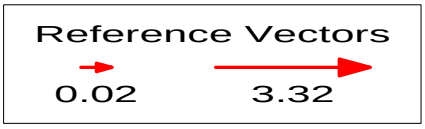


Figure B.4 CALMET simulation – average for April 1999
3 STATIONS - GREEN
25 STATIONS – RED





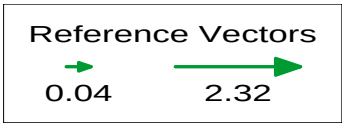


Figure B.5 CALMET simulation – average for May 1999
3 STATIONS - GREEN
25 STATIONS – RED

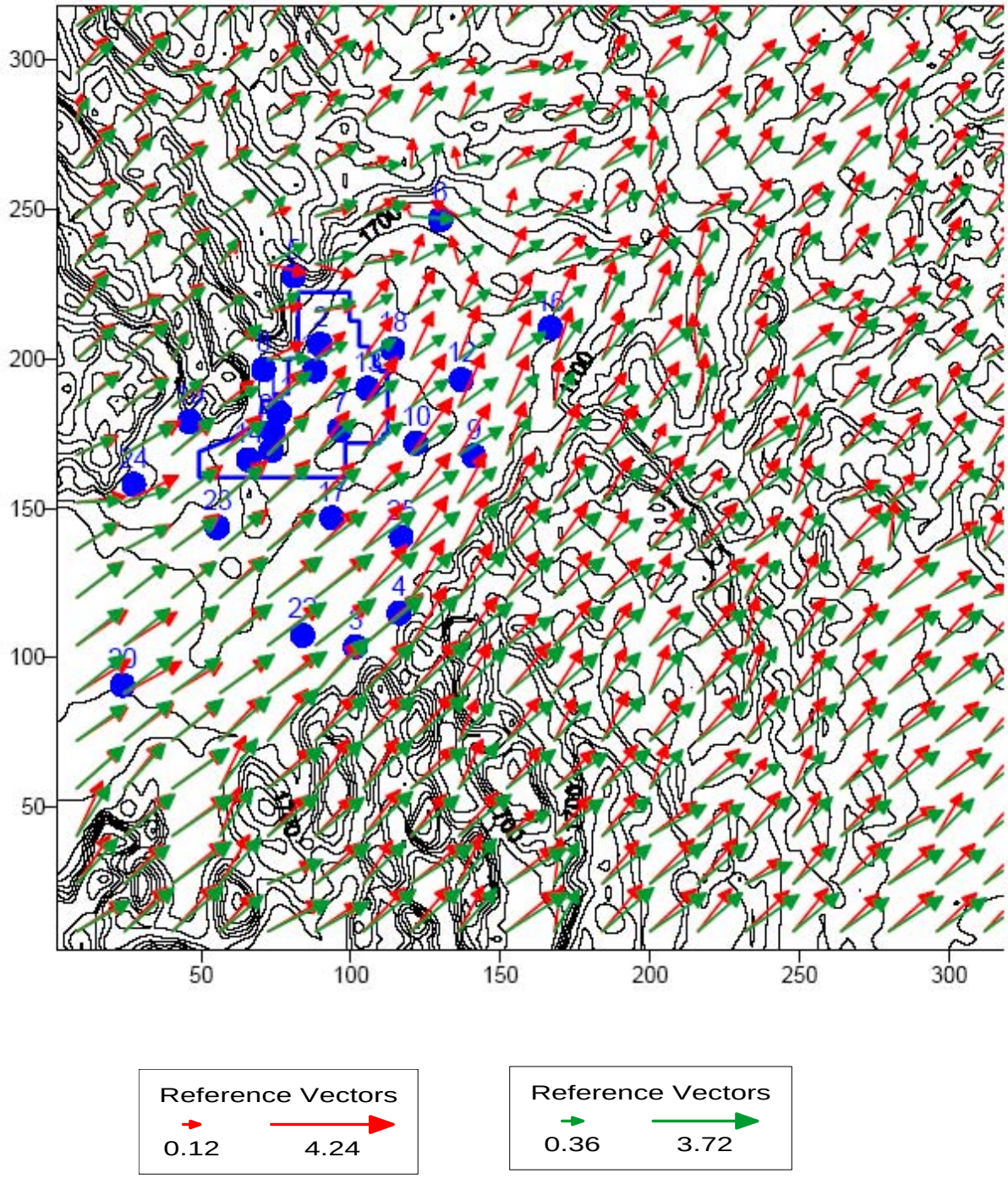


Figure B.6 CALMET simulation – average for June 1999
3 STATIONS - GREEN
25 STATIONS – RED

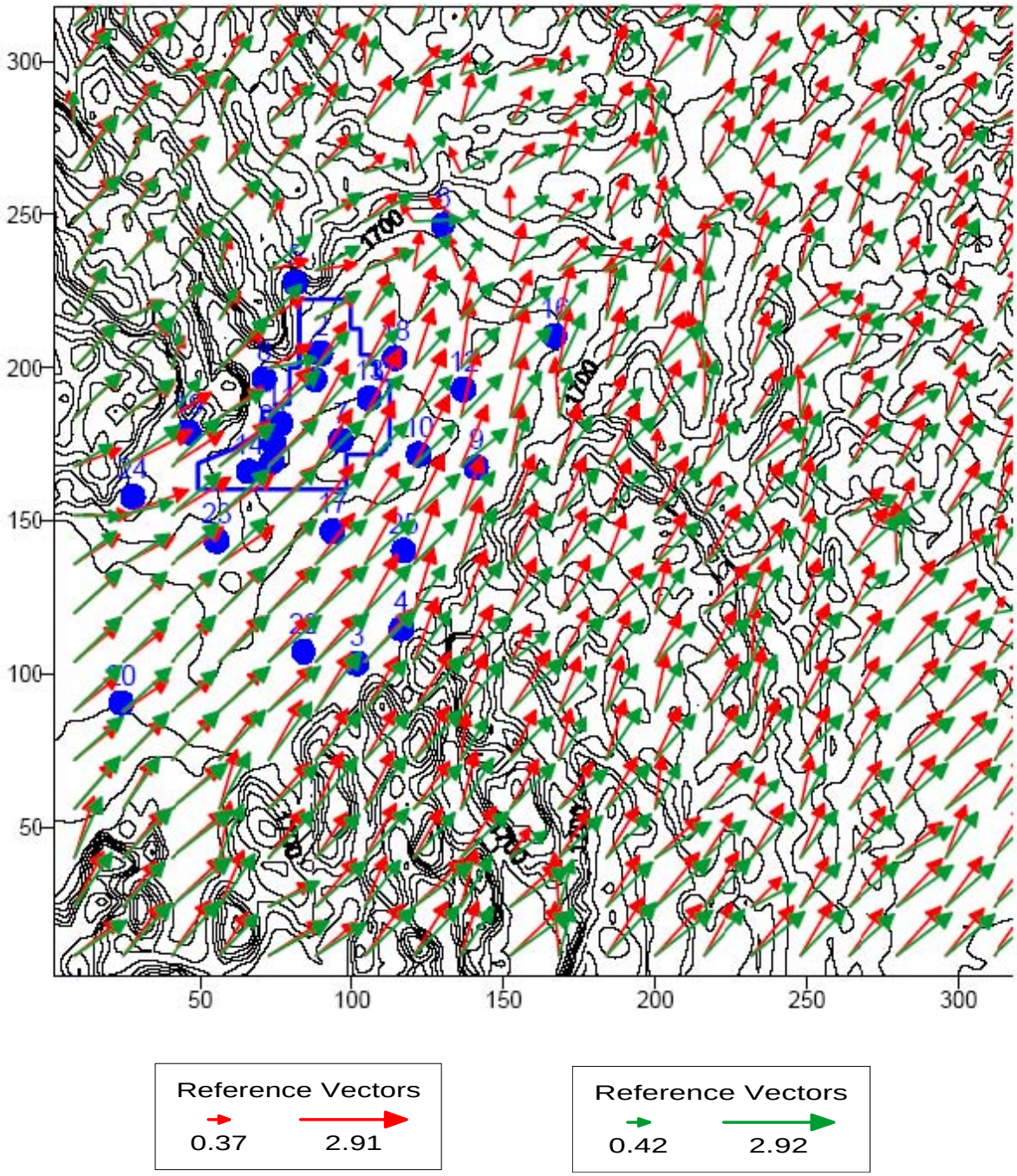


Figure B.7 CALMET simulation – average for July 1999
3 STATIONS - GREEN
25 STATIONS – RED

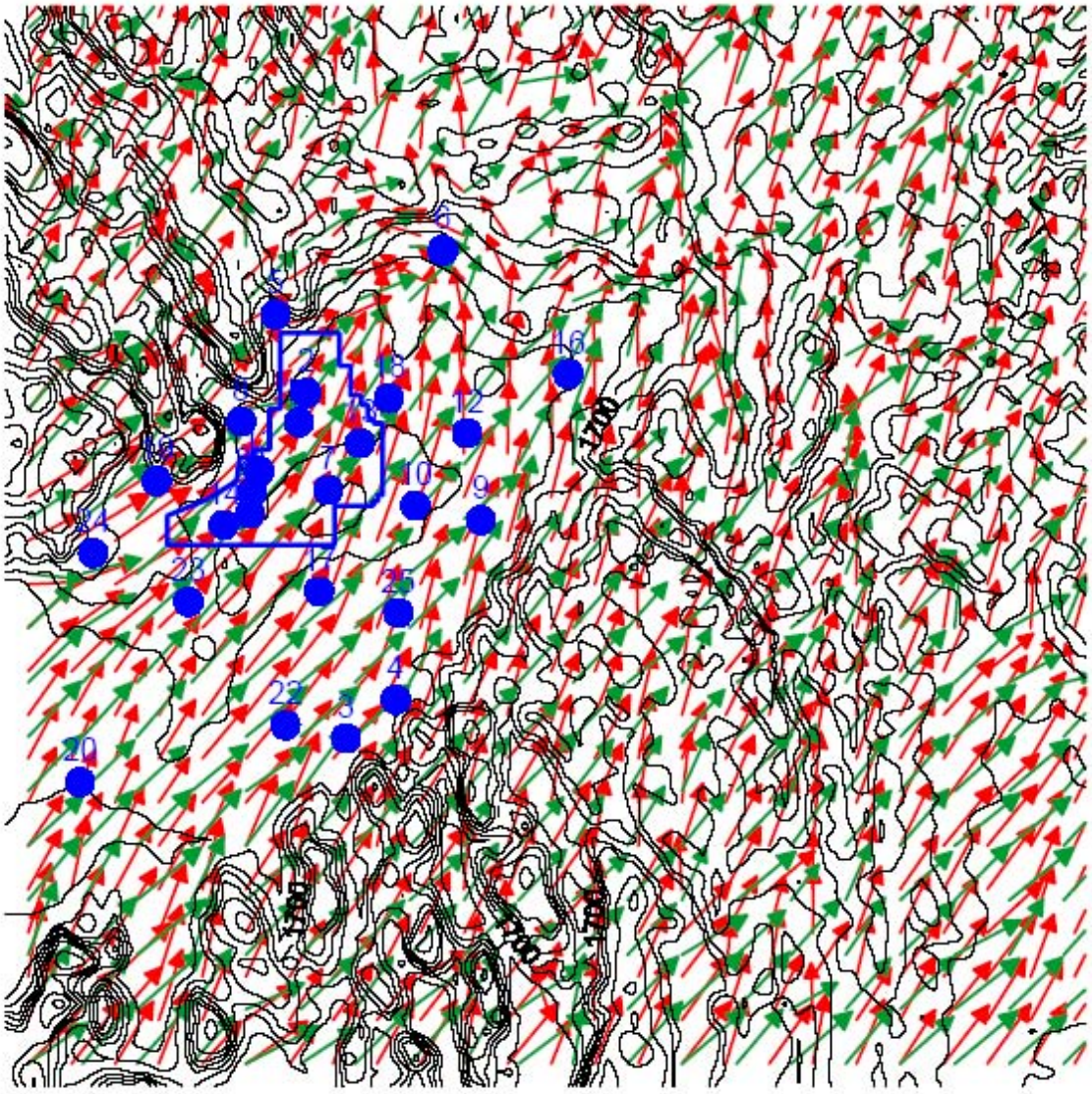


Figure B.8 CALMET simulation – average for August 1999
3 STATIONS - GREEN
25 STATIONS – RED

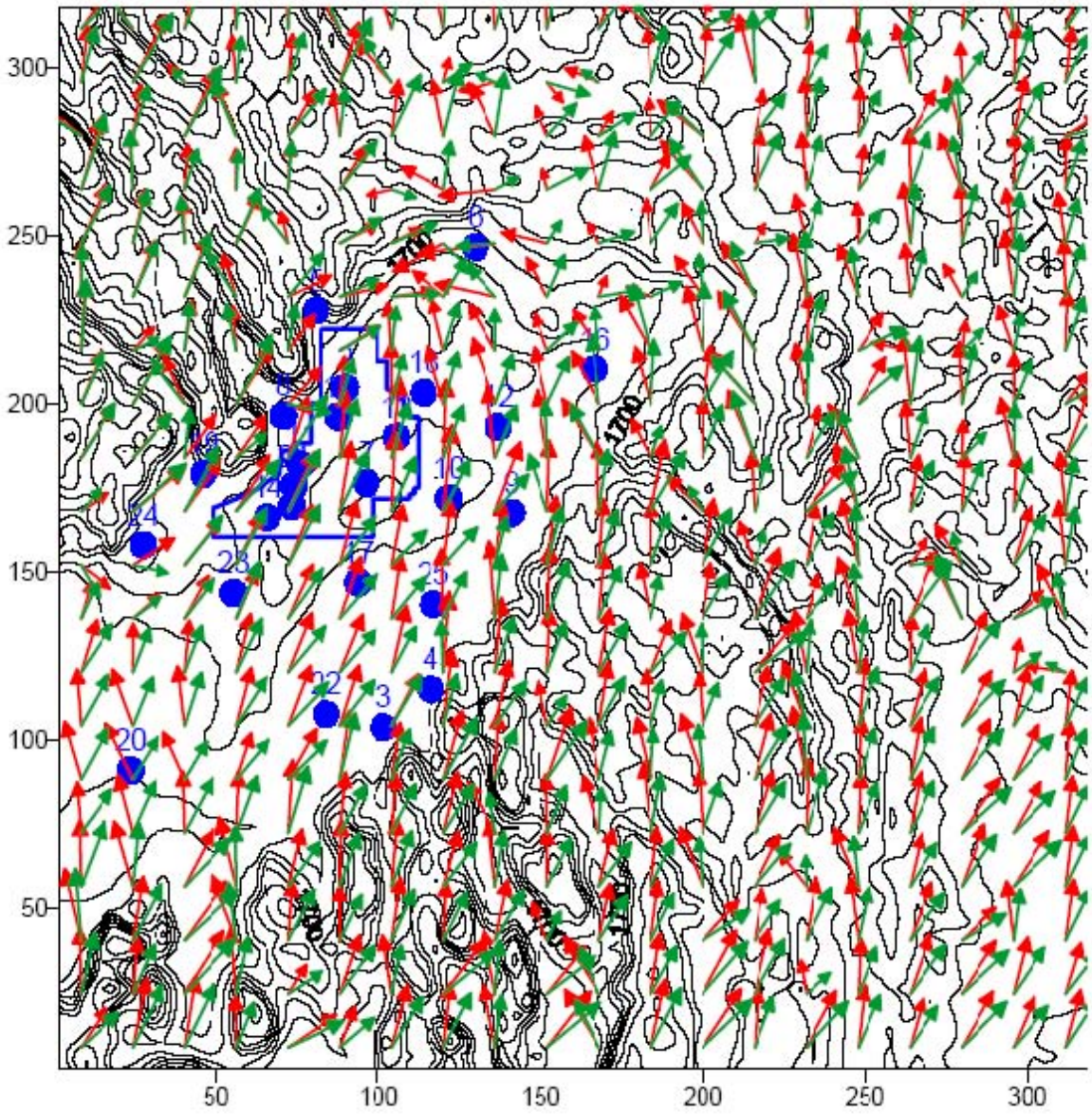


Figure B.9 CALMET simulation – average for September 1999
3 STATIONS - GREEN
25 STATIONS – RED

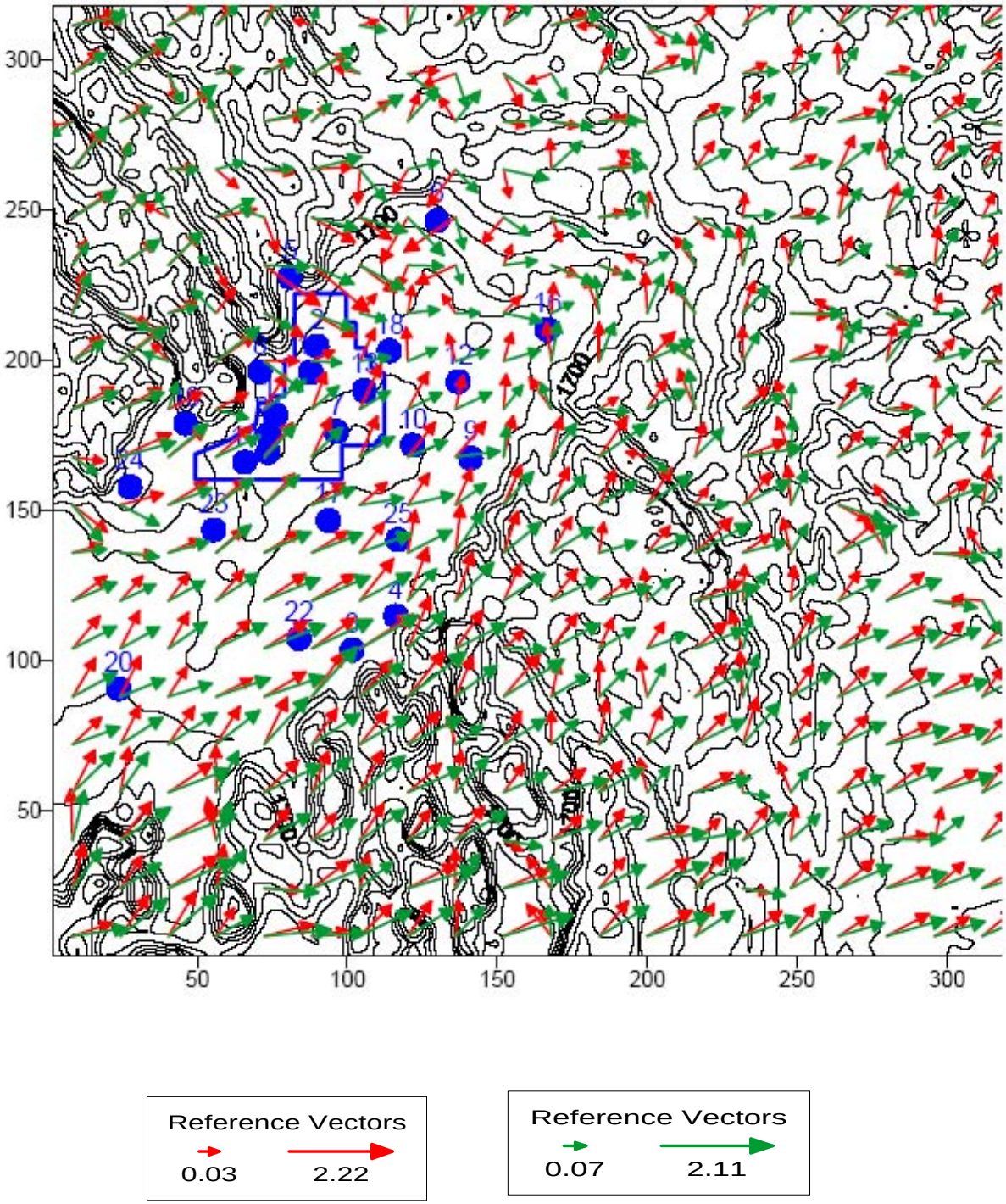


Figure B.10 CALMET simulation – average for October 1999
3 STATIONS - GREEN
25 STATIONS – RED

