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Civilian Radioactive Waste Management System
Management & Operating Contractor

Regional and Local Wind Patterns Near Yucca Mountain

B00000000-01717-5705-00081 REV 00

November 20, 1997

Prepared for:

U.S. Department of Energy
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Under Contract Number
DE-AC01-91RW00134

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EXECUTIVE SUMMARY

Airflow within the first few hundred meters of the ground surface in valley areas in the vicinity of Yucca Mountain is channeled by local topography. The wind patterns are aligned with the local terrain valley axis, particularly at night during stable conditions. Wind patterns also have a strong diurnal cycle of daytime winds from the south and nighttime winds from the north. Directions opposite the typical diurnal cycle occasionally occur during the influence of regional scale weather systems that overpower the topographic mechanisms. Wind speeds are frequently in the 1.8 to 5.4 meters per second (m/s) range.

Nighttime conditions typically include a temperature inversion from the surface to a few tens of meters above ground level (m-agl), with further stable conditions aloft for a few hundred meters above the inversion layer. The layers aloft are frequently decoupled (separated) from each other with significantly different wind directions. The lowest layers are typically associated with downslope or downvalley "drainage" winds that tend to follow the hydrologic gradient. The nighttime stable, near-surface levels experience considerably less mixing than in the day. Moderate wind speeds partially offset the thermally stable conditions, resulting in better dispersion than might occur during lesser wind speeds. Nighttime airflow from Midway Valley is typically through Jackass Flats and into Amargosa Valley. Southerly airflow occasionally occurs near the surface during the influence of strong regional scale weather systems. Southerly winds also occur aloft above the stable northerly downvalley airflow layers.

Unstable atmospheric stability conditions typically prevail during daytime hours. Strong vertical mixing occurs during unstable conditions, which tends to cause winds above the surface to be similar to the winds near the surface. Thus, the first few hundred meters above ground level are well mixed, and the transport direction is usually toward the north. When daytime winds are from the north with transport toward the south, the atmosphere usually has neutral stability, frequently with large wind speeds, resulting in good atmospheric dispersion conditions.

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1. INTRODUCTION

Regional and local airflow patterns and atmospheric dispersion characteristics relevant to Yucca Mountain Site Characterization Office (YMSCO) environmental impact studies are described in this report. Preclosure radiological safety assessments include estimating impacts due to potential releases of airborne radioactive material related to repository operations. The airflow pattern and dispersion characteristics identified in this report support the impact analyses.

The information in this report complements descriptions of meteorological conditions in the local Yucca Mountain vicinity given in annual summary reports on results from the network of nine stations operated by the Management and Operating Contractor (M&O) Radiological/ Environmental Field Programs Department (R/EFPD) (CRWMS M&O 1993a; 1993b; 1995c; 1995d; and 1996a). Another complementary report is the *Engineering Design Climatology and Regional Meteorological Conditions Report* (CRWMS M&O 1997a), which addresses site-specific and regional general meteorological conditions. That report contained climatological descriptions and estimates of certain design values of extreme wind and precipitation events that might occur.

Remaining portions of this section include information on background of the study, purpose and objectives, and the technical approach. Further report sections include information on data sources, local and regional airflow patterns, and conclusions.

1.1 BACKGROUND

The need to characterize local and regional airflow was recognized during planning for Yucca Mountain site characterization. Regional and local airflow topics were discussed in Section 5 of the *Site Characterization Plan* (DOE 1988) and Study Plan 8.3.1.12.2.1 covering the site-specific meteorological monitoring program operated to characterize atmospheric dispersion and general meteorology. The complexity of the mountainous terrain in the vicinity of Yucca Mountain is widely recognized to play a significant role in controlling local and regional airflow. This topic is addressed throughout this report.

The plan for the Meteorology Program in the Site Characterization Plan (SCP) Section 8.3.1.12 originally had four separate investigations. One investigation, 8.3.1.12.2, covered the operation of the nine (originally five) meteorological stations. The other three investigations were related to descriptions and analyses of regional meteorological conditions, 8.3.1.12.1, 8.3.1.12.3 and 8.3.1.12.4. Rather than separately manage three related regional meteorology studies, work on the three regional meteorology investigations were combined into a single planning document, the *Scientific Investigation Implementation Package* (SIIP) *for Regional Meteorology* (CRWMS M&O 1995b). The SIIP organized the work into the following three primary areas: atmospheric dispersion, engineering design, and general regional meteorology, with each of the three work areas being reported separately. The engineering design and regional meteorology reports were combined into the single report mentioned above (CRWMS M&O 1997a). This airflow report addresses atmospheric dispersion and regional scale airflow patterns relative to population centers.

1.2 PURPOSE AND OBJECTIVES

The purpose of this report is to characterize atmospheric dispersion and airflow patterns in the vicinity of the proposed Yucca Mountain geologic repository for high-level radioactive waste. The atmospheric dispersion and airflow pattern characteristics are a fundamental step in assessing impacts of potential releases of airborne radioactive material. The specific purpose of this report is to provide the dispersion and airflow characteristics described in Task 2 of the SIIP for Regional Meteorology (CRWMS M&O 1995b). This report does not attempt to repeat the wind characteristics information presented in Section 5 of the SCP (DOE 1988) nor in the original in-depth report on the area (Eglinton and Dreicer 1984). The objectives of this report are to:

- Describe local atmospheric dispersion characteristics.
- Identify regional airflow patterns relative to local population centers.

The scope of this study includes analyses of meteorological data taken by the Yucca Mountain Project R/EFPD, data taken at the Nevada Test Site (NTS), and the National Weather Service data.

1.3 TECHNICAL APPROACH

The known potential sources of regional data were summarized in the *Meteorological Data Synthesis Status Report* (CRWMS M&O 1996b). Some of these sources were chosen for the airflow analysis based on data availability and probable usefulness in meeting the objectives of the study. Literature sources on airflow and dispersion in complex terrain were studied, and are cited in discussions in this report. In addition, some special airflow studies were performed on and near Yucca Mountain.

The data were summarized and analyses were performed. Wind speed and direction joint-frequency distributions were created for lengthy periods. The distributions were plotted as wind rose figures to facilitate analyses. The results are provided and discussed in Sections 3 and 4.

The geographic scope of the study was approached in two steps. Detailed data were sought from nearby stations within 80 kilometers (km) of Yucca Mountain. These stations were the most likely to be utilized as representative of the Yucca Mountain area. Wind data from these sites may be used in providing impact assessment or design information for portions of Nevada that may be involved in the transportation of radioactive waste material through Nevada.

1.4 TERMINOLOGY

Descriptions of local and regional airflow patterns and atmospheric dispersion characteristics involve the use of meteorological terms and diagrams that may be unfamiliar to some readers of this report. For example, some of the wind and topographic directions discussed in this section are abbreviated, such as north-northeast becomes NNE. Therefore, information is provided in this section to assist the reader in understanding the terminology and information presentation tools used.

Of the numerous references available on the subjects, the reader seeking further information on select topics is referred to the literature sources listed in Table 1-1 as starting points. Also, discussions of wind patterns and weather systems involve distance and motion sizes, or scales. Table 1-2 defines the terms used to describe terms relevant to the airflow topic; these meteorological terms are based on definitions in a popular glossary (AMS 1996).

Table 1-1. Selected Meteorological References by Topic

Topic	Reference
Basic Meteorology	Lutgens and Tarbuck (1995) AMS (1996)
Mountain Meteorology	Barry (1981) Blumen (1990)
Great Basin Climate and Meteorology	Hidy and Klieforth (1990) Houghton, Sakamoto, and Gifford (1975)

Wind rose plots are used extensively in this report as graphic presentations of joint wind speed and direction frequency distributions. Figure 1-1 is a sample wind rose which is intended to support the following figure explanation. The wind rose figure resembles the spokes of a wheel; each spoke corresponds to one of the 16 wind direction categories. Each direction category encompasses 22.5 degrees, and is centered on a cardinal direction (N, NNE, etc.). For example, the east category represents winds from the directions 78.75 degrees through 101.25 degrees, or 11.25 degrees either side of 90 degrees. The length of the line on a direction in the figure is proportional to the frequency of occurrence of winds from the corresponding direction. The concentric circles in the figure (not the sample) represent increments of 5 percent frequency of occurrence values. The number of circles in a particular figure is determined by the maximum frequency of occurrence in a given plot, to keep the data contained within a page while optimizing the visual resolution in the figure. If the winds were evenly distributed, each category would be represented by 6.25 percent of the hours.

The direction lines are divided into segments, corresponding to the frequency of occurrence of winds with speeds in six categories. The six speed categories correspond to the following typical climatological summary ranges (all in meters per second, m/s): 0 to less than 1.8, 1.8 to less than 3.3, 3.3 to less than 5.4, 5.4 to less than 8.5, 8.5 to 11.0, and greater than 11.0.

1.5 POPULATION CENTERS

The population centers near Yucca Mountain have been identified by socioeconomic data analyses performed in support of the radiological monitoring program (CRWMS M&O 1997b). The most recent annual report identified resident and daytime populations, and agricultural use of some land areas. The results were presented based on the grid used in radiological analyses. The grid has 16 arc sectors structured the same as the sectors used in the wind joint-frequency distributions; each sector has 10 eight-kilometer length segments, starting from a four-kilometer radius in the center. The grid is centered on the Zone 11 Universal Transverse Mercator coordinates easting 551135.7 meters, and northing 4078351.6 meters.

Table 1-2. Definition of Selected Meteorological Terms for this Report

Term	Definition
Boundary Layer	The atmospheric layer from the earth's surface up to an altitude of a few hundred meters, in which wind characteristics are strongly influenced by surface topography.
Local	The area in the immediate vicinity of Yucca Mountain, extending toward the east through Jackass Flats, and toward the south into Amargosa Valley.
Mesoscale	The dimensions of the atmosphere from a few to a few tens of kilometers horizontally, and vertically up to at least one kilometer above ground level.
Microscale	The dimensions of the atmosphere up to a few kilometers horizontally, and about 100 meters above ground level (m-agl) or more when topography is influencing the surface boundary layer.
Regional	The area within about 100 kilometers of Yucca Mountain, including the Las Vegas metropolitan area.
Season	Winter: December, January and February Spring: March, April and May Summer: June, July and August Fall: September, October and November.
Slope Winds (upslope and downslope)	The winds generated by density differences between the air near elevated terrain and the air at a horizontal distance over lower terrain; downslope winds, also known as drainage winds, occur at night from surface cooling, and flow generally down the terrain slope; upslope winds occur in daytime from surface heating, and flow generally up the terrain slope.
SODAR	An acronym (Sound Detection And Ranging) describing an acoustic Doppler sounder, records wind and turbulence information aloft measured by acoustic sounding method with analysis of Doppler shift in return signals.
Synoptic Scale	An area larger than tens of kilometers up to continental and ocean scales; it is used to describe large-scale weather systems that affect multi-state areas in the western United States.
Tethersonde®	A tethered balloon with wind and temperature sensors attached to the tether line; the sensors have radio telemetry to a ground station which continuously displays and records the data.
Valley Winds (upvalley and downvalley)	The larger scale winds related to slope winds that tend to follow the axis of a valley rather than a local terrain slope; upvalley winds flow toward higher terrain, and downvalley winds flow toward lower terrain.
Wind Rose	A circular plot graphic portrayals of joint wind speed and wind direction frequency distribution data.

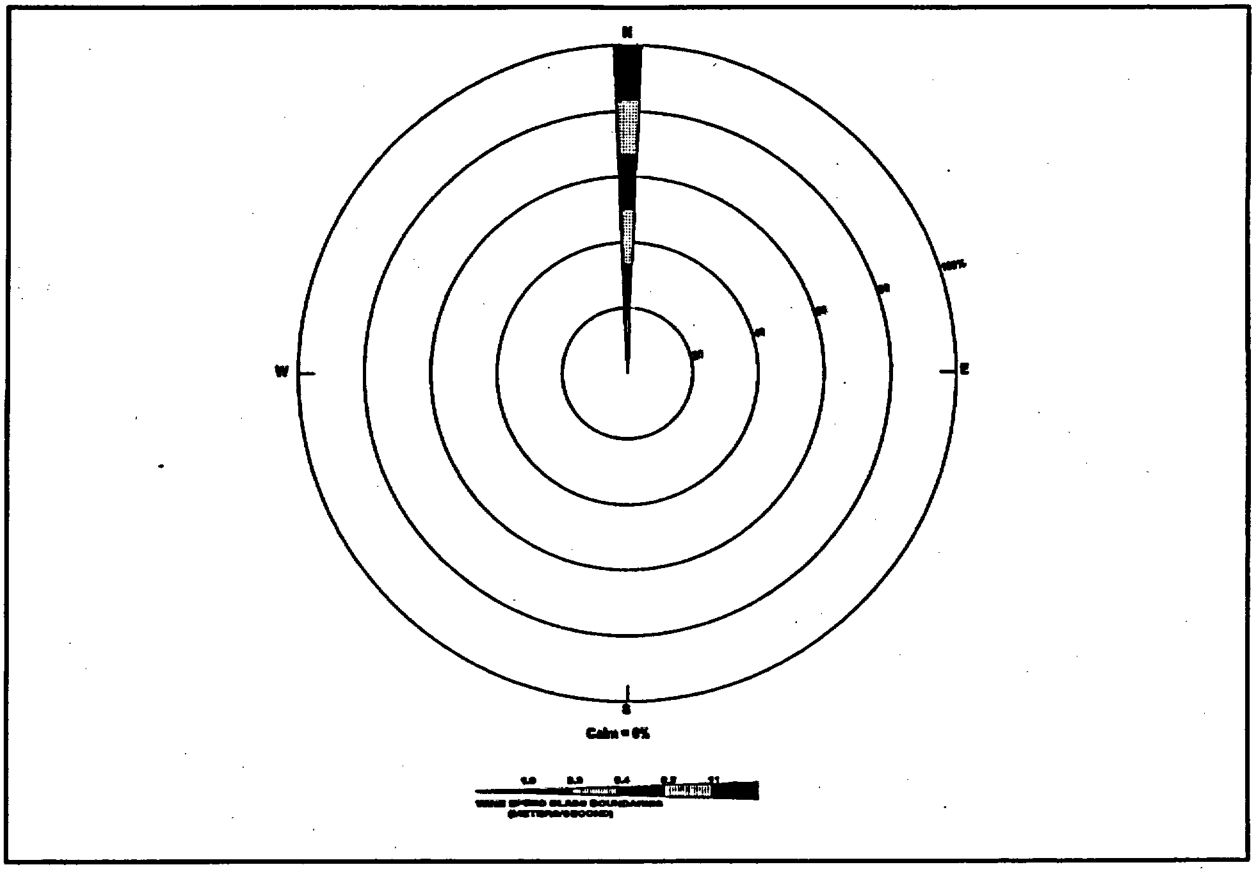

Figure 1-1. Sample Wind Rose

The population data show a few communities near Yucca Mountain with population greater than 1,000 residents that are identified for purposes of this report as "population centers." These populated areas are identified in Figure 1-2. Location of these areas are described relative to Yucca Mountain using the 10 distance sectors in each of the 16 compass directions used in the geographic grid in the population study cited above.

- Amargosa Valley is a large area of mixed residential and agricultural uses with less than 1,300 residents, extending from 20 km to 44 km in the SSE to SSW sectors.
- Beatty has approximately 1,800 residents in two grid cells, approximately 18 kilometers (km) WNW.
- Indian Springs has less than 1,500 residents in two grid cells approximately 80 km ESE.
- Pahrump has approximately 12,700 residents approximately 80 km SSE.

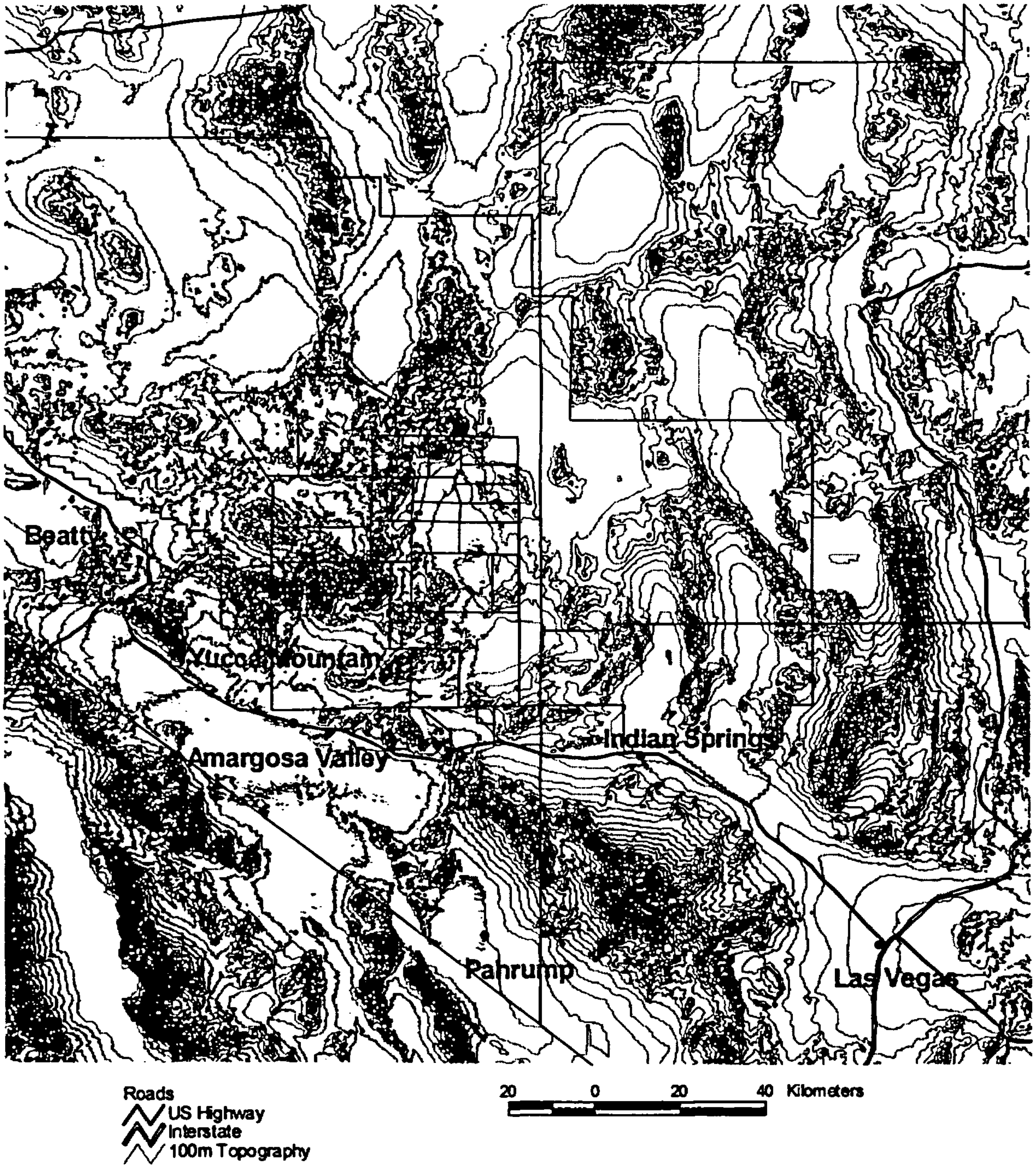

Figure 1-2. Location of Population Centers

2. METEOROLOGICAL DATA SOURCES

The sources of local and regional meteorological data used in this report are identified in this section. These sources reflect the intent to focus on information that has become available since the climate descriptions were written for Section 5 of the SCP. Information on most of the data sources can be found in the *Meteorological Data Synthesis Status Report* (CRWMS M&O 1996b).

2.1 YUCCA MOUNTAIN SITE CHARACTERIZATION OFFICE: RADIOLOGICAL AND ENVIRONMENTAL FIELD PROGRAMS DEPARTMENT

The R/EFPD network of nine meteorological stations is the primary source of site-specific meteorological and climatic data from the immediate vicinity of the Yucca Mountain. These data are required for various purposes (DOE 1988, SCP Subsection 8.3.1.12) including providing meteorological input data for atmospheric dispersion modeling.

The original network of five stations was established as an environmental monitoring network in December 1985. The network was expanded to nine stations during 1992 to improve airflow characterization in and around Midway Valley and the nearest populated area in the community of Amargosa Valley. The network site locations were chosen to provide meteorological data from a range of topographic exposures in and near the proposed locations of surface facilities in Midway Valley, and along the airflow pathway from Midway Valley toward the south into Amargosa Valley. The atmospheric dispersion modeling activities within the Yucca Mountain Project have only recently been initiated, so no specific comparison on adequacy of site locations to provide model input data was possible when the site locations were being chosen.

The meteorological measurements were chosen conform with regulatory guidance on meteorological data input for atmospheric dispersion modeling, and other general meteorological monitoring purposes. The measurements were modified during 1993 to comply with changes in the monitoring guidance. The locations of the nine stations in the R/EFPD network are identified in Figure 2-1 and Table 2-1. The relevant measurements and data summaries for the airflow characterization are:

- Horizontal wind speed and direction were measured at 10 meters above ground level (m-agl) using sensitive cup anemometers and wind vanes. Wind measurements are also measured at the 60 m-agl level at Site 1.

- Air temperature, and the temperature difference between 2 m-agl and 10 m-agl, have been measured in mechanically aspired shields since September 1993. Prior to then, air temperature was measured at 10 m-agl in naturally aspirated shields. The temperature difference between 10 m-agl and 60 m-agl has always been made at Site 1.

- Onsite data processing at the R/EFPD stations has always included one-second samples being averaged for one-hour periods. Beginning in September 1993, maximum three-second average wind speeds and maximum one-minute wind speed with corresponding wind direction were also recorded, and ten-minute averages were added.

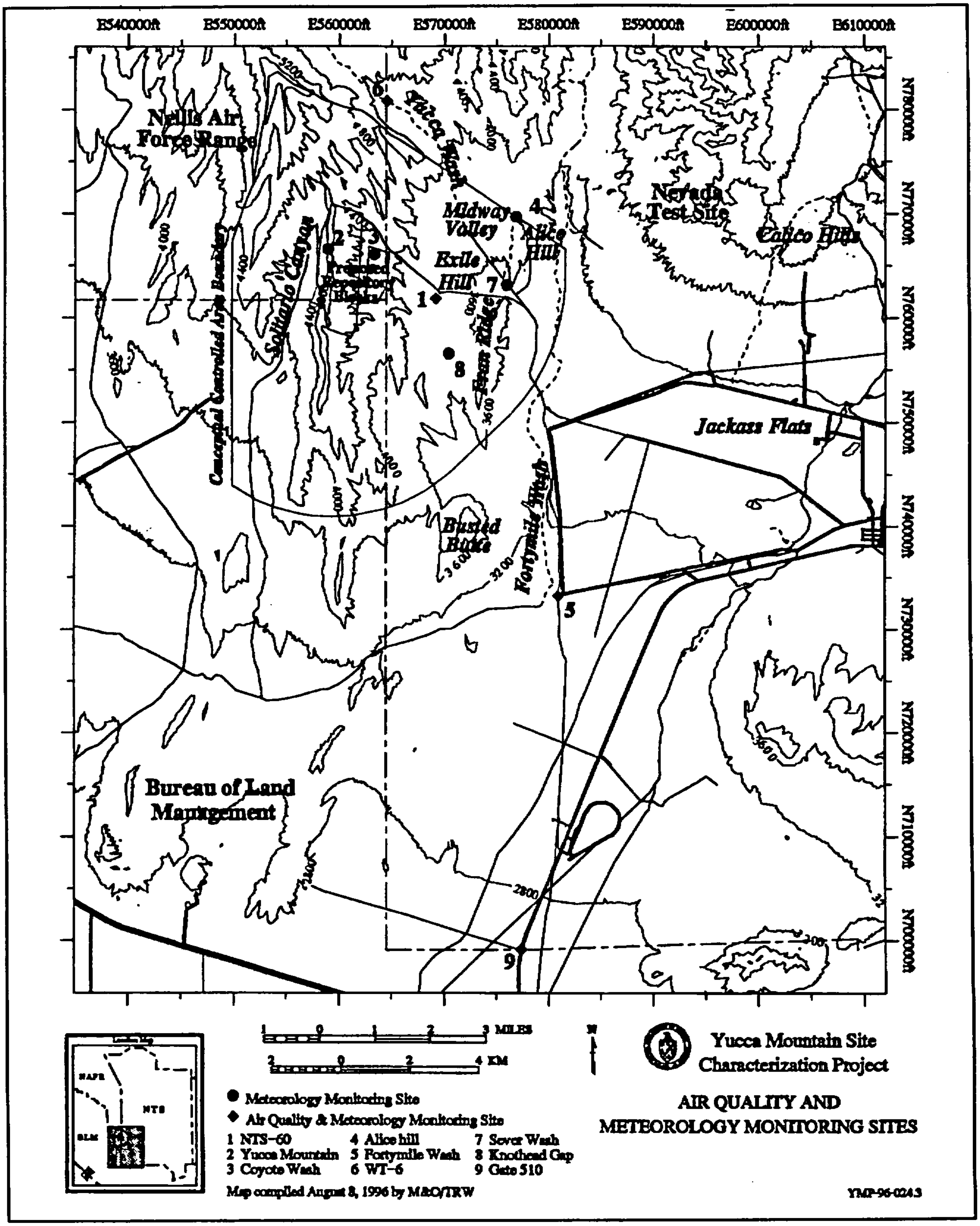

Figure 2-1. Locations of the Meteorological Monitoring Sites

Table 2-1. Coordinates of the Meteorological Monitoring Sites

Site	UTM Coordinates Zone 11 (meters)	Nevada Coordinates System Central Zone (feet)	Latitude-Longitude[1] (deg° min' sec")	Elevation (above mean sea level)
Site 1 (NTS-60)	550,784E 4,077,374N	569,126E 761,795N	116°25'50"W 36°50'34"N	3750 ft 1143 m
Site 2 (Yucca Mountain)	547,646E 4,078,753N	558,844E 766,356N	116°27'56"W 36°51'19"N	4850 ft 1478 m
Site 3 (Coyote Wash)	548,874E 4,078,701N	562,874E 766,171N	116°27'06"W 36°51'17"N	4195 ft 1279 m
Site 4 (Alice Hill)	553,117E 4,079,779N	576,810E 769,661N	116°24'15"W 36°51'51"N	4050 ft 1234 m
Site 5 (Fortymile Wash)	554,385E 4,068,727N	580,843E 733,378N	116°23'26"W 36°45'52"N	3125 ft 953 m
Site 6 (WT-6)	549,388E 4,083,097N	564,612E 780,592N	116°26'45"W 36°53'40"N	4315 ft 1315 m
Site 7 (Sever Wash)	552,800E 4,077,847N	575,747E 763,324N	116°24'28"W 36°50'49"N	3545 ft 1081 m
Site 8 (Knothead Gap)	551,161E 4,075,773N	570,344E 756,538N	116°25'35"W 36°49'42"N	3710 ft 1131 m
Site 9 (Gate-510)	553,418E 4,058,398N	577,554E 699,491N	116°24'08"W 36°40'17"N	2750 ft 838 m

[1] NAD27 (North American Datum of 1927)

The design and operation of the R/EFPD network complies with the regulatory monitoring guidance used by the U.S. Environmental Protection Agency (EPA 1987) and the U.S. Nuclear Regulatory Commission (NRC 1972). The EPA monitoring guidance is a frequently used standard for routine data collection programs for environmental monitoring purposes. The NRC guidance was also utilized to ensure that adequate data would be collected suitable for NRC regulatory atmospheric modeling. In addition to environmental regulatory guidance, the R/EFPD meteorological monitoring program was operated in accordance with approved Yucca Mountain quality assurance requirements, including oversight by quality assurance personnel. As such, the data are considered valid for "quality-affecting" purposes.

2.2 NEVADA TEST SITE: NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, AIR RESOURCES LABORATORY/SPECIAL OPERATIONS AND RESEARCH DIVISION

Primary weather support for operations at the NTS has been provided for many years by the Air Resources Laboratory/Special Operations and Research Division (ARL/SORD) group, under this designation and that of predecessor organizations, such as the National Weather Service Nuclear Support Office. Much of their data collection is focused on real-time acquisition, analysis, and presentation for operational purposes.

The NTS data of interest for the airflow study is from the automated Meteorological Data Acquisition (MEDA) weather stations. Over 30 MEDA stations have operated on, and in the region around, the NTS. Many of these stations are located in parts of the NTS that are not relevant for this study involving characterizing airflow from the Yucca Mountain area toward populated areas. The stations of interest in this airflow study are:

- MEDA6 is in the southwest portion of Yucca Flat, about 38 km northeast of Yucca Mountain. Data from this station complement the data from MEDA26 and the Desert Rock Airport.
- MEDA26 is located in Jackass Flats, approximately 15 km east of Yucca Mountain. This station is useful to improve understanding of airflow related to the Fortymile Wash area, the primary air transport pathway between Yucca Mountain and the populated Amargosa Valley area.
- MEDA36 is in the valley floor area southeast of Indian Springs, which is approximately half way between Yucca Mountain and Las Vegas, Nevada along a potential airflow pathway.

2.3 NATIONAL WEATHER SERVICE PRIMARY STATIONS

Regional scale airflow patterns were investigated by examining National Climatic Data Center (NCDC) Surface Airways wind data from Nevada and a few nearby stations in California and Utah. Winds aloft data were also used in the analysis and came from the twice-daily upper-air routine observations made at the Desert Rock station (DRA), which is located near Mercury, Nevada in the southern portion of the NTS. It is also near a potential air transport pathway between Yucca Mountain and Las Vegas.

The regional surface stations with adequate data recovery rates representative for either daytime or nighttime hours are listed in Table 2-2, and are identified in Figure 2-2 by the airways three-letter code shown in Table 2-2. The map in Figure 2-2 shows topographic contours to show the general higher terrain in central Nevada in the north-south oriented mountain ranges, and the highest portion of the Sierra Nevada mountains in California, northwest of the Yucca Mountain area.

Table 2-2. Regional Observing Sites

Station Name	Station Identification	Dates of Data	Record Years	Latitude (Degrees North)	Longitude (Degrees West)	Elevation (meters)
Bishop, CA	BIH	01/01/1964 To 04/30/1995	32	37.37	118.37	1252.1
Cedar City, UT	CDC	01/01/1964 To 12/31/1995	32	37.70	113.10	1709.9
Daggett, CA	DAG	01/01/1964 To 12/31/1995	32	34.85	116.78	585.8
Desert Rock, NV	DRA	05/15/1978 to 12/31/1995	18	36.67	116.02	1006.1
Elko, NV	EKO	01/01/1964 To 12/31/1995	32	40.83	115.78	1539.2
Ely, NV	ELY	01/01/1964 To 07/31/1994	31	39.28	114.85	1905.9
Las Vegas, NV	LAS	01/01/1964 To 08/31/1995	32	36.08	115.17	659.0
Lovelock, NV	LOL	01/01/1964 To 12/31/1995	29	40.07	118.55	1188.7
Fallon, NV	NFL	01/01/1965 To 12/31/1995	31	39.42	118.72	1199.0
China Lake, CA	NID	01/01/1964 To 12/28/1995	32	35.68	117.68	676.7
Milford, UT	MLF	01/01/1964 To 04/28/1989	26	38.43	113.02	1533.1
Reno, NV	RNO	01/01/1964 To 08/31/1995	32	39.50	119.78	1342.2
Tonopah, NV	TPH	01/01/1964 To 12/31/1995	32	38.07	117.08	1655.1
Winnemucca, NV	WMC	01/01/1964 To 09/30/1994	31	40.90	117.80	1310.8

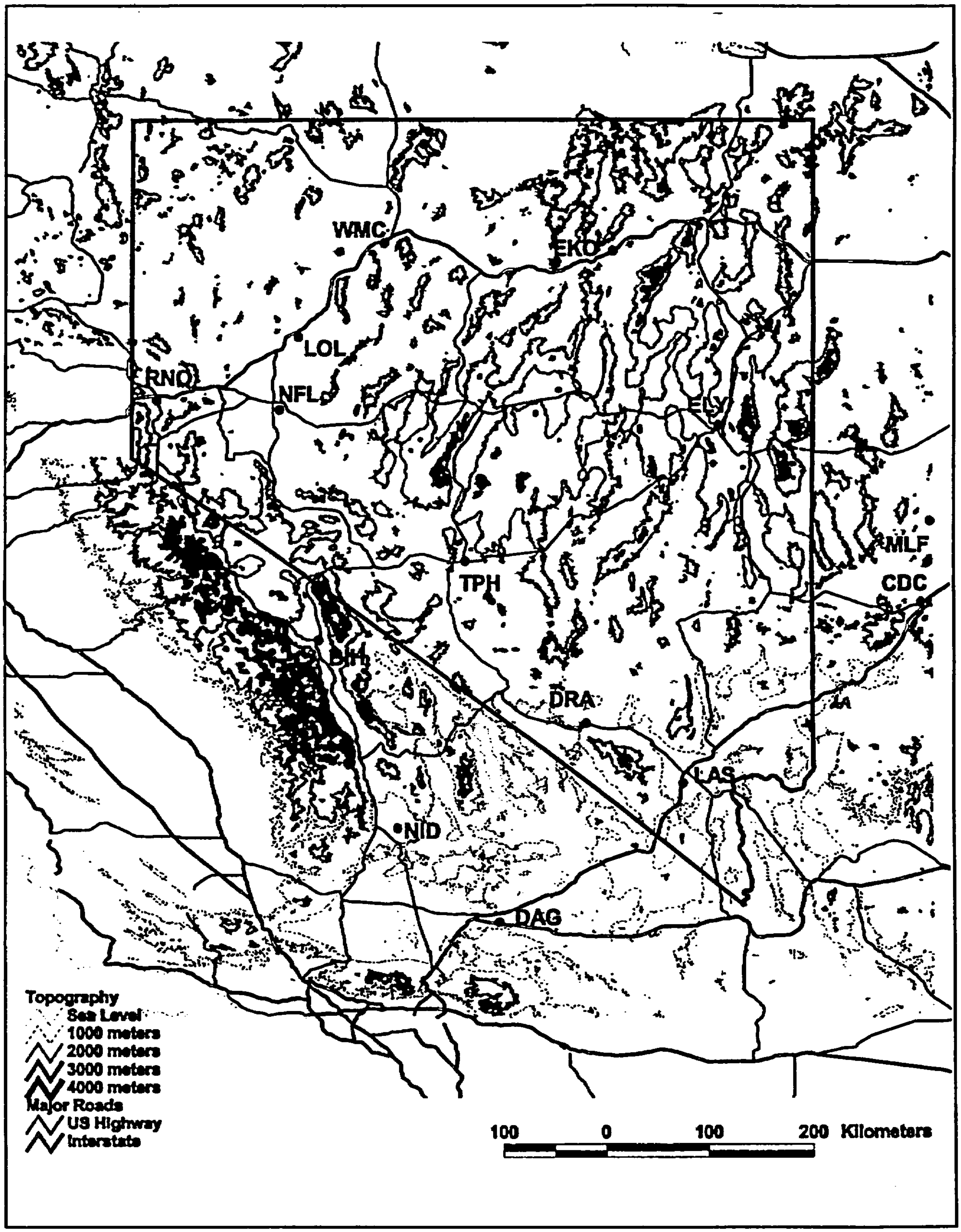

Figure 2-2. Locations of the Regional Monitoring Sites

2.4 DATA QUALITY

The meteorological data used in this report came from three sources. The primary "local" data source was the R/EFPD monitoring program, which is described in Subsection 2.1. This monitoring program has met the appropriate Yucca Mountain Project quality assurance requirements to produce qualified data. These data may be used to resolve safety and waste isolation issues related to the proposed geologic repository. Wind data obtained from NCDC have been validated by NCDC, and are considered valid for many engineering and environmental purposes. Similarly, the wind data from the ARL/SORD group are useful for the purposes of this report. However, at this time these data have not been "qualified" under the YMP process. The qualification process could be undertaken if the need were demonstrated.

An Activity Evaluation was performed according to QAP-2-0, *Conduct of Activities*. The evaluation determined that the *Quality Assurance Requirements and Description* (QARD) (DOE 1997) does apply to the activity *Scientific Investigation Implementation Package for Regional Meteorology*, (CRWMS M&O 1995b). This report on airflow characteristics is included within the scope of the evaluation of regional meteorology.

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3. LOCAL AIRFLOW

Local airflow is addressed in this section as the air movement and atmospheric dispersion processes acting on the scale of Yucca Mountain with its nearby areas, and extending to the south into Amargosa Valley. Airflow and dispersion are complex combinations of transport (movement by the mean wind) and atmospheric mixing processes. Transport and mixing are related and both involve diurnal and seasonal cycles. Airflow discussions are focused on the transport of potential releases of airborne material from sources in Midway Valley on the east side of Yucca Mountain related to repository operations.

Local airflow characteristics in the immediate vicinity of Yucca Mountain and Amargosa Valley are described in this section. Amargosa Valley is approximately 25 km south of the proposed repository area in Midway Valley on the east side of Yucca Mountain. Airflow near Yucca Mountain shows spatial and temporal characteristics that are a complex product of regional weather conditions and local topographic features. Specific wind and atmospheric stability features are distinctive to the Yucca Mountain area, but the underlying processes are similar to those observed in similar western United States complex terrain environments.

The primary influence on local wind patterns is topography. Topography controls winds in two ways. Acting as a barrier, hills, ridges, and mountains tend to channel winds along the axes of valleys. Topographic channeling can occur on winds generated by a broad range of forces, from upslope or downslope winds to winds driven by regional-scale weather mechanisms. Topography also generates winds due to air density differences between horizontal levels over higher and lower terrain areas. The upslope and downslope wind generation mechanisms follows a diurnal cycle related to surface heating and cooling.

The topographic wind force mechanisms related to ground surface heating and cooling operate on the obvious diurnal (daytime and nighttime) cycle. Thus, diurnal cycles are a primary feature of wind patterns, and are described in Section 3.1. In addition to topographic controls, the wind patterns are also the result of synoptic-scale and mesoscale weather patterns. Some of these patterns are described in Section 4. The seasonal cycle of the weather patterns causes seasonal changes in the local wind patterns, which also are described in Section 3.1.

Local airflow is described beginning with Subsection 3.1, Wind Patterns. The wind pattern descriptions are approached from the aspects mentioned above: topographic channeling, diurnal and seasonal cycles. The mixing processes aspect of dispersion is addressed in Subsection 3.2 on atmospheric stability. Further development of the nighttime airflow and vertical atmospheric structure is given in Subsection 3.3. Finally, the linkages between local and regional scale airflow characteristics are given in Subsection 3.4.

3.1 WIND PATTERNS

Wind data from the R/EFPD monitoring network on and near Yucca Mountain are the focus of the wind pattern analysis. The R/EFPD sites represent an array of topographic exposures, and are part of a comprehensive set of meteorological data including multiple indicators of atmospheric stability, temperature, humidity, precipitation, and barometric pressure.

3.1.1 Topographic Channeling

It is well recognized that winds resulting from regional or larger scale weather patterns in areas of ridges or mountains and valleys often tend to follow the direction of the axes of the valleys. This phenomenon is known in some literature as valley winds, or topographic channeling. The extent to which topography can act as a barrier causing the channeling depends on atmospheric stability and wind speed. Stability, in this sense, is a measure of the tendency of the air to react to vertical displacement. Stable air tends to return to its original level following a vertical displacement, so stable airflow is more likely to flow around obstacles than up and over them. Conversely, neutral or unstable air is less channeled because it is more likely to flow over obstacles. In addition to stability, wind speed also influences channeling. Wind speed is one measure of the kinetic energy of the airflow, and kinetic energy is needed to flow over terrain. Higher wind speeds correspond to more kinetic energy, and less channeling (Blumen 1990).

When regional scale weather patterns have small pressure gradients resulting in low wind speeds, different topographic influence mechanisms are manifested in the local airflow. These mechanisms tend to cause winds to blow either up (daytime) or down (nighttime) hill and valley slopes; these winds are known as slope winds. Slope winds in complex terrain areas can merge, tending to follow the main terrain features, which is another form of topographic channeling (Blumen 1990). Slope winds are addressed in greater detail in Subsection 3.1.2, which covers the diurnal cycle in the wind patterns.

The region around Yucca Mountain and southern Nevada is a complex array of elevated terrain around areas of lower terrain. Some areas are regularly spaced and oriented ridges and valleys, while others are complicated mountain areas. The wind roses and discussions in this section are presented to demonstrate the significant extent which winds in the Yucca Mountain and southern Nevada areas are channeled by surrounding topography. Figure 2-1 shows the locations of the R/EFPD monitoring network stations, and Table 2-1 contains descriptions of the site locations. Figure 2-2 shows the regional area with topographic contours, and those meteorological stations that report airways data. These stations are identified in Table 2-2.

At least eight of the nine R/EFPD meteorological monitoring sites are located near higher terrain, some more so than others. The R/EFPD network was sited to characterize the complex airflows occurring in the complicated terrain of Yucca Mountain and vicinity. Detail on the surrounding topography, organized by topography type, follows.

- Site 3 has the greatest degree of terrain confinement; it is near the middle of a narrow portion of Coyote Wash, part way down the east side of Yucca Mountain. The sides of the wash slope steeply upward within a few tens of meters of the tower. The wash is narrower and oriented approximately 290 degrees (WNW) with a wider opening to the east and southeast.

- Sites 1, 7, and 8 are located on the west, southwest, and northeast sides of Midway Valley, respectively. Midway Valley is surrounded by Yucca Mountain on the west side, Fran Ridge on the east, significantly higher terrain to the north of Yucca Wash, and a saddle on the south side. Midway Valley is elongated along a basically north and south direction between the Yucca Mountain ridge on the west and the combination of Fran Ridge and Alice Hill on the east. The surface topography drainage is on the east-central side, between Fran Ridge and Alice Hill, near Site 7. Site 1 is at an elevation of 1,143 meters above mean sea level (m-msl), and Site 8 is at 1,131 m-msl. Site 7 is at an elevation of 1,081 m-msl in the gap between Alice Hill and Fran Ridge, near the lowest point of the terrain of the hydrographic drainage of most of Midway Valley. Site 7 is slightly west of Alice Hill, giving it at least a semicircle of unobstructed terrain exposure through Midway Valley. The additional terrain feature at Site 1 is the lower end of Drill Hole Wash, which is approximately toward the northwest, 315 degrees from Site 1.

- Site 4 is on top of Alice Hill at an elevation of 1,234 m-msl, which forms the northeast side of Midway Valley. Although the top of Alice Hill is over 100 m above the nearby valley floor, it has higher terrain to the NW through NE.

- Site 6 is on the south side of Yucca Wash on the NTS side of the boundary with the Nellis Air Force Gunnery Range at an elevation of 1,315 m-msl. The terrain features of the north end of the Yucca Mountain ridge and higher terrain to the north form a significant valley oriented toward 315 degrees, NW.

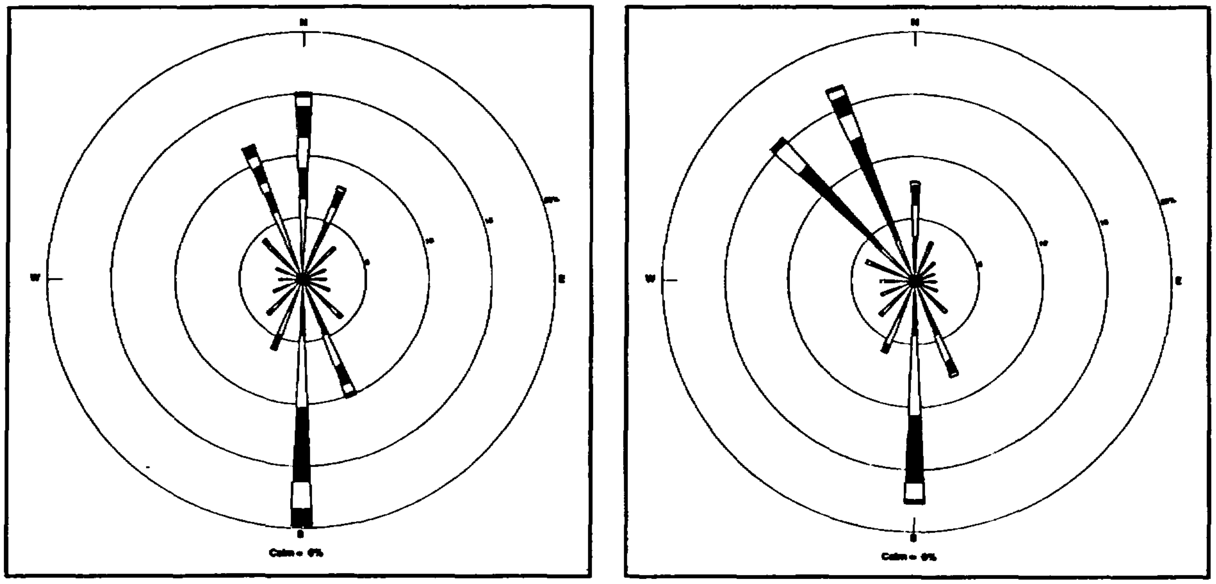
- Site 2 is on the top of the Yucca Mountain ridge, at an elevation of 1,478 m-msl. The Site is about 2 km north of the road leading up the east side of the ridge; there is still higher terrain within a few km NW and NE.

- Site 5 is on the east edge of Fortymile Wash, about halfway down the west side of Jackass Flats between Fortymile Canyon and the southern border of the NTS and the community of Amargosa Valley, previously known as Lathrop Wells. While the terrain in this area seems flat, there is an appreciable slope from north to south. The elevation drops from 1,067 m-msl to 838 m-msl in about 21 km. The elevation at Site 5 is 953 m-msl, near the fork of Jackass Flats that divides the portion extending northward toward Fortymile Canyon from the upper Jackass Flats area to the northeast.

- Site 9 is 5.35 km south of Site 5 at an elevation of 838 m-msl, in the center of lower Jackass Flats on the southern border of the NTS, immediately north of the Amargosa Valley area.

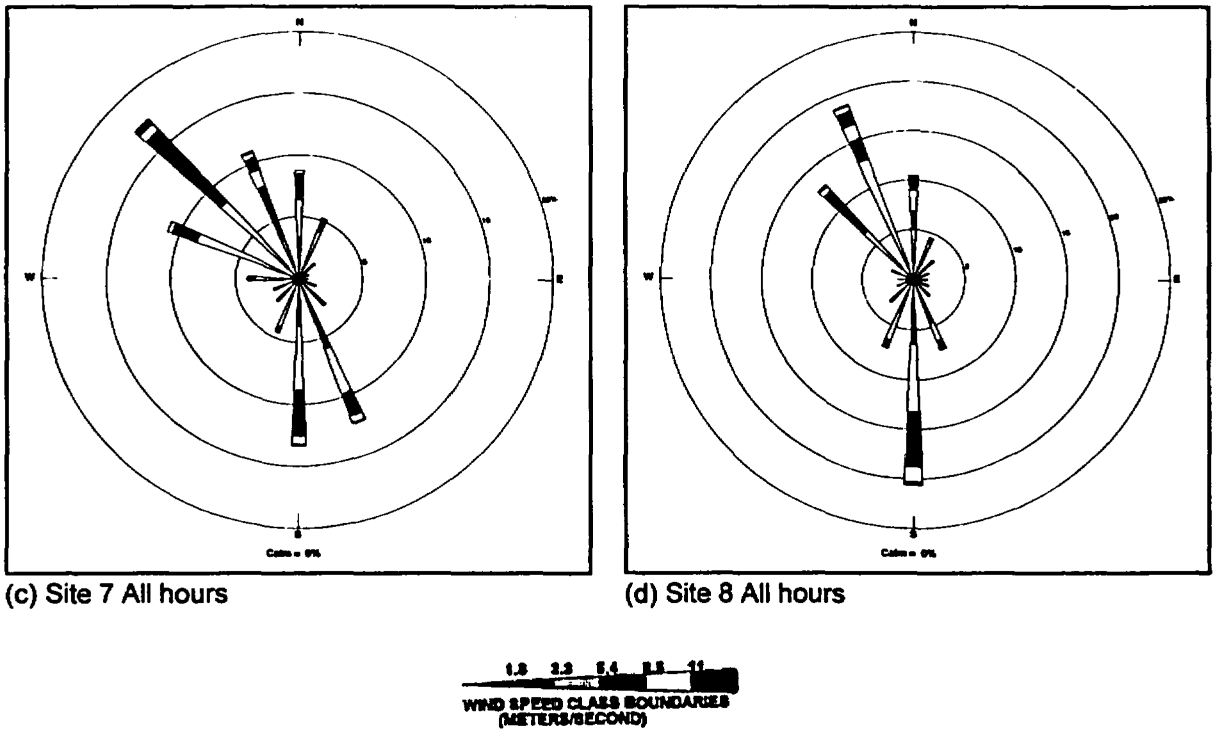
Figures 3-1 through 3-3 contain wind rose plots from the nine R/EFPD monitoring sites based on all of the data collected from the beginning of operations through 1996. Sites 1 through 5 began operating in December 1985; Sites 6 through 9 began operating by the beginning of 1993. Most of the wind roses show a bi-modal distribution of prevailing wind directions, that is, there are two dominant directions for each site.

The dominant directions shown in the wind roses in Figures 3-1 through 3-3 correspond to the alignment of nearby topography discussed above, demonstrating a strong correlation between dominant directions and the topographic settings of the sites, or topographic channeling. The sites in Figure 3-1 are located in Midway Valley. For example, the southerly winds at both levels of Site 1 correspond to airflow from the south through Midway Valley. There were approximately 37 and 32 percent of the hours with southerly winds at 60 and 10 m-agl, respectively. The other main



(a) Site 1-60m All hours

(b) Site 1-10m All hours

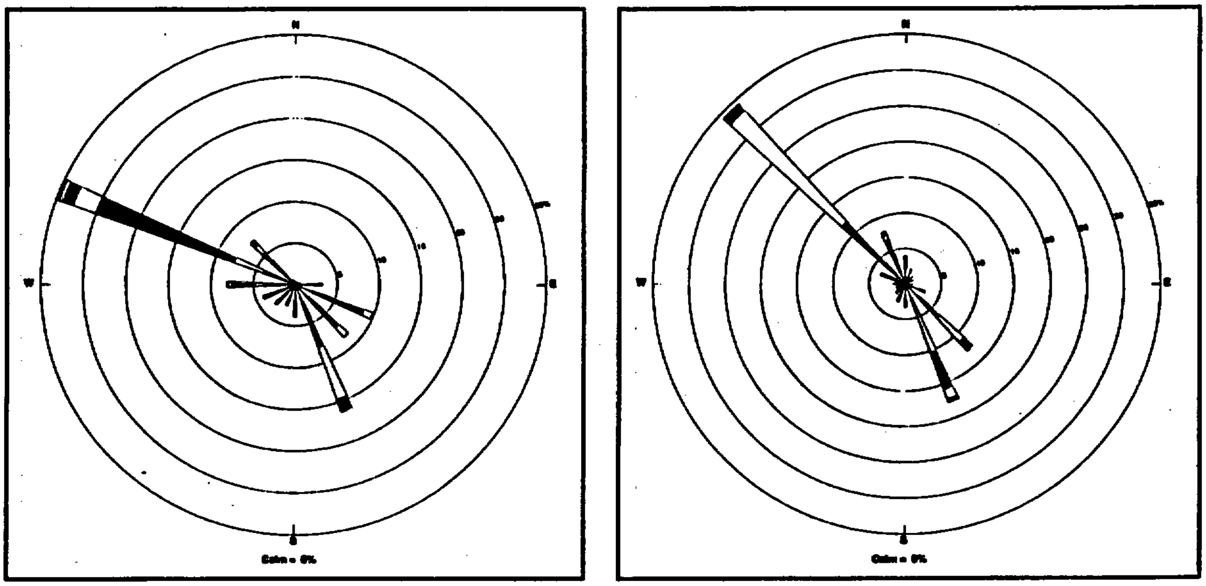


(c) Site 7 All hours

(d) Site 8 All hours

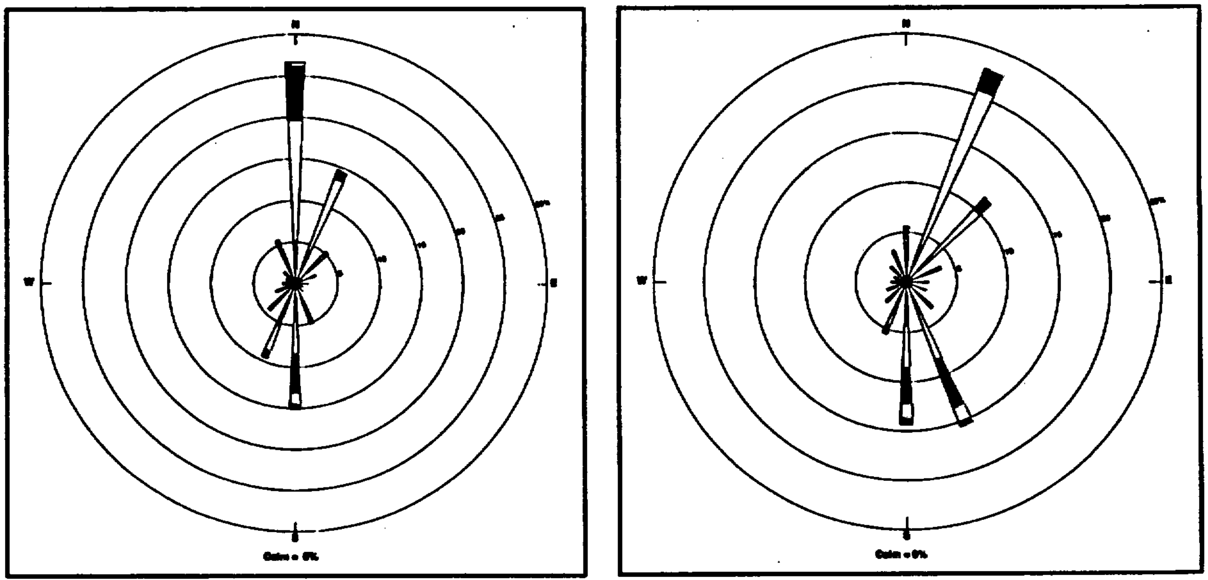
Note: The diagram is the frequency of occurrence for each wind direction from which the wind is blowing.

Figure 3-1. Wind Rose Plots for EFPD Sites 1, 7, and 8 (all hours)



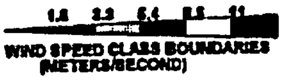
(a) Site 3 All hours

(b) Site 6 All hours



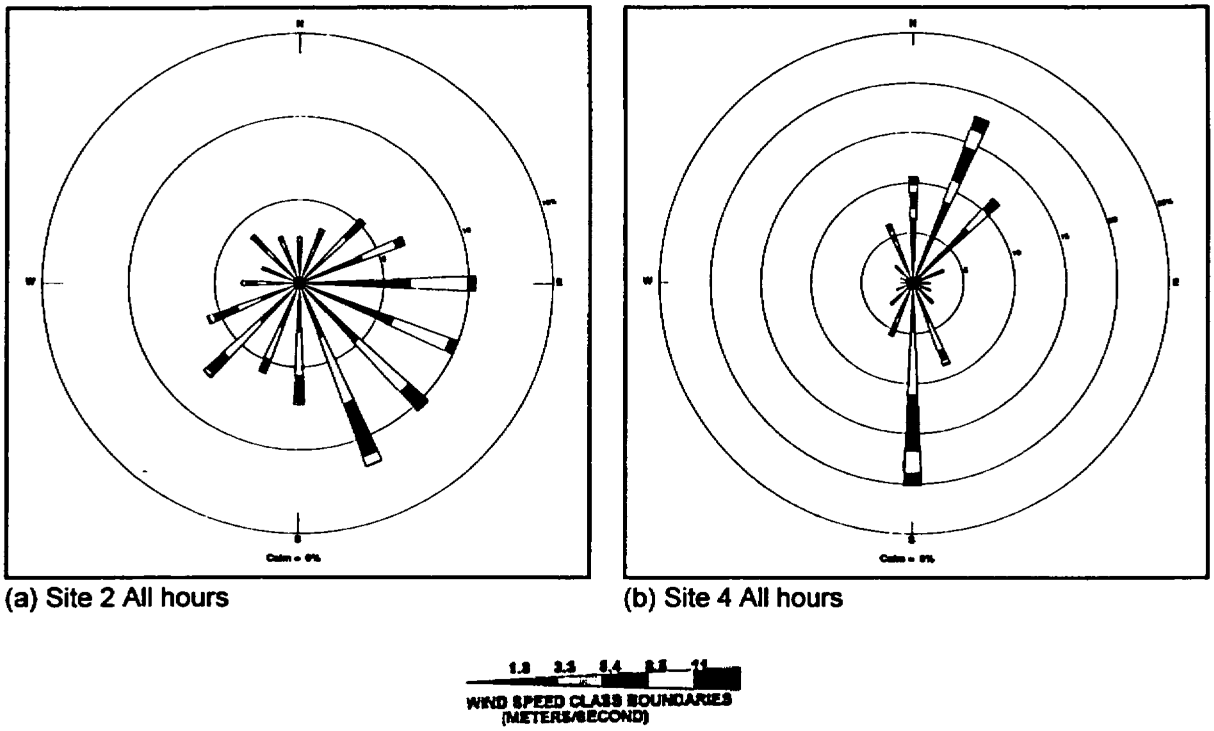
(c) Site 5 All hours

(d) Site 9 All hours



Note: The diagram is the frequency of occurrence for each wind direction from which the wind is blowing.

Figure 3-2. Wind Rose Plots for EFPD Sites 3, 6, 5, and 9 (all hours)



(a) Site 2 All hours

(b) Site 4 All hours

Note: The diagram is the frequency of occurrence for each wind direction from which the wind is blowing.

Figure 3-3. Wind Rose Plots for EFPD Sites 2 and 4 (all hours) directions were centered on NNW-N at 60 m-agl, and NW-NNW at 10 m-agl. The northwest to northerly directions occurred during approximately 35 and 43 percent of the hours at 60 and 10 m-agl, respectively. These directions correspond to the local topography at those elevations that influence airflow at nighttime hours. Further discussion of the seasonal and diurnal features of the wind patterns is provided in the next two sections.

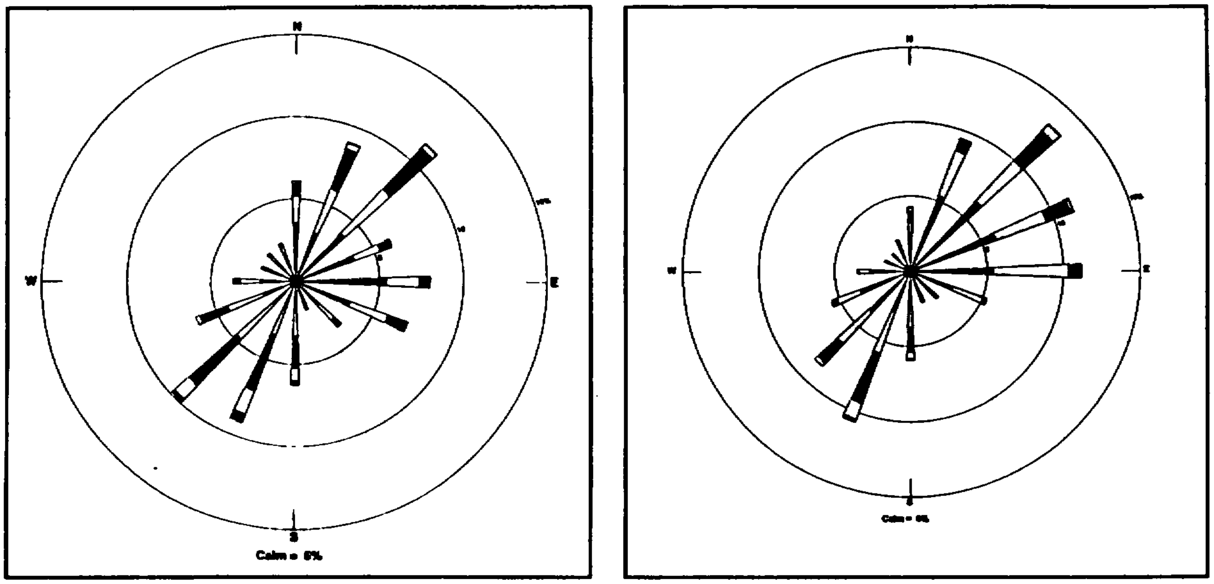
The dominant directions at Sites 7 and 8 in the eastern and southern portions of Midway Valley also show the prevailing southerly winds and northwest or northerly winds, depending on the influence of nearby topography. The wind roses from Sites 3 and 6 in Figure 3-2 show the significant concentration of winds from the directions of the narrower portions of the nearby canyon-type topography. Wind roses from Sites 5 and 9 in Figure 3-2 show the orientation of the Jackass Flats and Fortymile Wash topography. Wind roses shown in Figure 3-3 from Site 4, on top of Alice Hill over 100 m above the nearby floor of Midway Valley, show the bimodal southerly and northerly distribution that indicates the channeling of Midway Valley. This indicates that channeling occurs in layers aloft within the valley. The exception to the topographic channeling characteristic is seen in the wind rose in Figure 3-3 from Site 2, which is located near the north end of the crest of the Yucca Mountain ridge.

Figure 3-4 shows wind roses for all available hours for Desert Rock Airport and ARL/SORD sites MEDA26, MEDA6 and MEDA36. These wind roses show additional examples of topographic channeling of winds by surrounding topography. The stations are located in valley floor areas, with terrain surrounding the valleys.

The Desert Rock Airport meteorological station (DRA) is on the NTS 5 km SW of Mercury, Nevada, and 43 km SE of Yucca Mountain. DRA has higher terrain north and east of Mercury, the north end of the Spring Mountain range to the S and SW, and the Specter Range hills to the W. There is a gap in the surrounding terrain toward the SW between the Spring Mountains and the Specter Range. The wind rose from DRA shows one dominant direction with winds from this gap toward the SW, and a second dominant direction from the NE.

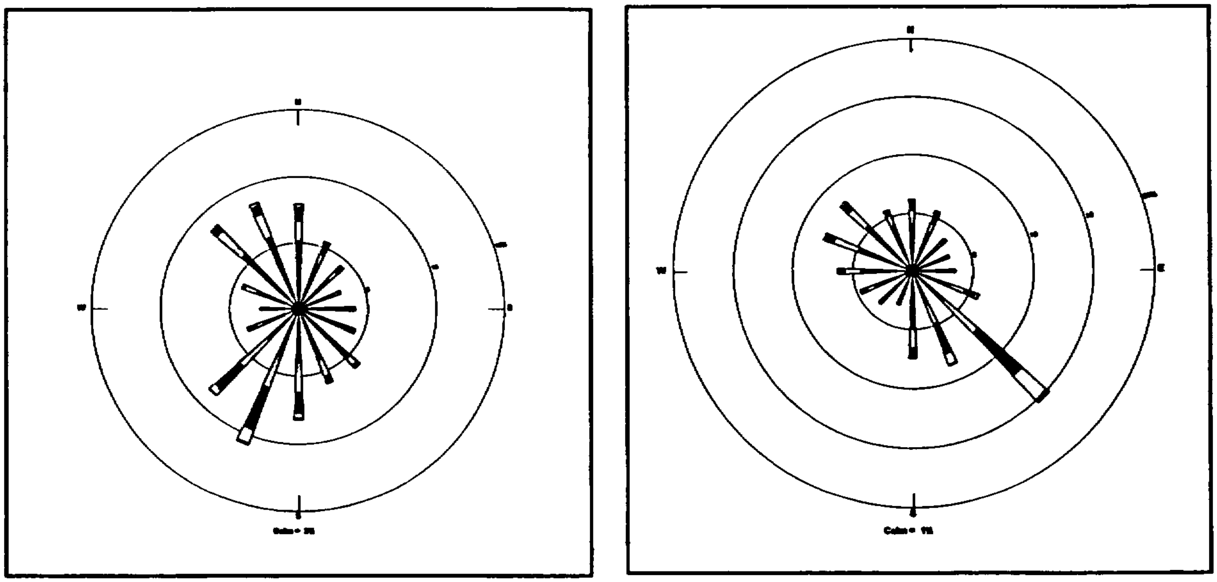
Station MEDA26 is located in upper Jackass Flats, east of the YMP field operations area. Jackass Flats is a broad valley area, with Skull Mountain on the south side. Skull Mountain is oriented approximately SW to NE. The terrain on the north side of upper Jackass Flats is oriented approximately east-west. The wind rose from MEDA26 in Figure 3-4 shows winds from the NNE through E, and from the S through WSW, corresponding to the terrain surrounding Jackass Flats.

Station MEDA6 is located on the southwest side of the Yucca Flat dry lake on the NTS, approximately 40 km northeast of Yucca Mountain. Yucca Flat is a large dry lake in a valley oriented generally north and south. The wind rose in Figure 3-4 shows more frequent winds from the northwest and southwest; the lesser dominance of directions compared to other locations is due to the location in a broad dry lake area compared to a valley that does not drain toward a nearby central area.



(a) Desert Rock (DRA), NV all hours

(b) MEDA26 all hours



(c) MEDA6 all hours

(d) MEDA36 all hours

Note: The diagram is the frequency of occurrence for each wind direction from which the wind is blowing.

Figure 3-4. Diurnal Wind Rose Plots of ARL/SORD Sites

Station MEDA36 is located SE of Indian Springs, Nevada approximately halfway between Yucca Mountain and Las Vegas. The station is near the southern end of an elongated north-south dry lake with higher terrain on both east and west sides. The area is north of the large Spring Mountain range, which is generally oriented NW to SE, and west of the Sheep Mountain range, which is oriented nearly perpendicular to the Spring Mountain range. The wind rose from MEDA36 shown in Figure 3-4 shows a dominant wind direction from the southeast; this direction is aligned with the gap between the Sheep Mountains and Spring Mountains, in the valley containing U.S. Highway 95 that leaves the Las Vegas valley to the northwest. The other directions are mostly in the quadrant from WNW through NNE, reflecting the two low areas toward the WNW and N with mountain ranges on both sides.