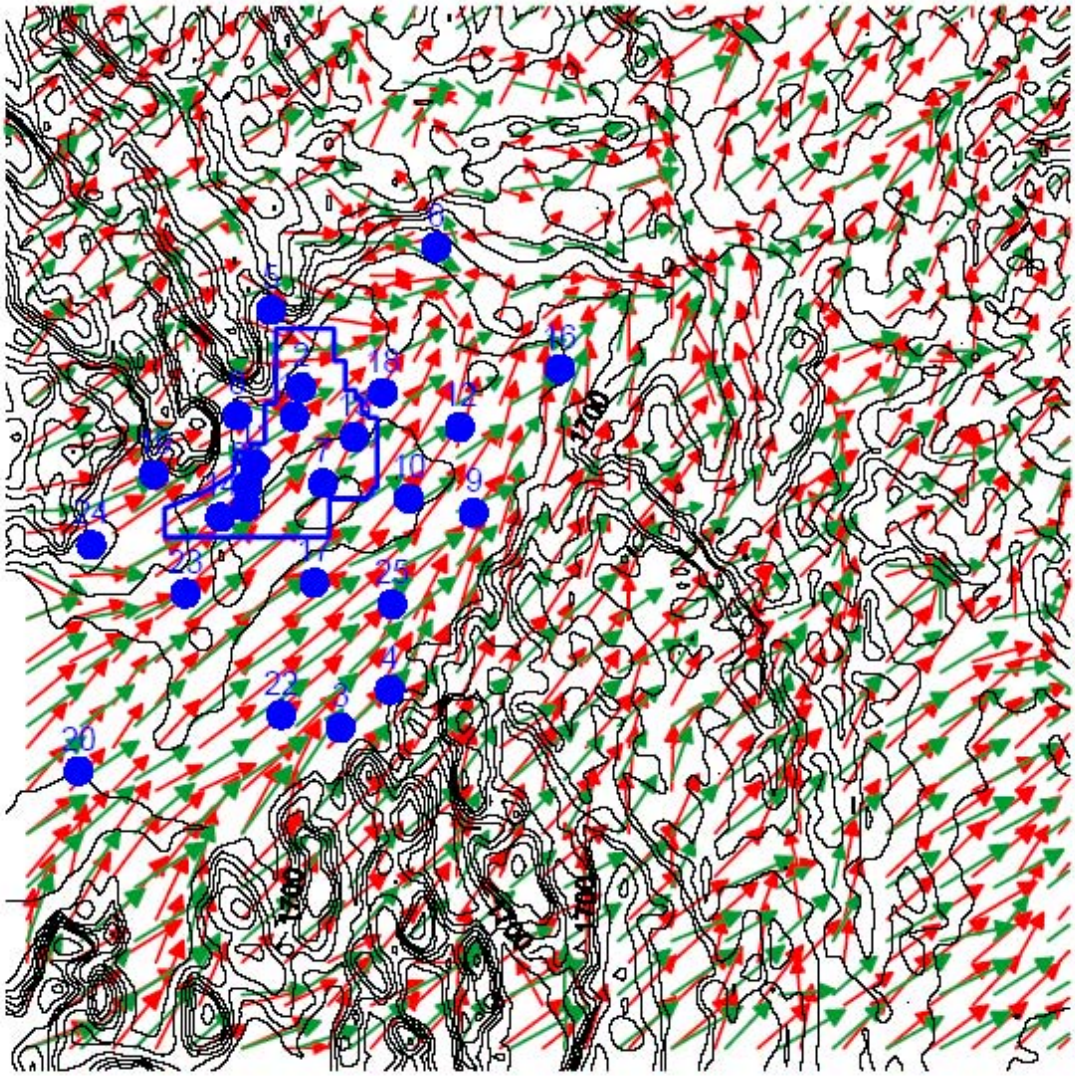


Figure B.11 CALMET simulation – average for November 1999
3 STATIONS - GREEN
25 STATIONS – RED

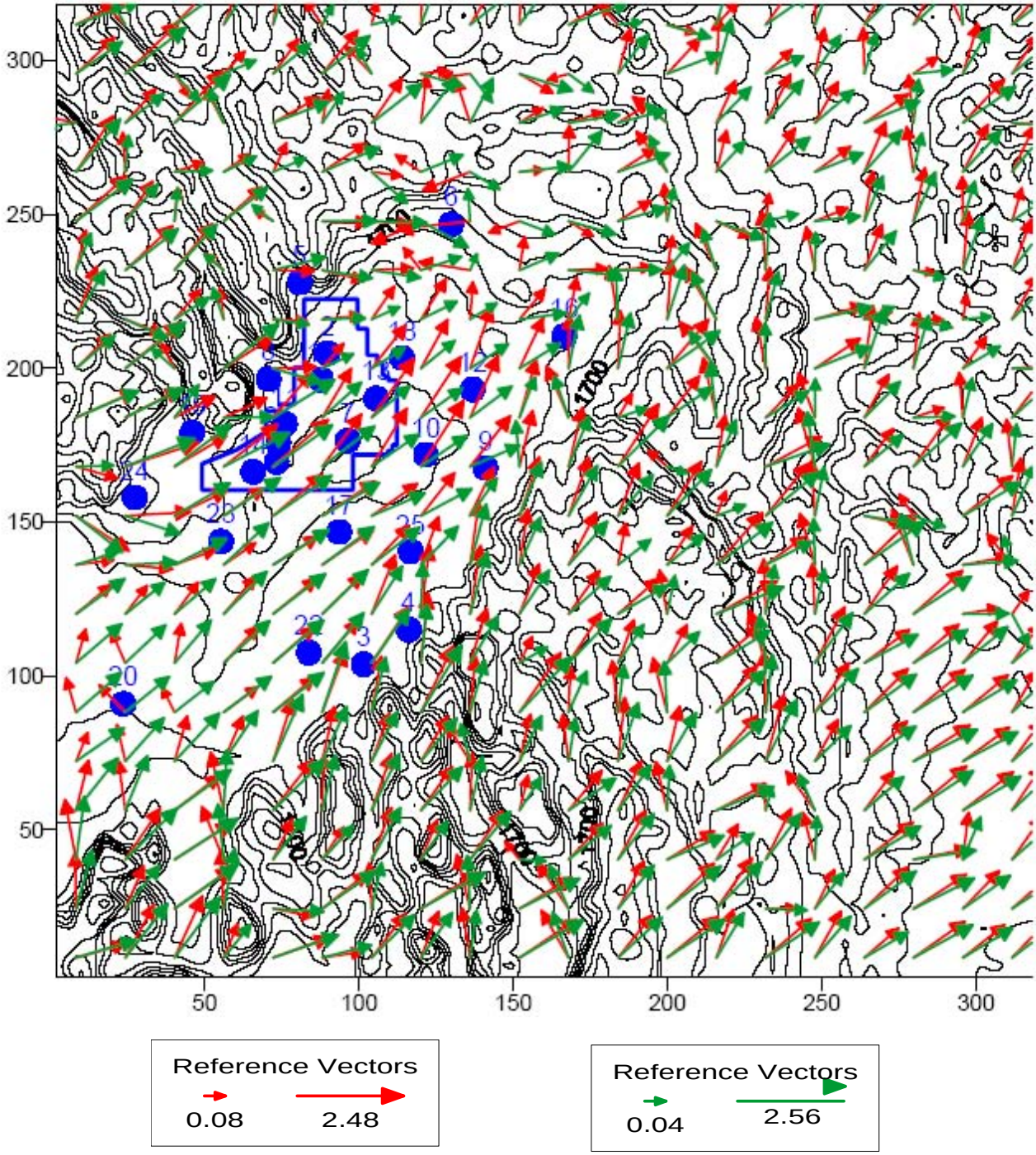
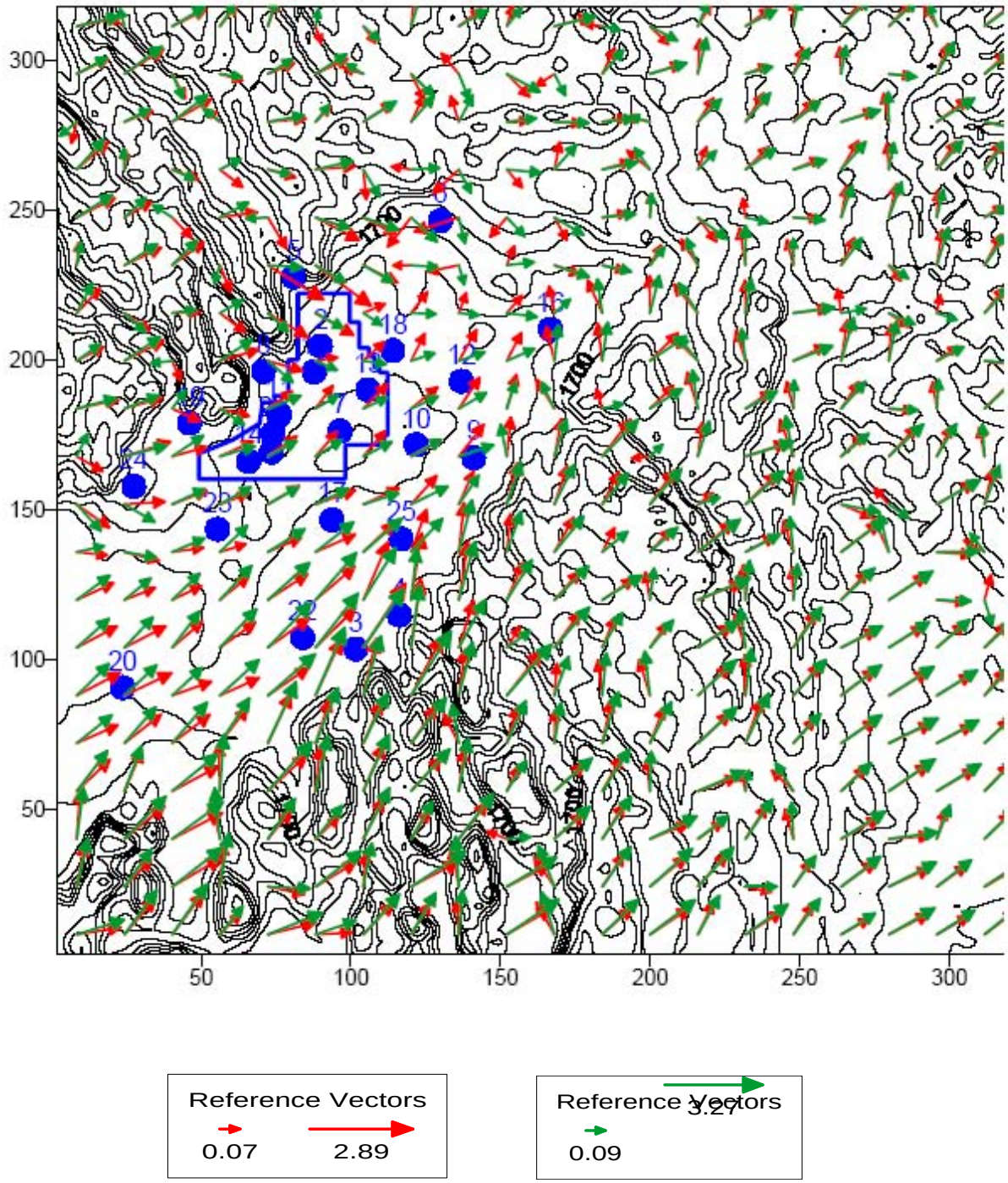


Figure B.12 CALMET simulation – average for December 1999
3 STATIONS - GREEN
25 STATIONS – RED