3.1.2 Diurnal Cycle

After topographic channeling, the second most significant feature of local and regional wind patterns is the regular diurnal wind cycle of airflow toward higher terrain in the daytime, and away from higher terrain at night. The diurnal cycle occurs most often during clear sky conditions, which are characteristic of the arid southern Great Basin climate. The diurnal cycle of winds is typically related to the "slope winds" mentioned in Subsection 3.1.1. The downslope winds occurring during nighttime hours are frequently called "drainage" winds, because they typically follow the directions of hydrologic drainage in complex terrain. The numerous meteorological textbooks and research publications with material on this topic such as those identified in Section 1 indicate both the importance of the topic to many meteorological applications, and the challenge presented in understanding the phenomenon.

The basic cause of the diurnal cycle of wind patterns is the pressure differences between the same absolute elevation levels over higher and lower terrain. The local horizontal pressure differences arise from the air density differences, which are caused by temperature differences between air at the surface near elevated terrain compared to air at the same absolute level which is higher above ground over nearby lower terrain. The air above the higher terrain is heated or cooled by the nearby ground surface; the ground temperature differences are due to ground heating during daytime, and ground cooling at night from long-wave radiation losses (Blumen 1990).

The complexity in the wind patterns arises from the interaction of factors such as the site-specific topographic shapes, orientations, ground surface characteristics, and the occurrences of regional or synoptic scale atmospheric pressure patterns, which enhance or negate the airflow tendency due to the topographic mechanisms. Topographic channeling tends to steer the wind directions along topographic contour lines, particularly during the stable periods. Stable airflow tends to flow around terrain, rather than over the barriers, while neutral and unstable airflow can more readily flow over terrain (Blumen 1990).

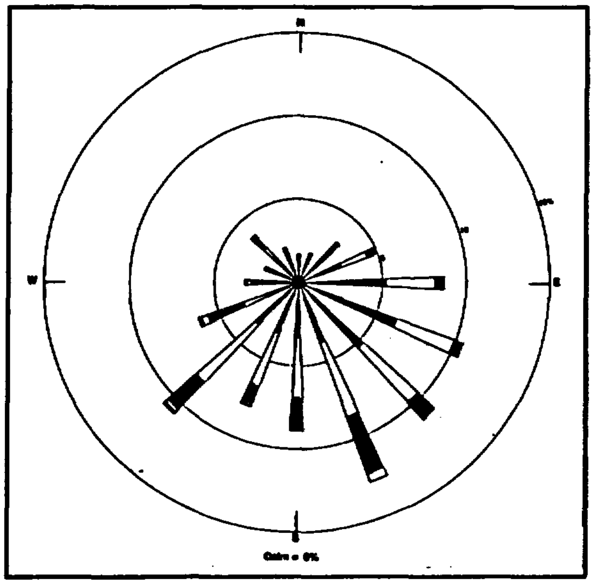
The wind roses and discussions in this section are presented to demonstrate the significant extent to which winds in the Yucca Mountain and southern Nevada areas exhibit diurnal cycles related to topography. Discussions of the diurnal cycle overlap with those on atmospheric stability, which is addressed separately in Subsection 3.2. The upslope and upvalley daytime winds coincide with neutral or unstable conditions, while some drainage winds and some downslope and downvalley winds occur during stable conditions. Airflow during stable periods is more complex than during neutral and unstable periods from an atmospheric dispersion perspective; it can also be more important, since the stable periods minimize vertical mixing and dilution of airborne pollutants. Another reason for the stable periods being more important for Yucca Mountain is the most stable periods typically occur with airflow downslope from the east side of Yucca Mountain through Fortymile Wash toward Amargosa Valley, which is the nearest populated area to Yucca Mountain.

Figures 3-5 through 3-9 contain wind rose plots separately from daytime and nighttime hours from the nine R/EFPD monitoring sites based on all of the data collected from the beginning of operations through 1996. Sites 1 through 5 began operating in December 1985; Sites 6 through 9 began operating by the beginning of 1993. Most of the wind rose diurnal pairs show complementary dominant wind directions related to the plots shown in Figures 3-1 through 3-3, with the southerly winds occurring during the daytime hours, and the northerly winds occurring at night. These directions correspond to the generally higher terrain occurring to the north of the monitoring network area, and lower terrain to the south. The east side of the Yucca Mountain ridge is a series of canyons and washes with axes generally oriented from northwest to southeast.

Wind data shown in Figure 3-5 from Site 2, which is on the crest of the Yucca Mountain ridge, indicate virtually no topographic channeling. The daytime wind rose shows a broad spread of winds from the E through SW directions. Nighttime winds were spread less, with the dominant directions being from the NE through SSE. Both the daytime and nighttime wind speeds were generally in the 1.8 through 5.4 m/s categories.

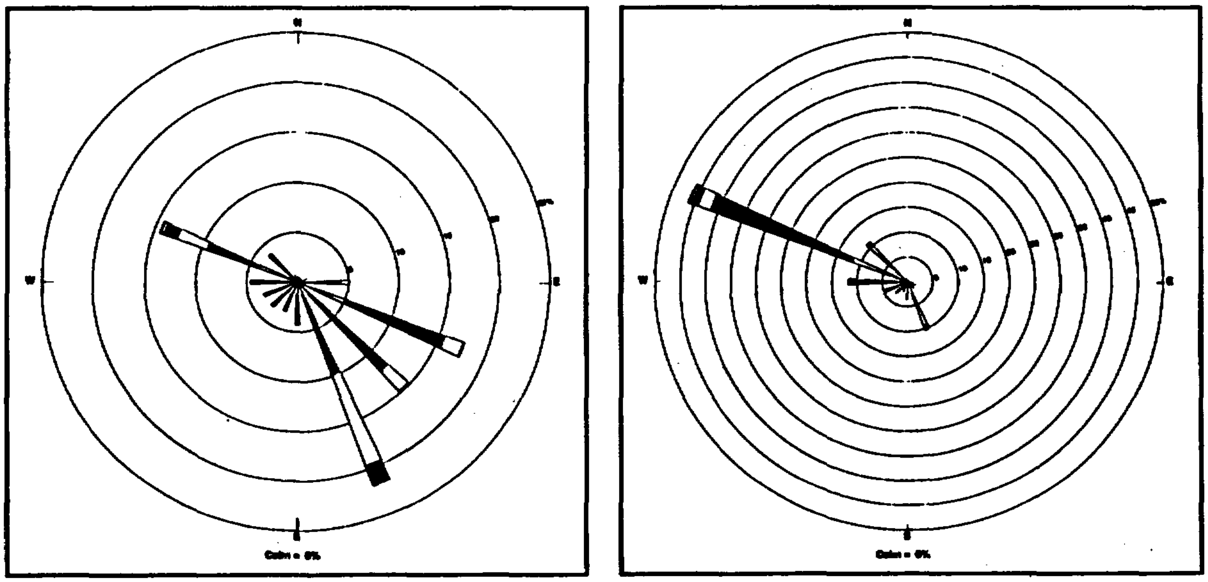
In contrast to Site 2, the wind data from Site 3 shown in Figure 3-5 show extensive channeling. Site 3 is near the center of a wash with steep sides near, and uphill (WNW) of the site, opening more on the downhill side toward the SE. The dominant daytime wind directions from the ESE through SSE occur during nearly 55 percent of the hours, and from the WNW direction down the wash during nearly 15 percent of the hours. The nighttime wind rose shows evidence of a classic drainage wind result; over 45 percent of the nighttime hours were WNW, with an additional 25 percent from W and NW. Wind speeds at all hours at Site 3 are generally in the 1.8 to 5.4 m/s range, with higher wind speeds occurring only about five percent of the hours, corresponding to either WNW or SSE directions. The nighttime wind speeds were virtually all less than 3.3 m/s.

The daytime wind roses from the 60-m and 10-m levels at Site 1 both shown in Figure 3-6 have winds from the S and SSE during over 42 percent of the hours. Site 1 is in the west-central portion of Midway Valley, at least one km east of the steeply rising terrain of the east side of Yucca Mountain. The 60-m daytime winds were from the NNW through NNE during about 20 percent of the hours. The 10-m daytime winds were similar, but they were more northwesterly with the dominant directions being NW through N. Nearly all of the daytime winds had speeds at least 3.3 m/s. The nighttime winds at the 60-m level of Site 1 were from the NNW and N during about 40 percent of the hours, with an additional 17 percent occurring from the NW and NNE. Nearly one-half of the northerly winds have wind speeds less than 1.8 m/s. About 20 percent of the nighttime hours had winds from the SSE through SSW, most of these southerly winds were with speeds greater than 3.3 m/s.



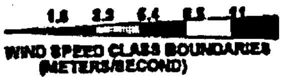
(a) Site 2 - Day

(b) Site 2 - Night



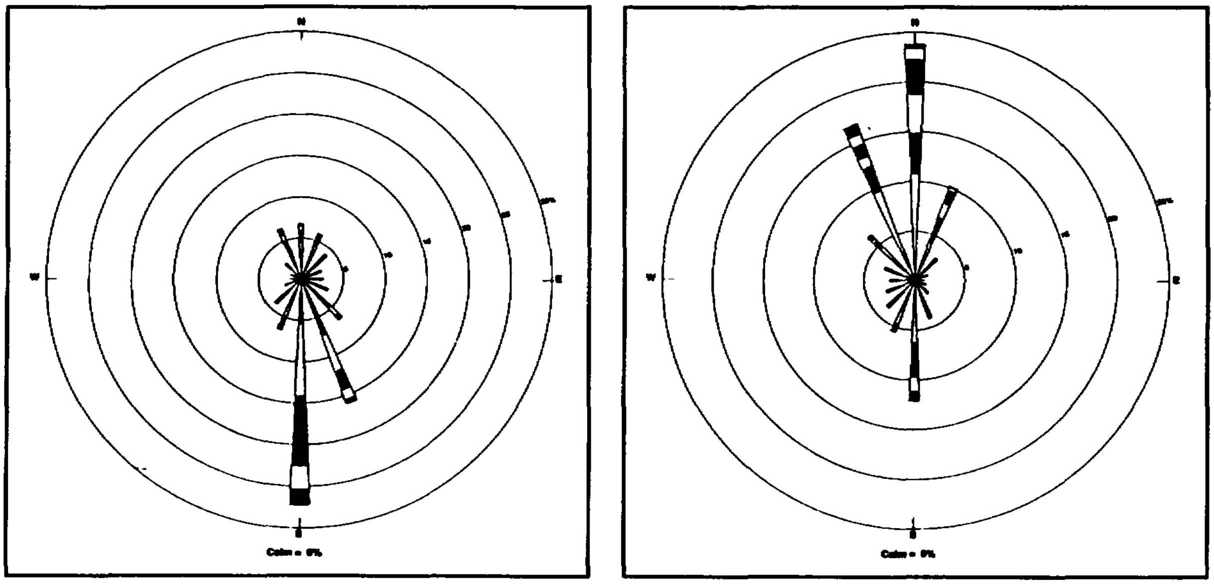
(c) Site 3 - Day

(d) Site 3 - Night



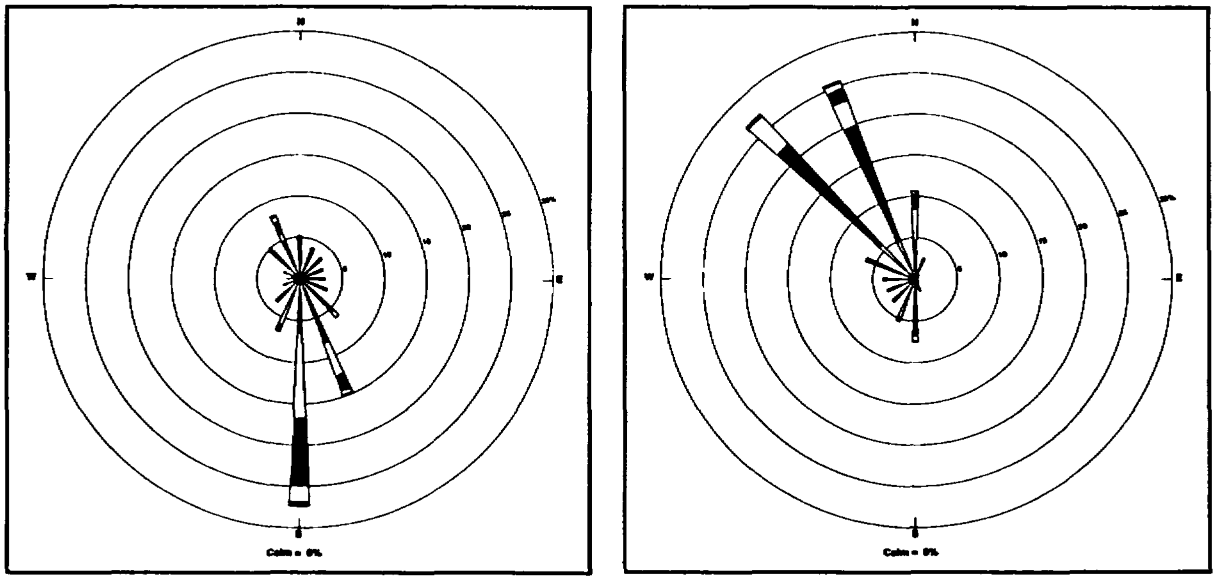
Note: The diagram is the frequency of occurrence for each wind direction from which the wind is blowing.

Figure 3-5. Diurnal Wind Rose Plots of EFPD Sites 2 and 3



(a) Site 1-60m - Day

(b) Site 1-60m - Night

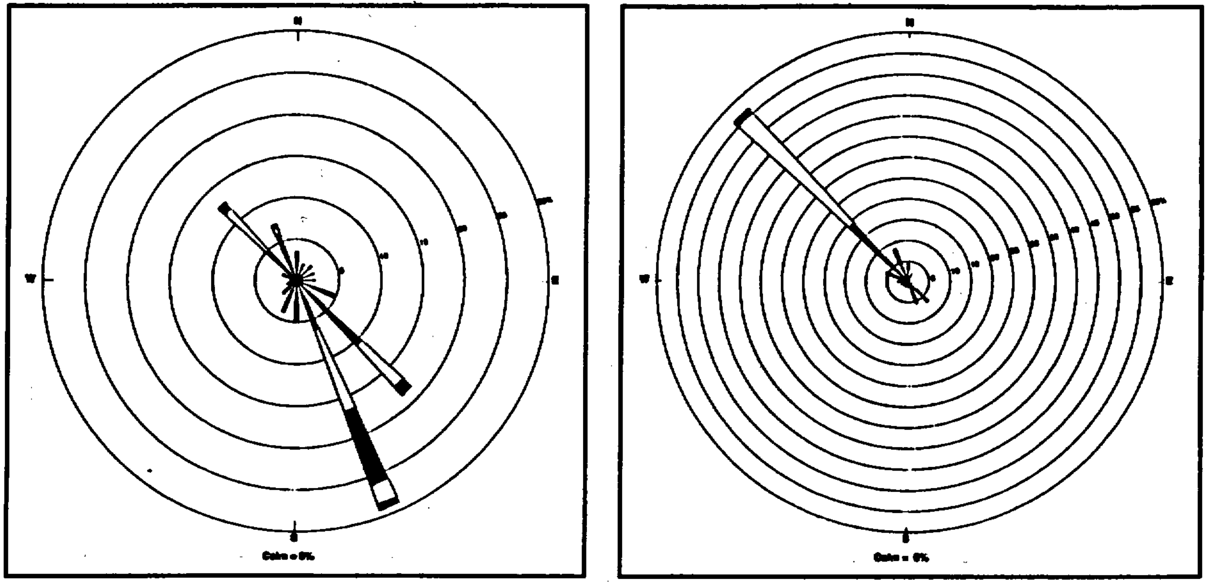


(c) Site 1-10m - Day

(d) Site 1-10m - Night

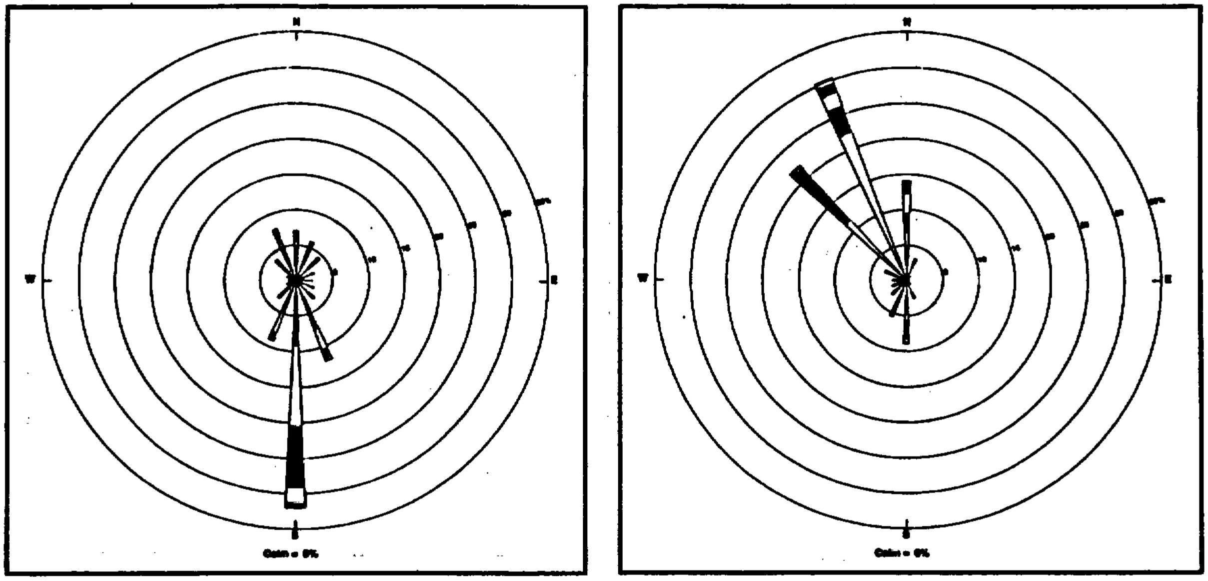
Note: The diagram is the frequency of occurrence for each wind direction from which the wind is blowing.

Figure 3-6. Diurnal Wind Rose Plots of EFPD Site 1



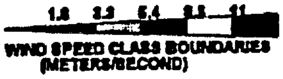
(a) Site 6 - Day

(b) Site 6 - Night



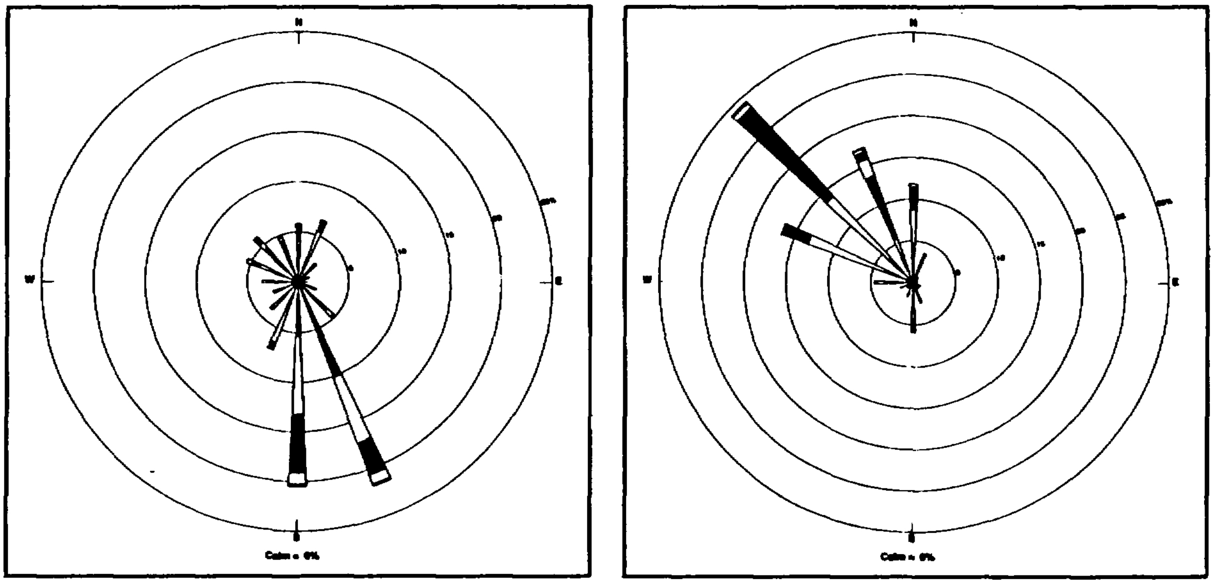
(c) Site 8 - Day

(d) Site 8 - Night



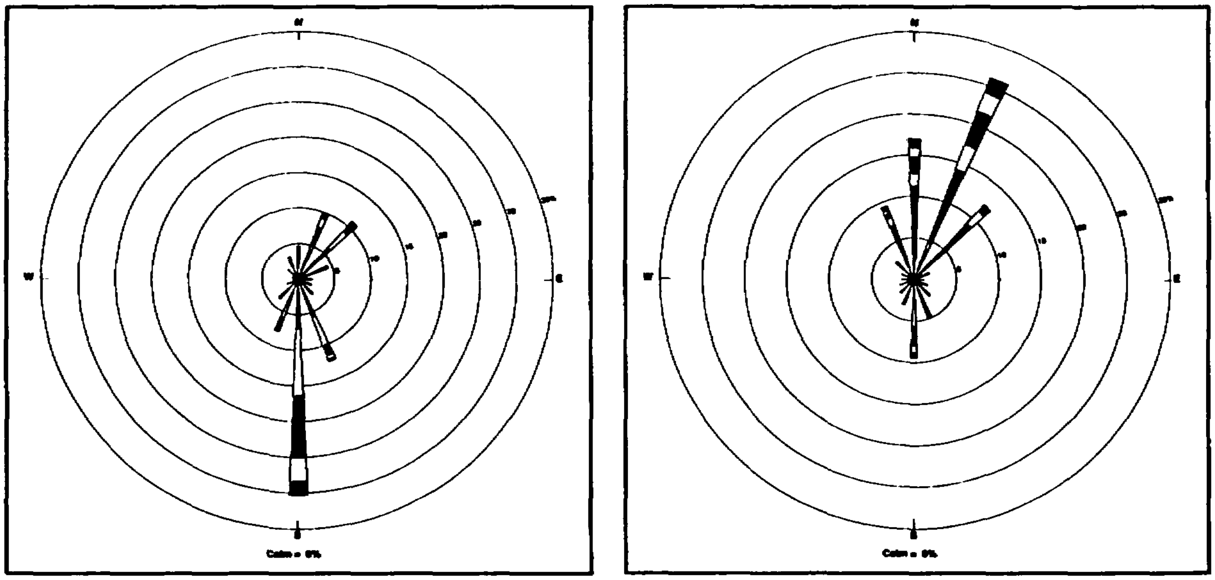
Note: The diagram is the frequency of occurrence for each wind direction from which the wind is blowing.

Figure 3-7. Diurnal Wind Rose Plots of EFPD Sites 6 and 8



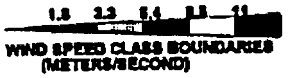
(a) Site 7 - Day

(b) Site 7 - Night



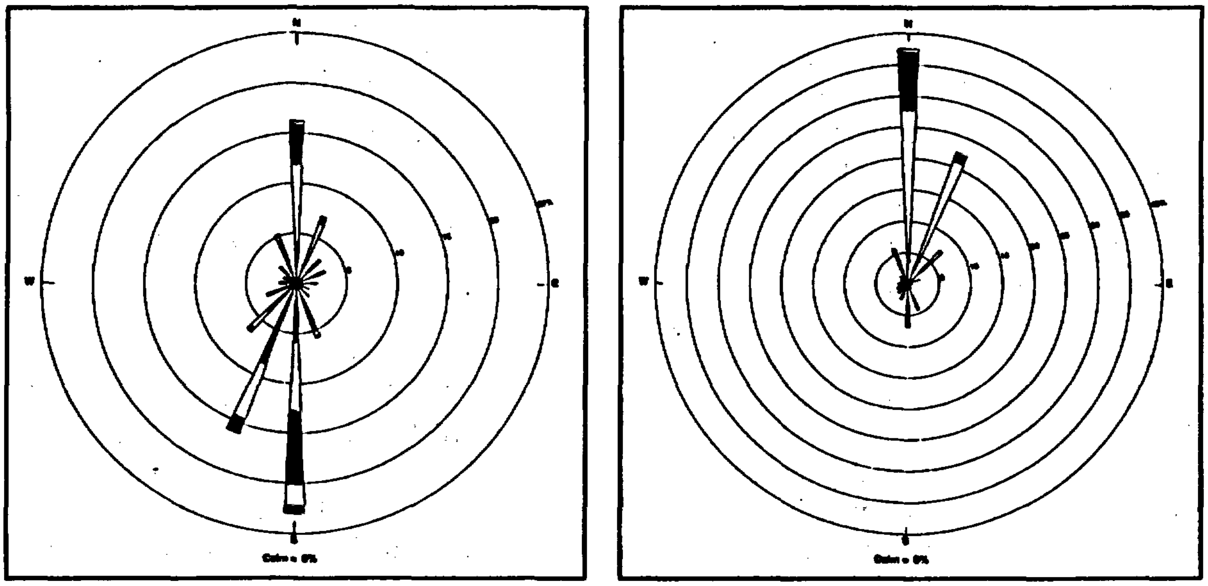
(c) Site 4 - Day

(d) Site 4 - Night

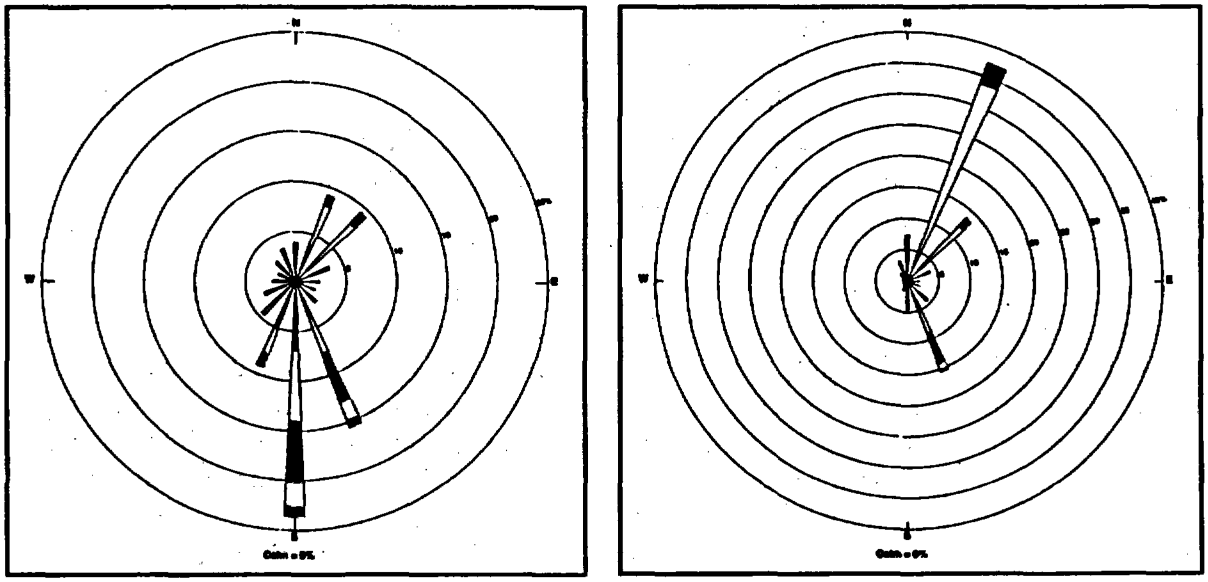


Note: The diagram is the frequency of occurrence for each wind direction from which the wind is blowing.

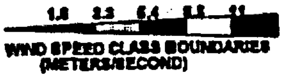
Figure 3-8. Diurnal Wind Rose Plots of EFPD Sites 7 and 4



(a) Site 5 - Day (b) Site 5 - Night



(c) Site 9 - Day (d) Site 9 - Night



Note: The diagram is the frequency of occurrence for each wind direction from which the wind is blowing.

Figure 3-9. Diurnal Wind Rose Plots of EFPD Sites 5 and 9

Wind data from Site 6 shown in Figure 3-7 reflect the site location in upper Yucca Wash, which flows down from NW to SE, meeting the beginning of Fortymile Wash near Alice Hill. The daytime winds at Site 6 are from the upslope SE or SSE directions during nearly 50 percent of the hours. An additional 20 percent of the hours have winds from the downvalley directions including NW and NNW. The daytime speeds are generally in the 3.3 to 8.5 m/s speed categories. The nighttime winds at Site 6 show the greatest extent of channeling of all the R/EFPD monitoring sites. Winds were from the NW direction during over 55 percent of the nighttime hours, and from the adjacent WNW and NNW categories another 15 percent of the hours. Upslope SE and SSE winds occurred during less than 15 percent of the hours.

Site 8 is in the saddle on the south side of Midway Valley between Bow Ridge and Fran Ridge. The daytime wind rose from Site 8 shown in Figure 3-7 resembles that from the 10-m level at Site 1; about 50 percent of the hours had winds from the SSE through SSW, with most of the directions in the south category. Most of the daytime speeds were at least 3.3 m/s. Most of the remaining winds were from the NW through NE directions, often with speeds greater than 3.3 m/s. Thus, the daytime winds at this location were channeled through Midway Valley. About 65 percent of the nighttime hours had winds from the NW through N directions with speeds less than 3.3 m/s. Less than 15 percent of the hours had wind directions from S or SSW. This shows that the nighttime airflow at 10 m-agl is representative of flow through Midway Valley as controlled by surrounding higher terrain, and not of the topographic gradient in the immediate vicinity of the monitoring site. This answers an important question regarding drainage winds in the vicinity of the south portal of the Exploratory Studies Facility, that the airflow in this area is more likely to proceed out of Midway Valley toward the south than to follow the surface topographic gradient toward the northeast and exit the Valley past Site 7 between Fran Ridge and Alice Hill.

Site 7 is in the gap between Alice Hill and Fran Ridge. The daytime wind rose shown in Figure 3-8 indicates that about 45 percent of the hours had winds from the S or SSE with speeds at least 3.3 m/s. These directions are along, and slightly east of, Fran Ridge. The observation that the daytime winds are not more from ESE and SE through the gap between Alice Hill and Fran Ridge is one example of the limited tendency for topography to channel neutral or unstable airflow. The nighttime wind rose from Site 7 shows light northwesterly drainage winds occurring most of the nighttime hours; about 65 percent of the hours were from the WNW through NNW, typically with speeds less than 3.3 m/s. Less than 10 percent of the nighttime hours had winds from the southerly directions, and most of these had speeds greater than 3.3 m/s.

Viewed from Midway Valley, Alice Hill seems to be a significantly tall topographic feature that might not experience the amount of topographic channeling as sites located on the valley floor. Site 4 is on top of Alice Hill. The wind roses from Site 4 in Figure 3-8 show that the higher terrain of the Yucca Mountain ridge to the west and the mountainous area to the north cause topographic channeling of winds above the surface but within a large valley. About 50 percent of the hours had winds from the SSE through SSW directions, which corresponds to flow uphill through lower Jackass Flats continuing northward toward the Fortymile Canyon. Over 20 percent of the daytime hours had winds from the NNE and NE directions. The nighttime hours had winds from the NNW through NE during nearly 65 percent of the hours, including about 26 percent from the NNE direction alone. These directions correspond to the higher terrain northwest through northeast of this site, with focus on the Fortymile Canyon to the NNE. Winds were from the SSE and S directions during nearly 15 percent of the hours.

Site 5 is about halfway down the west side of Jackass Flats between Fortymile Canyon and the southern border of the NTS and the community of Amargosa Valley. Site 5 is at 953 m-msl near the fork of Jackass Flats that divides the portion extending northward toward Fortymile Canyon from the upper Jackass Flats area to the northeast. The daytime wind rose for Site 5 shown in Figure 3-9 has dominant southerly winds, with about 38 percent of the hours from S and SSW. An additional about 12 percent of the hours are from SSE and SW. The winds were from the NNW through NNE directions during about 28 percent of the hours. Daytime speeds were typically greater than 3.3 m/s. These primary wind directions coincide with the major terrain features of Jackass Flats in this area. The nighttime wind rose shows a well-developed drainage wind characteristic with over 70 percent of the hours from NNW through NE directions; about 37 percent were from the N direction alone. The winds from the NNW and N probably came from the Fortymile Canyon area, while the winds from the NNE and NE probably came from the upper Jackass Flats area. Less than 15 percent of the nighttime hours were from the S or SSW directions. The nighttime wind speeds were typically greater than 3.3 m/s. The northerly speeds greater than 5.4 m/s are probably associated with channeled northerly winds rather than drainage winds.