APPENDIX C: SAMPLE CALPUFF CONTROL FILE

APPENDIX C: SAMPLE CALPUFF CONTROL FILE

```
Modeling test source 20m Stack
One Pollutant

---------------- Run title (3 lines) ------------------------------------------

                    CALPUFF MODEL CONTROL FILE
                    --------------------------

--------------------------------------------------------------------------------

INPUT GROUP: 0 -- Input and Output File Names

--------------
Default Name  Type          File Name
------------  ----          ---------
CALMET.DAT    input    * METDAT =             *
    or
ISCMET.DAT    input    * ISCDAT =             *
    or
PLMMET.DAT    input    * PLMDAT =             *
    or
PROFILE.DAT   input    * PRFDAT =             *
SURFACE.DAT   input    * SFCDAT =             *
RESTARTB.DAT  input    * RSTARTB=             *
--------------------------------------------------------------------------------
CALPUFF.LST   output   ! PUFLST =cpuf57.LST  !
CONC.DAT      output   ! CONDAT =cpuf57.con     !
DFLX.DAT      output   ! DFDAT  =cpuf57.dry     !
WFLX.DAT      output   ! WFDAT  =cpuf57.wet     !

VISB.DAT      output   * VISDAT =VISB.DAT     *
RESTARTE.DAT  output   * RSTARTE=             *
--------------------------------------------------------------------------------
Emission Files
--------------
PTEMARB.DAT   input    ! PTDAT  =  PTEMARB.DAT  !
VOLEMARB.DAT  input    * VOLDAT =             *
BAEMARB.DAT   input    * ARDAT  =             *
LNEMARB.DAT   input    * LNDAT  =             *
--------------------------------------------------------------------------------
Other Files
-----------
OZONE.DAT     input    * OZDAT  =             *
VD.DAT        input    * VDDAT  =             *
CHEM.DAT      input    * CHEMDAT=             *
H2O2.DAT      input    * H2O2DAT=             *
HILL.DAT      input    * HILDAT=             *
HILLRCT.DAT   input    * RCTDAT=             *
COASTLN.DAT   input    * CSTDAT=             *
FLUXBDY.DAT   input    * BDYDAT=             *
BCON.DAT      input    * BCNDAT=             *
DEBUG.DAT     output   ! DEBUG =DEBUG.DAT     !
MASSFLX.DAT   output   * FLXDAT=             *
MASSBAL.DAT   output   * BALDAT=             *
FOG.DAT       output   * FOGDAT=             *
--------------------------------------------------------------------------------
All file names will be converted to lower case if LCFILES = T
Otherwise, if LCFILES = F, file names will be converted to UPPER CASE
         T = lower case      ! LCFILES = T !
         F = UPPER CASE
NOTE: (1) file/path names can be up to 70 characters in length

Provision for multiple input files
----------------------------------

     Number of CALMET.DAT files for run (NMETDAT)
                                    Default: 1       ! NMETDAT =   12  !

     Number of PTEMARB.DAT files for run (NPTDAT)
```

```
                                    Default: 0       ! NPTDAT =  1  !

     Number of BAEMARB.DAT files for run (NARDAT)
                                    Default: 0       ! NARDAT =  0  !

     Number of VOLEMARB.DAT files for run (NVOLDAT)
                                    Default: 0       ! NVOLDAT =  0  !

!END!

-------------
Subgroup (0a)
-------------

  The following CALMET.DAT filenames are processed in sequence if NMETDAT>1

Default Name  Type          File Name
------------  ----          ---------
 none         input    ! METDAT=c:\P33294\calmet\JAN58.DAT  !  !END!
 none         input    ! METDAT=c:\P33294\calmet\FEB58.DAT  !  !END!
 none         input    ! METDAT=c:\P33294\calmet\MAR58.DAT  !  !END!
 none         input    ! METDAT=c:\P33294\calmet\APR58.DAT  !  !END!
 none         input    ! METDAT=c:\P33294\calmet\MAY58.DAT  !  !END!
 none         input    ! METDAT=c:\P33294\calmet\JUN58.DAT  !  !END!
 none         input    ! METDAT=c:\P33294\calmet\JUL58.DAT  !  !END!
 none         input    ! METDAT=c:\P33294\calmet\AUG58.DAT  !  !END!
 none         input    ! METDAT=c:\P33294\calmet\SEP58.DAT  !  !END!
 none         input    ! METDAT=c:\P33294\calmet\OCT58.DAT  !  !END!
 none         input    ! METDAT=c:\P33294\calmet\NOV58.DAT  !  !END!
 none         input    ! METDAT=c:\P33294\calmet\DEC58.DAT  !  !END!


--------------------------------------------------------------------------------

INPUT GROUP: 1 -- General run control parameters
--------------

    Option to run all periods found
    in the met. file     (METRUN)   Default: 0       ! METRUN =   0  !

         METRUN = 0 - Run period explicitly defined below
         METRUN = 1 - Run all periods in met. file

     Starting date:   Year (IBYR) -- No default       ! IBYR =  1957  !
     (used only if   Month (IBMO) -- No default       ! IBMO =  1  !
      METRUN = 0)      Day (IBDY) -- No default       ! IBDY =  1  !
                      Hour (IBHR) -- No default       ! IBHR =  0  !

     Base time zone        (XBTZ) -- No default       ! XBTZ = 7.0  !
        PST = 8., MST = 7.
        CST = 6., EST = 5.

     Length of run (hours) (IRLG) -- No default       ! IRLG =  8736  !

     Number of chemical species (NSPEC)
                                    Default: 5       ! NSPEC =  1   !

     Number of chemical species
     to be emitted  (NSE)           Default: 3       ! NSE =  1   !

     Flag to stop run after
     SETUP phase (ITEST)            Default: 2       ! ITEST =  2   !
     (Used to allow checking
     of the model inputs, files, etc.)
           ITEST = 1 - STOPS program after SETUP phase
           ITEST = 2 - Continues with execution of program
                       after SETUP

     Restart Configuration:


        Control flag (MRESTART)     Default: 0       ! MRESTART =  0   !
```

```
           0 = Do not read or write a restart file
           1 = Read a restart file at the beginning of
               the run
           2 = Write a restart file during run
           3 = Read a restart file at beginning of run
               and write a restart file during run

        Number of periods in Restart
        output cycle (NRESPD)        Default: 0       ! NRESPD =  0   !

           0 = File written only at last period
          >0 = File updated every NRESPD periods

     Meteorological Data Format (METFM)
                                  Default: 1       ! METFM =  1   !

           METFM = 1 - CALMET binary file (CALMET.MET)
           METFM = 2 - ISC ASCII file (ISCMET.MET)
           METFM = 3 - AUSPLUME ASCII file (PLMMET.MET)
           METFM = 4 - CTDM plus tower file (PROFILE.DAT) and
                       surface parameters file (SURFACE.DAT)

     PG sigma-y is adjusted by the factor (AVET/PGTIME)**0.2
     Averaging Time (minutes) (AVET)
                                  Default: 60.0    ! AVET = 60. !
     PG Averaging Time (minutes) (PGTIME)
                                  Default: 60.0    ! PGTIME = 60. !


!END!


--------------------------------------------------------------------------------

INPUT GROUP: 2 -- Technical options
--------------


     Vertical distribution used in the
     near field (MGAUSS)                  Default: 1     ! MGAUSS =  1   !
        0 = uniform
        1 = Gaussian

     Terrain adjustment method
     (MCTADJ)                             Default: 3     ! MCTADJ =  3   !
        0 = no adjustment
        1 = ISC-type of terrain adjustment
        2 = simple, CALPUFF-type of terrain
            adjustment
        3 = partial plume path adjustment

     Subgrid-scale complex terrain
     flag (MCTSG)                         Default: 0     ! MCTSG =  0   !
        0 = not modeled
        1 = modeled

     Near-field puffs modeled as
     elongated 0 (MSLUG)                  Default: 0     ! MSLUG =  0   !
        0 = no
        1 = yes (slug model used)

     Transitional plume rise modeled ?
     (MTRANS)                             Default: 1     ! MTRANS =  1   !
        0 = no  (i.e., final rise only)
        1 = yes (i.e., transitional rise computed)

     Stack tip downwash? (MTIP)           Default: 1     ! MTIP =  1  !
        0 = no  (i.e., no stack tip downwash)
        1 = yes (i.e., use stack tip downwash)

     Vertical wind shear modeled above
```

```
stack top? (MSHEAR)                    Default: 0     ! MSHEAR =  0  !
   0 = no  (i.e., vertical wind shear not modeled)
   1 = yes (i.e., vertical wind shear modeled)

Puff splitting allowed? (MSPLIT)       Default: 0     ! MSPLIT =  0  !
   0 = no (i.e., puffs not split)
   1 = yes (i.e., puffs are split)

Chemical mechanism flag (MCHEM)        Default: 1     ! MCHEM =  0   !
   0 = chemical transformation not
       modeled
   1 = transformation rates computed
       internally (MESOPUFF II scheme)
   2 = user-specified transformation
       rates used
   3 = transformation rates computed
       internally (RIVAD/ARM3 scheme)
   4 = secondary organic aerosol formation
       computed (MESOPUFF II scheme for OH)

Aqueous phase transformation flag (MAQCHEM)
(Used only if MCHEM = 1, or 3)         Default: 0     ! MAQCHEM =  0   !
   0 = aqueous phase transformation
       not modeled
   1 = transformation rates adjusted
       for aqueous phase reactions

Wet removal modeled ? (MWET)           Default: 1     ! MWET =  1   !
   0 = no
   1 = yes

Dry deposition modeled ? (MDRY)        Default: 1     ! MDRY =  1   !
   0 = no
   1 = yes
   (dry deposition method specified
    for each species in Input Group 3)

Method used to compute dispersion
coefficients (MDISP)                   Default: 3     ! MDISP =  3   !

   1 = dispersion coefficients computed from measured values
       of turbulence, sigma v, sigma w
   2 = dispersion coefficients from internally calculated
       sigma v, sigma w using micrometeorological variables
       (u*, w*, L, etc.)
   3 = PG dispersion coefficients for RURAL areas (computed using
       the ISCST multi-segment approximation) and MP coefficients in
       urban areas
   4 = same as 3 except PG coefficients computed using
       the MESOPUFF II eqns.
   5 = CTDM sigmas used for stable and neutral conditions.
       For unstable conditions, sigmas are computed as in
       MDISP = 3, described above.  MDISP = 5 assumes that
       measured values are read

Sigma-v/sigma-theta, sigma-w measurements used? (MTURBVW)
(Used only if MDISP = 1 or 5)          Default: 3     ! MTURBVW =  0  !
   1 = use sigma-v or sigma-theta measurements
       from PROFILE.DAT to compute sigma-y
       (valid for METFM = 1, 2, 3, 4)
   2 = use sigma-w measurements
       from PROFILE.DAT to compute sigma-z
       (valid for METFM = 1, 2, 3, 4)
   3 = use both sigma-(v/theta) and sigma-w
       from PROFILE.DAT to compute sigma-y and sigma-z
       (valid for METFM = 1, 2, 3, 4)
   4 = use sigma-theta measurements
       from PLMMET.DAT to compute sigma-y
       (valid only if METFM = 3)

Back-up method used to compute dispersion
when measured turbulence data are
```

```
missing (MDISP2)                      Default: 3     ! MDISP2 =  4  !
(used only if MDISP = 1 or 5)
   2 = dispersion coefficients from internally calculated
       sigma v, sigma w using micrometeorological variables
       (u*, w*, L, etc.)
   3 = PG dispersion coefficients for RURAL areas (computed using
       the ISCST multi-segment approximation) and MP coefficients in
       urban areas
   4 = same as 3 except PG coefficients computed using
       the MESOPUFF II eqns.

PG sigma-y,z adj. for roughness?      Default: 0     ! MROUGH =  0  !
(MROUGH)
   0 = no
   1 = yes

Partial plume penetration of          Default: 1     ! MPARTL =  1  !
elevated inversion?
(MPARTL)
   0 = no
   1 = yes

Strength of temperature inversion     Default: 0     ! MTINV =  0  !
provided in PROFILE.DAT extended records?
(MTINV)
   0 = no (computed from measured/default gradients)
   1 = yes

PDF used for dispersion under convective conditions?
                                      Default: 0     ! MPDF =  0  !
(MPDF)
   0 = no
   1 = yes

Sub-Grid TIBL module used for shore line?
                                      Default: 0     ! MSGTIBL = 0  !
(MSGTIBL)
   0 = no
   1 = yes

Boundary conditions (concentration) modeled?
                                      Default: 0     ! MBCON = 0  !
(MBCON)
   0 = no
   1 = yes


Analyses of fogging and icing impacts due to emissions from
arrays of mechanically-forced cooling towers can be performed
using CALPUFF in conjunction with a cooling tower emissions
processor (CTEMISS) and its associated postprocessors.  Hourly
emissions of water vapor and temperature from each cooling tower
cell are computed for the current cell configuration and ambient
conditions by CTEMISS. CALPUFF models the dispersion of these
emissions and provides cloud information in a specialized format
for further analysis. Output to FOG.DAT is provided in either
'plume mode' or 'receptor mode' format.

Configure for FOG Model output?
                                      Default: 0     ! MFOG =  0   !
(MFOG)
   0 = no
   1 = yes  - report results in PLUME Mode format
   2 = yes  - report results in RECEPTOR Mode format


Test options specified to see if
they conform to regulatory
values? (MREG)                        Default: 1     ! MREG =  0   !

   0 = NO checks are made
   1 = Technical options must conform to USEPA values
```

```
                        METFM    1
                        AVET     60. (min)
                        MGAUSS   1
                        MCTADJ   3
                        MTRANS   1
                        MTIP     1
                        MCHEM    1 (if modeling SOx, NOx)
                        MWET     1
                        MDRY     1
                        MDISP    3
                        MROUGH   0
                        MPARTL   1
                        SYTDEP   550. (m)
                        MHFTSZ   0


!END!


--------------------------------------------------------------------------------

INPUT GROUP: 3a, 3b -- Species list
-------------------

------------
Subgroup (3a)
------------

  The following species are modeled:

! CSPEC =          I131 !         !END!

                                                      Dry                 OUTPUT GROUP
    SPECIES          MODELED          EMITTED       DEPOSITED               NUMBER
     NAME         (0=NO, 1=YES)    (0=NO, 1=YES)    (0=NO,                (0=NONE,
   (Limit: 12                                        1=COMPUTED-GAS        1=1st CGRUP,
    Characters                                       2=COMPUTED-PARTICLE   2=2nd CGRUP,
    in length)                                       3=USER-SPECIFIED)     3= etc.)

!          I131  =         1,               1,           1,                 0   !

!END!

-------------
Subgroup (3b)
-------------
  The following names are used for Species-Groups in which results
  for certain species are combined (added) prior to output.  The
  CGRUP name will be used as the species name in output files.
  Use this feature to model specific particle-size distributions
  by treating each size-range as a separate species.
  Order must be consistent with 3(a) above.



--------------------------------------------------------------------------------


INPUT GROUP: 4 -- Grid control parameters
--------------


METEOROLOGICAL grid:

            No. X grid cells (NX)      No default     ! NX =  80   !
            No. Y grid cells (NY)      No default     ! NY =  80   !
         No. vertical layers (NZ)      No default     ! NZ =  11  !

           Grid spacing (DGRIDKM)      No default     ! DGRIDKM = 4. !
                                       Units: km

                Cell face heights
```

```
                  (ZFACE(nz+1))      No defaults
                                     Units: m
      ! ZFACE = 0.,20.,40.,80.,140.,200.,500.,750.,2000.,2500.,3000.,3500. !

          Reference Coordinates
         of SOUTHWEST corner of
              grid cell(1, 1):

          X coordinate (XORIGKM)     No default     ! XORIGKM =   0. !
          Y coordinate (YORIGKM)     No default     ! YORIGKM =    0. !
                                    Units: km

               UTM zone (IUTMZN)     No default     ! IUTMZN =   0   !

   Reference coordinates of CENTER
        of the domain (used in the
    calculation of solar elevation
                          angles)


Computational grid:

     The computational grid is identical to or a subset of the MET. grid.
     The lower left (LL) corner of the computational grid is at grid point
     (IBCOMP, JBCOMP) of the MET. grid.  The upper right (UR) corner of the
     computational grid is at grid point (IECOMP, JECOMP) of the MET. grid.
     The grid spacing of the computational grid is the same as the MET. grid.

        X index of LL corner (IBCOMP)      No default     ! IBCOMP =   1  !
                  (1 <= IBCOMP <= NX)

        Y index of LL corner (JBCOMP)      No default     ! JBCOMP =   1  !
                  (1 <= JBCOMP <= NY)


        X index of UR corner (IECOMP)      No default     ! IECOMP =  80   !
                  (1 <= IECOMP <= NX)

        Y index of UR corner (JECOMP)      No default     ! JECOMP =  80   !
                  (1 <= JECOMP <= NY)


SAMPLING GRID (GRIDDED RECEPTORS):

     The lower left (LL) corner of the sampling grid is at grid point
     (IBSAMP, JBSAMP) of the MET. grid.  The upper right (UR) corner of the
     sampling grid is at grid point (IESAMP, JESAMP) of the MET. grid.
     The sampling grid must be identical to or a subset of the computational
     grid.  It may be a nested grid inside the computational grid.
     The grid spacing of the sampling grid is DGRIDKM/MESHDN.

        Logical flag indicating if gridded
        receptors are used (LSAMP)         Default: T     ! LSAMP = T !
        (T=yes, F=no)

        X index of LL corner (IBSAMP)      No default     ! IBSAMP =   1  !
         (IBCOMP <= IBSAMP <= IECOMP)

        Y index of LL corner (JBSAMP)      No default     ! JBSAMP =   1  !
         (JBCOMP <= JBSAMP <= JECOMP)


        X index of UR corner (IESAMP)      No default     ! IESAMP =  80  !
         (IBCOMP <= IESAMP <= IECOMP)

        Y index of UR corner (JESAMP)      No default     ! JESAMP =  80  !
         (JBCOMP <= JESAMP <= JECOMP)


       Nesting factor of the sampling
```

```
        grid (MESHDN)                       Default: 1     ! MESHDN =  1  !
        (MESHDN is an integer >= 1)

!END!


------------------------------------------------------------------------------


INPUT GROUP: 5 -- Output Options
--------------
                                          *                          *
     FILE                         DEFAULT VALUE              VALUE THIS RUN
     ----                         -------------              --------------

   Concentrations (ICON)              1                    !  ICON =  1   !
   Dry Fluxes (IDRY)                  1                    !  IDRY =  1   !
   Wet Fluxes (IWET)                  1                    !  IWET =  1   !
   Relative Humidity (IVIS)           1                    !  IVIS =  0   !
    (relative humidity file is
     required for visibility
     analysis)
   Use data compression option in output file?
   (LCOMPRS)                          Default: T         ! LCOMPRS = T !

   *
    0 = Do not create file, 1 = create file


    DIAGNOSTIC MASS FLUX OUTPUT OPTIONS:

       Mass flux across specified boundaries
       for selected species reported hourly?
       (IMFLX)                        Default: 0         ! IMFLX =  0  !
         0 = no
         1 = yes (FLUXBDY.DAT and MASSFLX.DAT filenames
                  are specified in Input Group 0)

       Mass balance for each species
       reported hourly?
       (IMBAL)                        Default: 0         ! IMBAL =  0  !
         0 = no
         1 = yes (MASSBAL.DAT filename is
              specified in Input Group 0)


    LINE PRINTER OUTPUT OPTIONS:

       Print concentrations (ICPRT)    Default: 0         ! ICPRT =  0   !
       Print dry fluxes (IDPRT)        Default: 0         ! IDPRT =  0   !
       Print wet fluxes (IWPRT)        Default: 0         ! IWPRT =  0   !
       (0 = Do not print, 1 = Print)

       Concentration print interval
       (ICFRQ) in hours                Default: 1         ! ICFRQ =  1   !
       Dry flux print interval
       (IDFRQ) in hours                Default: 1         ! IDFRQ =  1   !
       Wet flux print interval
       (IWFRQ) in hours                Default: 1         ! IWFRQ =  1   !

       Units for Line Printer Output
       (IPRTU)                         Default: 1         ! IPRTU =  3   !
                      for              for
                Concentration    Deposition
           1 =       g/m**3          g/m**2/s
           2 =      mg/m**3         mg/m**2/s
           3 =      ug/m**3         ug/m**2/s
           4 =      ng/m**3         ng/m**2/s
           5 =     Odour Units

       Messages tracking progress of run
       written to the screen ?
```

```
       (IMESG)                          Default: 2         ! IMESG =  2   !
         0 = no
         1 = yes (advection step, puff ID)
         2 = yes (YYYYJJJHH, # old puffs, # emitted puffs)


     SPECIES (or GROUP for combined species) LIST FOR OUTPUT OPTIONS

                 ---- CONCENTRATIONS ----   ------ DRY FLUXES ------   ------ WET FLUXES ------
-- MASS FLUX --
   SPECIES
   /GROUP        PRINTED?  SAVED ON DISK?   PRINTED?  SAVED ON DISK?   PRINTED?  SAVED ON DISK?
SAVED ON DISK?
   -------       ------------------------   ------------------------   ------------------------
---------------
!         I131 =     0,           1,           0,           1,           0,           1,
0   !

     OPTIONS FOR PRINTING "DEBUG" QUANTITIES (much output)

       Logical for debug output
       (LDEBUG)                                 Default: F     ! LDEBUG = F !

       First puff to track
       (IPFDEB)                                 Default: 1     ! IPFDEB =  1  !

       Number of puffs to track
       (NPFDEB)                                 Default: 1     ! NPFDEB =  1  !

       Met. period to start output
       (NN1)                                    Default: 1     ! NN1 =  1   !

       Met. period to end output
       (NN2)                                    Default: 10    ! NN2 =  10  !

!END!

------------------------------------------------------------------------------


INPUT GROUP: 6a, 6b, & 6c -- Subgrid scale complex terrain inputs
-------------------------

---------------
Subgroup (6a)
---------------
       Number of terrain features (NHILL)       Default: 0     ! NHILL =  0   !

       Number of special complex terrain
       receptors  (NCTREC)                      Default: 0     ! NCTREC =  0   !


       Terrain and CTSG Receptor data for
       CTSG hills input in CTDM format ?
       (MHILL)                                  No Default     ! MHILL =  0   !
       1 = Hill and Receptor data created
           by CTDM processors & read from
           HILL.DAT and HILLRCT.DAT files
       2 = Hill data created by OPTHILL &
           input below in Subgroup (6b);
           Receptor data in Subgroup (6c)

       Factor to convert horizontal dimensions  Default: 1.0   ! XHILL2M = 1. !
       to meters (MHILL=1)

       Factor to convert vertical dimensions    Default: 1.0   ! ZHILL2M = 1. !
       to meters (MHILL=1)

       X-origin of CTDM system relative to      No Default     ! XCTDMKM = 0.0E00 !
       CALPUFF coordinate system, in Kilometers (MHILL=1)

       Y-origin of CTDM system relative to      No Default     ! YCTDMKM = 0.0E00 !
```

```
       CALPUFF coordinate system, in Kilometers (MHILL=1)

! END !

---------------
Subgroup (6b)
---------------

                      1 **
     HILL information

HILL           XC        YC       THETAH  ZGRID  RELIEF    EXPO 1    EXPO 2   SCALE 1    SCALE 2
AMAX1     AMAX2
 NO.           (km)      (km)      (deg.)   (m)     (m)       (m)       (m)       (m)        (m)
(m)       (m)
----          ----      ----      ------  -----  ------    ------    ------   -------    -------
-----     -----

---------------
Subgroup (6c)
---------------

    COMPLEX TERRAIN RECEPTOR INFORMATION

                     XRCT         YRCT        ZRCT          XHH
                     (km)         (km)         (m)
                    ------       -----      ------         ----

-------------------
1
     Description of Complex Terrain Variables:
          XC, YC  = Coordinates of center of hill
          THETAH  = Orientation of major axis of hill (clockwise from
                    North)
          ZGRID   = Height of the  0  of the grid above mean sea
                    level
          RELIEF  = Height of the crest of the hill above the grid elevation
          EXPO 1  = Hill-shape exponent for the major axis
          EXPO 2  = Hill-shape exponent for the major axis
          SCALE 1 = Horizontal length scale along the major axis
          SCALE 2 = Horizontal length scale along the minor axis
          AMAX    = Maximum allowed axis length for the major axis
          BMAX    = Maximum allowed axis length for the major axis

          XRCT, YRCT = Coordinates of the complex terrain receptors
          ZRCT    = Height of the ground (MSL) at the complex terrain
                    Receptor
          XHH     = Hill number associated with each complex terrain receptor
                    (NOTE: MUST BE ENTERED AS A REAL NUMBER)

   **
     NOTE: DATA for each hill and CTSG receptor are treated as a separate
           input subgroup and therefore must end with an input group terminator.

------------------------------------------------------------------------------

INPUT GROUP: 7 -- Chemical parameters for dry deposition of gases
--------------

      SPECIES     DIFFUSIVITY      ALPHA STAR      REACTIVITY    MESOPHYLL RESISTANCE     HENRY'S
LAW COEFFICIENT
       NAME        (cm**2/s)                                           (s/cm)
(dimensionless)
      -------     -----------      ----------      ----------    --------------------     -------
----------------
!         I131 =     0.1345,            1.,            2.,               25.,
18. !

!END!

------------------------------------------------------------------------------
INPUT GROUP: 8 -- Size parameters for dry deposition of particles
```

```
--------------

     For SINGLE SPECIES, the mean and standard deviation are used to
     compute a deposition velocity for NINT (see group 9) size-ranges,
     and these are then averaged to obtain a mean deposition velocity.

     For GROUPED SPECIES, the size distribution should be explicitly
     specified (by the 'species' in the group), and the standard deviation
     for each should be entered as 0.  The model will then use the
     deposition velocity for the stated mean diameter.

      SPECIES      GEOMETRIC MASS MEAN        GEOMETRIC STANDARD
       NAME             DIAMETER                  DEVIATION
                        (microns)                 (microns)
      -------      ------------------        ------------------

!END!


-------------------------------------------------------------------------------


INPUT GROUP: 9 -- Miscellaneous dry deposition parameters
--------------

     Reference cuticle resistance (s/cm)
     (RCUTR)                          Default: 30    !  RCUTR = 30.0 !
     Reference ground resistance  (s/cm)
     (RGR)                            Default: 10    !    RGR = 5.0 !
     Reference pollutant reactivity
     (REACTR)                         Default: 8     ! REACTR = 8.0 !

     Number of particle-size intervals used to
     evaluate effective particle deposition velocity
     (NINT)                           Default: 9     !   NINT =  9  !

     Vegetation state in unirrigated areas
     (IVEG)                           Default: 1     !   IVEG =  1   !
        IVEG=1 for active and unstressed vegetation
        IVEG=2 for active and stressed vegetation
        IVEG=3 for inactive vegetation

!END!


-------------------------------------------------------------------------------


INPUT GROUP: 10 -- Wet Deposition Parameters
---------------


                      Scavenging Coefficient -- Units: (sec)**(-1)

       Pollutant      Liquid Precip.       Frozen Precip.
       ---------      --------------       --------------
!        I131  =         1.0E-04,             3.0E-05 !

!END!


-------------------------------------------------------------------------------


INPUT GROUP: 11 -- Chemistry Parameters
---------------

     Ozone data input option (MOZ)     Default: 1            ! MOZ =  0   !
     (Used only if MCHEM = 1, 3, or 4)
        0 = use a monthly background ozone value
        1 = read hourly ozone concentrations from
            the OZONE.DAT data file
```

```
     Monthly ozone concentrations
     (Used only if MCHEM = 1, 3, or 4 and
      MOZ = 0 or MOZ = 1 and all hourly O3 data missing)
     (BCKO3) in ppb                    Default: 12*80.
     !  BCKO3 = 80.00, 80.00, 80.00, 80.00, 80.00, 80.00, 80.00, 80.00, 80.00, 80.00, 80.00,
80.00 !

     Monthly ammonia concentrations
     (Used only if MCHEM = 1, or 3)
     (BCKNH3) in ppb                   Default: 12*10.
     !  BCKNH3 = 10.00, 10.00, 10.00, 10.00, 10.00, 10.00, 10.00, 10.00, 10.00, 10.00, 10.00,
10.00 !

     Nighttime SO2 loss rate (RNITE1)
     in percent/hour                   Default: 0.2          ! RNITE1 = .2 !

     Nighttime NOx loss rate (RNITE2)
     in percent/hour                   Default: 2.0          ! RNITE2 = 2.0 !

     Nighttime HNO3 formation rate (RNITE3)
     in percent/hour                   Default: 2.0          ! RNITE3 = 2.0 !

     H2O2 data input option (MH2O2)    Default: 1            ! MH2O2 =  1   !
     (Used only if MAQCHEM = 1)
        0 = use a monthly background H2O2 value
        1 = read hourly H2O2 concentrations from
            the H2O2.DAT data file

     Monthly H2O2 concentrations
     (Used only if MQACHEM = 1 and
      MH2O2 = 0 or MH2O2 = 1 and all hourly H2O2 data missing)
     (BCKH2O2) in ppb                  Default: 12*1.
     !  BCKH2O2 = 1.00, 1.00, 1.00, 1.00, 1.00, 1.00, 1.00, 1.00, 1.00, 1.00, 1.00, 1.00 !


 --- Data for SECONDARY ORGANIC AEROSOL (SOA) Option
     (used only if MCHEM = 4)

     The SOA module uses monthly values of:
          Fine particulate concentration in ug/m^3 (BCKPMF)
          Organic fraction of fine particulate     (OFRAC)
          VOC / NOX ratio (after reaction)         (VCNX)
     to characterize the air mass when computing
     the formation of SOA from VOC emissions.
     Typical values for several distinct air mass types are:

        Month    1    2    3    4    5    6    7    8    9   10   11   12
                Jan  Feb  Mar  Apr  May  Jun  Jul  Aug  Sep  Oct  Nov  Dec

     Clean Continental
        BCKPMF   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
        OFRAC  .15  .15  .20  .20  .20  .20  .20  .20  .20  .20  .20  .15
        VCNX    50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.

     Clean Marine (surface)
        BCKPMF  .5   .5   .5   .5   .5   .5   .5   .5   .5   .5   .5   .5
        OFRAC  .25  .25  .30  .30  .30  .30  .30  .30  .30  .30  .30  .25
        VCNX    50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.

     Urban - low biogenic (controls present)
        BCKPMF  30.  30.  30.  30.  30.  30.  30.  30.  30.  30.  30.  30.
        OFRAC  .20  .20  .25  .25  .25  .25  .25  .25  .20  .20  .20  .20
        VCNX     4.   4.   4.   4.   4.   4.   4.   4.   4.   4.   4.   4.

     Urban - high biogenic (controls present)
        BCKPMF  60.  60.  60.  60.  60.  60.  60.  60.  60.  60.  60.  60.
        OFRAC  .25  .25  .30  .30  .30  .55  .55  .55  .35  .35  .35  .25
        VCNX    15.  15.  15.  15.  15.  15.  15.  15.  15.  15.  15.  15.

     Regional Plume
        BCKPMF  20.  20.  20.  20.  20.  20.  20.  20.  20.  20.  20.  20.
```

```
        OFRAC  .20  .20  .25  .35  .25  .40  .40  .40  .30  .30  .30  .20
        VCNX    15.  15.  15.  15.  15.  15.  15.  15.  15.  15.  15.  15.

     Urban - no controls present
        BCKPMF 100. 100. 100. 100. 100. 100. 100. 100. 100. 100. 100. 100.
        OFRAC  .30  .30  .35  .35  .35  .55  .55  .55  .35  .35  .35  .30
        VCNX     2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.

     Default: Clean Continental
     !  BCKPMF = 1.00, 1.00, 1.00, 1.00, 1.00, 1.00, 1.00, 1.00, 1.00, 1.00, 1.00, 1.00 !
     !  OFRAC  = 0.15, 0.15, 0.20, 0.20, 0.20, 0.20, 0.20, 0.20, 0.20, 0.20, 0.20, 0.15 !
     !  VCNX   = 50.00, 50.00, 50.00, 50.00, 50.00, 50.00, 50.00, 50.00, 50.00, 50.00, 50.00,
50.00 !


!END!

------------------------------------------------------------------------------


INPUT GROUP: 12 -- Misc. Dispersion and Computational Parameters
---------------

     Horizontal size of puff (m) beyond which
     time-dependent dispersion equations (Heffter)
     are used to determine sigma-y and
     sigma-z (SYTDEP)                          Default: 550.   ! SYTDEP = 5.5E02 !

     Switch for using Heffter equation for sigma z
     as above (0 = Not use Heffter; 1 = use Heffter
     (MHFTSZ)                                  Default: 0      ! MHFTSZ =  0   !

     Stability class used to determine plume
     growth rates for puffs above the boundary
     layer (JSUP)                              Default: 5      ! JSUP =  5   !

     Vertical dispersion constant for stable
     conditions (k1 in Eqn. 2.7-3)  (CONK1)    Default: 0.01   ! CONK1 = .01 !

     Vertical dispersion constant for neutral/
     unstable conditions (k2 in Eqn. 2.7-4)
     (CONK2)                                   Default: 0.1    ! CONK2 = .1 !

     Factor for determining Transition-point from
     Schulman-Scire to Huber-Snyder Building Downwash
     scheme (SS used for Hs < Hb + TBD * HL)
     (TBD)                                     Default: 0.5    ! TBD = .5 !
        TBD < 0   ==> always use Huber-Snyder
        TBD = 1.5 ==> always use Schulman-Scire
        TBD = 0.5 ==> ISC Transition-point

     Range of land use categories for which
     urban dispersion is assumed
     (IURB1, IURB2)                            Default: 10     ! IURB1 =  10  !
                                                        19     ! IURB2 =  19  !

     Site characterization parameters for single-point Met data files ---------
     (needed for METFM = 2,3,4)

        Land use category for modeling domain
        (ILANDUIN)                             Default: 20     ! ILANDUIN =  20  !

        Roughness length (m) for modeling domain
        (Z0IN)                                 Default: 0.25   ! Z0IN = .25 !

        Leaf area index for modeling domain
        (XLAIIN)                               Default: 3.0    ! XLAIIN = 3.0 !

        Elevation above sea level (m)
        (ELEVIN)                               Default: 0.0    ! ELEVIN = .0 !

        Latitude (degrees) for met location
```

```
   (XLATIN)                                Default: -999.  ! XLATIN = -999.0 !

   Longitude (degrees) for met location
   (XLONIN)                                Default: -999.  ! XLONIN = -999.0 !

Specialized information for interpreting single-point Met data files -----

   Anemometer height (m) (Used only if METFM = 2,3)
   (ANEMHT)                                Default: 10.    ! ANEMHT = 10.0 !

   Form of lateral turbulance data in PROFILE.DAT file
   (Used only if METFM = 4 or MTURBVW = 1 or 3)
   (ISIGMAV)                               Default: 1      ! ISIGMAV =  2  !
       0 = read sigma-theta
       1 = read sigma-v

   Choice of mixing heights (Used only if METFM = 4)
   (IMIXCTDM)                              Default: 0      ! IMIXCTDM =  0  !
       0 = read PREDICTED mixing heights
       1 = read OBSERVED mixing heights

Maximum length of a slug (met. grid units)
(XMXLEN)                                   Default: 1.0    ! XMXLEN = 1.0 !

Maximum travel distance of a puff/slug (in
grid units) during one sampling step
(XSAMLEN)                                  Default: 1.0    ! XSAMLEN = 1.0 !

Maximum Number of slugs/puffs release from
one source during one time step
(MXNEW)                                    Default: 99     ! MXNEW =  99   !

Maximum Number of sampling steps for
one puff/slug during one time step
(MXSAM)                                    Default: 99     ! MXSAM =  99   !

Number of iterations used when computing
the transport wind for a sampling step
that includes gradual rise (for CALMET
and PROFILE winds)
(NCOUNT)                                   Default: 2      ! NCOUNT =  2   !

Minimum sigma y for a new puff/slug (m)
(SYMIN)                                    Default: 1.0    ! SYMIN = 1.0  !

Minimum sigma z for a new puff/slug (m)
(SZMIN)                                    Default: 1.0    ! SZMIN = 1.0  !

Default minimum turbulence velocities
sigma-v and sigma-w for each
stability class (m/s)
(SVMIN(6) and SWMIN(6))     Default SVMIN : .50,  .50,  .50,  .50,  .50,  .50
                            Default SWMIN : .20,  .12,  .08,  .06,  .03,  .016

                          Stability Class :  A     B     C     D     E     F
                                            ---   ---   ---   ---   ---   ---
                                   ! SVMIN = 0.500, 0.500, 0.500, 0.500, 0.500, 0.500!
                                   ! SWMIN = 0.200, 0.120, 0.080, 0.060, 0.030, 0.016!

Divergence criterion for dw/dz across puff
used to initiate adjustment for horizontal
convergence (1/s)
Partial adjustment starts at CDIV(1), and
full adjustment is reached at CDIV(2)
(CDIV(2))                                  Default: 0.0,0.0  ! CDIV = .0, .0 !

Minimum wind speed (m/s) allowed for
non-calm conditions. Also used as minimum
speed returned when using power-law
extrapolation toward surface
(WSCALM)                                   Default: 0.5    ! WSCALM = .3 !
```

```
Maximum mixing height (m)
(XMAXZI)                                  Default: 3000.  ! XMAXZI = 3000.0 !

Minimum mixing height (m)
(XMINZI)                                  Default: 50.    ! XMINZI = 50.0 !

Default wind speed classes --
5 upper bounds (m/s) are entered;
the 6th class has no upper limit
(WSCAT(5))                       Default   :
                                 ISC RURAL : 1.54, 3.09, 5.14, 8.23, 10.8 (10.8+)

                             Wind Speed Class :  1     2     3     4     5
                                                 ---   ---   ---   ---   ---
                                    ! WSCAT = 1.54, 3.09, 5.14, 8.23, 10.80 !

Default wind speed profile power-law
exponents for stabilities 1-6
(PLX0(6))                        Default   : ISC RURAL values
                                 ISC RURAL : .07, .07, .10, .15, .35, .55
                                 ISC URBAN : .15, .15, .20, .25, .30, .30

                              Stability Class :  A     B     C     D     E     F
                                                 ---   ---   ---   ---   ---   ---
                                       ! PLX0 = 0.07, 0.07, 0.10, 0.15, 0.35, 0.55 !

Default potential temperature gradient
for stable classes E, F (degK/m)
(PTG0(2))                        Default: 0.020, 0.035
                                    ! PTG0 = 0.020,   0.035 !

Default plume path coefficients for
each stability class (used when option
for partial plume height terrain adjustment
is selected -- MCTADJ=3)
(PPC(6))                      Stability Class :  A     B     C     D     E     F
                                 Default  PPC : .50,  .50,  .50,  .50,  .35,  .35
                                                 ---   ---   ---   ---   ---   ---
                                       !  PPC = 0.50, 0.50, 0.50, 0.50, 0.35, 0.35 !

Slug-to-puff transition criterion factor
equal to sigma-y/length of slug
(SL2PF)                                Default: 10.        ! SL2PF = 10.0 !

Puff-splitting control variables ------------------------

  VERTICAL SPLIT
  --------------

  Number of puffs that result every time a puff
  is split - nsplit=2 means that 1 puff splits
  into 2
  (NSPLIT)                             Default:   3        ! NSPLIT =  3  !

  Time(s) of a day when split puffs are eligible to
  be split once again; this is typically set once
  per day, around sunset before nocturnal shear develops.
  24 values: 0 is midnight (00:00) and 23 is 11 PM (23:00)
  0=do not re-split    1=eligible for re-split
  (IRESPLIT(24))                       Default:  Hour 17 = 1
  !  IRESPLIT = 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1,0,0,0,0,0,0 !

  Split is allowed only if last hour's mixing
  height (m) exceeds a minimum value
  (ZISPLIT)                            Default: 100.       ! ZISPLIT = 100.0 !

  Split is allowed only if ratio of last hour's
  mixing ht to the maximum mixing ht experienced
  by the puff is less than a maximum value (this
  postpones a split until a nocturnal layer develops)
  (ROLDMAX)                            Default: 0.25       ! ROLDMAX = 0.25 !
```

```
       HORIZONTAL SPLIT
       ----------------

       Number of puffs that result every time a puff
       is split - nsplith=5 means that 1 puff splits
       into 5
       (NSPLITH)                          Default:   5        ! NSPLITH =  5  !

       Minimum sigma-y (Grid Cells Units) of puff
       before it may be split
       (SYSPLITH)                         Default:  1.0       ! SYSPLITH = 1.0 !

       Minimum puff elongation rate (SYSPLITH/hr) due to
       wind shear, before it may be split
       (SHSPLITH)                         Default:  2.        ! SHSPLITH = 2.0 !

       Minimum concentration (g/m^3) of each
       species in puff before it may be split
       Enter array of NSPEC values; if a single value is
       entered, it will be used for ALL species
       (CNSPLITH)                         Default:  1.0E-07   ! CNSPLITH = 1.0E-07 !

     Integration control variables ------------------------

       Fractional convergence criterion for numerical SLUG
       sampling integration
       (EPSSLUG)                          Default:   1.0e-04  ! EPSSLUG = 1.0E-04 !

       Fractional convergence criterion for numerical AREA
       source integration
       (EPSAREA)                          Default:   1.0e-06  ! EPSAREA = 1.0E-06 !

       Trajectory step-length (m) used for numerical rise
       integration
       (DSRISE)                           Default:   1.0      ! DSRISE = 1.0 !

!END!


--------------------------------------------------------------------------------


INPUT GROUPS: 13a, 13b, 13c, 13d -- Point source parameters
---------------------------------

---------------
Subgroup (13a)
---------------

     Number of point sources with
     parameters provided below      (NPT1)  No default  !  NPT1 =  0  !

     Units used for point source
     emissions below                (IPTU)  Default: 1  !  IPTU =   1  !
           1 =        g/s
           2 =       kg/hr
           3 =       lb/hr
           4 =     tons/yr
           5 =     Odour Unit * m**3/s  (vol. flux of odour compound)
           6 =     Odour Unit * m**3/min
           7 =     metric tons/yr

     Number of source-species
     combinations with variable
     emissions scaling factors
     provided below in (13d)        (NSPT1) Default: 0  !  NSPT1 =  0  !

     Number of point sources with
     variable emission parameters
     provided in external file      (NPT2)  No default  !  NPT2 =  1  !

     (If NPT2 > 0, these point
```

```
     source emissions are read from
     the file: PTEMARB.DAT)

!END!

---------------
Subgroup (13b)
---------------
                                    a
          POINT SOURCE: CONSTANT DATA
          ----------------------------
                                                                                b          c
  Source      X UTM     Y UTM     Stack   Base     Stack    Exit  Exit    Bldg.  Emission
   No.     Coordinate Coordinate Height Elevation Diameter  Vel.  Temp.   Dwash   Rates
              (km)      (km)       (m)       (m)       (m)   (m/s) (deg. K)
  ------   ---------- ---------- ------  ------   -------- ----- -------- ----- --------

--------

    a
     Data for each source are treated as a separate input subgroup
     and therefore must end with an input group terminator.

     SRCNAM  is a 12-character name for a source
             (No default)
     X       is an array holding the source data listed by the column headings
             (No default)
     SIGYZI  is an array holding the initial sigma-y and sigma-z (m)
             (Default: 0.,0.)
     FMFAC   is a vertical momentum flux factor (0. or 1.0) used to represent
             the effect of rain-caps or other physical configurations that
             reduce momentum rise associated with the actual exit velocity.
             (Default: 1.0  -- full momentum used)

    b
     0. = No building downwash modeled, 1. = downwash modeled
     NOTE: must be entered as a REAL number (i.e., with decimal point)

    c
     An emission rate must be entered for every pollutant modeled.
     Enter emission rate of zero for secondary pollutants that are
     modeled, but not emitted.  Units are specified by IPTU
     (e.g. 1 for g/s).

---------------
Subgroup (13c)
---------------

           BUILDING DIMENSION DATA FOR SOURCES SUBJECT TO DOWNWASH
           -------------------------------------------------------
Source                                                                    a
 No.       Effective building width and height (in meters) every 10 degrees
------     ------------------------------------------------------------------

--------

    a
     Each pair of width and height values is treated as a separate input
     subgroup and therefore must end with an input group terminator.

---------------
Subgroup (13d)
---------------
                                          a
          POINT SOURCE: VARIABLE EMISSIONS DATA
          --------------------------------------

     Use this subgroup to describe temporal variations in the emission
     rates given in 13b.  Factors entered multiply the rates in 13b.
     Skip sources here that have constant emissions.  For more elaborate
     variation in source parameters, use PTEMARB.DAT and NPT2 > 0.
```

```
     IVARY determines the type of variation, and is source-specific:
     (IVARY)                                Default: 0
           0 =       Constant
           1 =       Diurnal cycle (24 scaling factors: hours 1-24)
           2 =       Monthly cycle (12 scaling factors: months 1-12)
           3 =       Hour & Season (4 groups of 24 hourly scaling factors,
                                    where first group is DEC-JAN-FEB)
           4 =       Speed & Stab. (6 groups of 6 scaling factors, where
                                    first group is Stability Class A,
                                    and the speed classes have upper
                                    bounds (m/s) defined in Group 12
           5 =       Temperature   (12 scaling factors, where temperature
                                    classes have upper bounds (C) of:
                                    0, 5, 10, 15, 20, 25, 30, 35, 40,
                                    45, 50, 50+)

--------
    a
     Data for each species are treated as a separate input subgroup
     and therefore must end with an input group terminator.

------------------------------------------------------------------------------


INPUT GROUPS: 14a, 14b, 14c, 14d -- Area source parameters
--------------------------------

---------------
Subgroup (14a)
---------------

     Number of polygon area sources with
     parameters specified below (NAR1)       No default  !  NAR1 =  0   !

     Units used for area source
     emissions below           (IARU)       Default: 1  !  IARU =   1  !
           1 =        g/m**2/s
           2 =       kg/m**2/hr
           3 =       lb/m**2/hr
           4 =     tons/m**2/yr
           5 =     Odour Unit * m/s  (vol. flux/m**2 of odour compound)
           6 =     Odour Unit * m/min
           7 =     metric tons/m**2/yr

     Number of source-species
     combinations with variable
     emissions scaling factors
     provided below in (14d)        (NSAR1) Default: 0  !  NSAR1 =  0  !

     Number of buoyant polygon area sources
     with variable location and emission
     parameters (NAR2)                      No default  !  NAR2 =  0   !
     (If NAR2 > 0, ALL parameter data for
     these sources are read from the file: BAEMARB.DAT)

!END!

---------------
Subgroup (14b)
---------------
                                   a
          AREA SOURCE: CONSTANT DATA
          --------------------------
                                                          b
Source           Effect.    Base      Initial    Emission
 No.             Height   Elevation   Sigma z     Rates
                   (m)       (m)        (m)
-------          ------    ------     --------   ---------



--------
```

```
    a
     Data for each source are treated as a separate input subgroup
     and therefore must end with an input group terminator.
    b
     An emission rate must be entered for every pollutant modeled.
     Enter emission rate of zero for secondary pollutants that are
     modeled, but not emitted.  Units are specified by IARU
     (e.g. 1 for g/m**2/s).

---------------
Subgroup (14c)
---------------

           COORDINATES (UTM-km) FOR EACH VERTEX(4) OF EACH POLYGON
           ------------------------------------------------------
Source                                                          a
 No.       Ordered list of X followed by list of Y, grouped by source
------     ------------------------------------------------------------


--------
    a
     Data for each source are treated as a separate input subgroup
     and therefore must end with an input group terminator.


---------------
Subgroup (14d)
---------------
                                          a
          AREA SOURCE: VARIABLE EMISSIONS DATA
          ------------------------------------

     Use this subgroup to describe temporal variations in the emission
     rates given in 14b.  Factors entered multiply the rates in 14b.
     Skip sources here that have constant emissions.  For more elaborate
     variation in source parameters, use BAEMARB.DAT and NAR2 > 0.

     IVARY determines the type of variation, and is source-specific:
     (IVARY)                              Default: 0
           0 =       Constant
           1 =       Diurnal cycle (24 scaling factors: hours 1-24)
           2 =       Monthly cycle (12 scaling factors: months 1-12)
           3 =       Hour & Season (4 groups of 24 hourly scaling factors,
                                    where first group is DEC-JAN-FEB)
           4 =       Speed & Stab. (6 groups of 6 scaling factors, where
                                    first group is Stability Class A,
                                    and the speed classes have upper
                                    bounds (m/s) defined in Group 12
           5 =       Temperature   (12 scaling factors, where temperature
                                    classes have upper bounds (C) of:
                                    0, 5, 10, 15, 20, 25, 30, 35, 40,
                                    45, 50, 50+)



--------
    a
     Data for each species are treated as a separate input subgroup
     and therefore must end with an input group terminator.


--------------------------------------------------------------------------------

INPUT GROUPS: 15a, 15b, 15c -- Line source parameters
----------------------------

---------------
Subgroup (15a)
---------------

     Number of buoyant line sources
```

```
     with variable location and emission
     parameters (NLN2)                              No default  !  NLN2 =  0   !

     (If NLN2 > 0, ALL parameter data for
      these sources are read from the file: LNEMARB.DAT)

     Number of buoyant line sources (NLINES)        No default   ! NLINES =  0  !

     Units used for line source
     emissions below                (ILNU)          Default: 1  !  ILNU =   1  !
           1 =        g/s
           2 =       kg/hr
           3 =       lb/hr
           4 =     tons/yr
           5 =     Odour Unit * m**3/s  (vol. flux of odour compound)
           6 =     Odour Unit * m**3/min
           7 =     metric tons/yr

     Number of source-species
     combinations with variable
     emissions scaling factors
     provided below in (15c)        (NSLN1) Default: 0  !  NSLN1 =  0  !

     Maximum number of segments used to model
     each line (MXNSEG)                             Default: 7   ! MXNSEG =  7  !

     The following variables are required only if NLINES > 0.  They are
     used in the buoyant line source plume rise calculations.

        Number of distances at which                Default: 6   ! NLRISE =  6  !
        transitional rise is computed

        Average building length (XL)                No default   ! XL = .0 !
                                                    (in meters)

        Average building height (HBL)               No default   ! HBL = .0 !
                                                    (in meters)

        Average building width (WBL)                No default   ! WBL = .0 !
                                                    (in meters)

        Average line source width (WML)             No default   ! WML = .0 !
                                                    (in meters)

        Average separation between buildings (DXL)  No default   ! DXL = .0 !
                                                    (in meters)

        Average buoyancy parameter (FPRIMEL)        No default   ! FPRIMEL = .0 !
                                                    (in m**4/s**3)

!END!

---------------
Subgroup (15b)
---------------

          BUOYANT LINE SOURCE: CONSTANT DATA
          ----------------------------------
                                                                                 a
Source     Beg. X      Beg. Y      End. X     End. Y     Release    Base        Emission
 No.     Coordinate  Coordinate  Coordinate Coordinate  Height    Elevation      Rates
            (km)        (km)        (km)       (km)       (m)       (m)
------   ----------  ----------  ---------  ----------  -------   ---------    ---------

--------
```