Site 9 is in lower Jackass Flats near the center of the valley axis, about 2.5 km north of the highway intersection of U.S. 95 and SR373 in the area previously known as Lathrop Wells. The daytime wind rose shown in Figure 3-9 has about 48 percent of the hours with wind directions from the SSE through SSW directions, and nearly 20 percent from the NNE and NE directions. Most of the daytime speeds are at least 3.3 m/s. The nighttime pattern is similar to Site 5, with corresponding changes in valley orientation between the two sites. The drainage winds appeared with nearly 30 percent of the nighttime winds from the NNE with speeds between 3.3 and 5.4 m/s. About 58 percent of the nighttime hours had winds from the N through NE directions, and about 25 percent were from the SE through S directions.

In summary, the daytime wind results from the R/EFPD sites show that airflow was typically from the southerly directions at most of the sites through Jackass Flats and Midway Valley, apparently channeled by the north/south alignments of Fran Ridge and Yucca Mountain. At least some of the airflow through Midway Valley was diverted toward the northwest upvalley through Yucca Wash, giving the SE and SSE dominant directions at Site 6. The southeasterly winds seen at Sites 2 and 3 show that other airflow is channeled upslope and over the ridge-top through the washes that line the east side of Yucca Mountain. There may be enhancement of southeasterly airflow by the upslope tendency of the east side of Yucca Mountain. The data also show frequent occurrences of northeasterly winds during daytime hours, which are driven by regional scale weather patterns rather than the slope wind mechanisms.

The nighttime wind results from the R/EFPD sites show that airflow was typically either northerly or northwesterly, following the general topographic down-gradient direction of the area. The nighttime winds were channeled by local topography near the sites more so than were the daytime winds. Nighttime airflow is discussed further in later sections of this report.

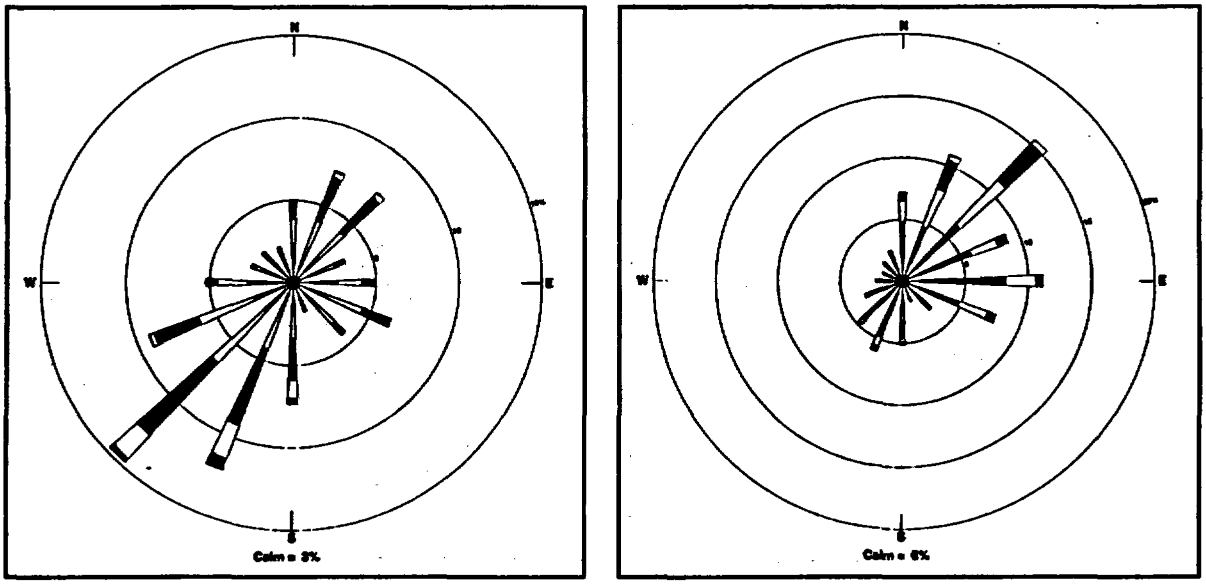
Wind roses for the diurnal periods from three ARL/SORD stations (Desert Rock Airport, MEDA26 in upper Jackass Flats, MEDA6 in Yucca Flat, and MEDA36 east of Indian Springs) are shown in Figures 3-10 and 3-11. These wind roses also show the generally southerly daytime winds with some channeling, and frequent northeasterly winds as well. The nighttime patterns showed generally northerly airflow, which is similar to the pattern observed at the R/EFPD sites.

The Desert Rock Airport station data shown in Figure 3-10 shows winds from the SSW through WSW directions during over 35 percent of the daytime hours, and from the N through NNE during about 20 percent of the hours. The nighttime winds were from the N through ESE directions during about 60 percent of the hours, this is a downslope direction from the Frenchman Flat area through Mercury extending onward toward Amargosa Valley. It is important to note that the nighttime winds were from the northwest during only about 5 percent of the hours. This reduces the probability that near-surface transport during the nighttime hours from the Jackass Flats area would continue onward through the Desert Rock area toward metropolitan Las Vegas.

Winds from the MEDA26 station in upper Jackass Flats north of Skull Mountain shown in Figure 3-10 showed winds from the SSW through WSW during about 40 percent of the daytime hours; about 25 percent of the daytime hours were with winds from the NE through E. Over 60 percent of the nighttime winds were from the NNE through E directions. More than one-half of the nighttime winds had speeds less than 3.3 m/s. The other half of the nighttime hours included winds up to 11 m/s, which were either totally driven by larger scale weather patterns, or at least were larger scale winds enhanced by a drainage wind tendency.

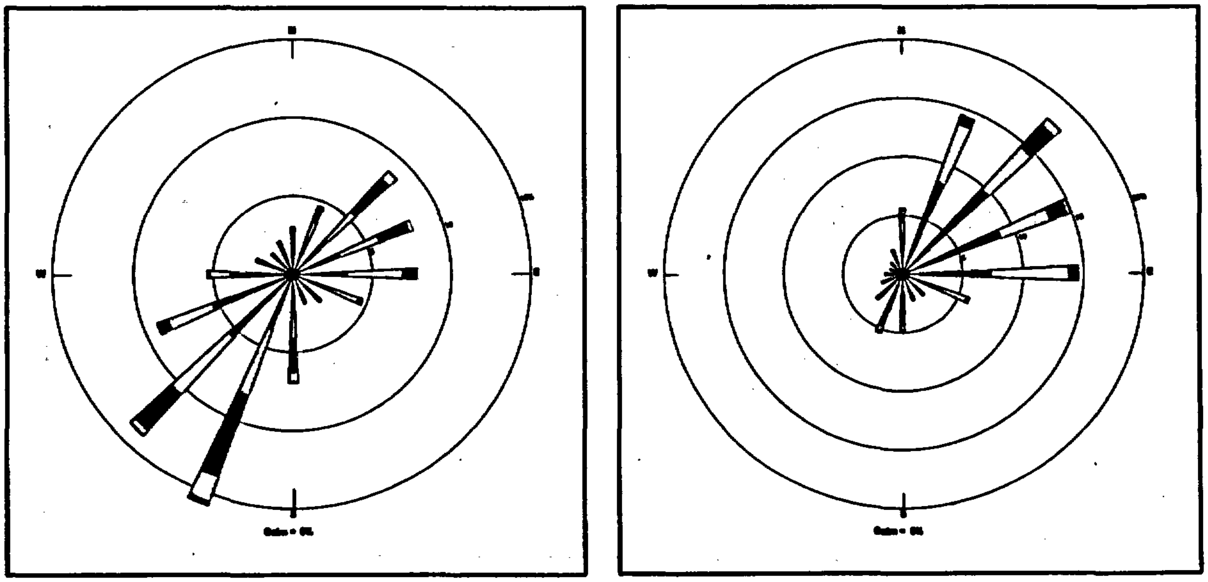
Winds from the MEDA6 station in Yucca Flats shown in Figure 3-11 showed winds from the SE through SW during about 45 percent of the daytime hours; about 29 percent of the daytime hours were with winds from the NW through NE. About 35 percent of the nighttime winds were from the NW through N directions and about 23 percent were from the S through SW. More than one-half of the nighttime winds had speeds less than 3.3 m/s. The spread in directions and the low wind speeds reflect the station location in the enclosed Yucca Flat dry lake area.

The MEDA36 station is east of Indian Springs, about halfway between Yucca Mountain and Las Vegas. The wind data shown in Figure 3-11 show winds from the ESE through SSE during nearly 35 percent of the daytime hours; 20 percent were from the SE alone. Most of the remaining daytime winds were divided between the WNW and NNE directions. The nighttime winds showed two dominate conditions occurring with similar frequencies. Winds were from the SE through S during about 30 percent of the hours with speeds often up to 8.5 m/s. Some of these winds could be related to a combination of well-developed drainage mechanism winds from the large Spring Mountains mountain range southeast of the site and the Sheep Range east of the site. The other nighttime directions were divided from SW to N, mostly in the W through NW directions.



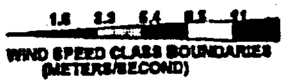
(a) Desert Rock (DRA), NV Day

(b) Desert Rock (DRA), NV Night



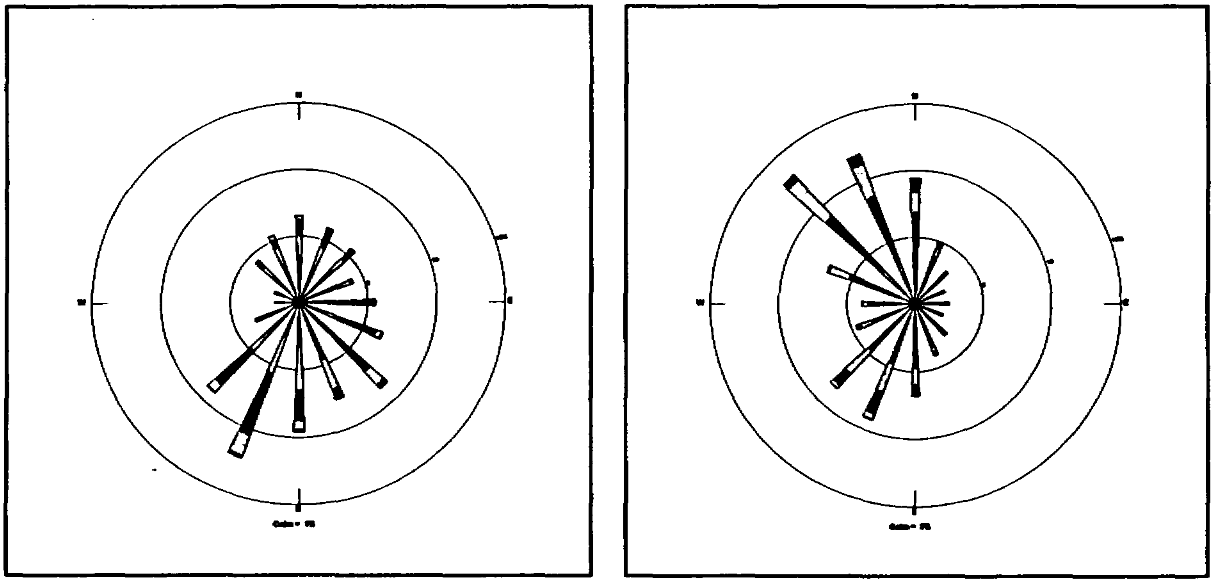
(c) MEDA26 Day

(d) MEDA26 Night



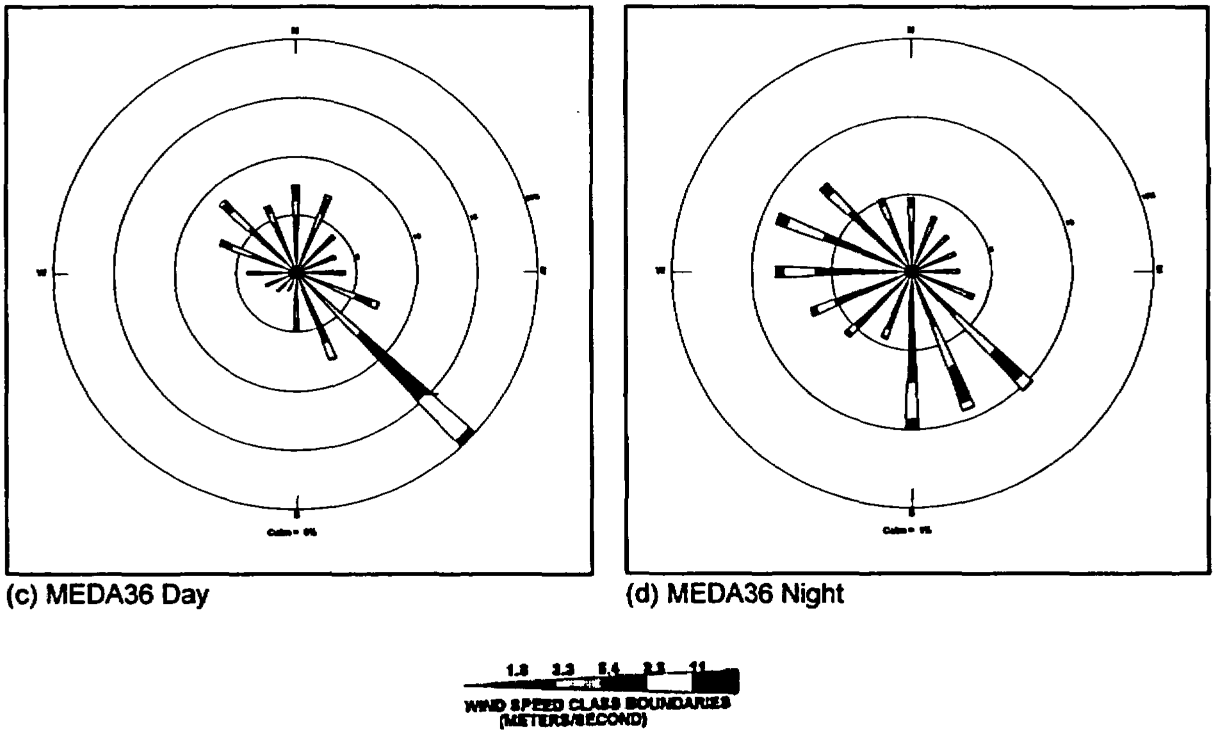
Note: The diagram is the frequency of occurrence for each wind direction from which the wind is blowing.

Figure 3-10. Diurnal Wind Rose Plots of DRA and MEDA26



(a) MEDA6 Day

(b) MEDA6 Night



(c) MEDA36 Day

(d) MEDA36 Night

Note: The diagram is the frequency of occurrence for each wind direction from which the wind is blowing.

Figure 3-11. Diurnal Wind Rose Plots of MEDA6 and MEDA36

3.1.3 Seasonal Cycle

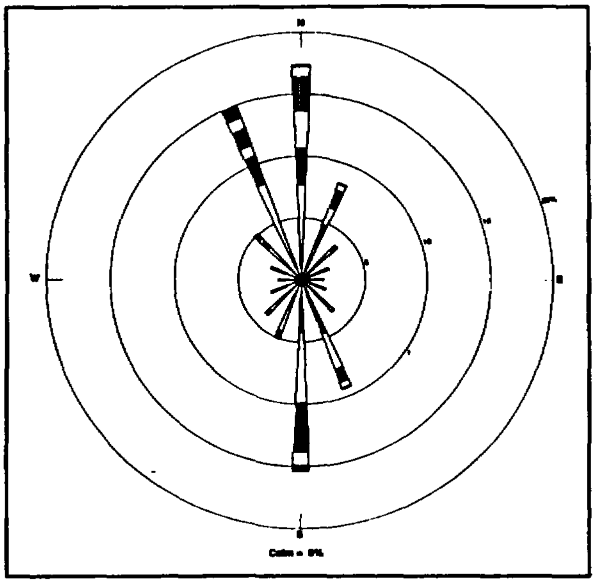
Local wind patterns undergo changes throughout the year following the climatic seasons. In one sense, the changes are partly due to the changes in the dominant diurnal cycle of the season. For example, the nighttime airflow characteristics have more opportunity to develop during winter months than in summer, and conversely for daytime characteristics during summer. On the other hand, some changes are also due to dominant mesoscale and synoptic weather patterns occurring in the region during the corresponding seasons. For example, some of the shift to more frequent northerly winds in winter with more nighttime hours is offset by an increase in weather frontal system passages with corresponding strong southerly winds that can overwhelm the drainage wind mechanisms.

An illustration of the seasonal cycle that affects all the sites in a similar way is shown in Figures 3-12 through 3-15, with wind roses summarizing data from all hours in the four climatic seasons at Sites 1, 2, and 9. Both the 10-m and 60-m levels at Site 1 were chosen for discussion in this section because Site 1 is the nearest R/EFPD site to the north portal of the Exploratory Studies Facility and proposed repository surface facility locations. Site 2 was also chosen because of the distinctive ridge-top pattens that occur at this site. Site 9 was chosen for comparison purposes and because it is the nearest R/EFPD site to the populated Amargosa Valley area.

The wind roses from Sites 1 and 9 data show the same dominant directions as those seen in the summaries for all seasons, with changes between the relative frequencies of southerly and northerly winds. The summer months show notably more frequent southerly winds with speeds typically between 3.3 and 8.5 m/s. The NW and NNW apparent drainage winds at Site 1 still occur during more than 25 percent of the hours, typically with speeds in the 1.8 to 3.3 m/s category. The corresponding apparent drainage NNE and NE winds at Site 9 also occur during about 25 percent of the hours, though the speeds are typically between 3.3 and 5.4 m/s.

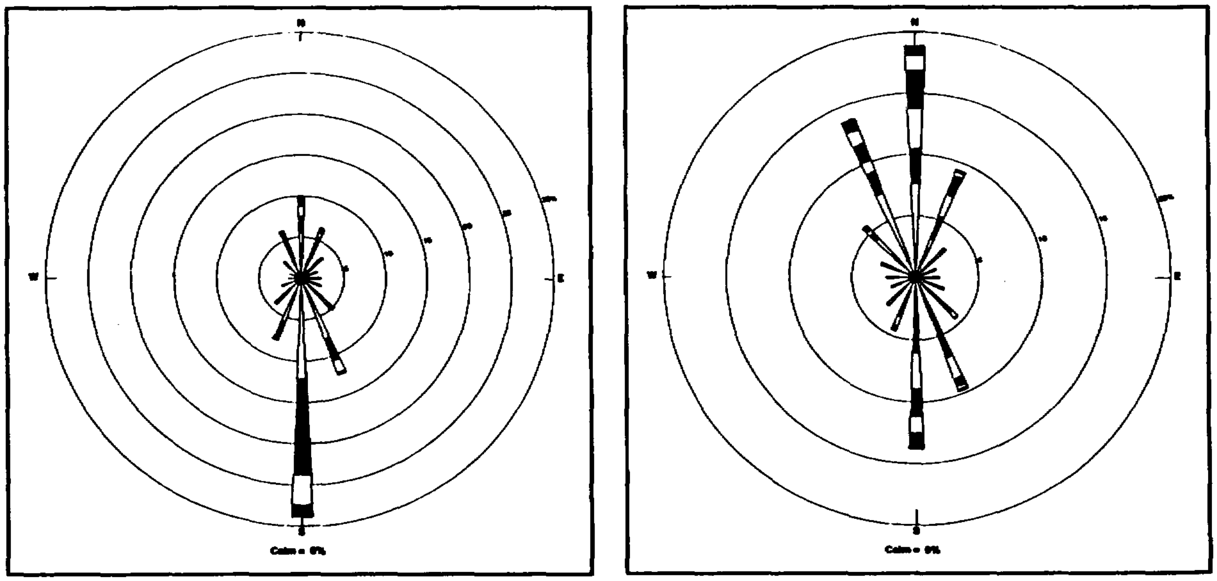
The seasonal wind roses from Site 2 shown in Figure 3-14 show the presence of another important meteorological event, strong northwesterly winds in every season but summer. The NW and NNW directions during winter and spring usually occur with speeds greater than 5.4 m/s, frequently greater than 11 m/s. Although these winds do not appear significant in comparison to the more typical southeasterly winds, the periods of strong northerly and northwesterly winds on the ridge top could be important to construction and operations in exposed locations.

The combination of diurnal and seasonal characteristics in the local wind patterns are shown in the wind roses for Sites 1, 2, and 9 in Figures 3-16 through 3-23. These seasonal diurnal wind roses can be compared with either the diurnal wind roses from all seasons in Figures 3-5 through 3-9, or the seasonal wind roses from all hours in Figure 3-12 through 3-15. The daytime, seasonal wind roses for data from both levels at Site 1 show the significant trend for southerly winds dominating in the summertime; nearly 85 percent of the daytime summer winds are from the directions between SE and SW, nearly 40 percent are from the south, alone. The speeds of these southerly winds are typically between 3.3 and 8.5 m/s. The daytime summer wind rose from Site 9 is similar to that from



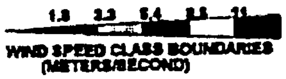
(a) Site 1-60m - Fall

(b) Site 1-60m - Spring



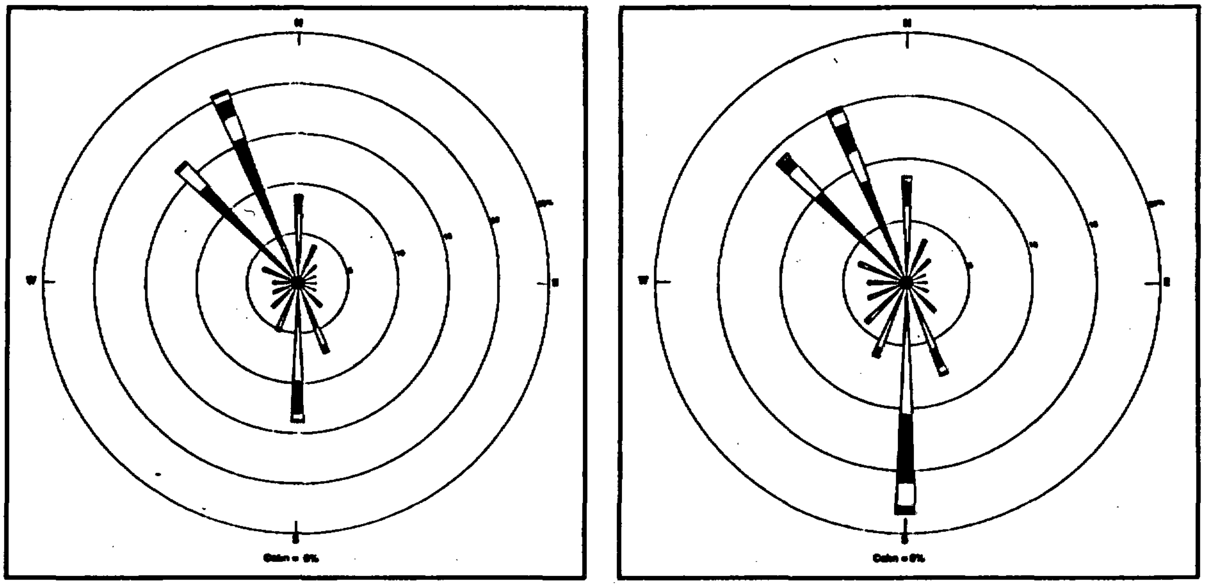
(c) Site 1-60m - Summer

(d) Site 1-60m - Winter



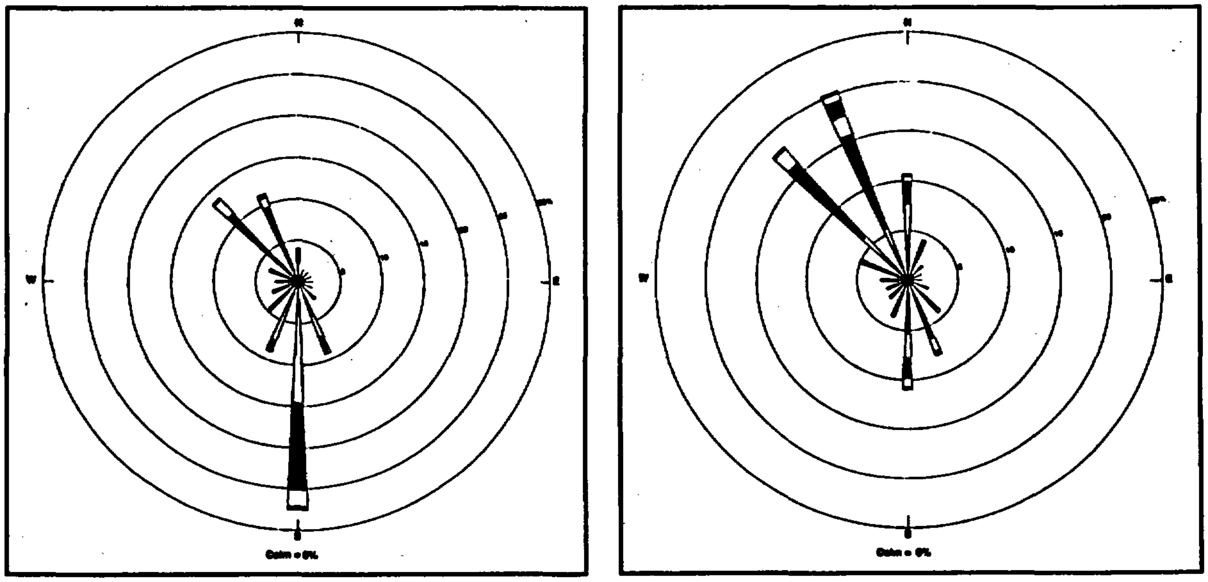
Note: The diagram is the frequency of occurrence for each wind direction from which the wind is blowing.

Figure 3-12. Seasonal Wind Rose Plots of EFPD Site 1-60 meter Level



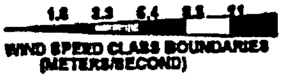
(a) Site 1-10m - Fall

(b) Site 1-10m - Spring



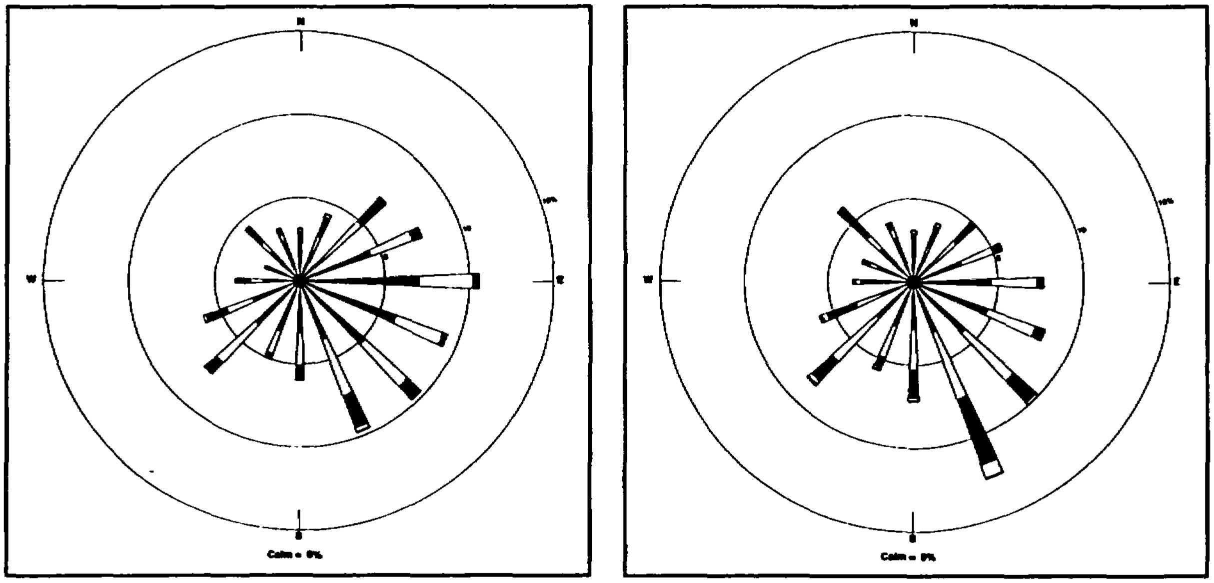
(c) Site 1-10m - Summer

(d) Site 1-10m - Winter



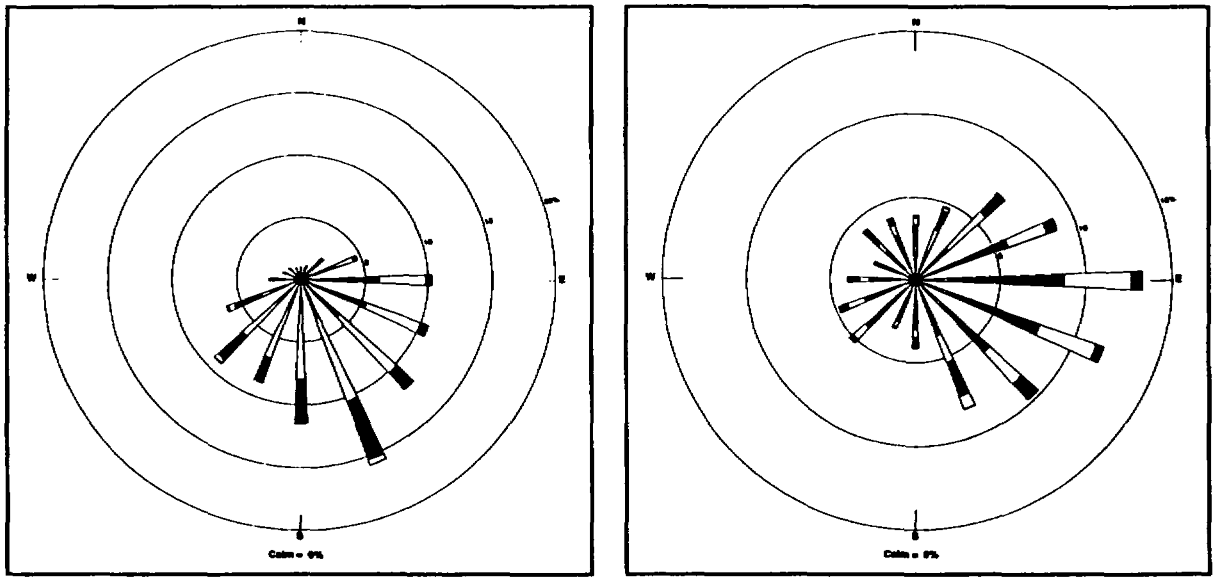
Note: The diagram is the frequency of occurrence for each wind direction from which the wind is blowing.

Figure 3-13. Seasonal Wind Rose Plots of EFPD Site 1-10 meter Level



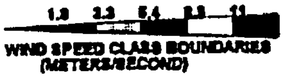
(a) Site 2 - Fall

(b) Site 2 - Spring



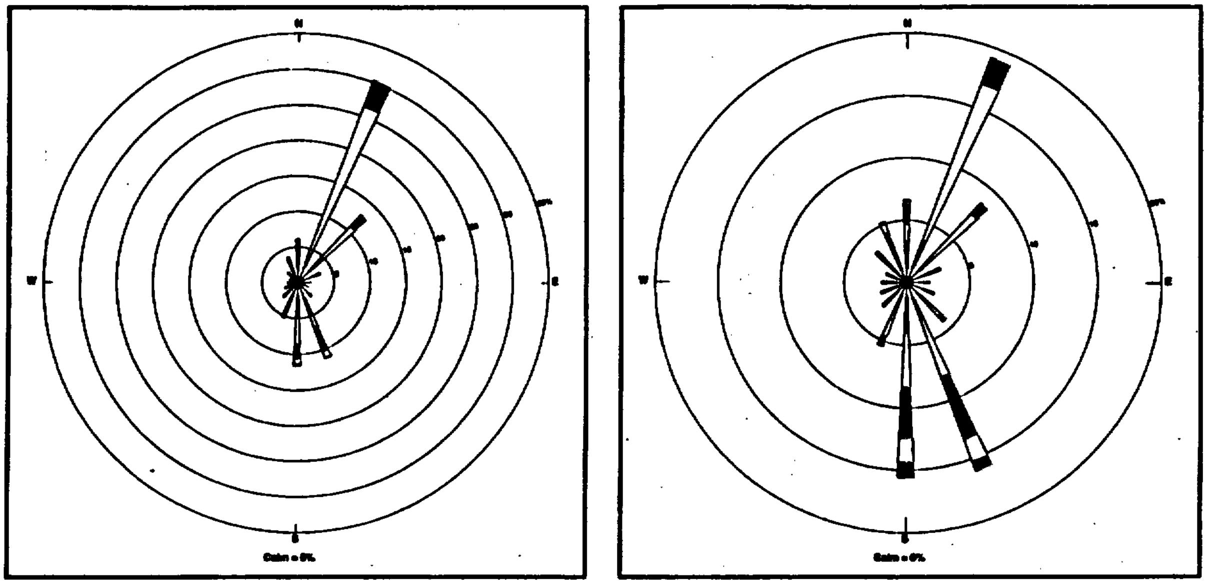
(c) Site 2 - Summer

(d) Site 2 - Winter



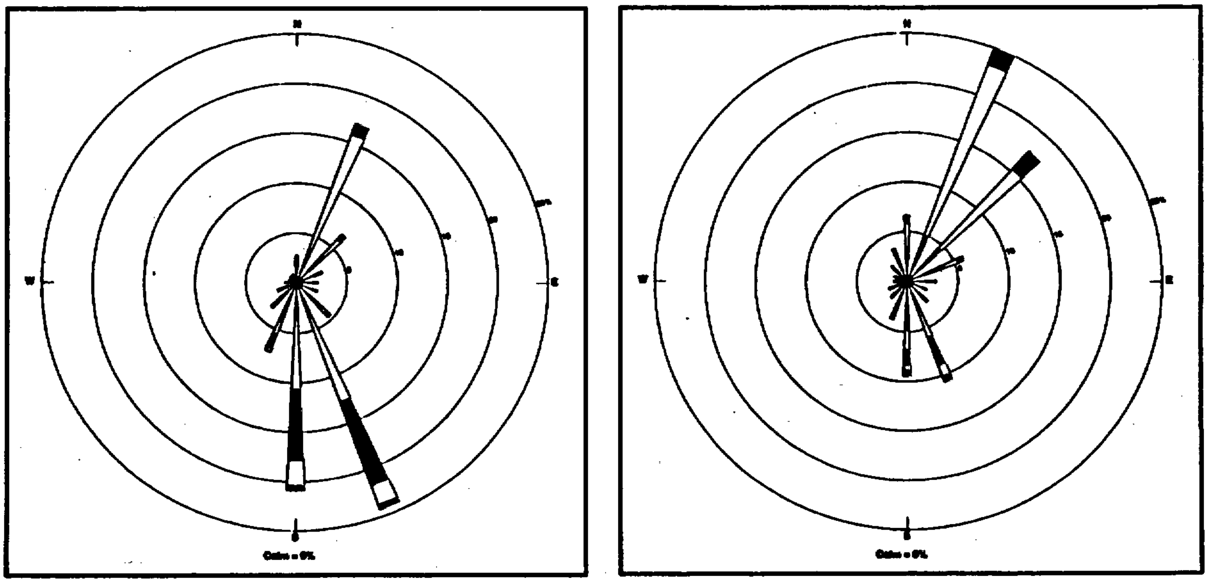
Note: The diagram is the frequency of occurrence for each wind direction from which the wind is blowing.