a
Data for each source are treated as a separate input subgroup and therefore must end with an input group terminator.

b
An emission rate must be entered for every pollutant modeled.

```
     Enter emission rate of zero for secondary pollutants that are
     modeled, but not emitted.  Units are specified by ILNTU
     (e.g. 1 for g/s).

---------------
Subgroup (15c)
---------------
                                                        a
          BUOYANT LINE SOURCE: VARIABLE EMISSIONS DATA
          --------------------------------------------

     Use this subgroup to describe temporal variations in the emission
     rates given in 15b.  Factors entered multiply the rates in 15b.
     Skip sources here that have constant emissions.

     IVARY determines the type of variation, and is source-specific:
     (IVARY)                              Default: 0
           0 =       Constant
           1 =       Diurnal cycle (24 scaling factors: hours 1-24)
           2 =       Monthly cycle (12 scaling factors: months 1-12)
           3 =       Hour & Season (4 groups of 24 hourly scaling factors,
                                    where first group is DEC-JAN-FEB)
           4 =       Speed & Stab. (6 groups of 6 scaling factors, where
                                    first group is Stability Class A,
                                    and the speed classes have upper
                                    bounds (m/s) defined in Group 12
           5 =       Temperature   (12 scaling factors, where temperature
                                    classes have upper bounds (C) of:
                                    0, 5, 10, 15, 20, 25, 30, 35, 40,
                                    45, 50, 50+)



--------
    a
     Data for each species are treated as a separate input subgroup
     and therefore must end with an input group terminator.


-------------------------------------------------------------------------------


INPUT GROUPS: 16a, 16b, 16c -- Volume source parameters
---------------------------

---------------
Subgroup (16a)
---------------

     Number of volume sources with
     parameters provided in 16b,c (NVL1)     No default  !  NVL1 =  0   !

     Units used for volume source
     emissions below in 16b       (IVLU)     Default: 1  !  IVLU =   1  !
           1 =        g/s
           2 =       kg/hr
           3 =       lb/hr
           4 =     tons/yr
           5 =     Odour Unit * m**3/s  (vol. flux of odour compound)
           6 =     Odour Unit * m**3/min
           7 =     metric tons/yr

     Number of source-species
     combinations with variable
     emissions scaling factors
     provided below in (16c)      (NSVL1)    Default: 0  !  NSVL1 =  0  !

     Number of volume sources with
     variable location and emission
     parameters                   (NVL2)     No default  !  NVL2 =   0   !

     (If NVL2 > 0, ALL parameter data for
```

these sources are read from the VOLEMARB.DAT file(s))

!END!

Subgroup (16b)

VOLUME SOURCE: CONSTANT DATA [a]

X UTM Coordinate (km)	Y UTM Coordinate (km)	Effect. Height (m)	Base Elevation (m)	Initial Sigma y (m)	Initial Sigma z (m)	Emission Rates [b]

---
a
Data for each source are treated as a separate input subgroup
and therefore must end with an input group terminator.

b
An emission rate must be entered for every pollutant modeled.
Enter emission rate of zero for secondary pollutants that are
modeled, but not emitted. Units are specified by IVLU
(e.g. 1 for g/s).

Subgroup (16c)

VOLUME SOURCE: VARIABLE EMISSIONS DATA [a]

Use this subgroup to describe temporal variations in the emission
rates given in 16b. Factors entered multiply the rates in 16b.
Skip sources here that have constant emissions. For more elaborate
variation in source parameters, use VOLEMARB.DAT and NVL2 > 0.

IVARY determines the type of variation, and is source-specific:
(IVARY) Default: 0

- 0 = Constant
- 1 = Diurnal cycle (24 scaling factors: hours 1-24)
- 2 = Monthly cycle (12 scaling factors: months 1-12)
- 3 = Hour & Season (4 groups of 24 hourly scaling factors, where first group is DEC-JAN-FEB)
- 4 = Speed & Stab. (6 groups of 6 scaling factors, where first group is Stability Class A, and the speed classes have upper bounds (m/s) defined in Group 12
- 5 = Temperature (12 scaling factors, where temperature classes have upper bounds (C) of: 0, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 50+)

---
a
Data for each species are treated as a separate input subgroup
and therefore must end with an input group terminator.

INPUT GROUPS: 17a & 17b -- Non-gridded (discrete) receptor information
---

Subgroup (17a)

Number of non-gridded receptors (NREC) No default ! NREC = 0 !

```
!END!

---------------
Subgroup (17b)
---------------
                                                  a
           NON-GRIDDED (DISCRETE) RECEPTOR DATA
           ------------------------------------

                  X UTM       Y UTM        Ground        Height   b
Receptor       Coordinate   Coordinate    Elevation   Above Ground
  No.             (km)        (km)           (m)           (m)
--------       ----------   ----------    ---------   ------------

-------------
    a
     Data for each receptor are treated as a separate input subgroup
     and therefore must end with an input group terminator.

    b
     Receptor height above ground is optional.  If no value is entered,
     the receptor is placed on the ground.
```

APPENDIX D: CALMET WIND FIELDS DURING SELECTED HOURS OF SF_6 EXPERIMENT

LIST OF FIGURES

Page No.