Figure 3-14. Seasonal Wind Rose Plots of EFPD Site 2



(a) Site 9 - Fall

(b) Site 9 - Spring

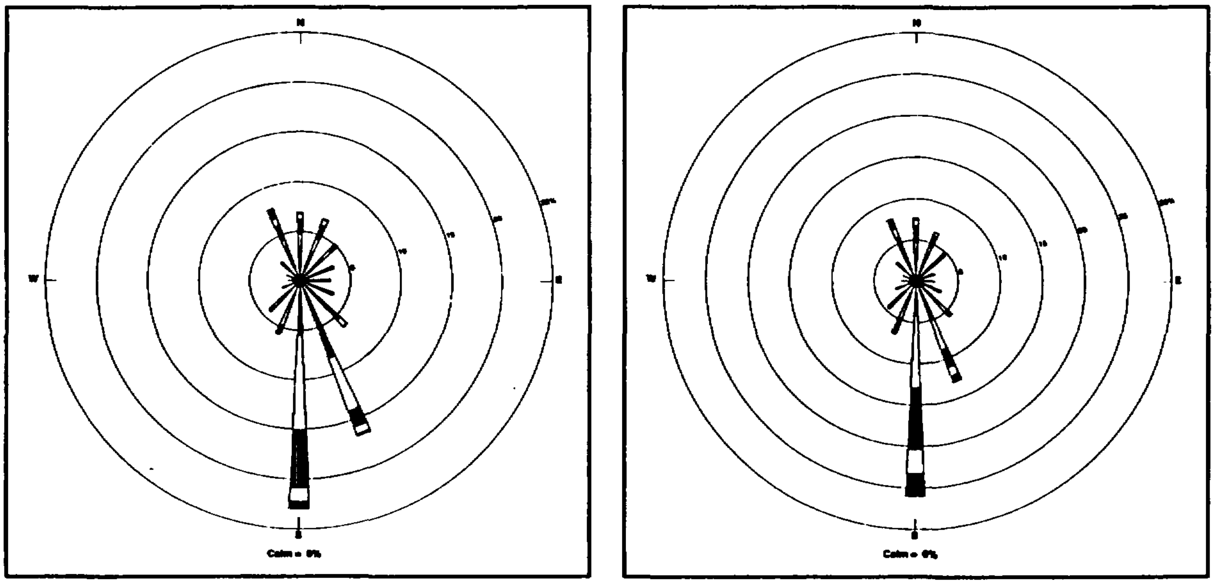


(c) Site 9 - Summer

(d) Site 9 - Winter

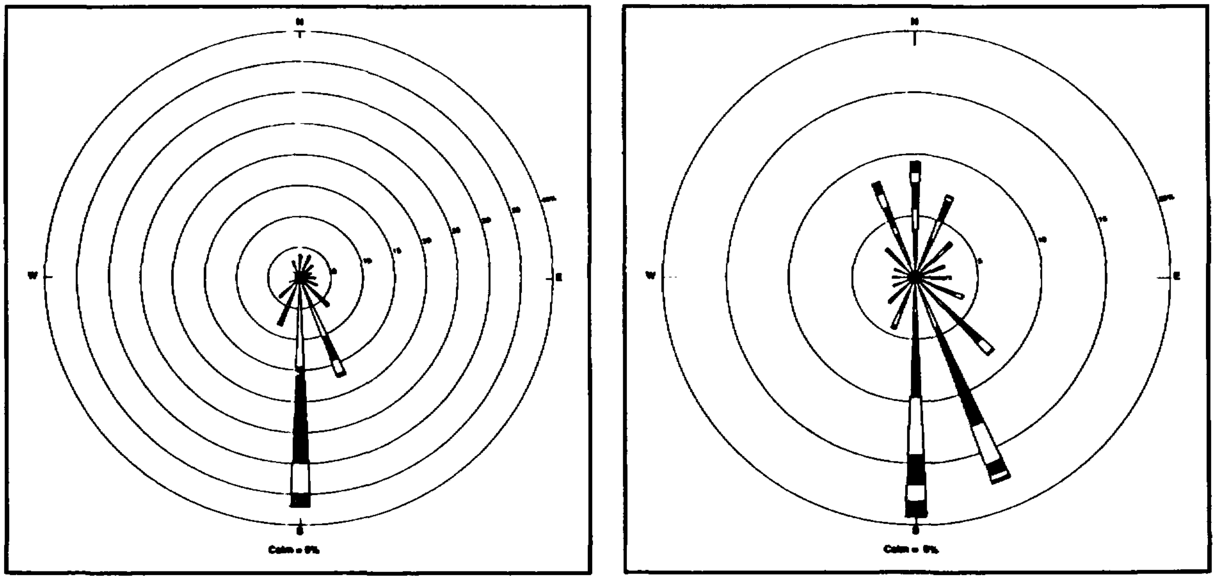
Note: The diagram is the frequency of occurrence for each wind direction from which the wind is blowing.

Figure 3-15. Seasonal Wind Rose Plots of EFPD Site 9



(a) Site 1-60m - Day Fall

(b) Site 1-60m - Day Spring

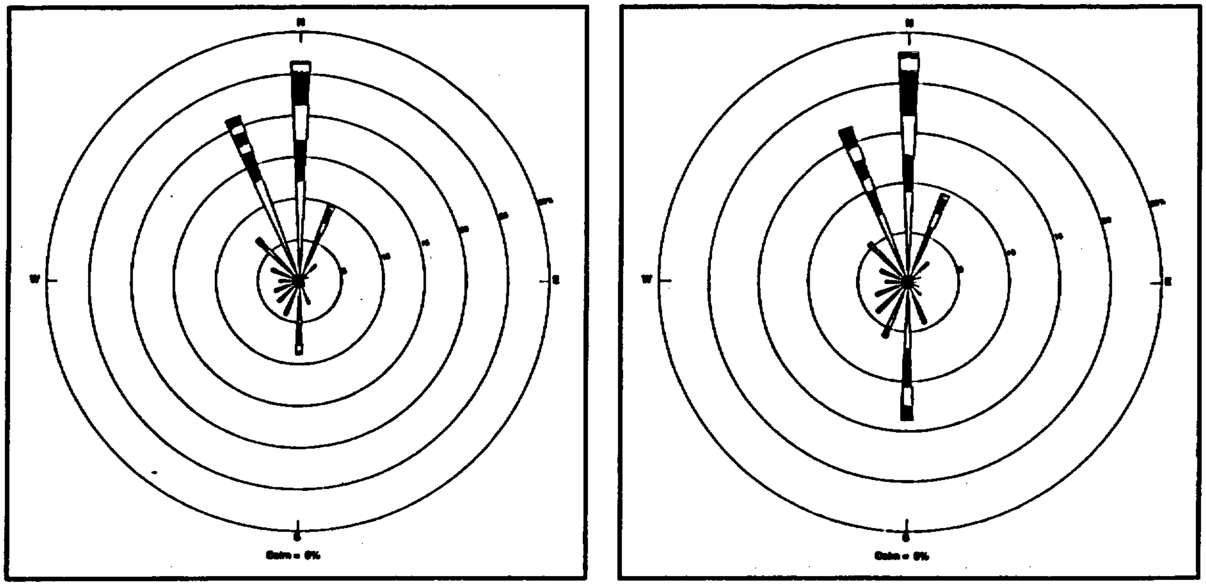


(c) Site 1-60m - Day Summer

(d) Site 1-60m - Day Winter

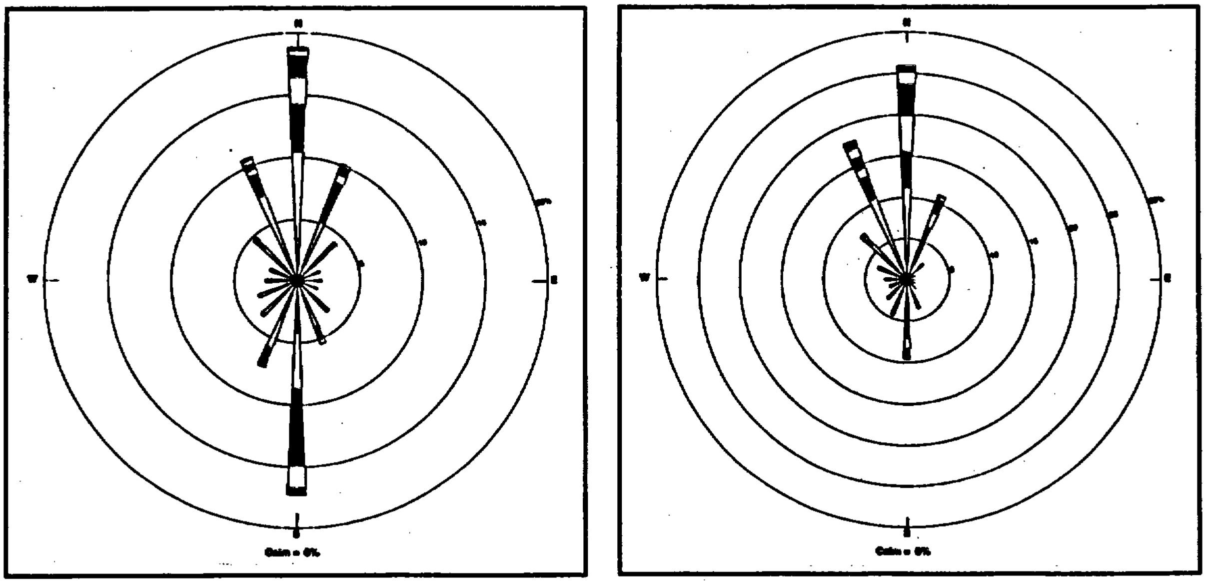
Note: The diagram is the frequency of occurrence for each wind direction from which the wind is blowing.

Figure 3-16. Seasonal Wind Rose Plots for Site 1-60 meter Level for Daytime Hours



(a) Site 1-60m - Night Fall

(b) Site 1-60m - Night Spring

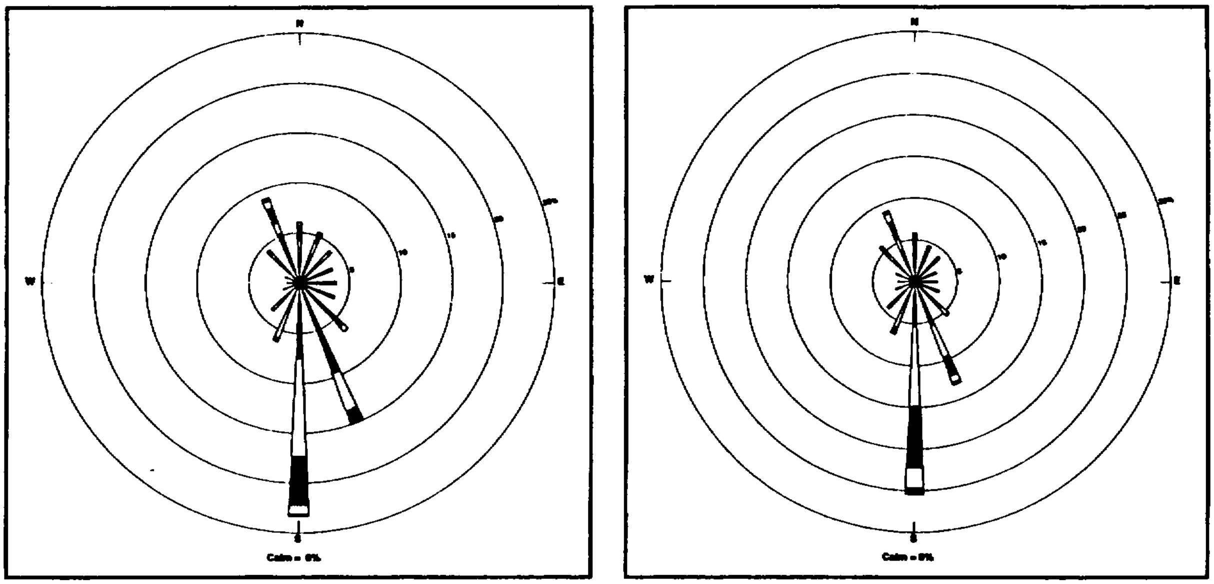


(c) Site 1-60m - Night Summer

(d) Site 1-60m - Night Winter

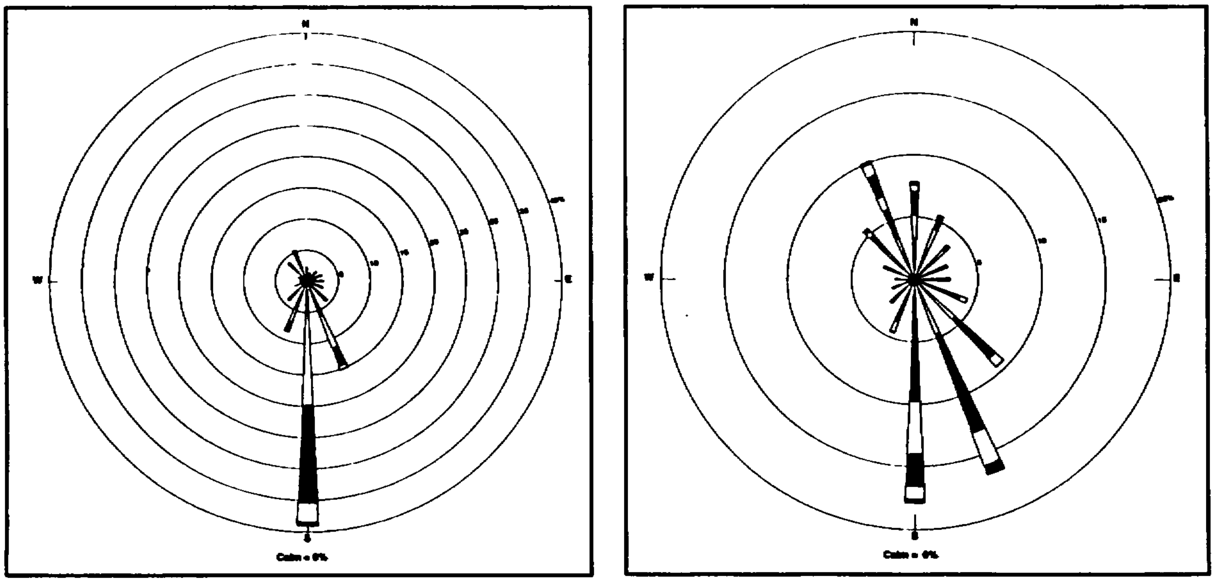
Note: The diagram is the frequency of occurrence for each wind direction from which the wind is blowing.

Figure 3-17. Seasonal Wind Rose Plots for Site 1-60 meter Level for Nighttime Hours



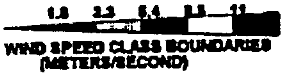
(a) Site 1-10m - Day Fall

(b) Site 1-10m - Day Spring



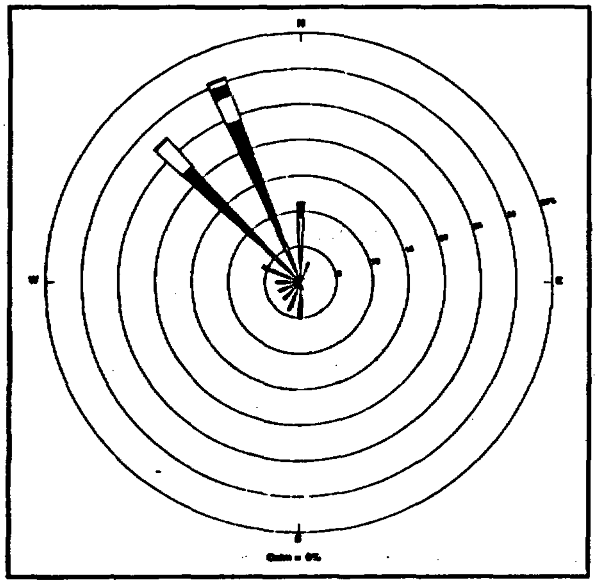
(c) Site 1-10m - Day Summer

(d) Site 1-10m - Day Winter



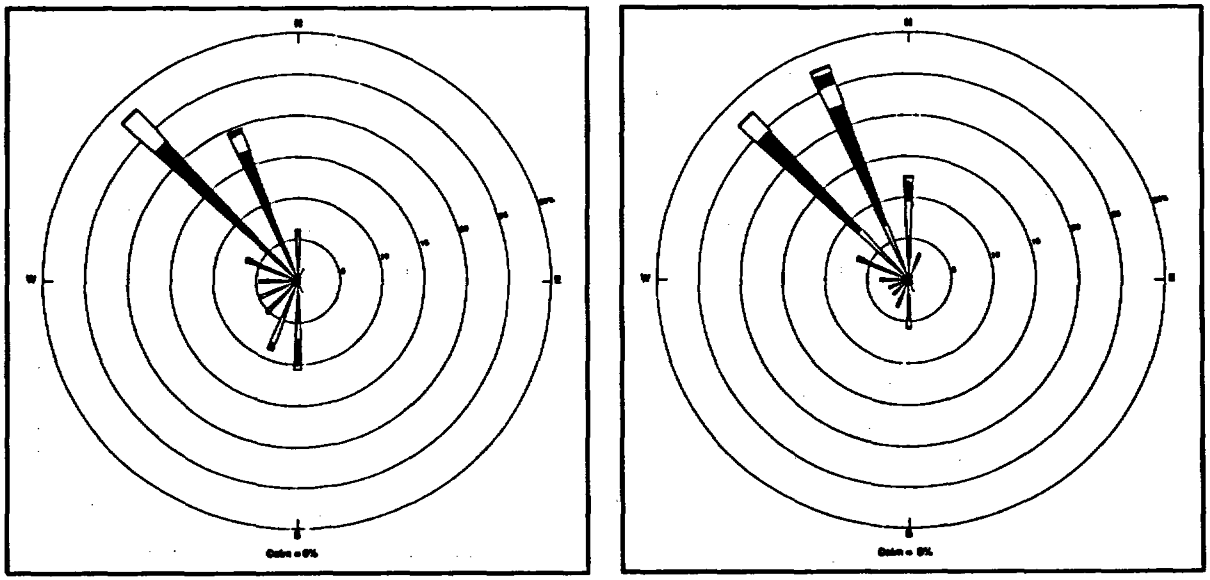
Note: The diagram is the frequency of occurrence for each wind direction from which the wind is blowing.

Figure 3-18. Seasonal Wind Rose Plots for Site 1-10 meter Level for Daytime Hours



(a) Site 1-10m - Night Fall

(b) Site 1-10m - Night Spring

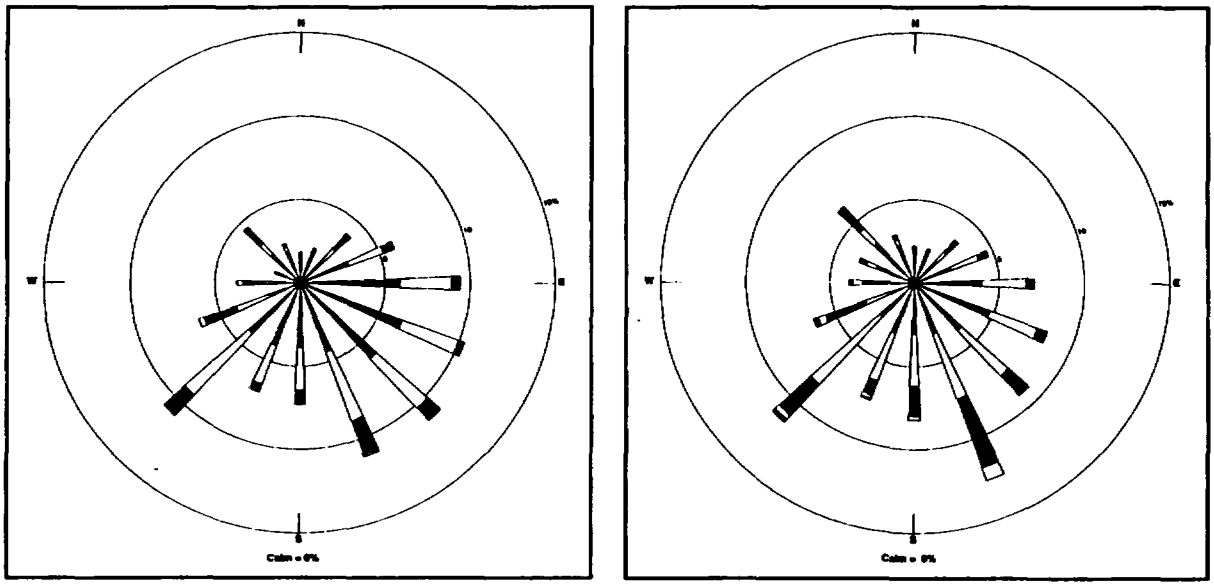


(c) Site 1-10m - Night Summer

(d) Site 1-10m - Night Winter

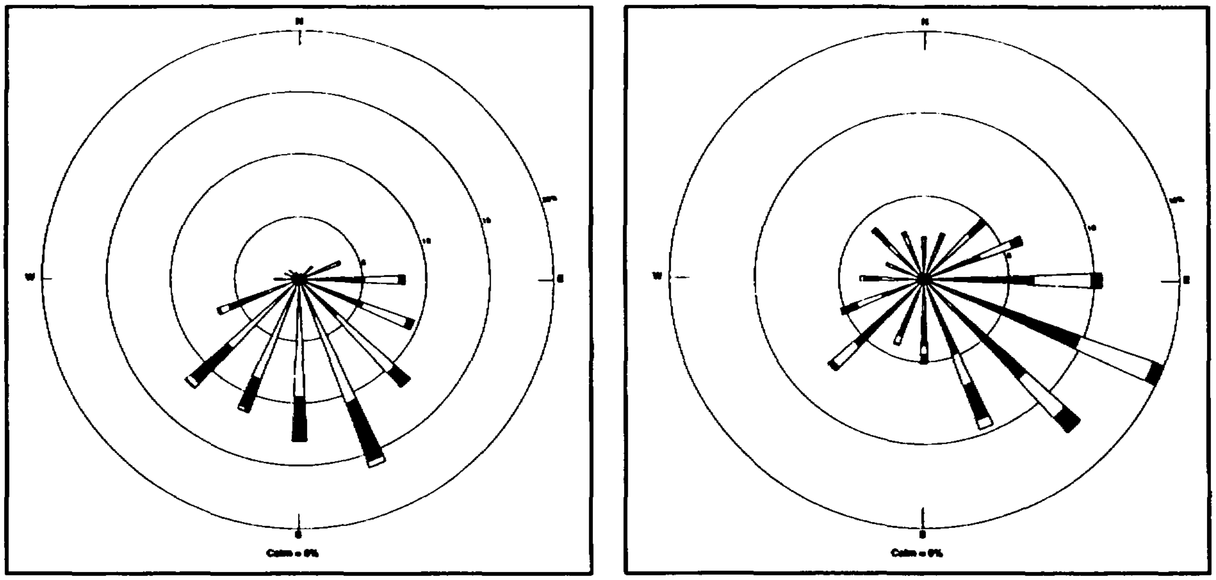
Note: The diagram is the frequency of occurrence for each wind direction from which the wind is blowing.

Figure 3-19. Seasonal Wind Rose Plots for Site 1-10 meter Level for Nighttime Hours



(a) Site 2 - Day Fall

(b) Site 2 - Day Spring

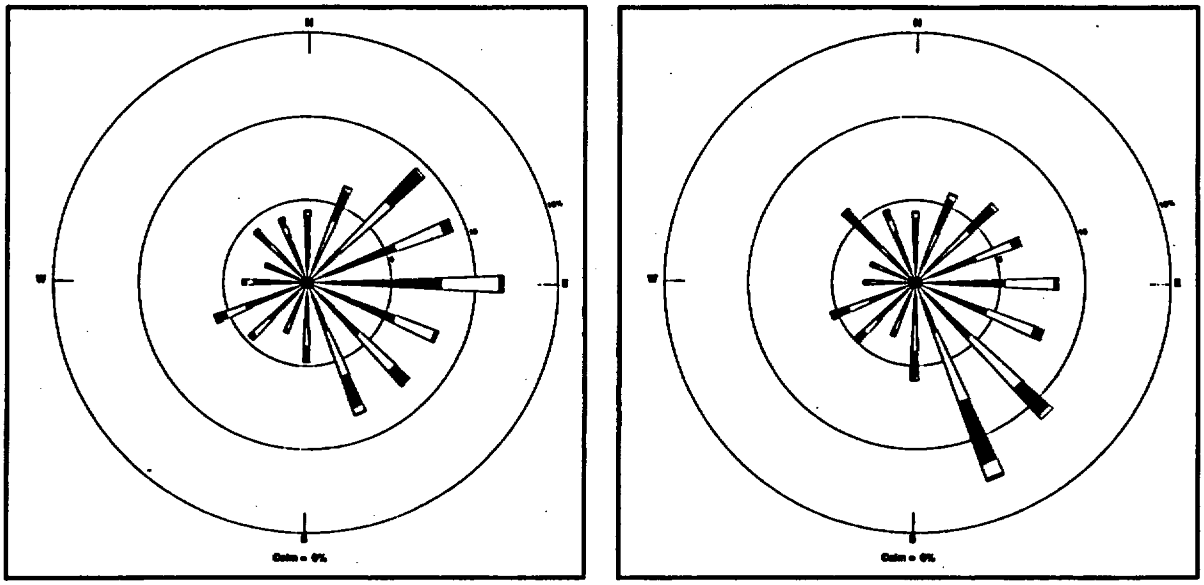


(c) Site 2 - Day Summer

(d) Site 2 - Day Winter

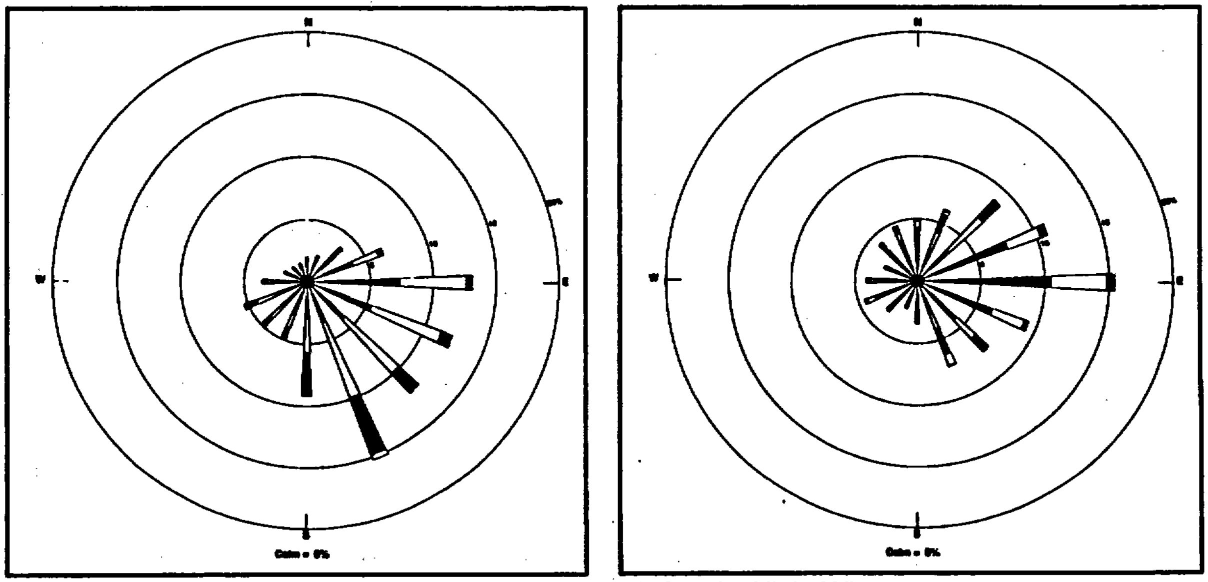
Note: The diagram is the frequency of occurrence for each wind direction from which the wind is blowing.

Figure 3-20. Seasonal Wind Rose Plots for Site 2 for Daytime Hours



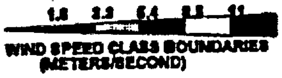
(a) Site 2 - Night Fall

(b) Site 2 - Night Spring



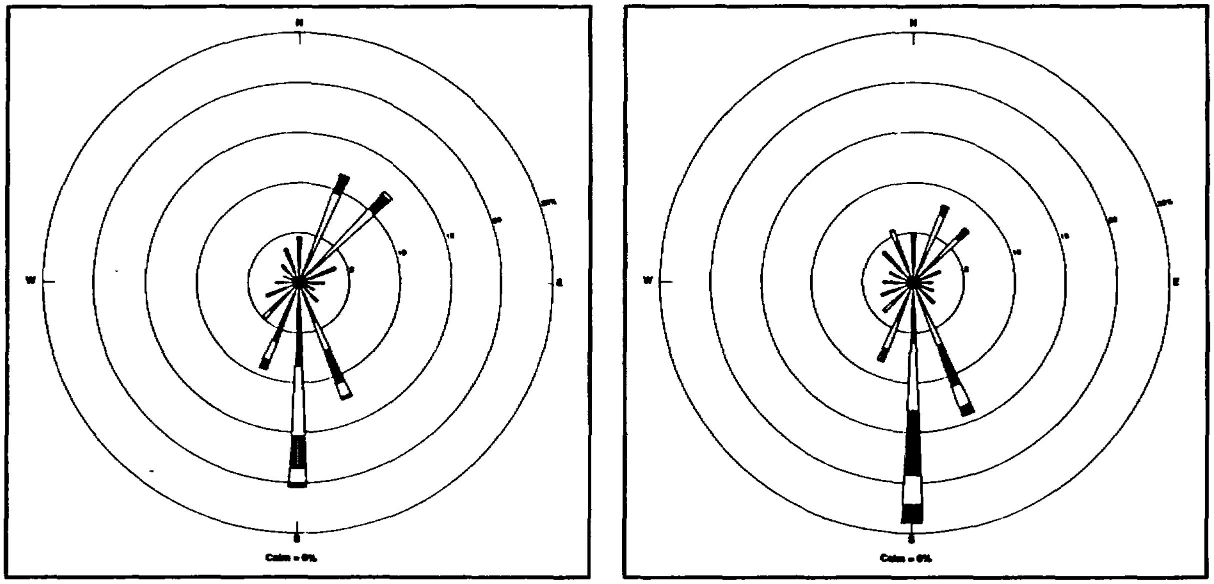
(c) Site 2 - Night Summer

(d) Site 2 - Night Winter



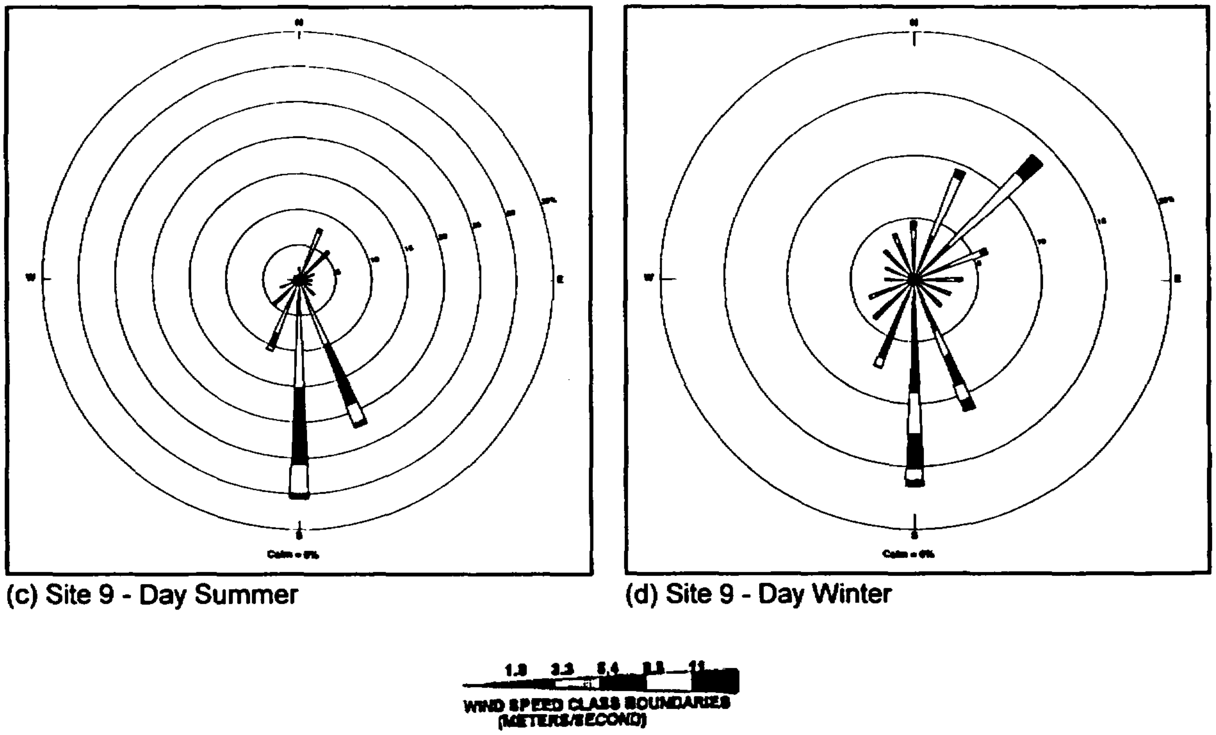
Note: The diagram is the frequency of occurrence for each wind direction from which the wind is blowing.