APPENDIX D: CALMET WIND FIELDS DURING SELECTED HOURS OF SF_6 EXPERIMENT

Figure D.1 SF_6 – Test 1 – 13:00, April 19, 1999

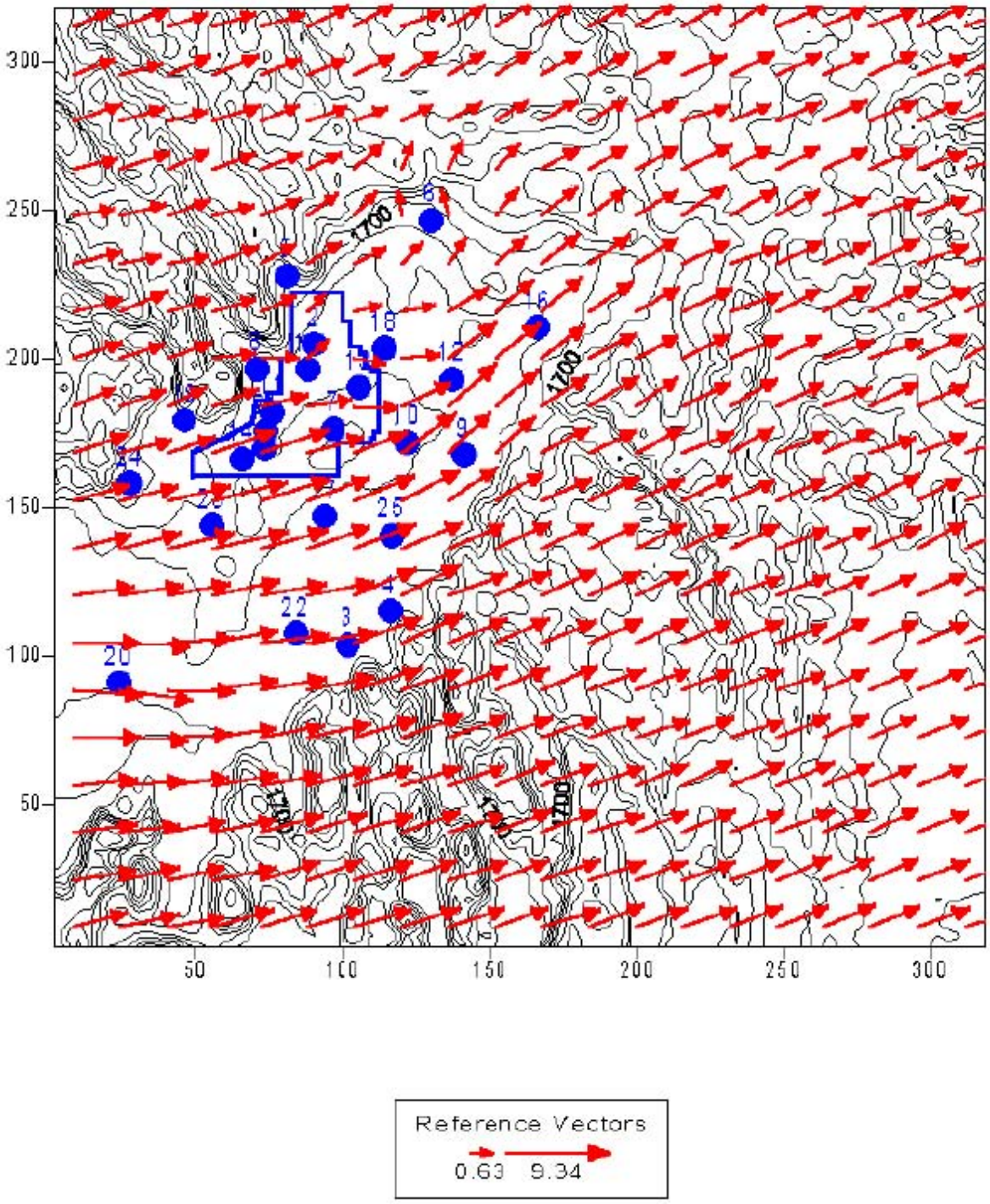


Figure D.2 SF_6 – Test 1 – 14:00, April 19, 1999

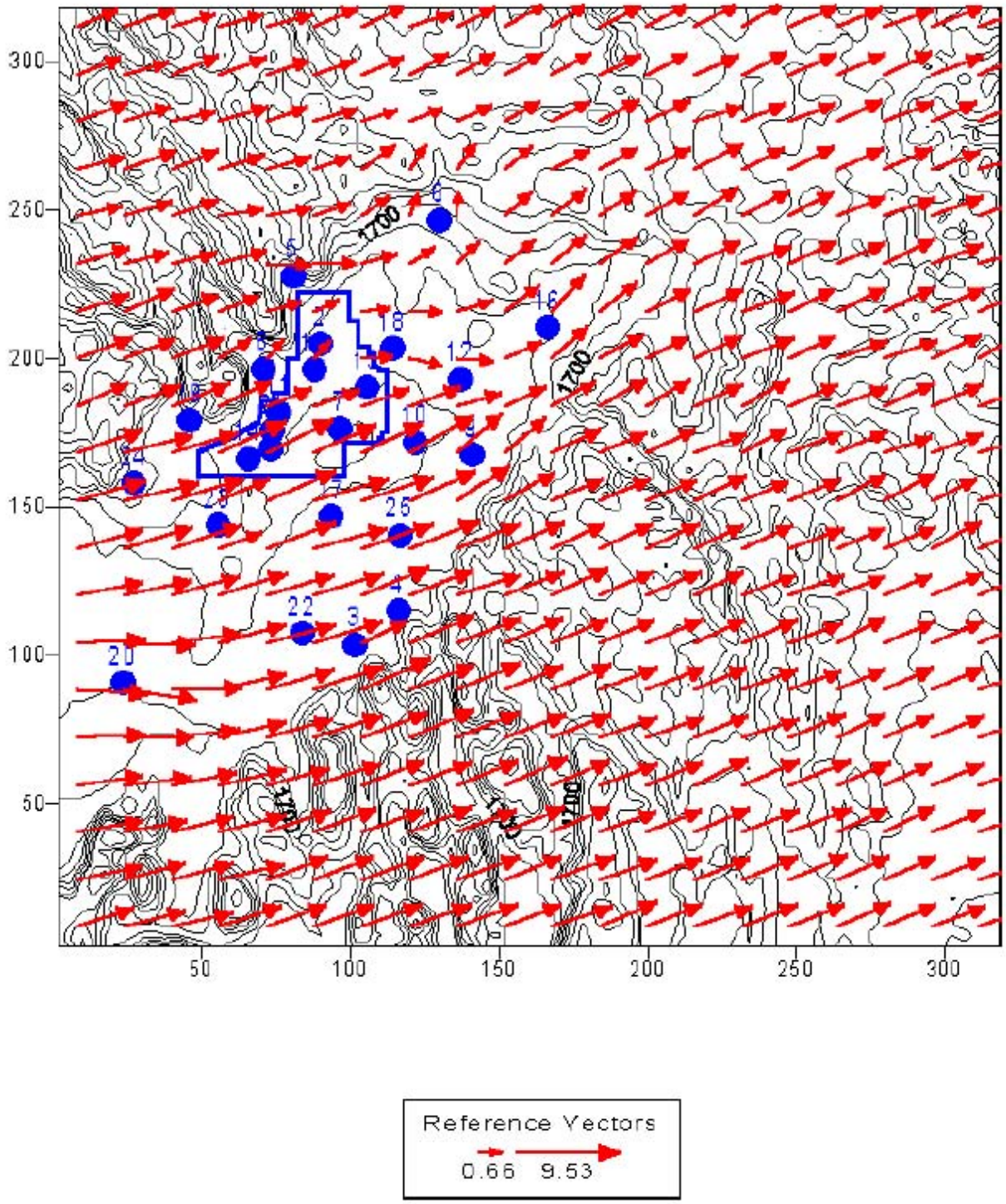


Figure D.3 SF_6 – Test 1 – 15:00, April 19, 1999

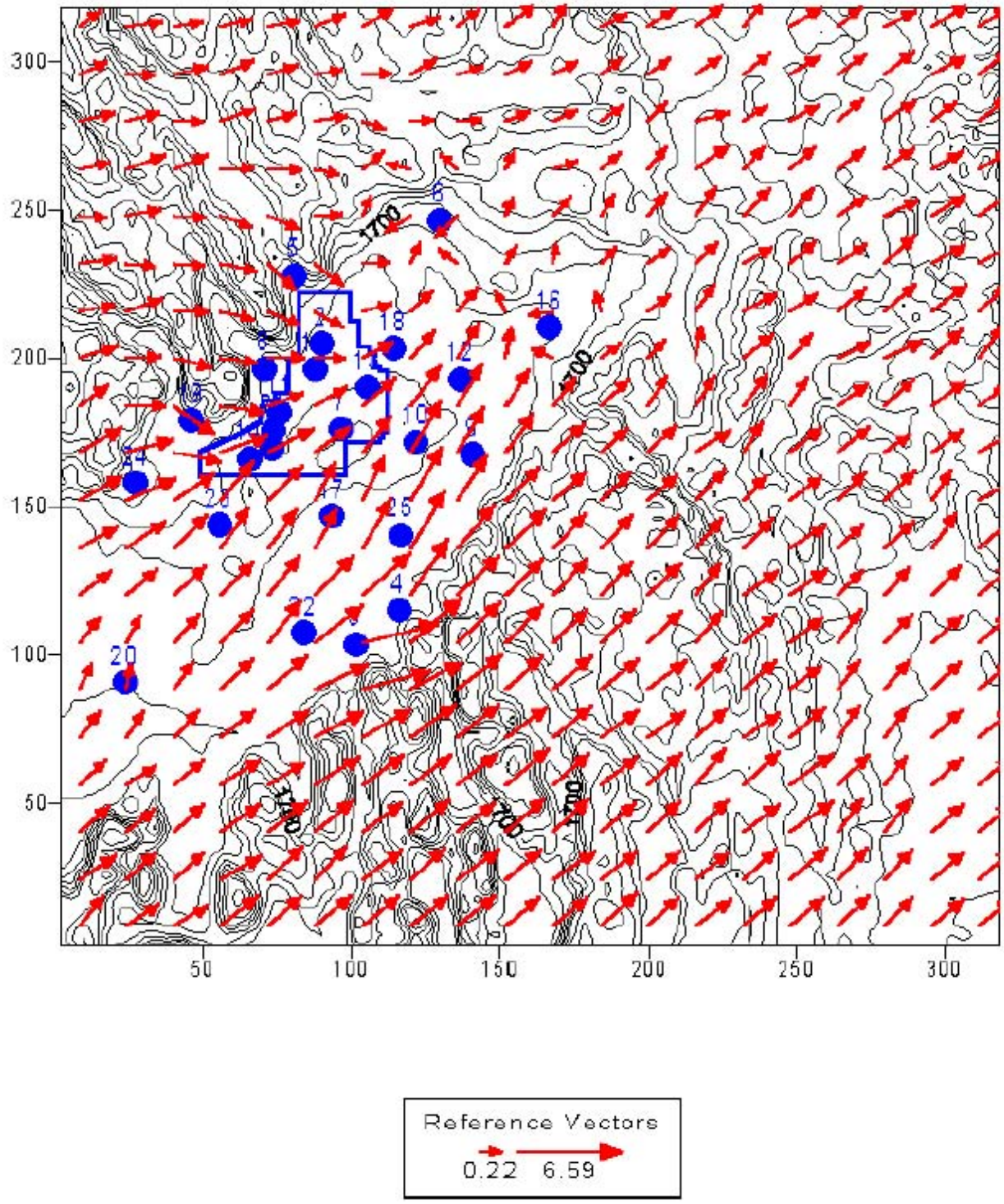


Figure D.4 SF_6 – Test 2 – 13:00, April 23, 1999

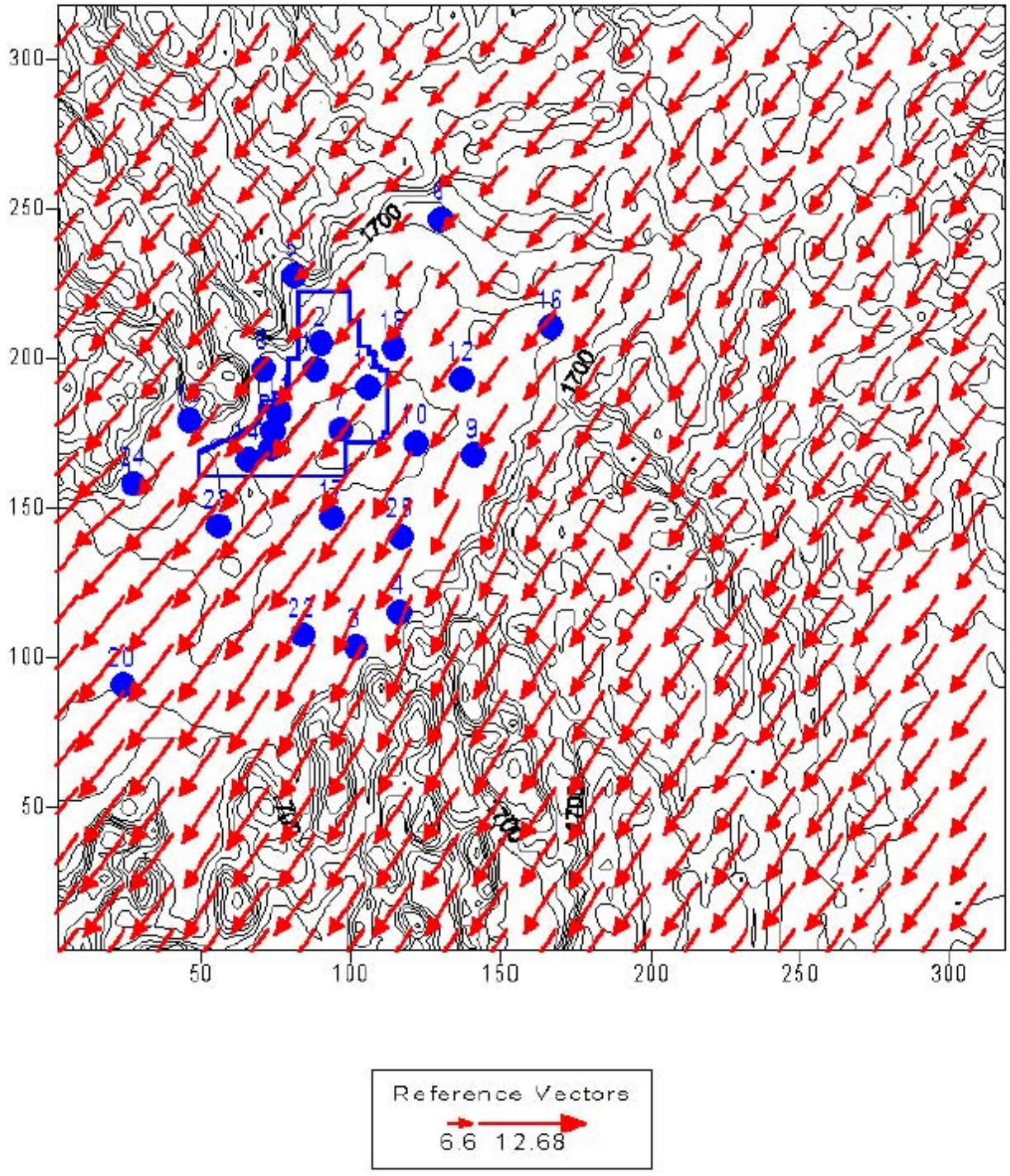


Figure D.5 SF_6 – Test 2 – 14:00, April 23, 1999

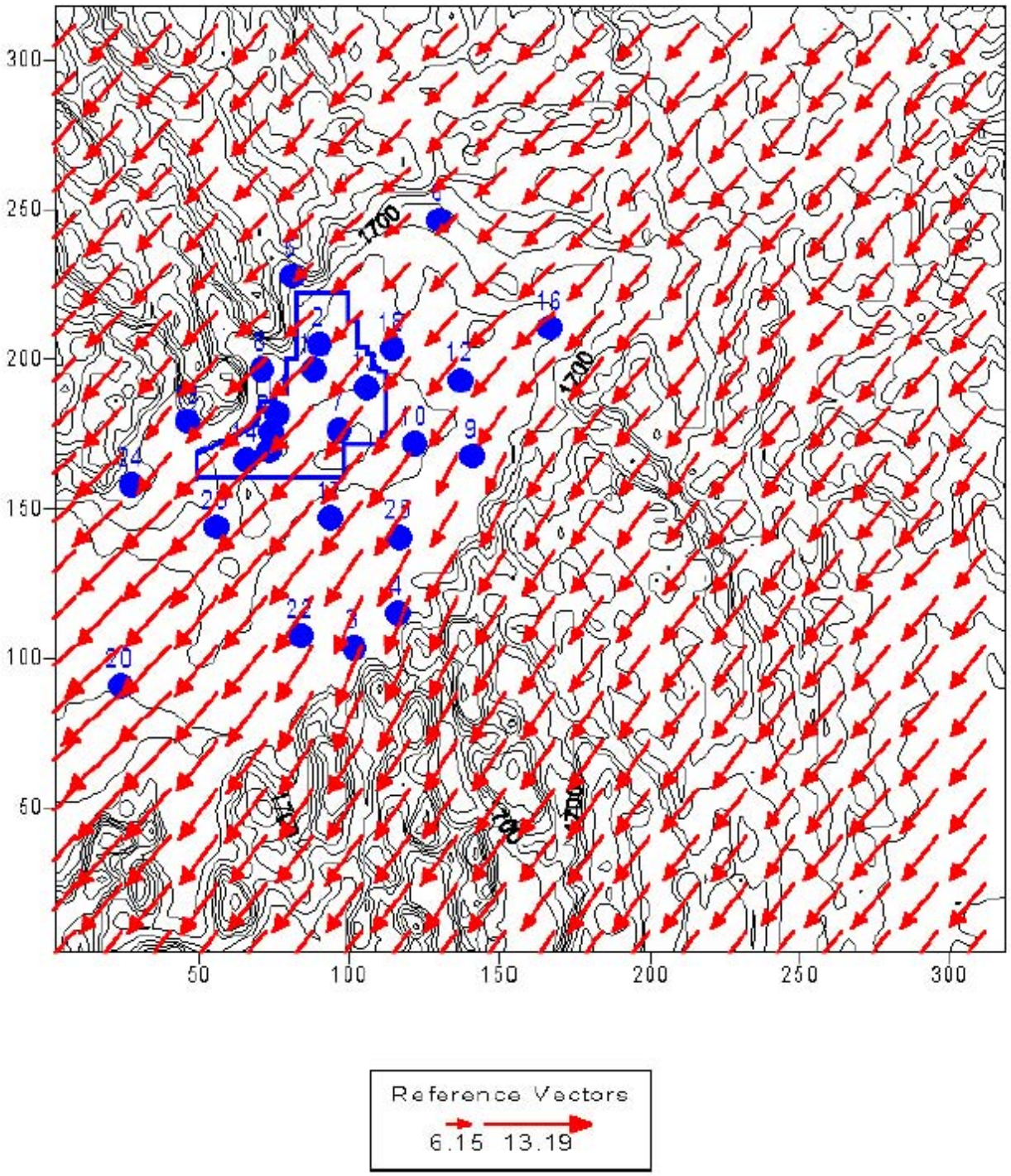


Figure D.6 SF_6 – Test 2 – 15:00, April 23, 1999