Figure 3-21. Seasonal Wind Rose Plots for Site 2 for Nighttime Hours



(a) Site 9 - Day Fall

(b) Site 9 - Day Spring

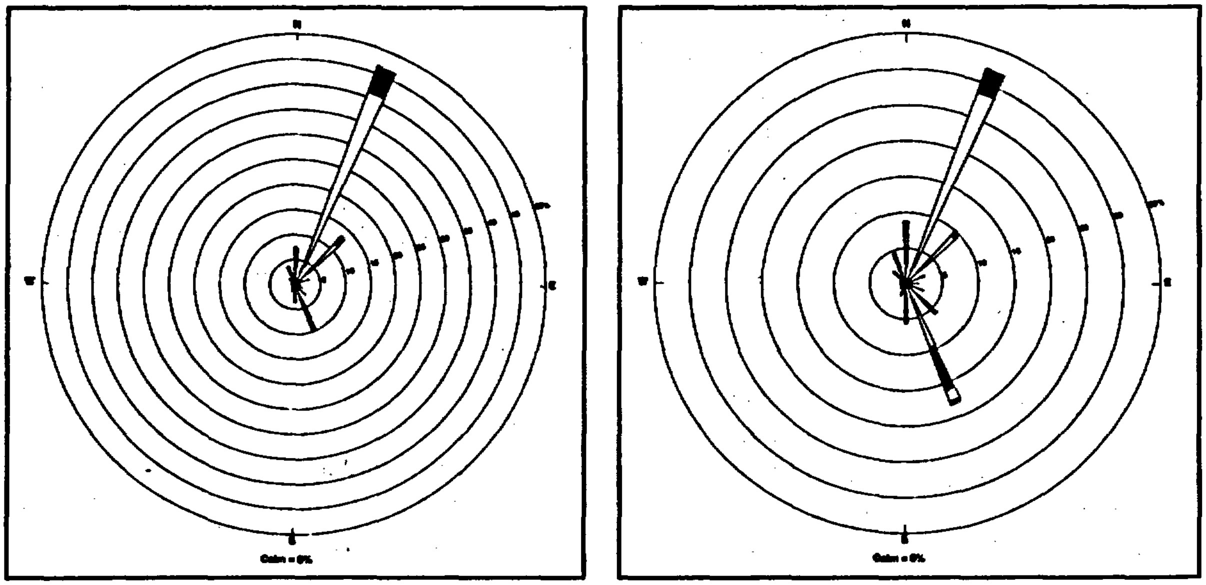


(c) Site 9 - Day Summer

(d) Site 9 - Day Winter

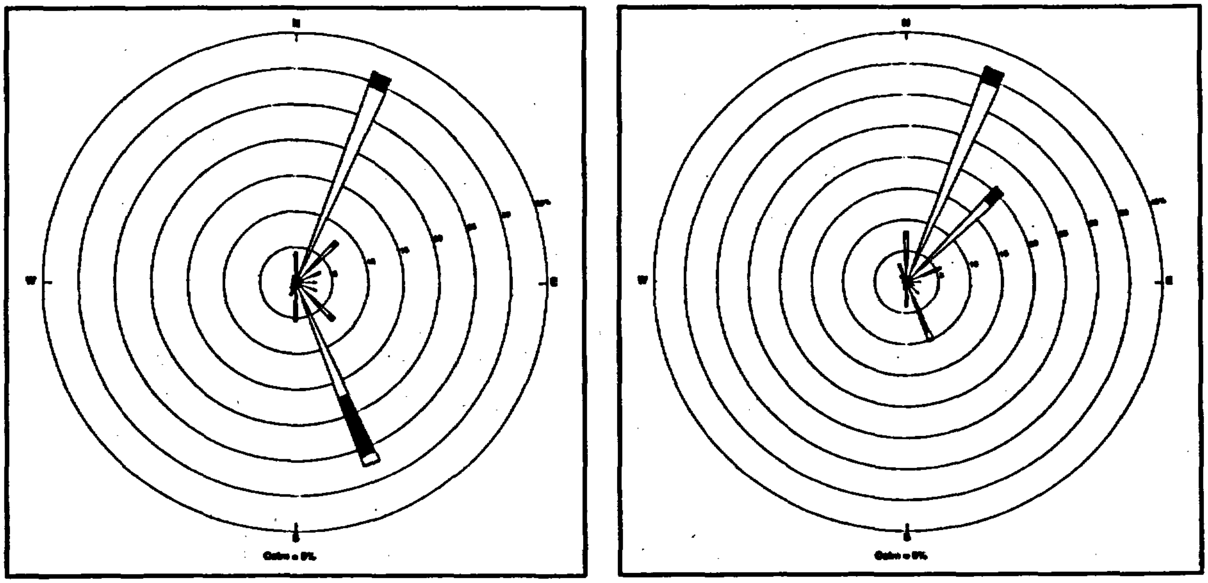
Note: The diagram is the frequency of occurrence for each wind direction from which the wind is blowing.

Figure 3-22. Seasonal Wind Rose Plots for Site 9 for Daytime Hours



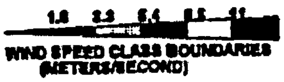
(a) Site 9 - Night Fall

(b) Site 9 - Night Spring



(c) Site 9 - Night Summer

(d) Site 9 - Night Winter



Note: The diagram is the frequency of occurrence for each wind direction from which the wind is blowing.

Figure 3-23. Seasonal Wind Rose Plots for Site 9 for Nighttime Hours

Site 1, except the southerly winds are distributed more evenly between the SSE through SSW directions, and there were more occurrences of winds above 8.5 m/s. Both sites show some occurrences of northerly winds during about 10 percent of the hours. The daytime spring and fall wind roses for all three sites are very similar, reflecting these seasons as transition periods between the dominant summer and winter periods.

The nighttime seasonal wind roses show the significant trend for northerly winds dominating in the winter; specific directions at each site are channeled by local topography more than are the daytime winds. The nighttime winds at Site 1 are from the NW and NNW during all seasons, typically with speeds less than 3.3 m/s. The corresponding winds at Site 9 are from the NNE and NE, typically with speeds greater than 3.3 m/s. The nighttime summer wind rose from Site 1 data shows about twice the frequency of southerly winds than in winter. Site 2 does not experience the topographic channeling that occurs at Sites 1 and 9. The wind roses from Site 2 shown in Figure 3-30 show a seasonal change with more frequent northerly winds in fall, winter and spring than in the summer. The winter wind roses from Site 2 show more frequent easterly component winds than occur during the other months. The summer nighttime data show the fewest occurrences of winds greater than 5.4 m/s, indicating the least amount of strong weather patterns during the summer.

3.2 ATMOSPHERIC STABILITY

Atmospheric stability is the second primary topic of atmospheric dispersion. It is an indicator of the potential strength of the horizontal and vertical atmospheric mixing processes. A primary study of atmospheric dispersion resulted in the six "Pasquill Stability Categories" (EPA 1987). One extreme is the F-category, which is "very stable", restricted mixing conditions that occur during nights with little cloud cover and low wind speeds; this is typical of surface-based temperature inversion periods. The other extreme is the A-category "extremely unstable", vigorous mixing conditions which occur during days with strong to moderate isolation and low wind speeds; these are typical of large negative temperature gradients and strong vertical motions. The "neutral" category is associated with moderate mixing conditions, which occur during either night or day with moderate to high wind speeds.

The application of the stability data is to determine dispersion coefficients for atmospheric modeling tasks. The models describe dispersion of the airborne material as spreading horizontally and vertically most rapidly during unstable periods, and the slowest spread occurring during the stable periods.

Two common measures of atmospheric stability applicable to onsite measurements in Nuclear Regulatory Commission (NRC 1972), American Nuclear Society and American National Standard Institute (ANS/ANSI 1984), and Environmental Protection Agency (EPA 1987) monitoring guidance are the vertical temperature gradient (delta-temperature, or delta-T) and the standard deviation of the horizontal wind direction (sigma-theta, σ_θ, or sigma-A, σ_A). Other indicators include some direct and indirect measures of atmospheric turbulence, and the technique incorporating direct solar radiation and low-level temperature difference measurements known as "SRDT" (solar radiation, delta-T), (EPA 1987). The original Pasquill stability category schemes were based on solar insolation, cloud cover, and surface wind speed (EPA 1987). The primary NRC and ANS/ANSI stability indicator was the vertical temperature gradient, typically between 10 and 60 m-agl. The EPA use of vertical temperature gradient data is based on the measurements between 2 and 10 m-agl.

One method used in EPA monitoring guidance (EPA 1987) to assign stability categories utilizes hourly sigma-A (standard deviation of the horizontal wind direction) values with wind speed and time of day. This method has become commonly accepted in many regulatory applications.

Unstable periods occur with large negative vertical temperature gradients (strong surface heating), and typically occur during daytime periods with large values of turbulence indicators, such as sigma-A. Moderate negative vertical temperature gradients or values of turbulence indicators and higher wind speed periods indicate neutral stability. Stable periods are characterized by positive vertical temperature gradients, low values of turbulence indicators, and moderate to slow wind speeds. Some stability schemes also assign stable categories to nighttime periods with low wind speeds and large sigma-A values, since the apparently large sigma-A is probably due to the wind "meandering", or slowly undergoing large direction changes.

The Yucca Mountain area typically has unstable and neutral conditions during daytime hours with stable conditions typical of the nighttime hours. This diurnal stability cycle is a product of the typical arid, cloud-free environment of the region. In daytime solar energy heats the ground surface promoting convective vertical mixing and high wind speeds; both factors contribute to effective mixing conditions. During the nighttime hours the clear sky allows the ground to cool creating a positive vertical temperature gradient (temperature increasing with height), which suppresses vertical mixing. The cool air near the ground is more dense than warmer air; this density difference between air over elevated terrain and that overlying adjacent valley areas creates the "drainage" wind mechanism.

Results of the occurrences of Pasquill Stability Categories based on the night-adjusted Sigma-A method from the R/EFPD meteorological monitoring program sites for the years 1994 through 1996 are shown in Table 3-1. The overall averages indicate an even distribution among the unstable (A through C) and stable (E and F) periods with the most occurrences of neutral stability hours. Some of the differences in results between individual sites are attributed to topographic exposure differences.

Table 3-1. Occurrences of Pasquill Stability Categories at R/EFPD Sites

	A	B	C	D	E	F
Site 1	17.5	12.3	10.7	28.4	14.7	16.5
Site 2	8.7	14.7	13.8	40.5	14.9	7.4
Site 3	27.1	18.4	3.5	8.4	19.6	23.0
Site 4	8.9	10.6	12.2	45.0	12.7	10.6
Site 5	12.0	12.1	10.4	51.1	9.1	5.4
Site 6	12.5	17.1	10.3	25.9	24.5	9.8
Site 7	18.0	13.5	10.8	22.2	7.0	28.6
Site 8	18.8	12.4	10.3	22.7	8.3	27.5
Site 9	12.3	10.4	9.0	42.8	21.7	3.9
Average	15.1	13.5	10.1	31.9	14.7	14.7

Note: Values shown are the percent of total hours for the Sites, with the averages in each stability category for all Sites.

The hilltop Sites 2 and 4, show fewer occurrences of the extremely unstable (A) and extremely stable (F) categories, with proportionately more occurrences in the neutral category (D). The shift in occurrences may be due to the generally greater wind speeds, and fewer occurrences of steady drainage winds at the hilltop sites compared to valley floor locations.

The two sites on the valley floor in southern Jackass Flats, Sites 5 and 9, and Site 6 in upper Yucca Wash, show fewer hours of extremely stable (F) categories, and slightly fewer hours of extremely unstable (A) categories. These are compensated by more hours in the slightly stable (E) and neutral (D) categories. The nighttime hours at these sites typically have wind speeds greater than the range allowed by the extremely stable (F) category, which moves those periods into the slightly stable (E) or neutral (D) categories. The greater wind speeds may be due to the site location in larger valley-type settings, where the drainage winds have had the opportunity to develop into a steady flow and accelerate to faster speeds during a longer downslope path.

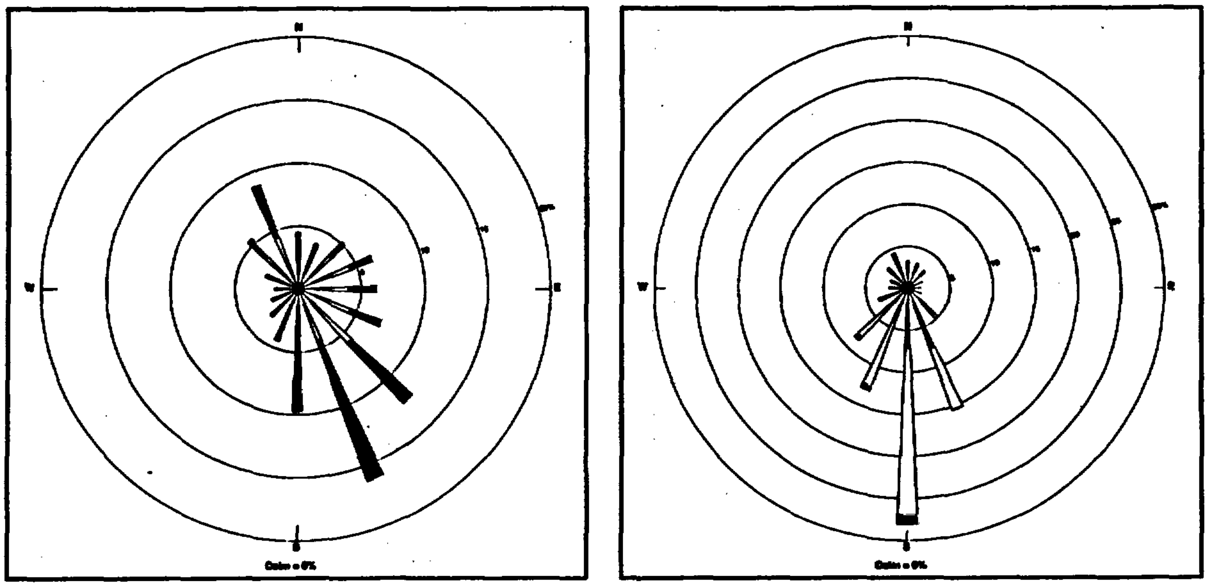
Site 3, in the narrow topographic confinement of Coyote Wash, shows nearly the opposite stability results as were seen in the previous two examples. The categories here are shifted toward the extremely unstable (A) and extremely stable (F) categories, with fewer occurrences of the neutral (D) category. This shift may be partly due to the typically slower wind speeds at Site 3, which allows for larger changes in wind direction during the daytime unstable periods, and steady, slower speed winds remaining in the extremely stable mode.

Sites 7 and 8 show very similar stability category distributions, which was not anticipated due to their dissimilar topographic exposures. Site 7 is in the low point of the hydrologic drainage on the east-central side of Midway Valley, while Site 8 is in the low saddle on the south side of Midway Valley. One speculative explanation for the similarity draws upon observations addressed in the next section. The nighttime stable layer in Midway Valley is structured to virtually isolate the lowest area at Site 7 from Midway Valley, such that it effectively is "draining" a small portion of Midway Valley rather than the whole valley.

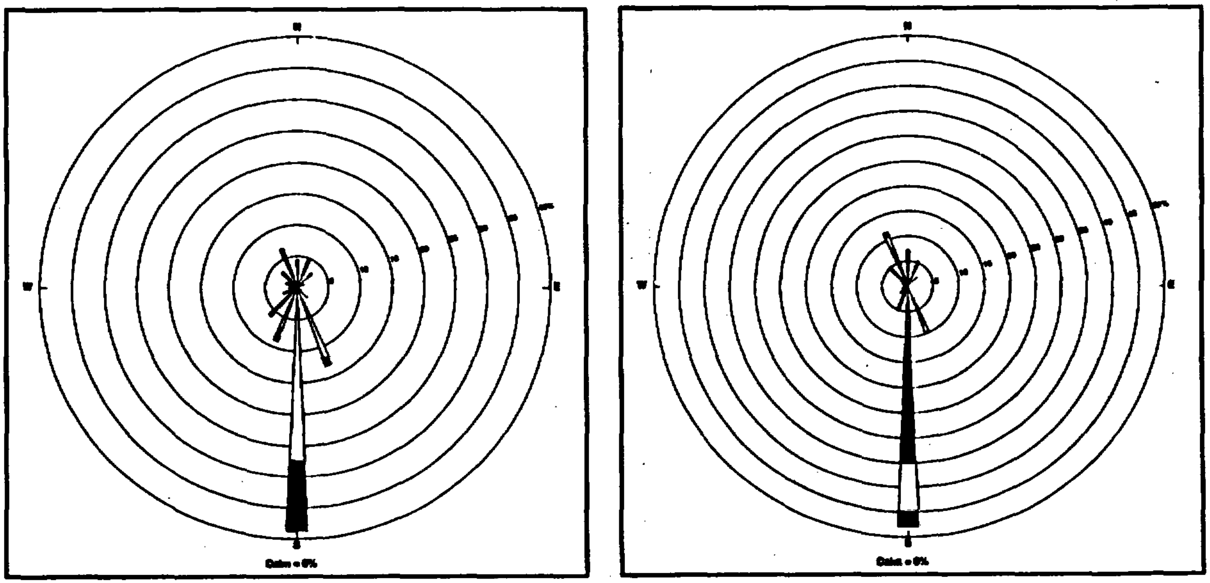
Site 1, in the western portion of Midway Valley, has a distribution that most closely resembles the averages of the occurrences at all sites.

The combination of joint-frequency distributions of wind data and the night-adjusted stability categories based on sigma-A data are a common tool used in input to atmospheric dispersion models. These three-dimensional joint-frequency distributions are summarized in the wind roses shown in Figures 3-24 through 3-41. The distributions of the stability categories for all wind conditions shown in Table 3-1 are relevant in interpreting these wind roses. Stability categories A through D can occur in daytime and D through F can occur at night, due to the method used to assign stability categories.

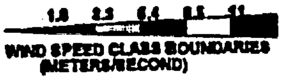
Stability category A (extremely unstable) occurs most often with winds from the southerly direction, which is generally upslope or upvalley at all the R/EFPD sites. Secondary maxima from the northerly directions occurred at Sites 1, 6, 7, and 8 the open exposure valley floor sites in and around Midway Valley. These northerly occurrences may be related to transition periods from northerly nighttime to southerly daytime airflow. The directions and relative focus or spread among the categories depends on the extent of topographic channeling, as discussed in Subsection 3.1.



(a) Site 1 - A Day (b) Site 1 - B Day

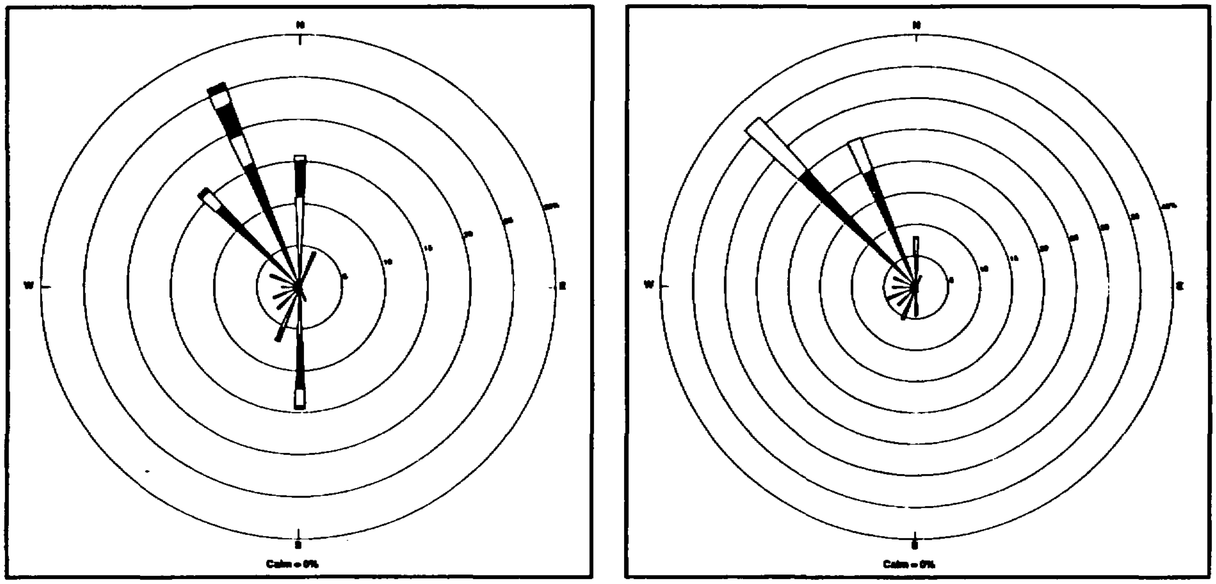


(c) Site 1 - C Day (d) Site 1 - D Day



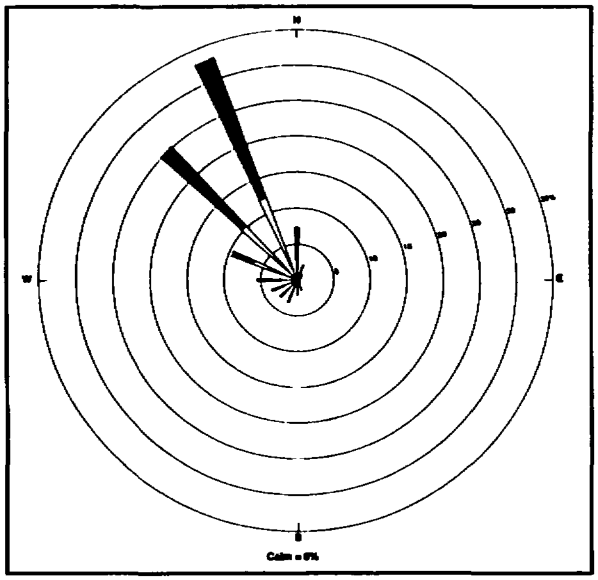
Note: The diagram is the frequency of occurrence for each wind direction from which the wind is blowing.

Figure 3-24. Wind Rose Plots for EFPD Site 1 for Daytime Stability Categories

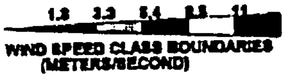


(a) Site 1 - D Night

(b) Site 1 - E Night

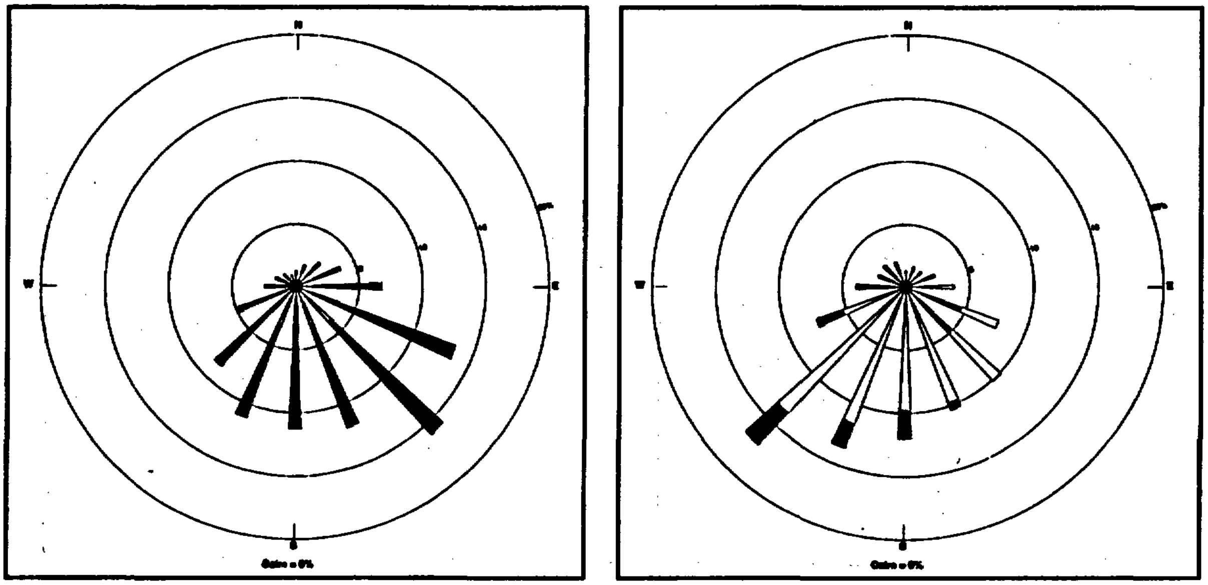


(c) Site 1 - F Night



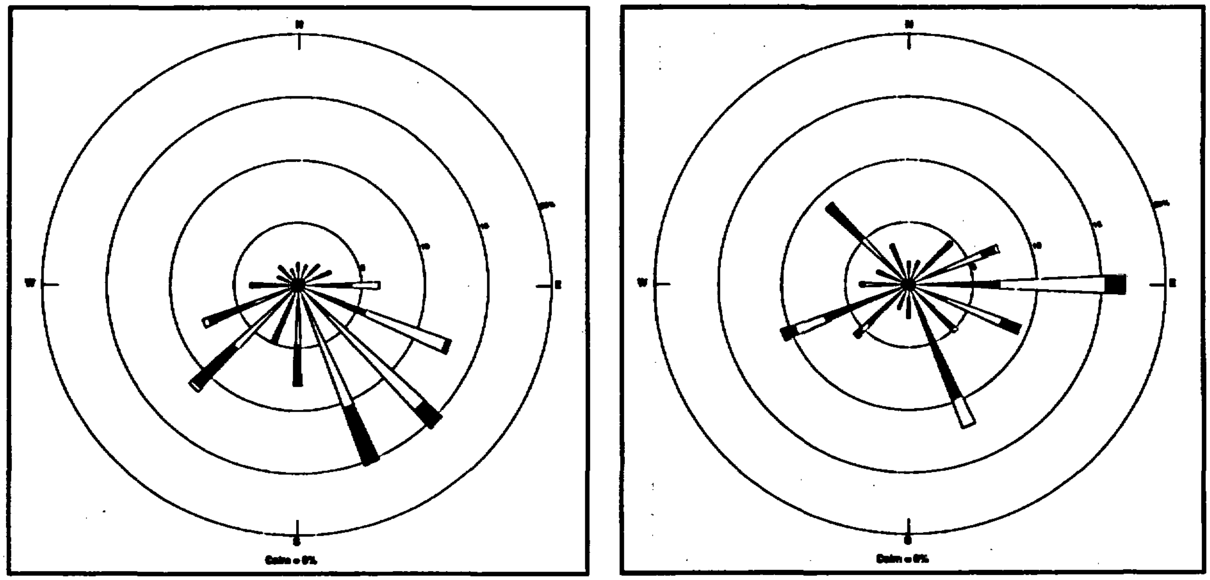
Note: The diagram is the frequency of occurrence for each wind direction from which the wind is blowing.

Figure 3-25. Wind Rose Plots for EFPD Site 1 for Nighttime Stability Categories



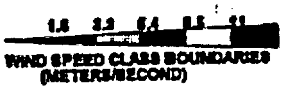
(a) Site 2 - A Day

(b) Site 2 - B Day



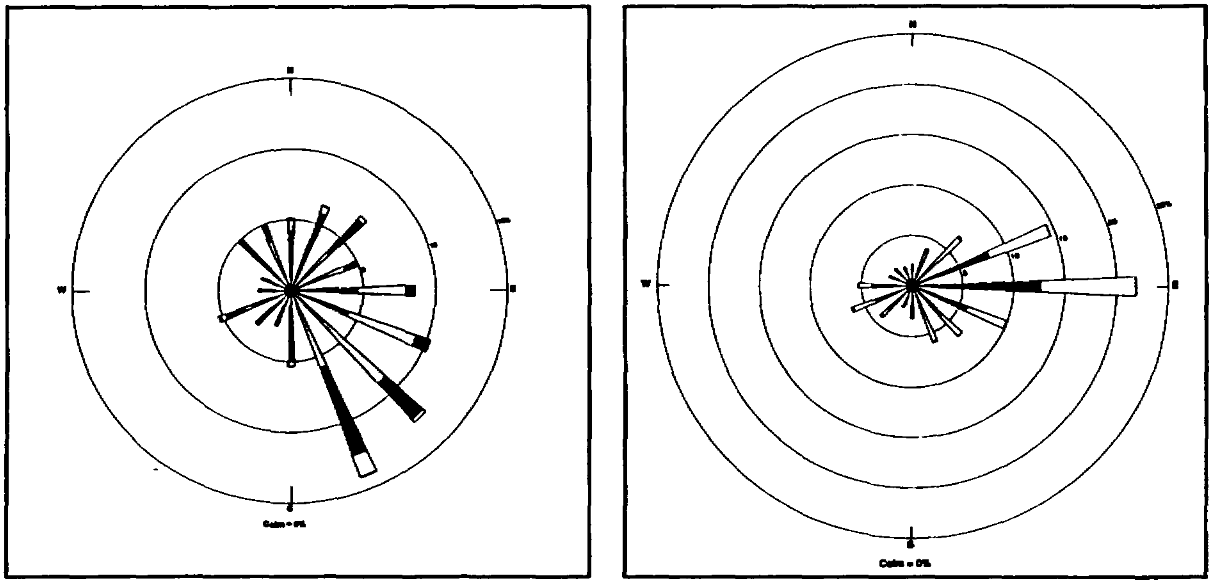
(c) Site 2 - C Day

(d) Site 2 - D Day



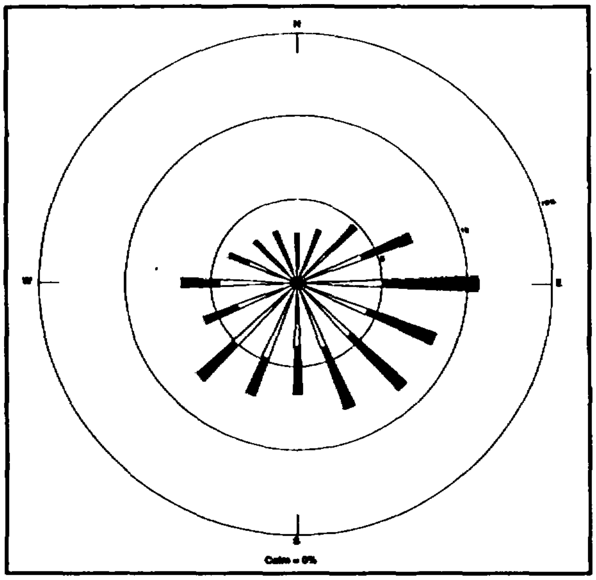
Note: The diagram is the frequency of occurrence for each wind direction from which the wind is blowing.