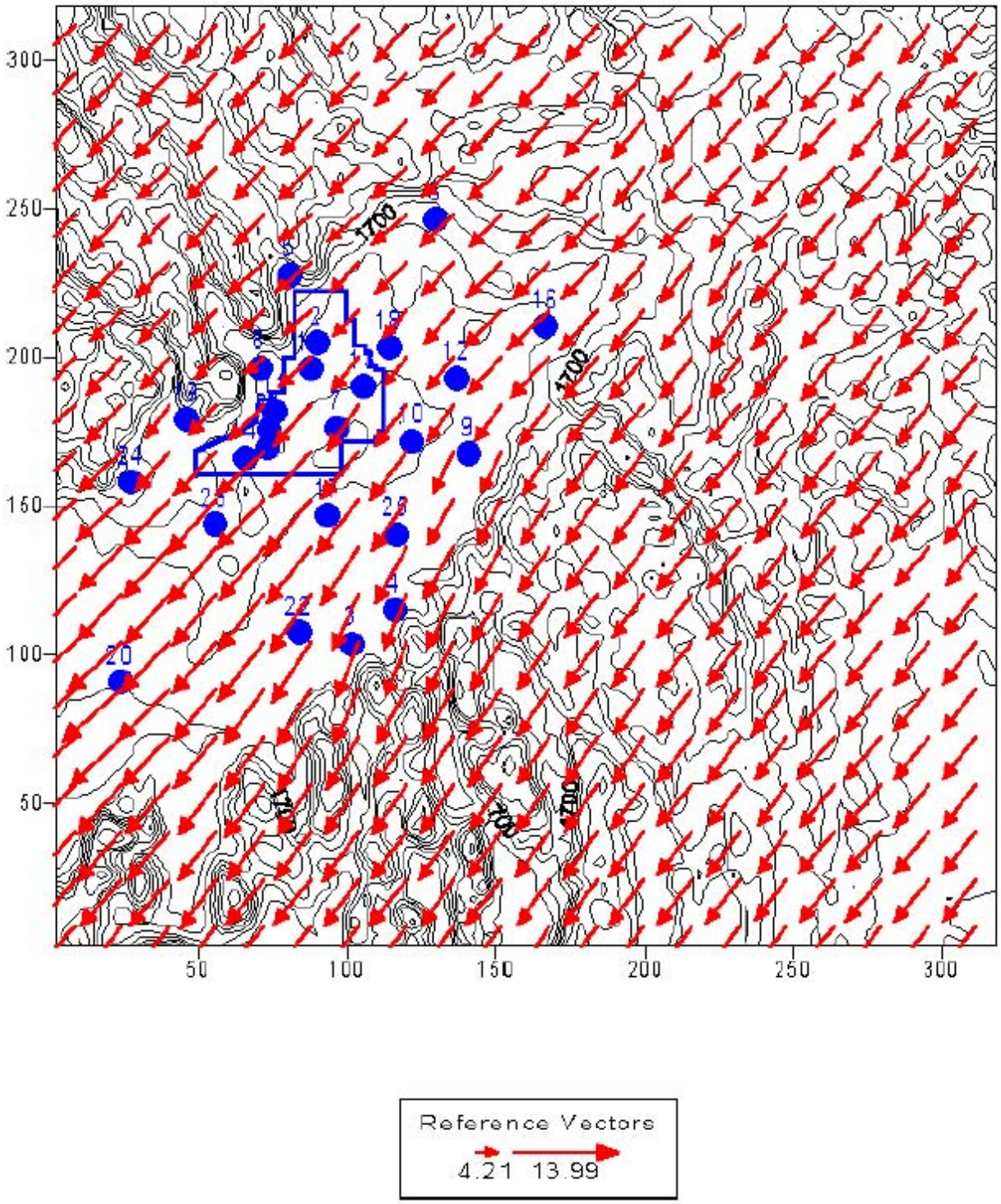


Figure D.7 SF_6 – Test 3 – 13:00, April 26, 1999

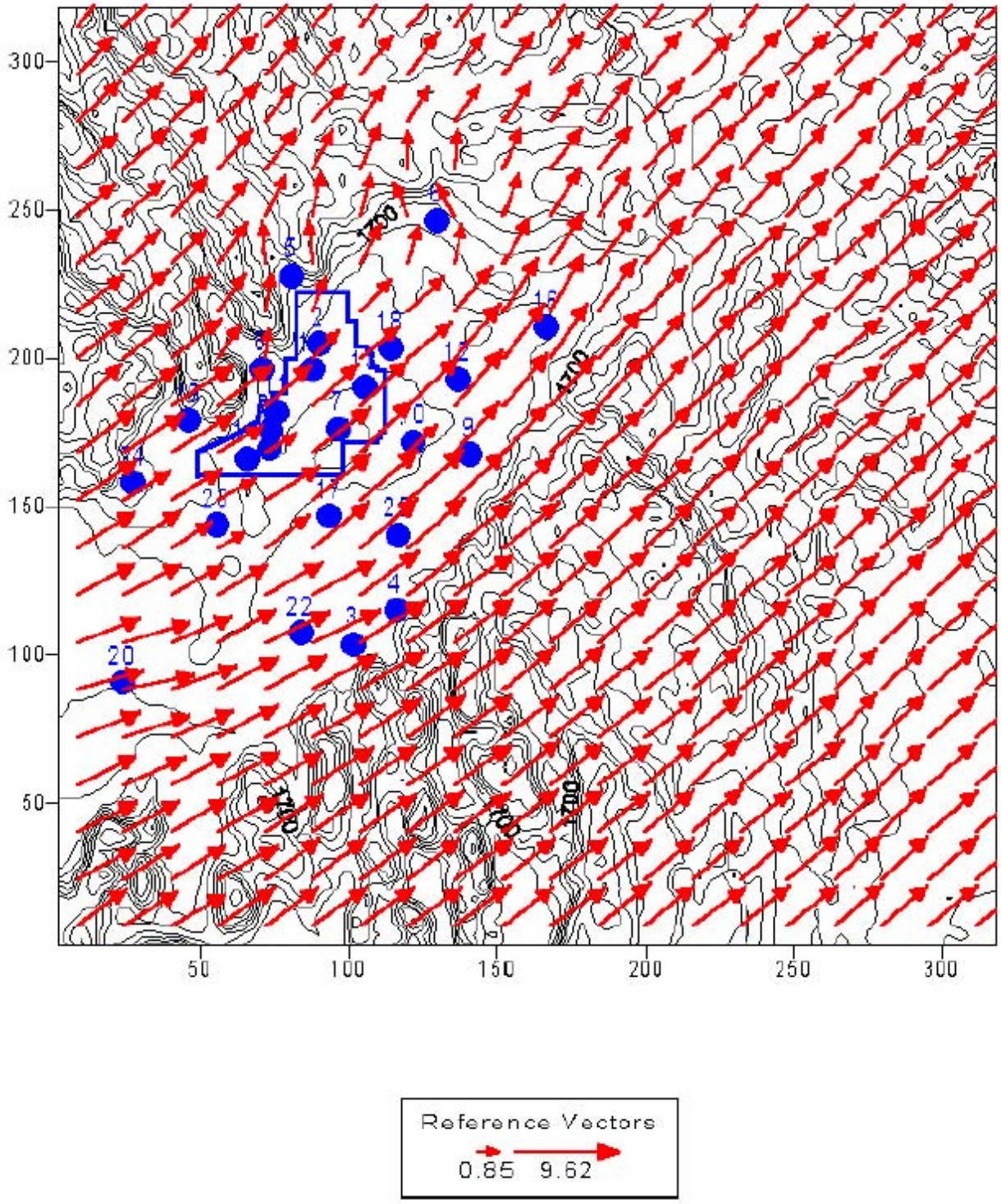


Figure D.8 SF_6 – Test 3 – 14:00, April 26, 1999

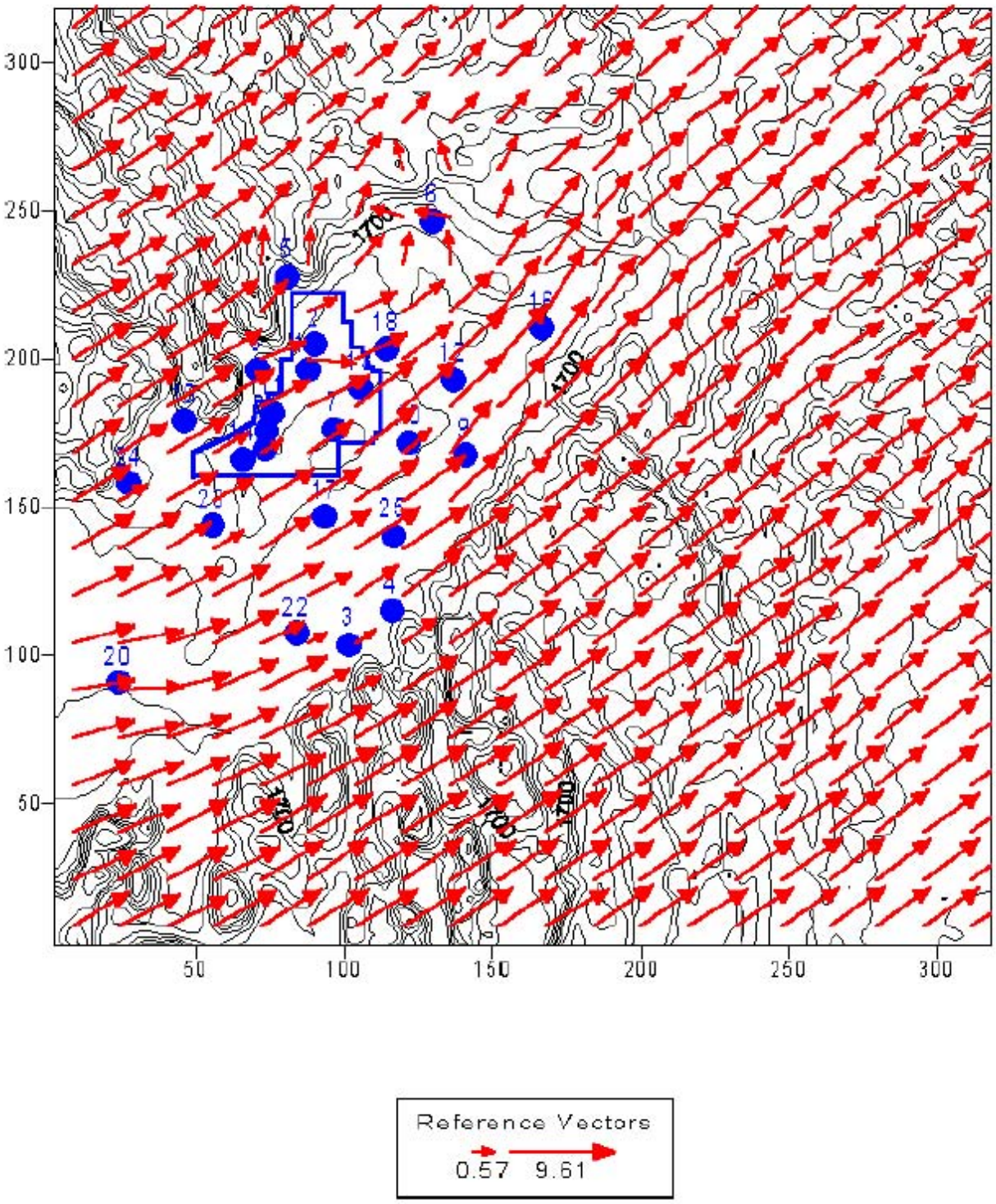


Figure D.9 SF_6 – Test 3 – 15:00, April 26, 1999

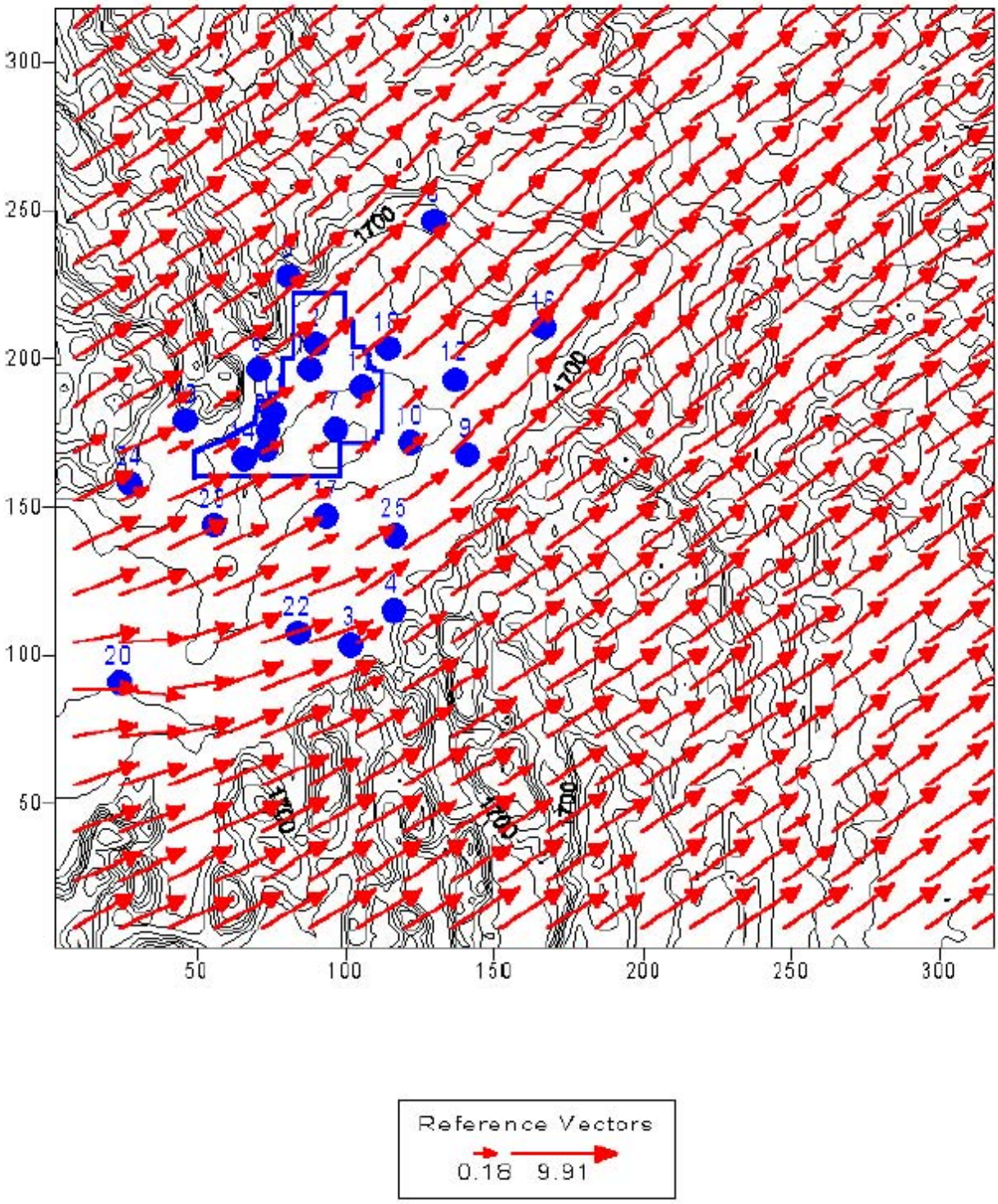


Figure D.10 SF_6 – Test 3 – 16:00, April 26, 1999

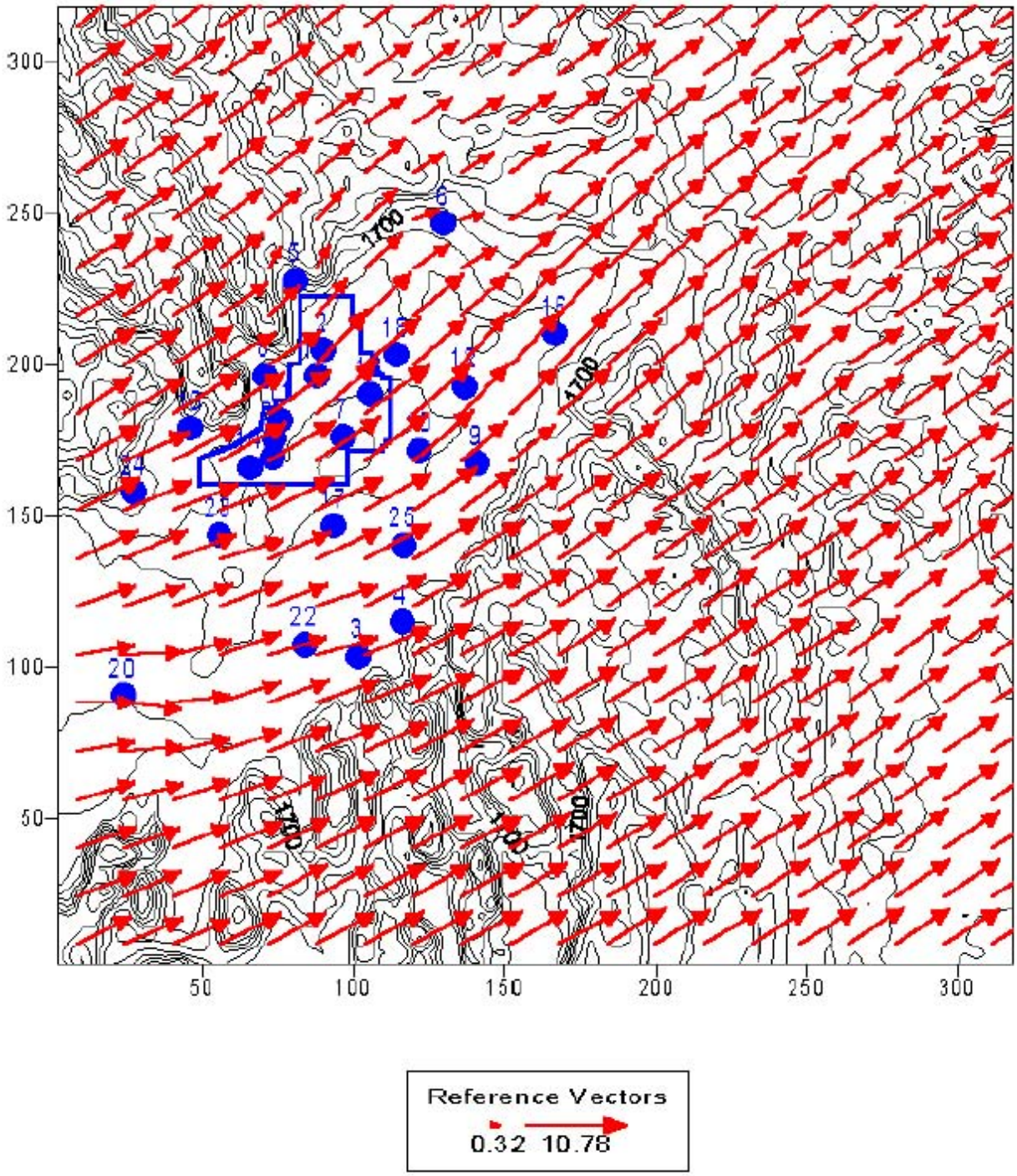


Figure D.11 SF_6 – Test 4 – 13:00, April 27, 1999

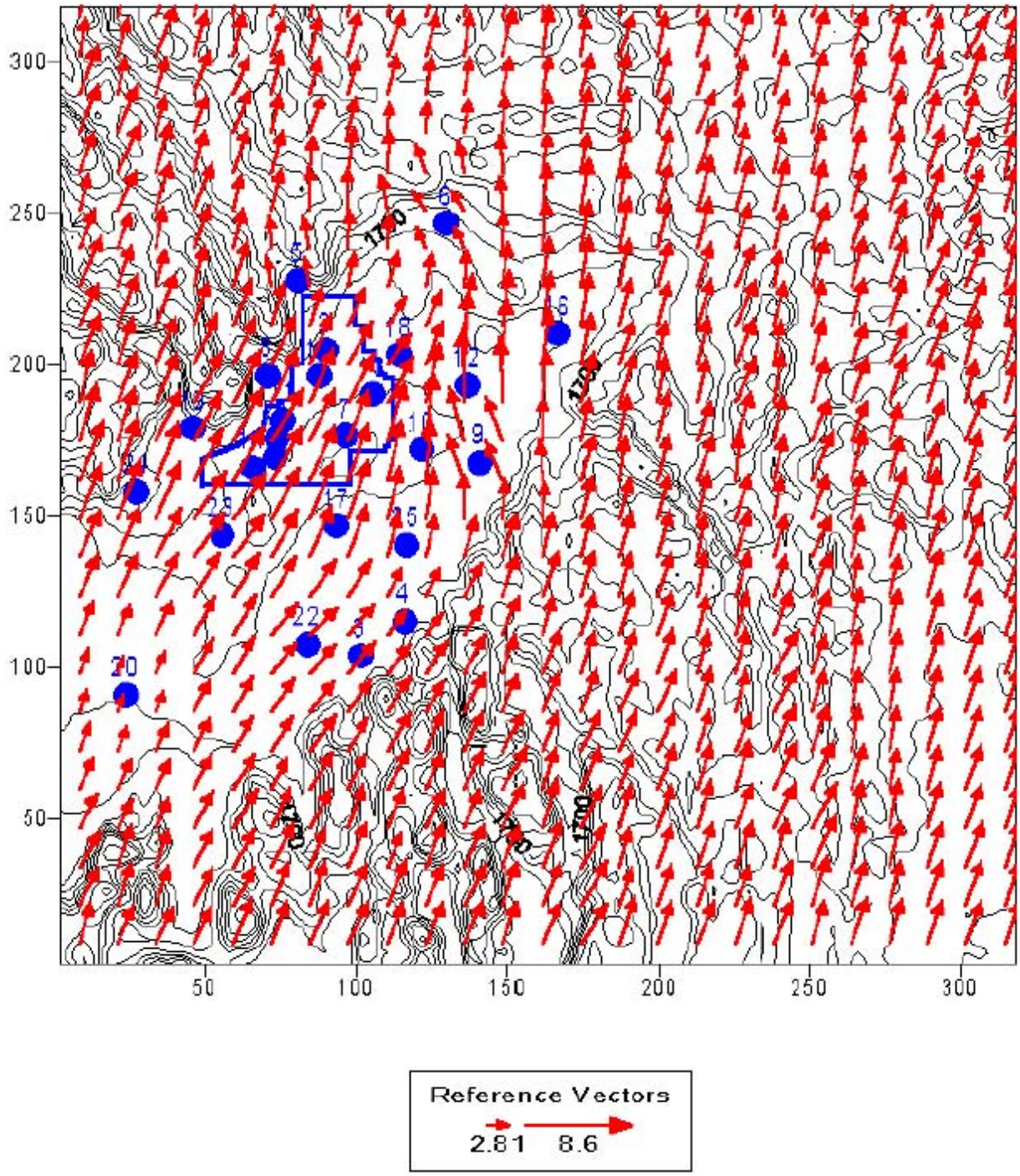


Figure D.12 SF_6 – Test 4 – 15:00, April 27, 1999