Figure 3-26. Wind Rose Plots for EFPD Site 2 for Daytime Stability Categories

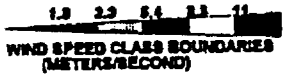


(a) Site 2 - D Night

(b) Site 2 - E Night

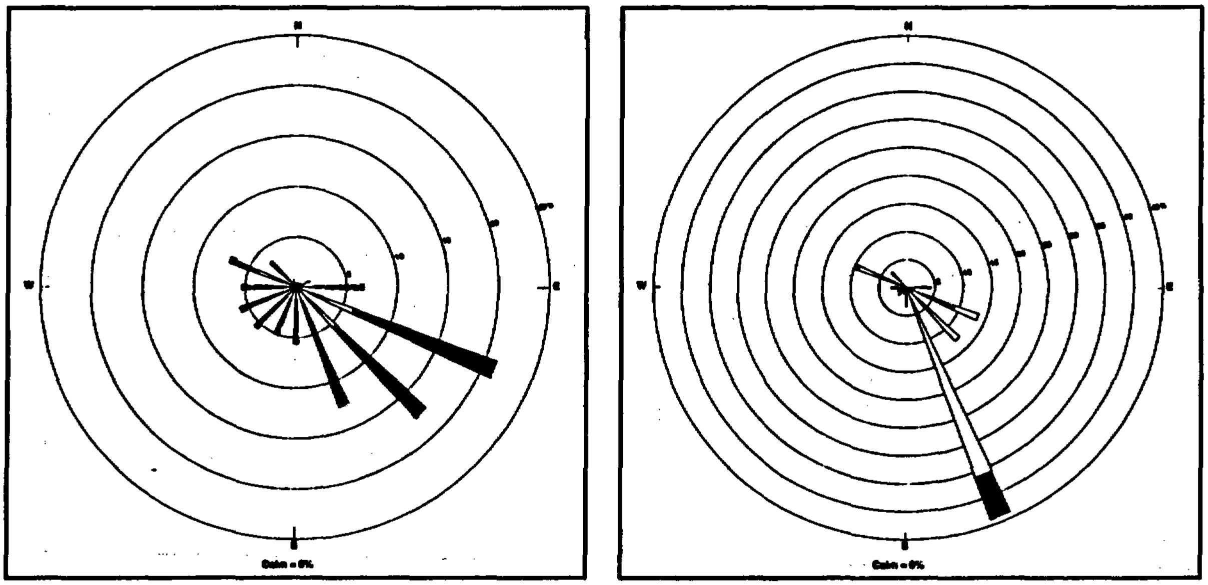


(c) Site 2 - F Night



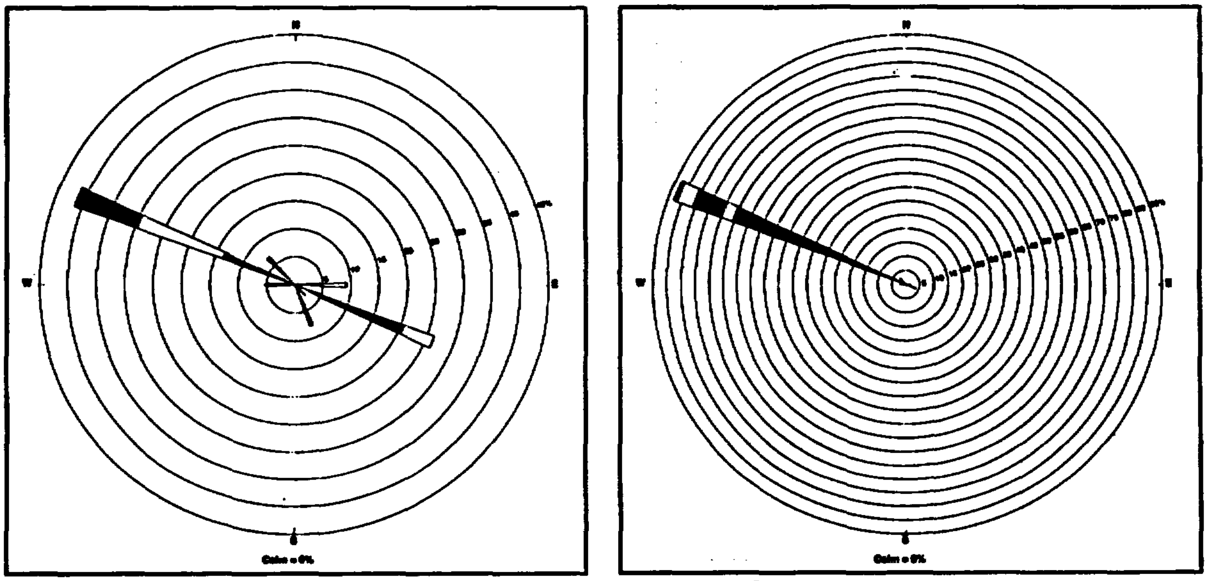
Note: The diagram is the frequency of occurrence for each wind direction from which the wind is blowing.

Figure 3-27. Wind Rose Plots for EFPD Site 2 for Nighttime Stability Categories



(a) Site 3 - A Day

(b) Site 3 - B Day

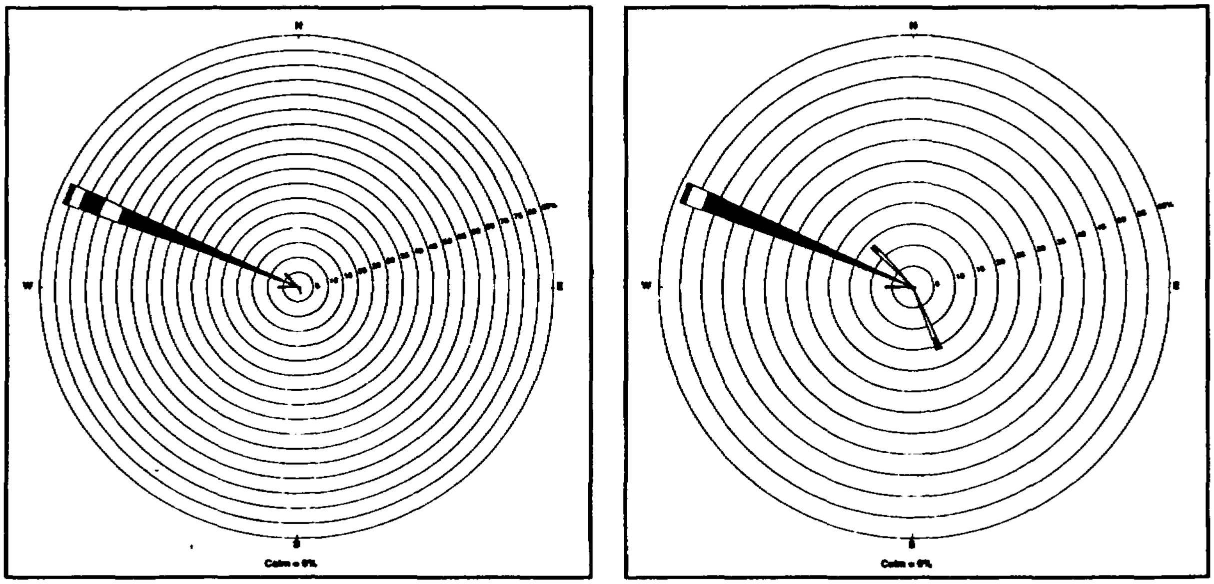


(c) Site 3 - C Day

(d) Site 3 - D Day

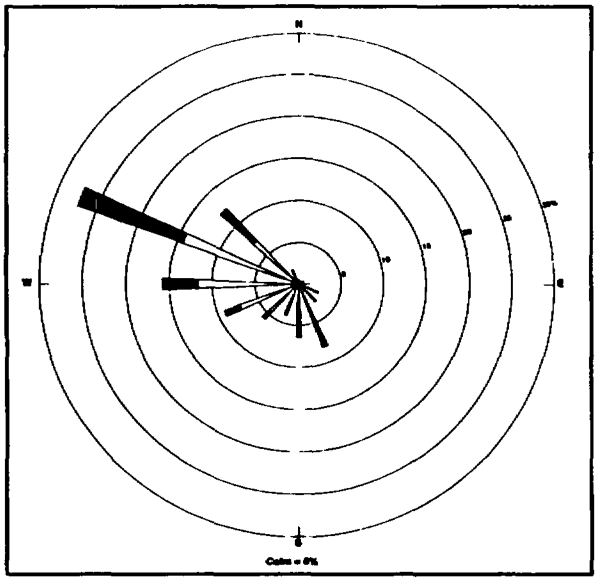
Note: The diagram is the frequency of occurrence for each wind direction from which the wind is blowing.

Figure 3-28. Wind Rose Plots for EFPD Site 3 for Daytime Stability Categories

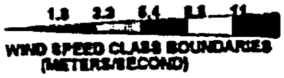


(a) Site 3 - D Night

(b) Site 3 - E Night

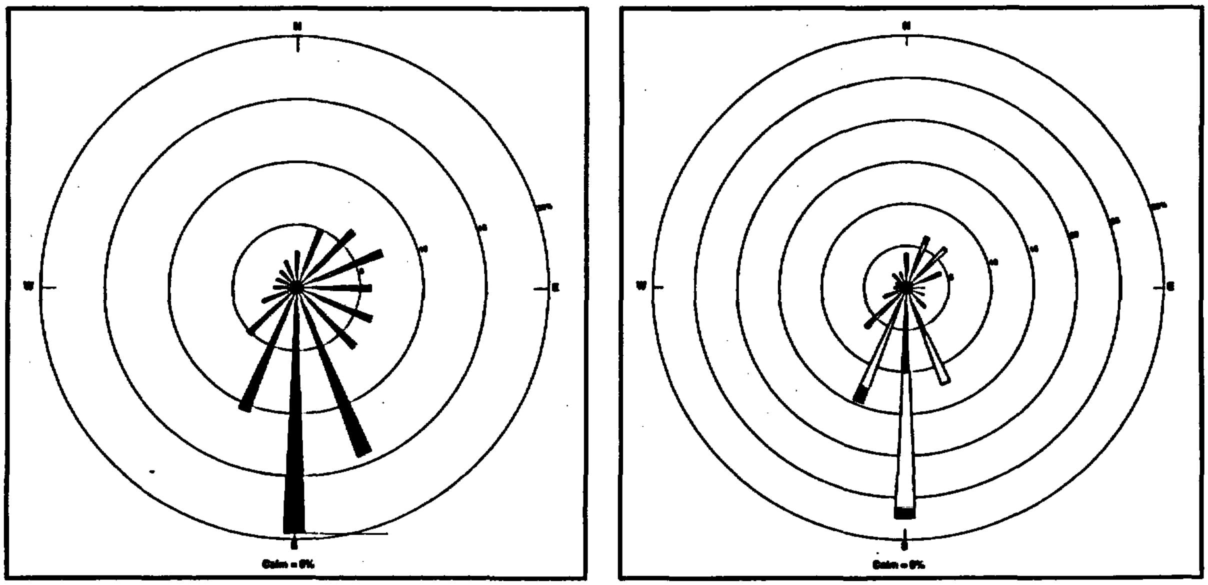


(c) Site 3 - F Night



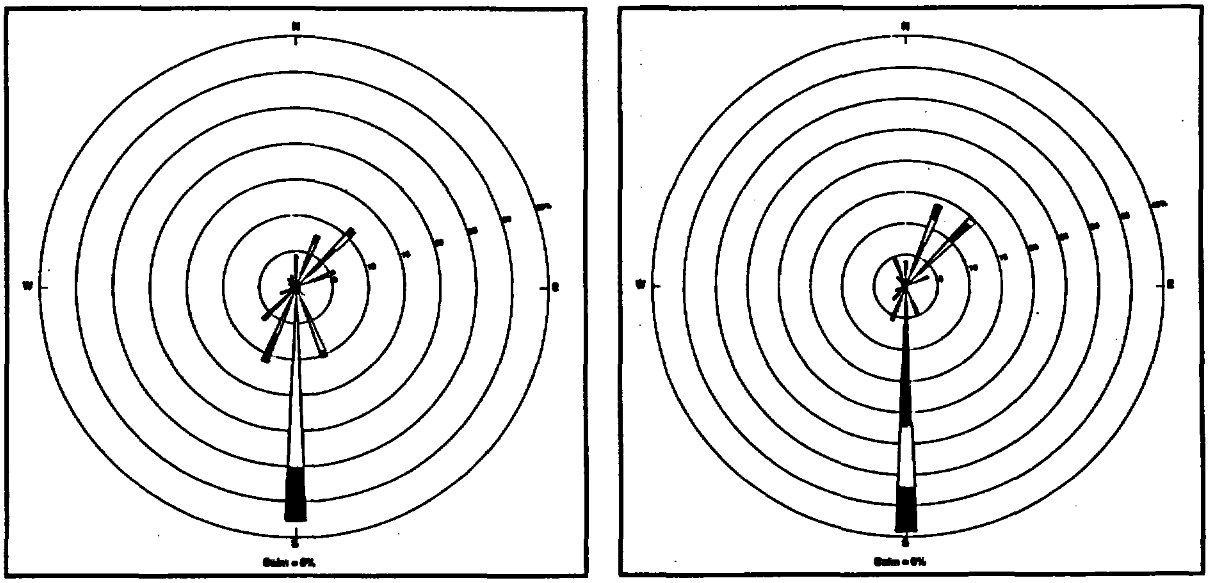
Note: The diagram is the frequency of occurrence for each wind direction from which the wind is blowing.

Figure 3-29. Wind Rose Plots for EFPD Site 3 for Nighttime Stability Categories



(a) Site 4 - A Day

(b) Site 4 - B Day

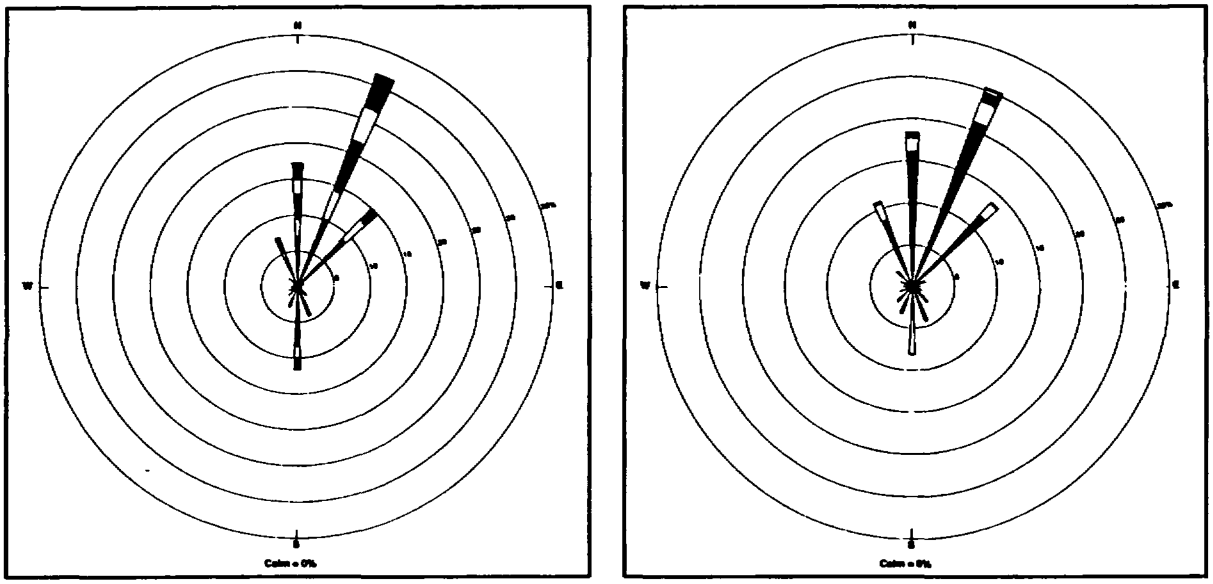


(c) Site 4 - C Day

(d) Site 4 - D Day

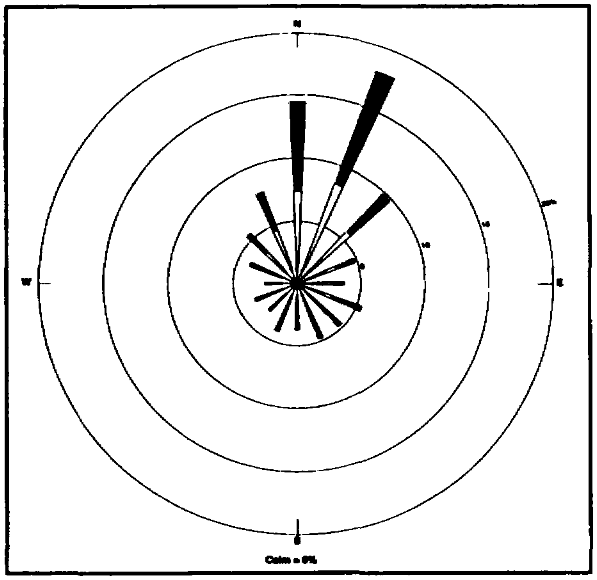
Note: The diagram is the frequency of occurrence for each wind direction from which the wind is blowing.

Figure 3-30. Wind Rose Plots for EFPD Site 4 for Daytime Stability Categories

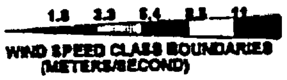


(a) Site 4 - D Night

(b) Site 4 - E Night

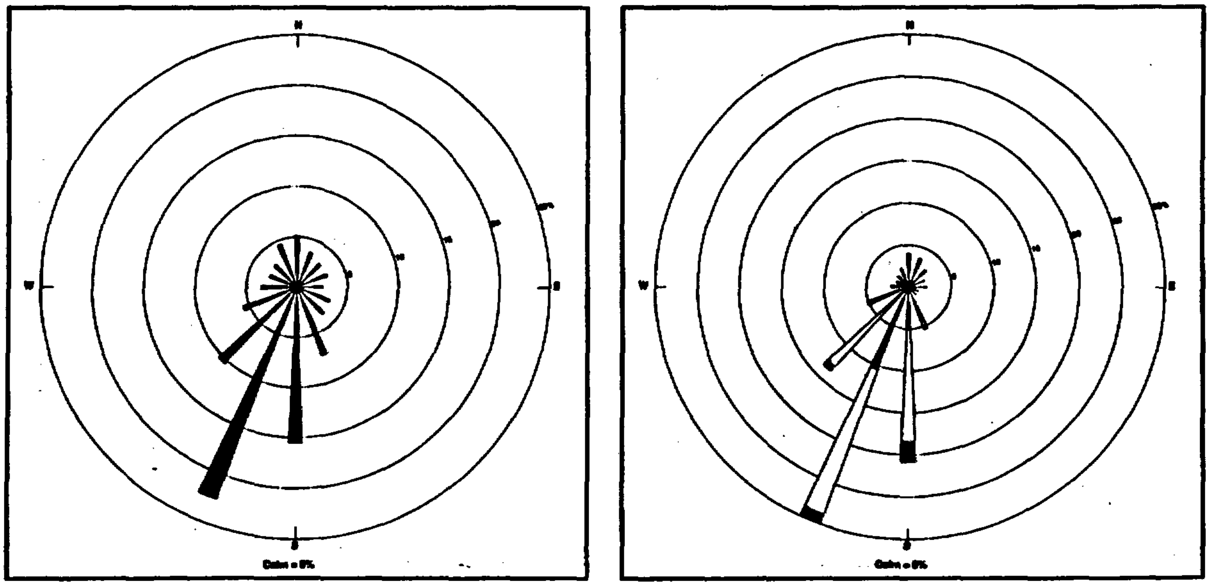


(c) Site 4 - F Night



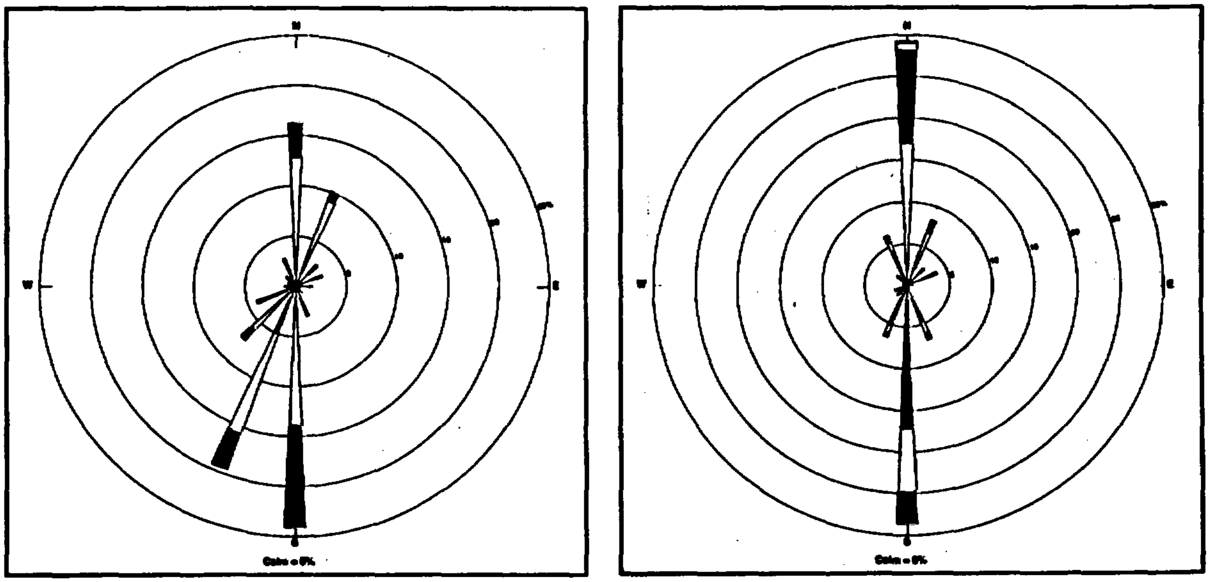
Note: The diagram is the frequency of occurrence for each wind direction from which the wind is blowing.

Figure 3-31. Wind Rose Plots for EFPD Site 4 for Nighttime Stability Categories



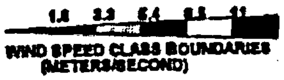
(a) Site 5 - A Day

(b) Site 5 - B Day



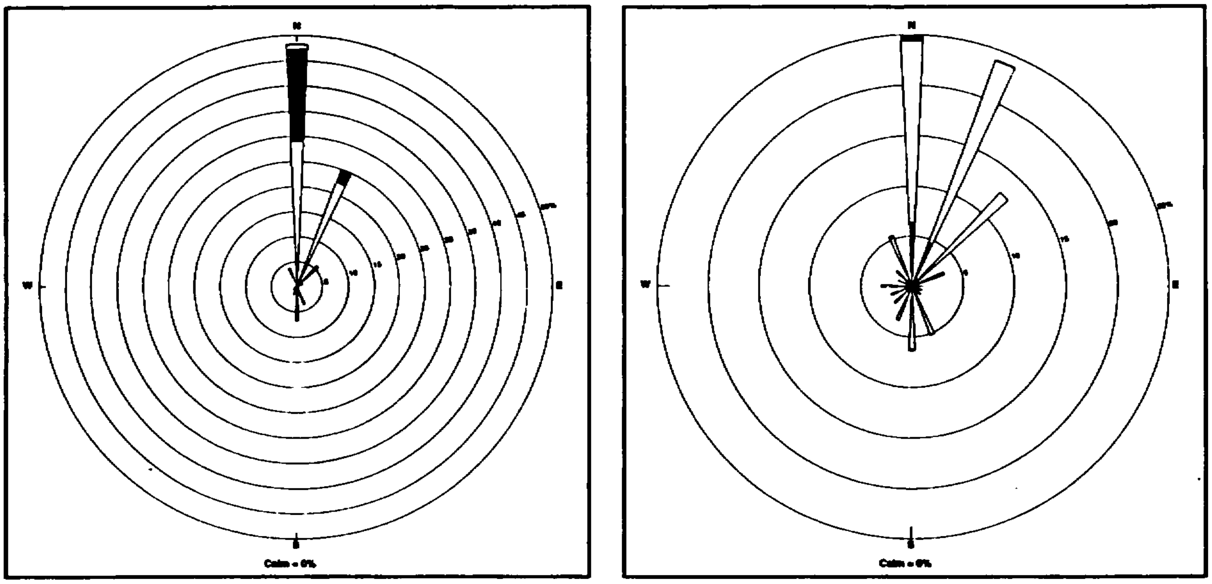
(c) Site 5 - C Day

(d) Site 5 - D Day



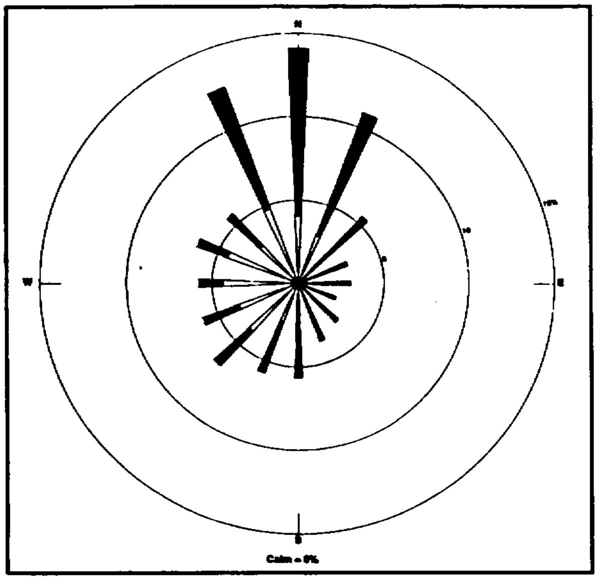
Note: The diagram is the frequency of occurrence for each wind direction from which the wind is blowing.

Figure 3-32. Wind Rose Plots for EFPD Site 5 for Daytime Stability Categories



(a) Site 5 - D Night

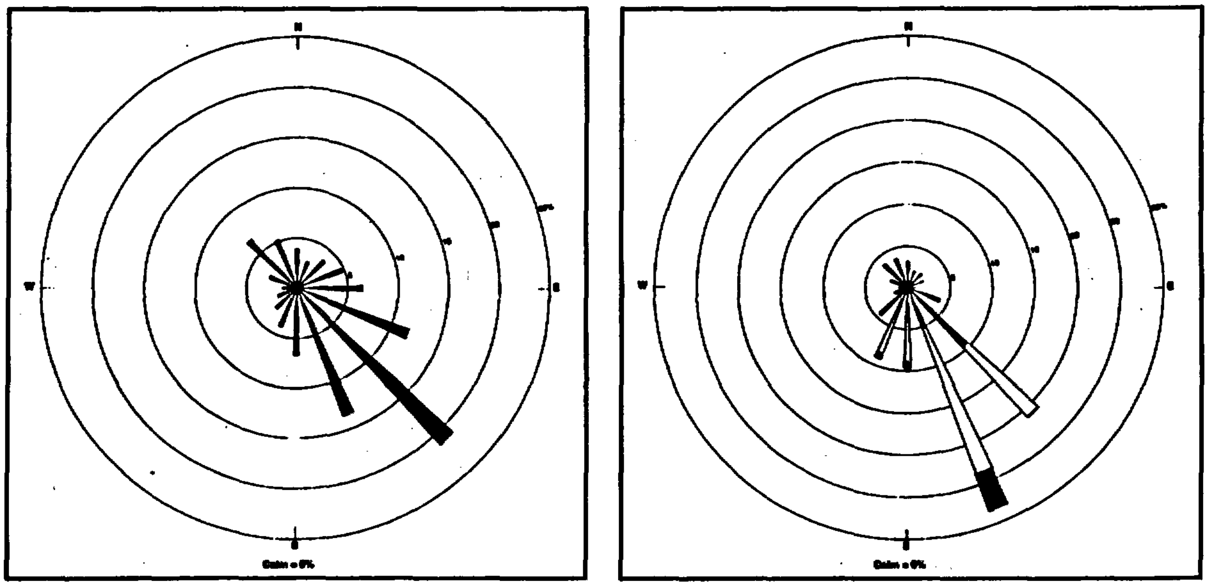
(b) Site 5 - E Night



(c) Site 5 - F Night

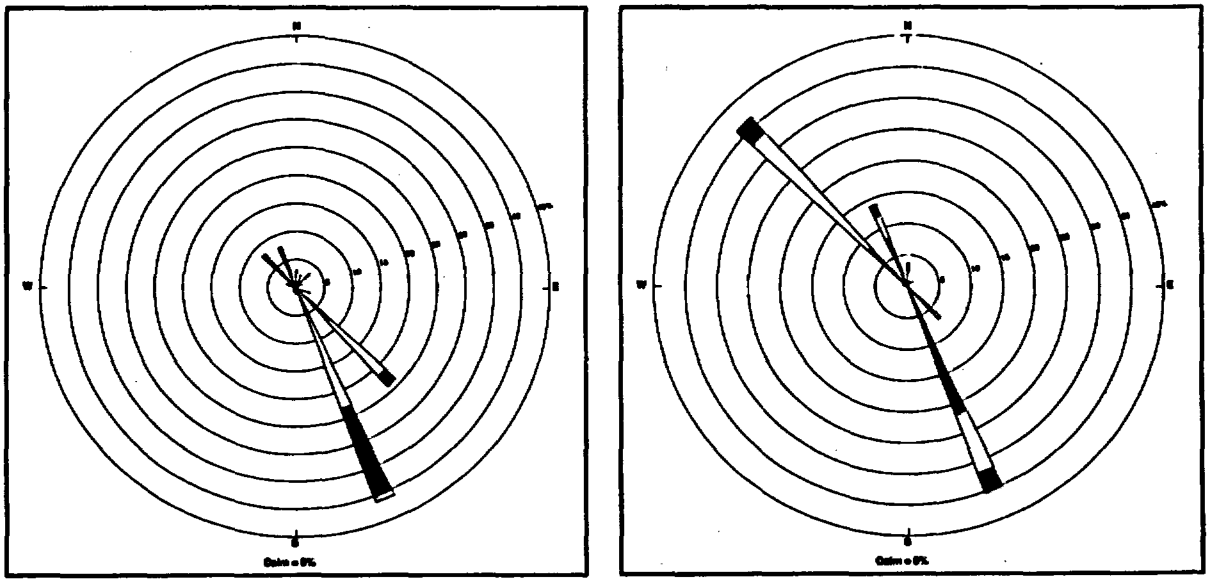
Note: The diagram is the frequency of occurrence for each wind direction from which the wind is blowing.

Figure 3-33. Wind Rose Plots for EFPD Site 5 for Nighttime Stability Categories



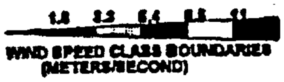
(a) Site 6 - A Day

(b) Site 6 - B Day



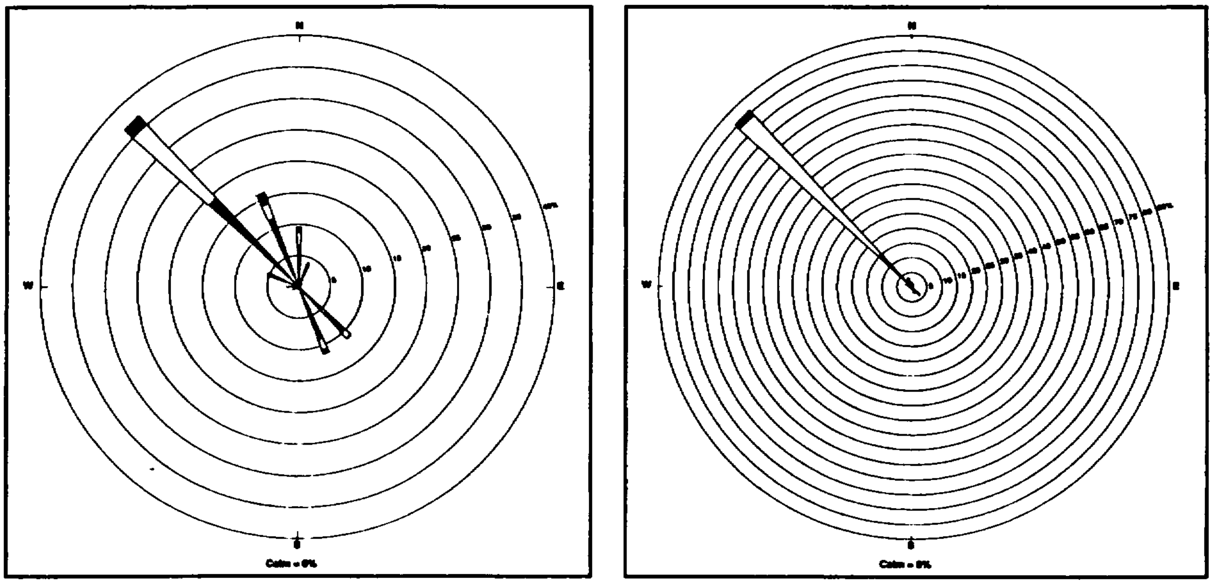
(c) Site 6 - C Day

(d) Site 6 - D Day

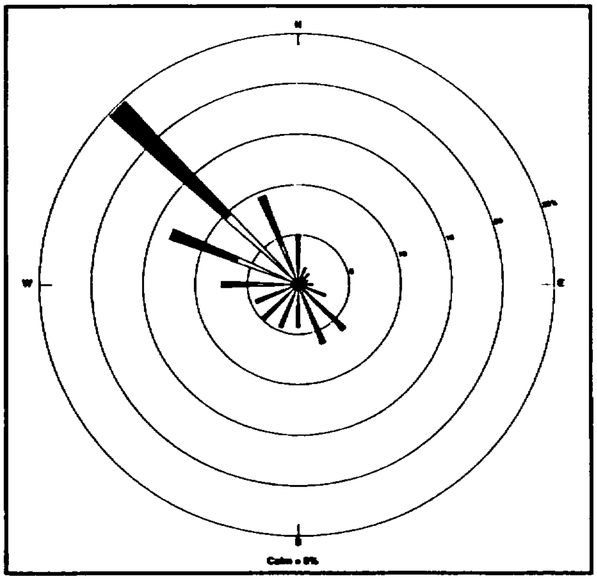


Note: The diagram is the frequency of occurrence for each wind direction from which the wind is blowing.