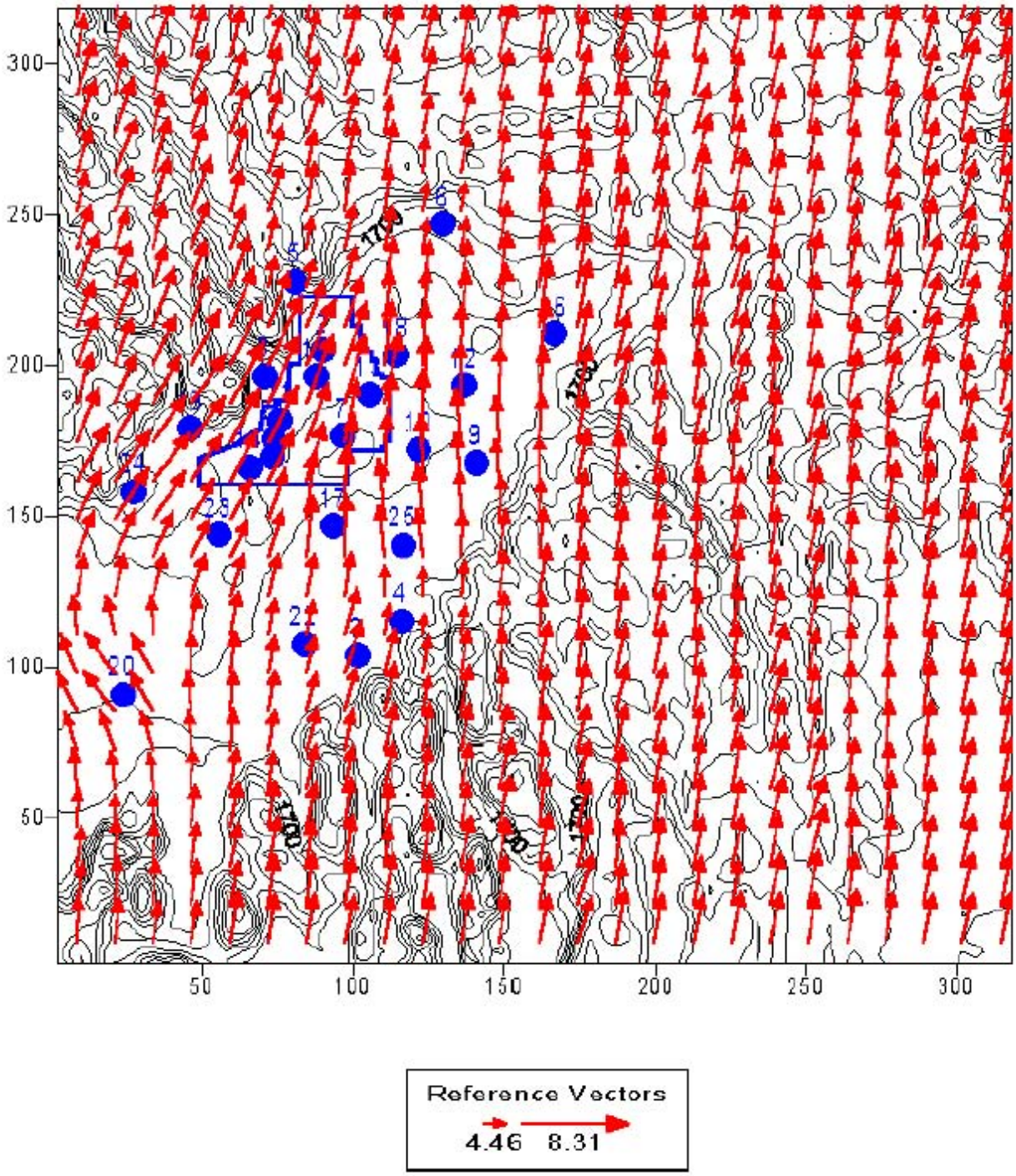


Figure D.13 SF_6 – Test 4 – 16:00, April 27, 1999

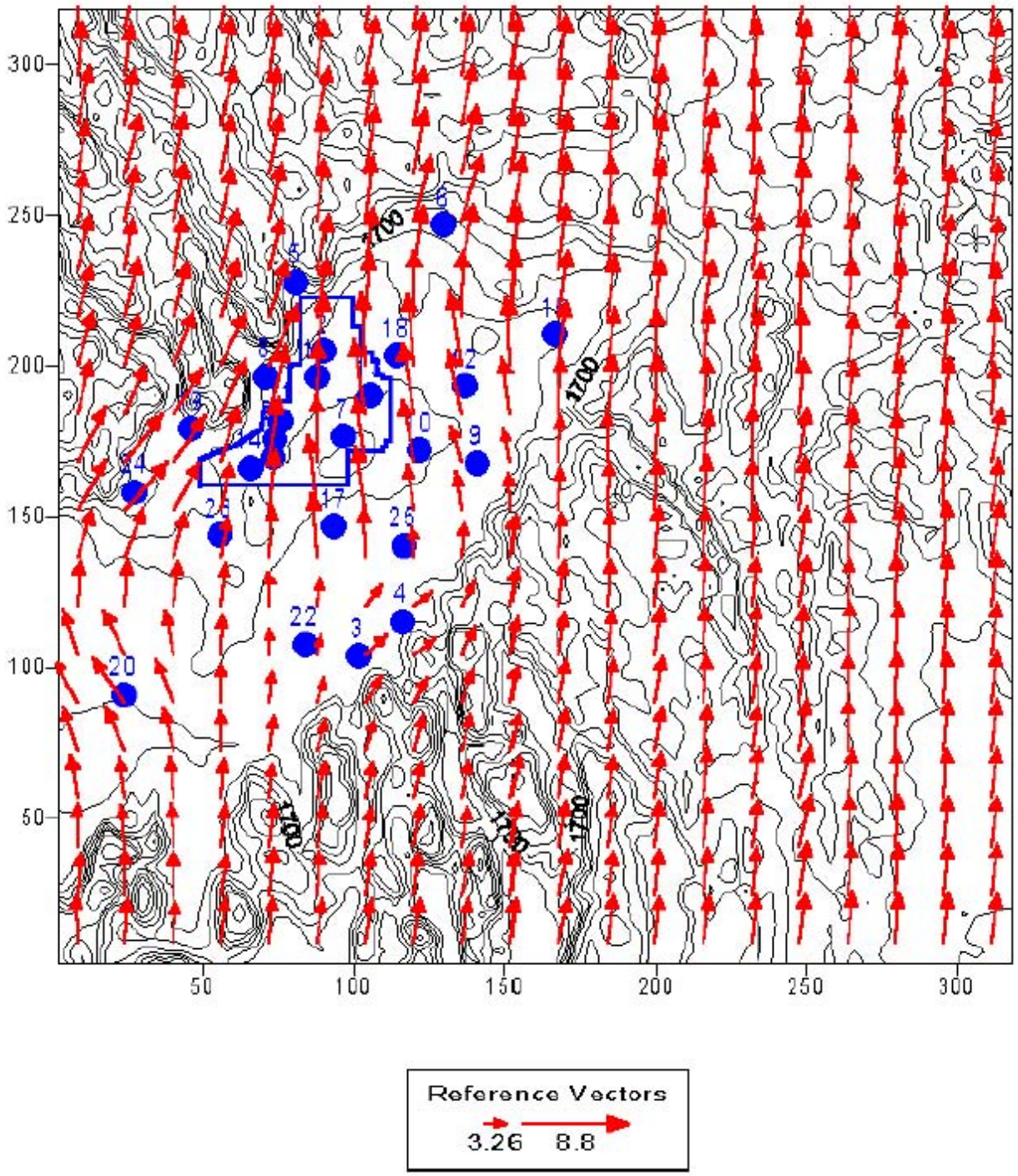


Figure D.14 SF_6 – Test 5 – 12:00, May 02, 1999

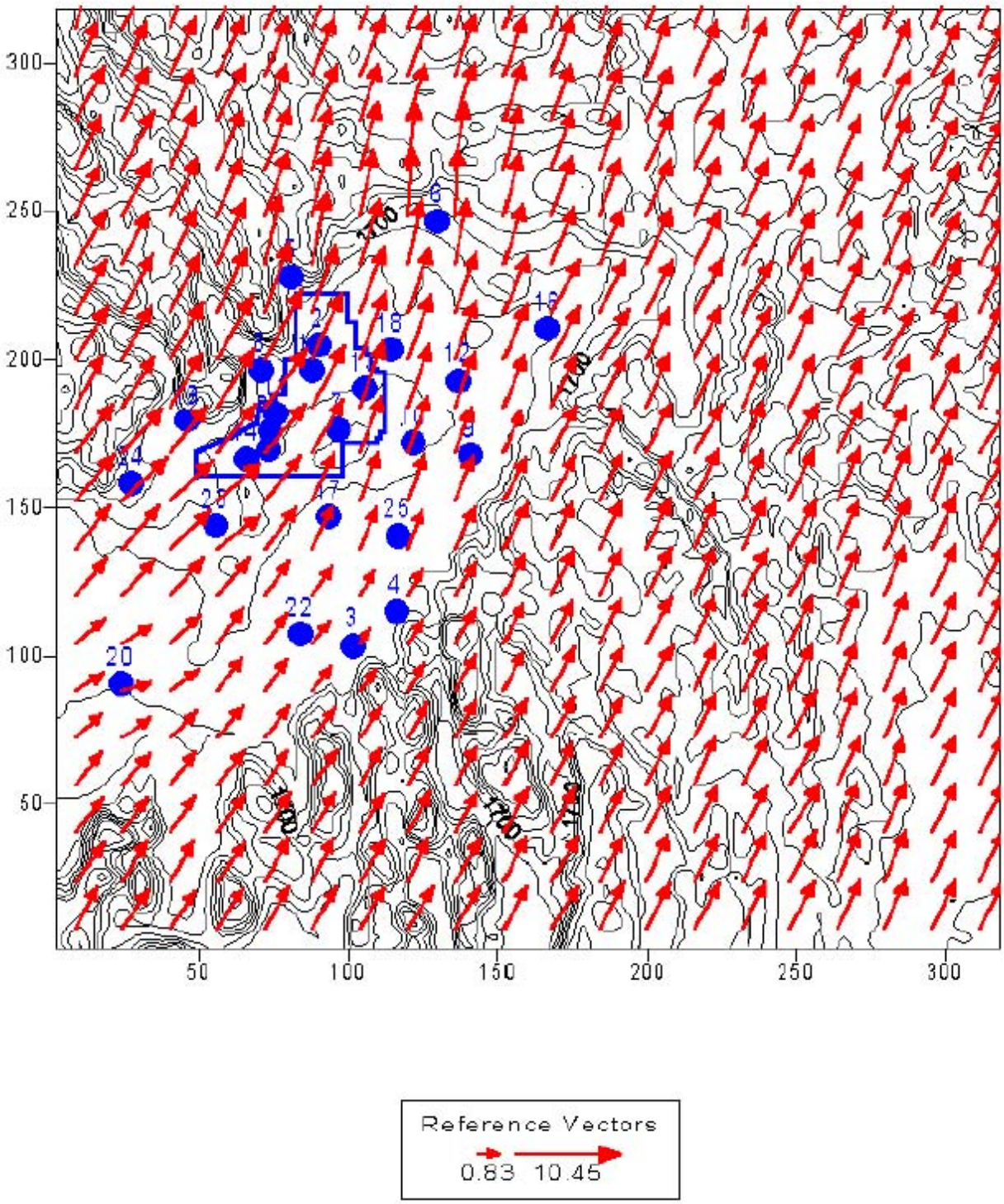


Figure D.15 SF_6 – Test 5 – 16:00, May 02, 1999

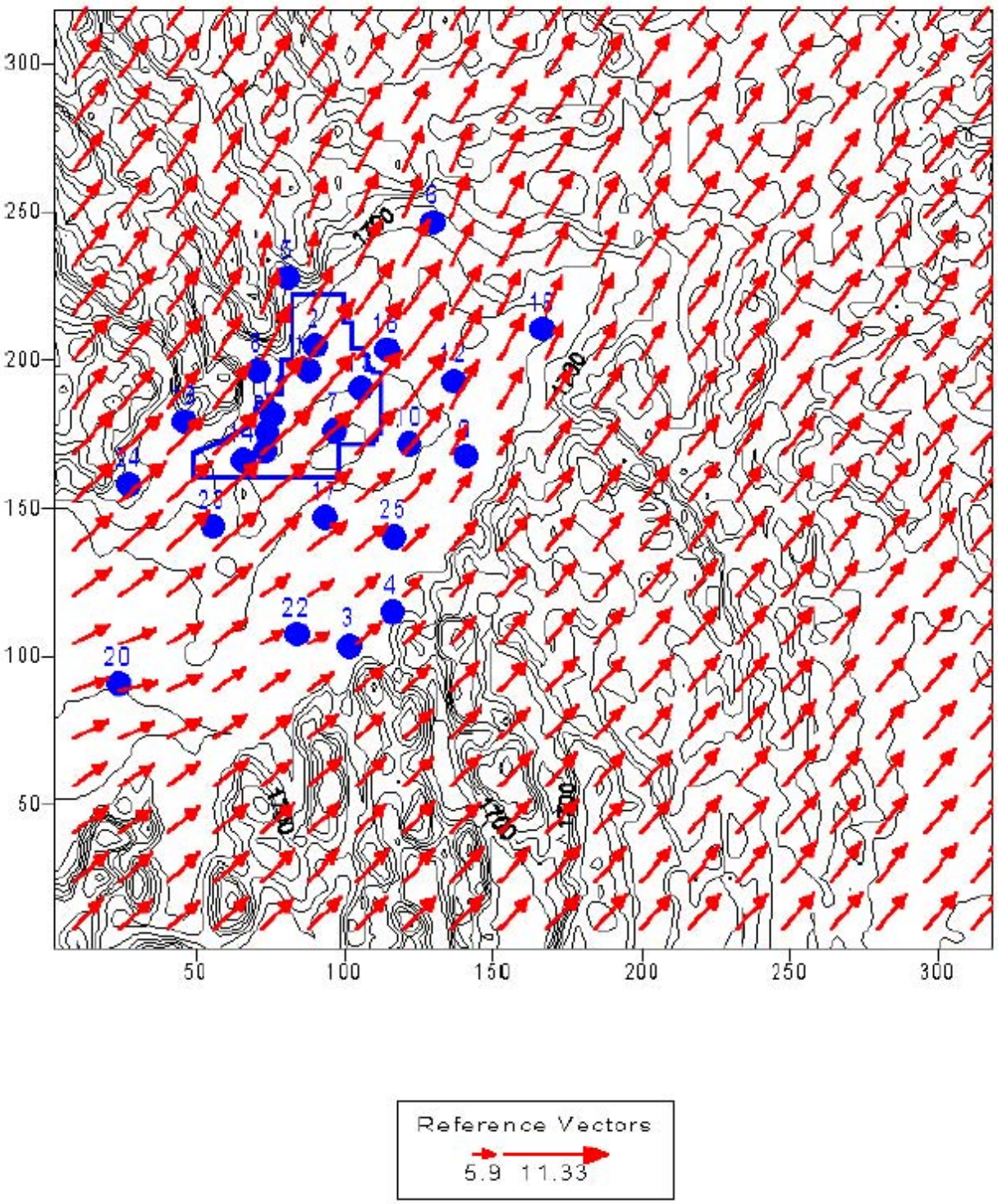


Figure D.16 SF_6 – Test 6 – 13:00, May 07, 1999

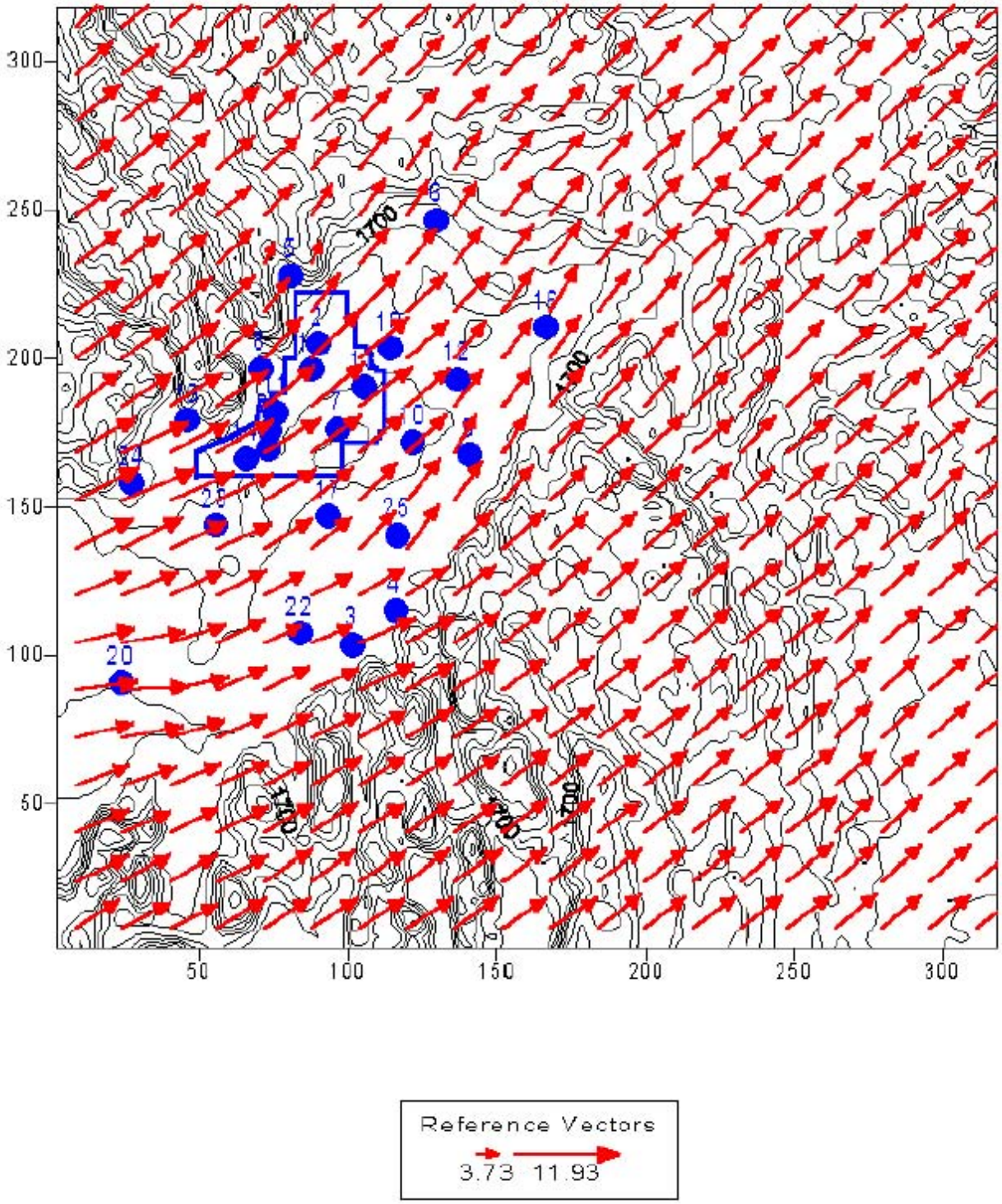


Figure D.17 SF_6 – Test 6 – 17:00, May 07, 1999

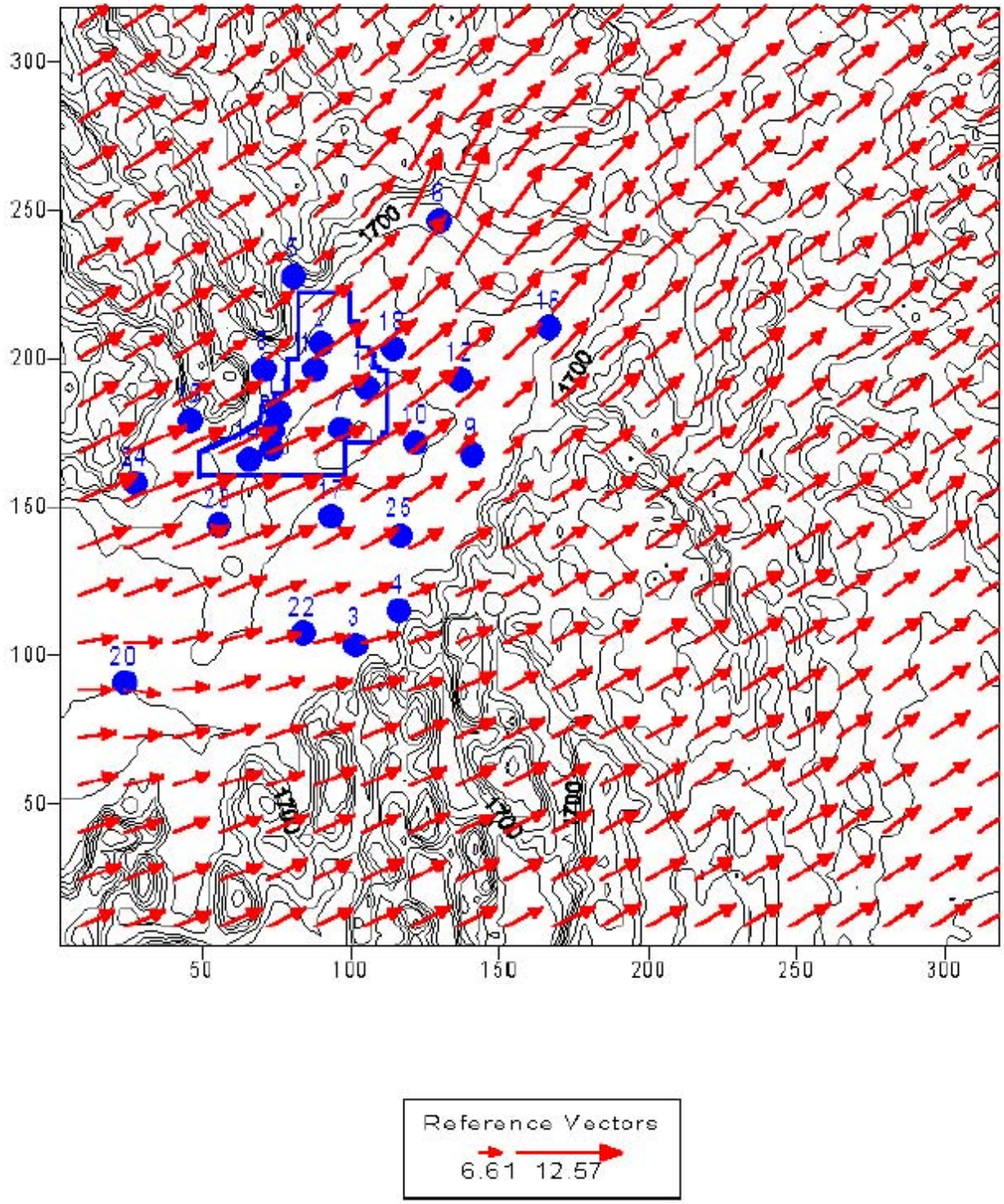


Figure D.18 SF_6 – Test 7 – 01:00, May 08, 1999