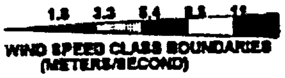
Figure 3-34. Wind Rose Plots for EFPD Site 6 for Daytime Stability Categories



(a) Site 6 - D Night (b) Site 6 - E Night

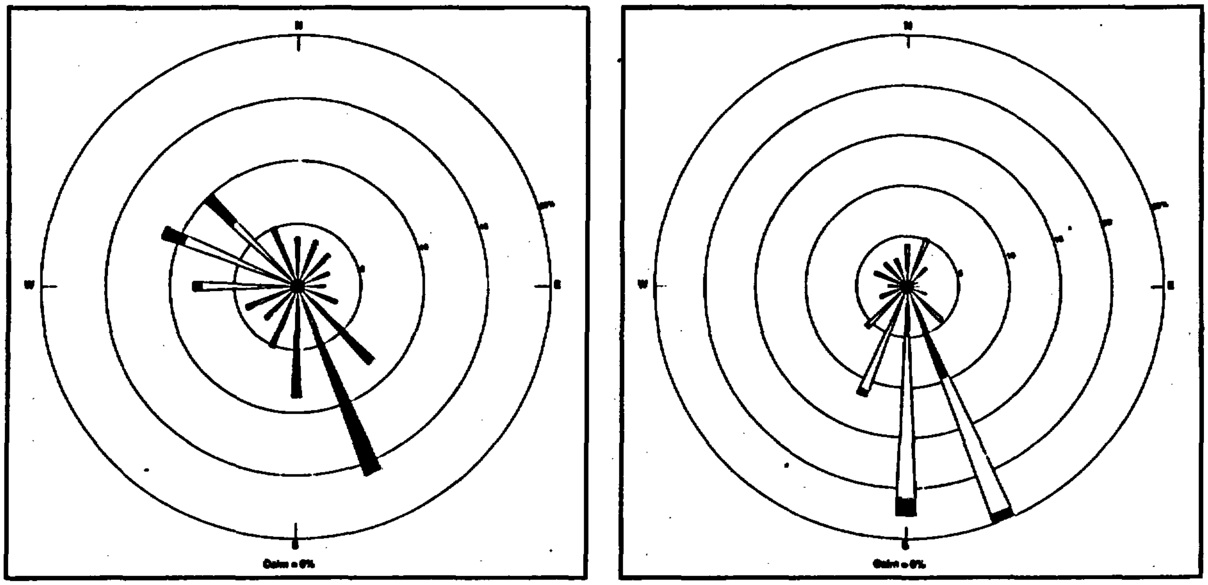


(c) Site 6 - F Night



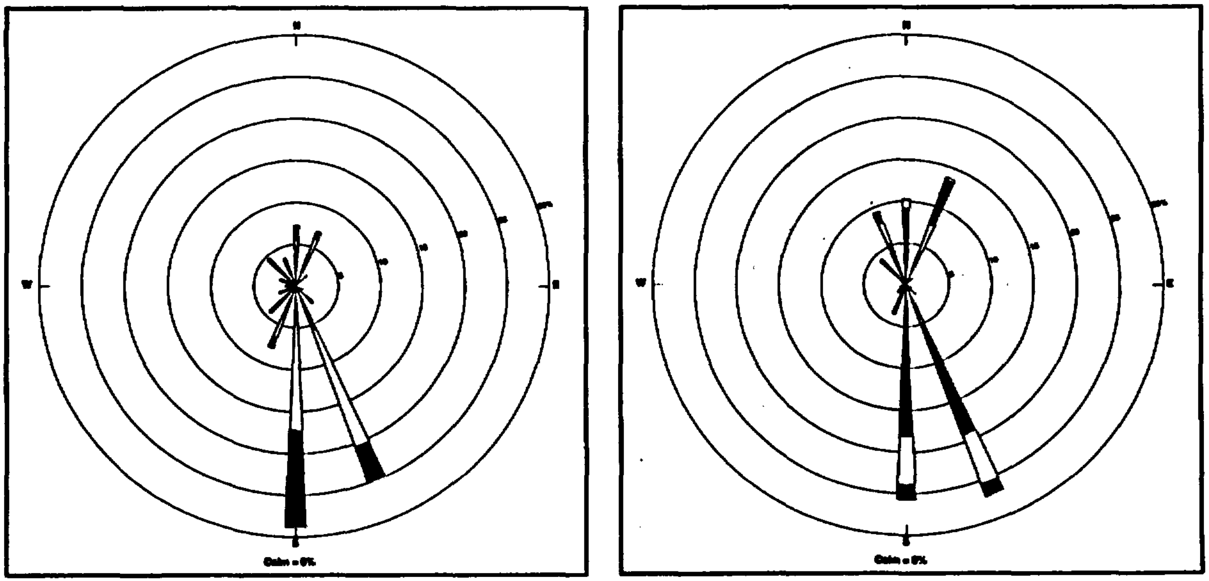
Note: The diagram is the frequency of occurrence for each wind direction from which the wind is blowing.

Figure 3-35. Wind Rose Plots for EFPD Site 6 for Nighttime Stability Categories



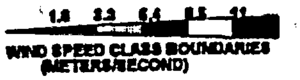
(a) Site 7 - A Day

(b) Site 7 - B Day



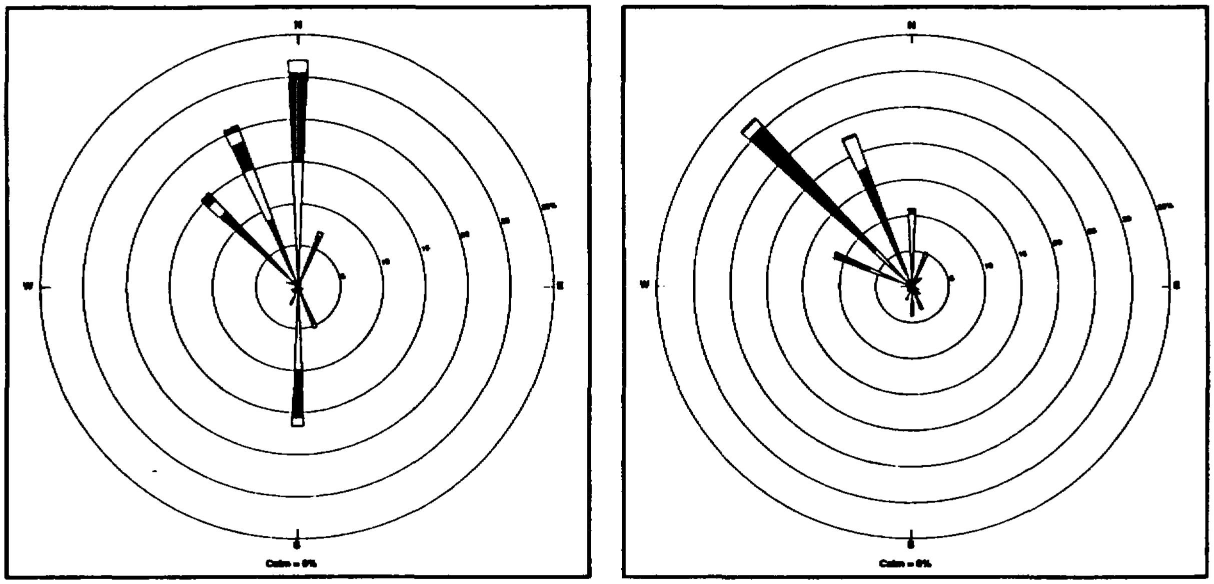
(c) Site 7 - C Day

(d) Site 7 - D Day



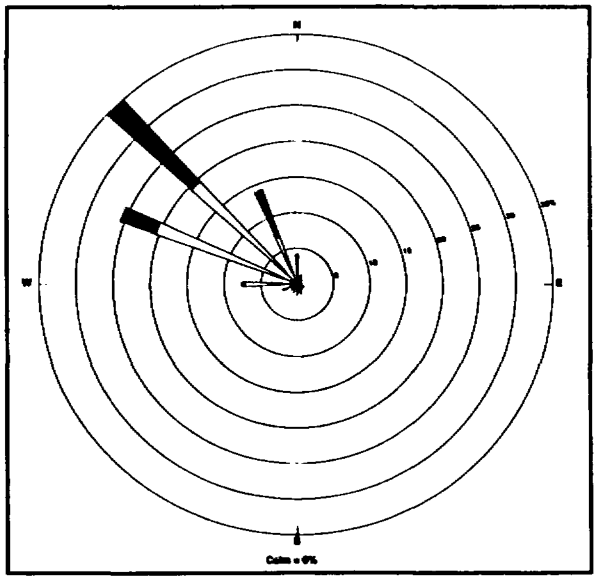
Note: The diagram is the frequency of occurrence for each wind direction from which the wind is blowing.

Figure 3-36. Wind Rose Plots for EFPD Site 7 for Daytime Stability Categories

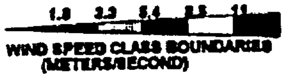


(a) Site 7 - D Night

(b) Site 7 - E Night

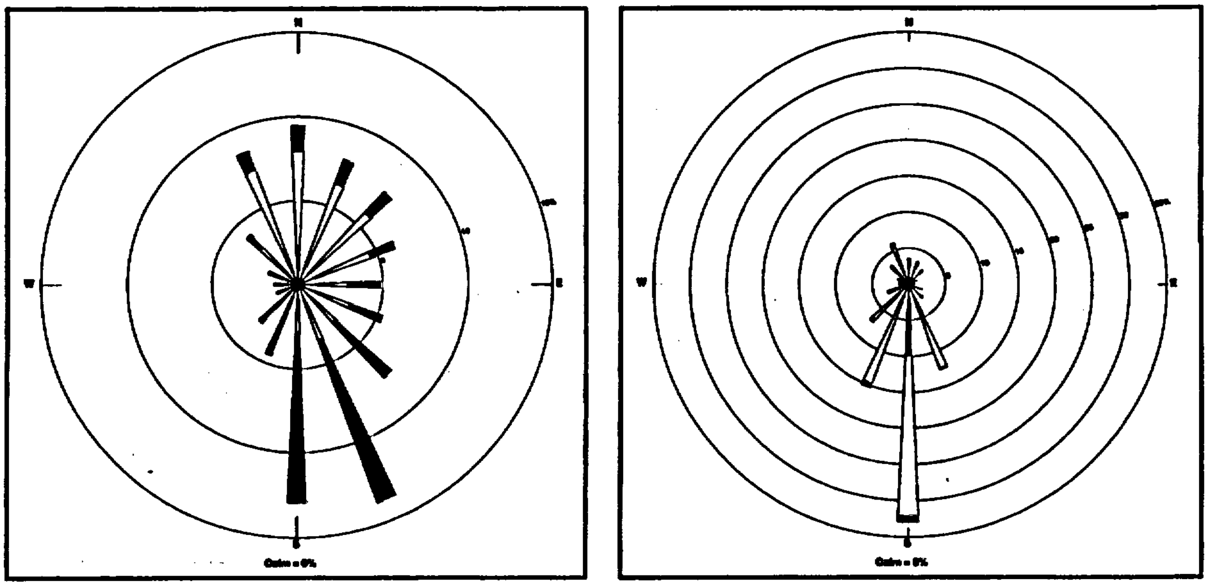


(c) Site 7 - F Night



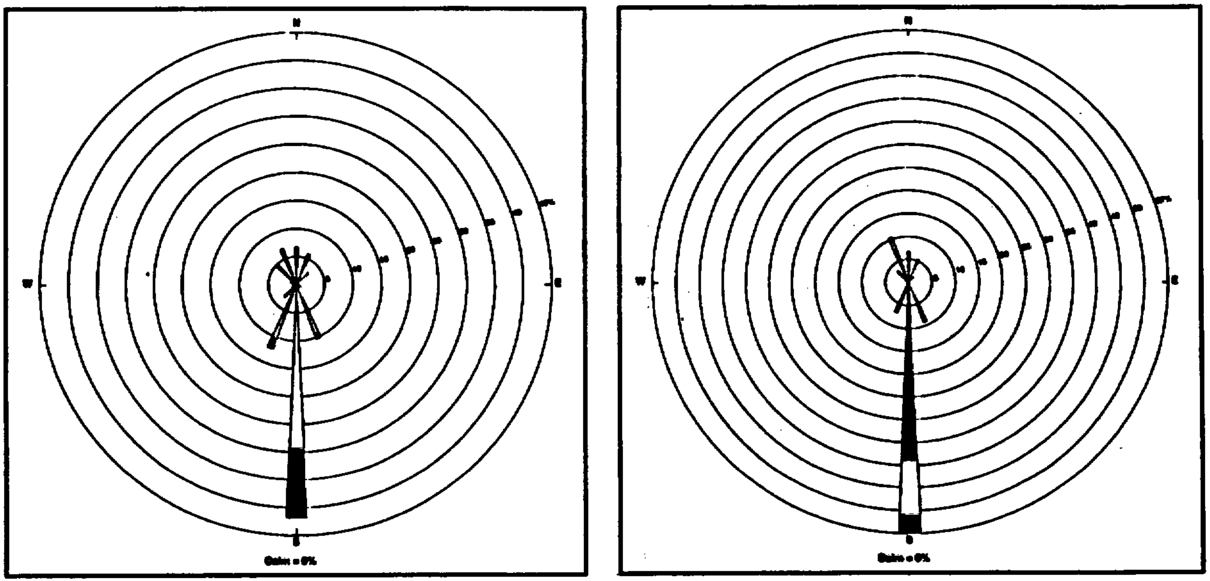
Note: The diagram is the frequency of occurrence for each wind direction from which the wind is blowing.

Figure 3-37. Wind Rose Plots for EFPD Site 7 for Nighttime Stability Categories



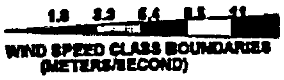
(a) Site 8 - A Day

(b) Site 8 - B Day



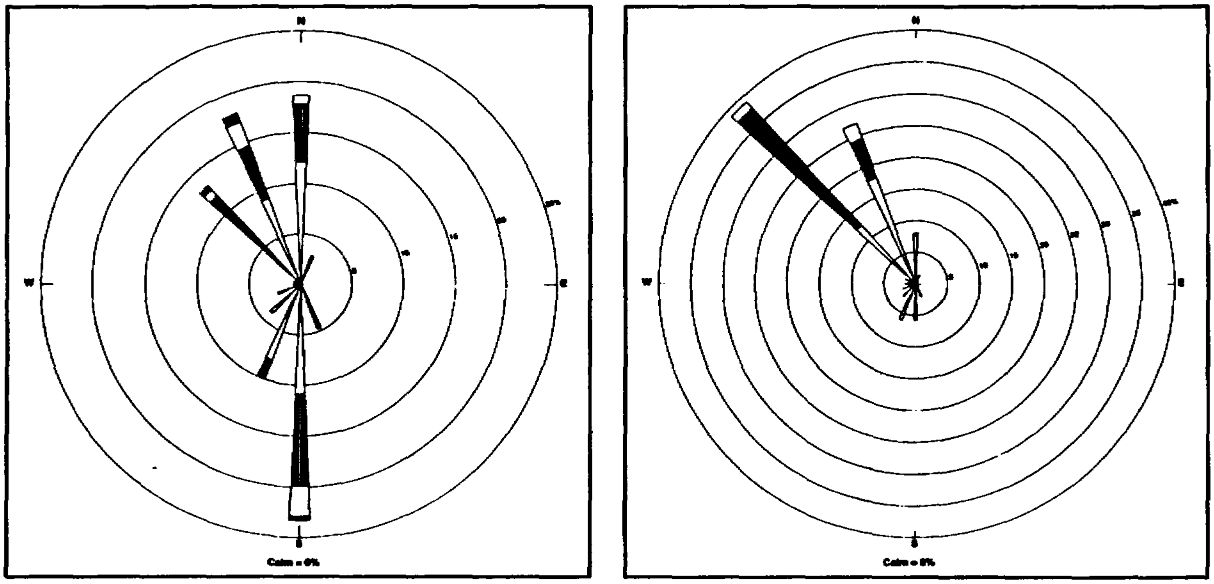
(c) Site 8 - C Day

(d) Site 8 - D Day



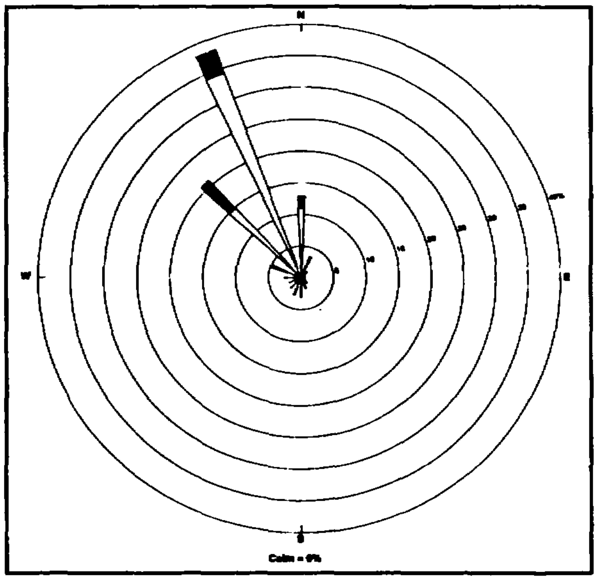
Note: The diagram is the frequency of occurrence for each wind direction from which the wind is blowing.

Figure 3-38. Wind Rose Plots for EFPD Site 8 for Daytime Stability Categories

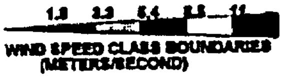


(a) Site 8 - D Night

(b) Site 8 - E Night

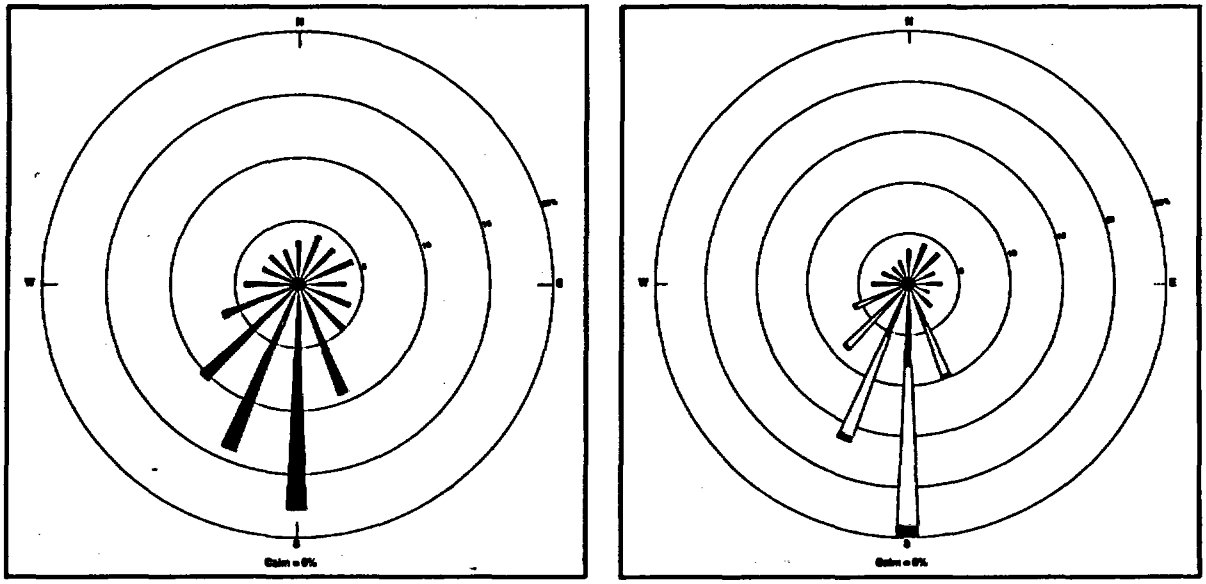


(c) Site 8 - F Night



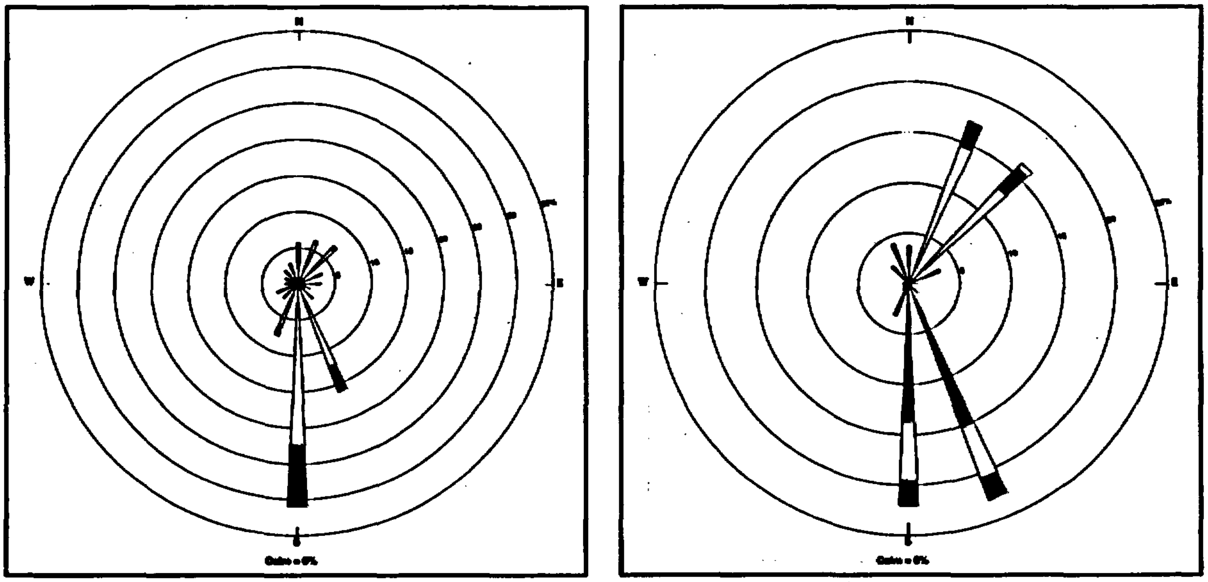
Note: The diagram is the frequency of occurrence for each wind direction from which the wind is blowing.

Figure 3-39. Wind Rose Plots for EFPD Site 8 for Nighttime Stability Categories



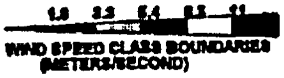
(a) Site 9 - A Day

(b) Site 9 - B Day



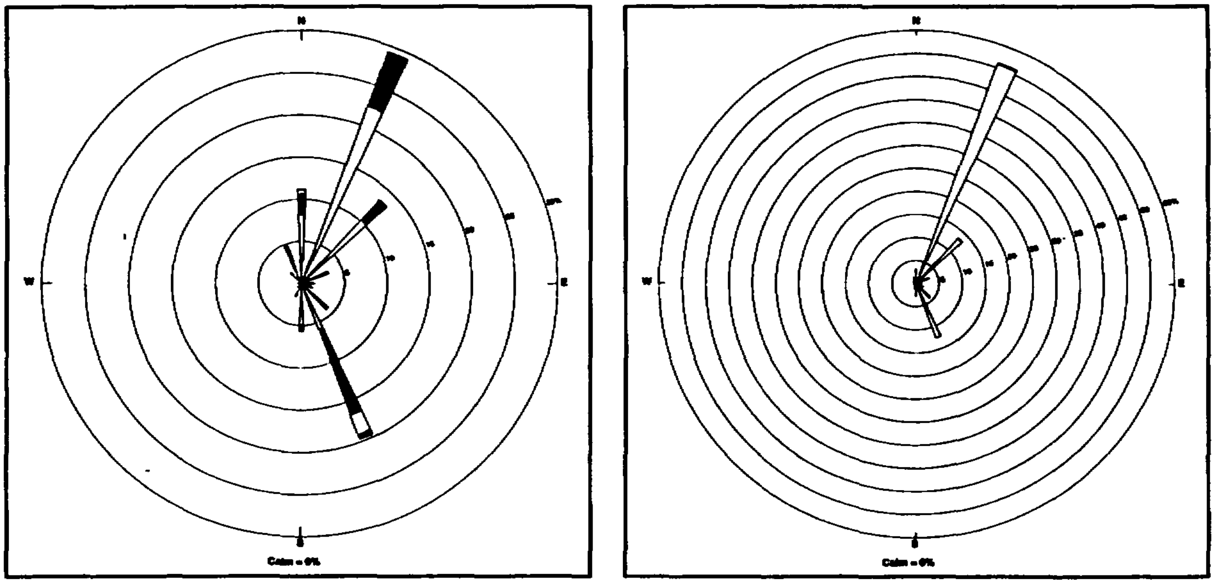
(c) Site 9 - C Day

(d) Site 9 - D Day



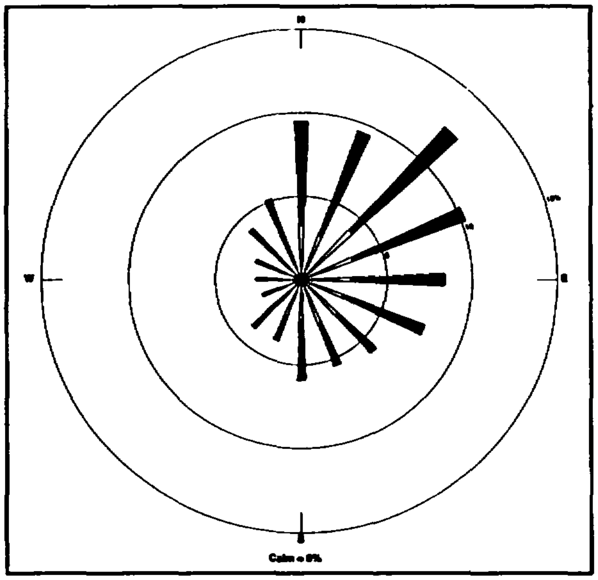
Note: The diagram is the frequency of occurrence for each wind direction from which the wind is blowing.

Figure 3-40. Wind Rose Plots for EFPD Site 9 for Daytime Stability Categories



(a) Site 9 - D Night

(b) Site 9 - E Night



(c) Site9 - F Night

Note: The diagram is the frequency of occurrence for each wind direction from which the wind is blowing.

Figure 3-41. Wind Rose Plots for EFPD Site 9 for Nighttime Stability Categories

Stability category B (moderately unstable) also occurs most often with winds from the southerly direction. Results from the B category show greater preference for one or two direction categories than the results from the A category. These results do not show the secondary maxima from other directions. The greater focus of B compared to A category winds may indicate that the B winds correspond to post-transition daytime periods, when the upslope and upvalley winds were established.

Stability category C (slightly unstable) also occurs most often with winds from the southerly direction at most sites, with even greater preference for particular categories compared to the A and B results. An apparent exception is the data from Site 3 which had more C category winds from the WNW, or downslope direction. These occurrences do not represent routine conditions at the site; the C category winds were present at Site 3 during only 3.5 percent of the total hours.

Stability category D (neutral) in the daytime occurs with winds from both dominant directions, with greater preference for the southerly (upslope) directions at most sites. The exception is Site 3, with over 87 percent of the daytime neutral category winds from the WNW (downslope) direction. Again, the neutral category at Site 3 occurred during only 8.4 percent of the total hours (including nighttime), so these conditions are exceptional.

Stability category D (neutral) in the nighttime also occurs with winds from both dominant directions, only with greater preference for the northerly (downslope) directions at all sites.

Stability category E (moderately stable) also occurs with winds from both dominant directions, but the greater emphasis is on the northerly (downslope) directions. Sites 1, 3, 6, and 9 show strong dominance of these winds from specific directions related to the topographic channeling in the downslope directions.

Stability category F (very stable) occurs with winds from both dominant directions, with greater dominance from the northerly (downslope) directions. The wind roses for the category F periods show greater diversity in directions than those from the category E periods. This result seems to contradict the determination of stability categories being partly based on larger sigma-A (greater wind variability) associated with category E. An explanation may be that the slightly faster speeds associated with E category winds may be steadier in direction over long periods of time than the slower speed category F winds. As with the category A periods of winds from directions other than the primary slope direction, some occurrences of category F could occur during the transition into the nighttime period.

3.3 NIGHTTIME VERTICAL STRUCTURE

Airflow during the nighttime period is particularly important in atmospheric dispersion studies because the periods of the greatest surface-level concentrations are generally associated with stable, low wind speed conditions. For the area near Yucca Mountain, the typical stable, nighttime airflow could bring material potentially emitted near the proposed repository surface facilities toward Amargosa Valley, which is the nearest area populated by members of the general public.

The location of the proposed surface facility area in Midway Valley near the base of the eastern slope of Yucca Mountain experiences significant differences in nighttime airflow characteristics between the near-surface and ridge-top heights, particularly in approximately the first 100 m-agl. With uncertainties related to the height above ground level of potential emission points, and possible additional plume rise if the emission is warmer than the environment or has vertical momentum due to a stack gas velocity, the structure of the stable layers aloft is a significant airflow topic.

One good demonstration of the nighttime airflow differences between vertically separated levels is a comparison between the 10 and 60 m-agl wind roses for Site 1 shown in Figure 3-6. Approximately 53 percent of the nighttime hours had winds from the NW and NNW at the 10-m level. Only about 10 percent of the total hours with winds from these directions were with speeds greater than 3.3 m/s. This direction is aligned with downslope airflow from Drill Hole Wash, a major topographic feature on the east side of Yucca Mountain draining into Midway Valley. Including the WNW and N directions adds another 17 percent of the total hours, bringing the total for generally northwesterly flow at 10 m-agl to about 70 percent. The winds were from either S or SSW during about 13 percent of the hours, typically with speeds greater than 3.3 m/s.

By comparison, winds at the 60-m level were from either the NNW or N directions during about 40 percent of the nighttime hours, with another 17 percent from the NW or NNE directions. The wind speeds at 60 m-agl were less than 1.8 m/s and from the NNW or N during about 20 percent of the hours, compared to about 11 percent at these speeds from the NW and NNW directions at the 10-m level. These directions are aligned with the general Yucca Mountain ridge line and the east side of Midway Valley, rather than a downslope drainage from Yucca Mountain. Southerly winds occur more frequently at the 60-m level, about 18 percent of the time compared to 13 percent at the 10-m level. On the other hand, over 20 percent of the hours were with speeds greater than 3.3 m/s, compared to less than 10 percent at the 10-m level.

Greater differences in the wind patterns are evident in the nighttime wind roses shown in Figure 3-8 for Site 4, on the top of Alice Hill, and Site 7, at the base of Alice Hill. Site 7 is in the gap between Alice Hill and Fran Ridge; this gap is the hydrologic drainage for Midway Valley. The horizontal distance between the two sites is less than 2 km, but the vertical separation is 153 m. The nighttime wind roses in Figure 3-7 from Alice Hill show winds from the NNW through NE directions during about 60 percent of the hours; about one-half of those hours have speeds less than 3.3 m/s. These directions are aligned with higher terrain in the Calico Hills area, and Fortymile Canyon. In comparison to the wind roses from Site 4, the wind roses from Site 7 show that about 75 percent of the nighttime winds were from the WNW through N directions, mostly with speeds less than 3.3 m/s. These directions are aligned with the local topographic gradient of the lower portion of Midway Valley. Thus, there is typically more than 60 degrees difference in the nighttime wind directions between these two locations.

The nighttime wind rose from Site 2 shown in Figure 3-5 shows winds on top of Yucca Mountain from the NE through SSE directions 57 percent of the hours; the most frequent direction category is east, accounting for about 12 percent of the hours. This direction is 90 degrees from the typical northerly winds associated with downslope and downvalley winds occurring at the other R/EFPD monitoring sites. The explanation for the easterly winds is not clear at this point. It may be related to regional airflow patterns, or large scale downvalley airflow from higher terrain northeast of Yucca Mountain flowing toward Crater Flat to the west and south of Yucca Mountain.

Although summary wind data from vertically separated routine monitoring sites can provide valuable information about nighttime vertical structure, obtaining further information on stability and airflow structure requires additional field measurements. Detailed information on the characteristics of wind and air temperature aloft within Midway Valley was obtained during short-term intensive field studies performed by R/EFPD staff. Some of the studies were performed with the National Oceanic and Atmospheric Administration, Air Resources Laboratory, Atmospheric Turbulence and Diffusion Division NOAA/ARL/ATDD from Oak Ridge, Tennessee. Wind and temperature measurements were made using Tethersonde® systems, an acoustic Doppler sounder (SODAR), and temporary surface-based meteorological stations. Time exposure photographs were taken of smoke releases as visual tracers during one of the studies.

The results of the first study reported (CRWMS M&O 1995a) some similar vertical temperature characteristics in the valley floor locations within Midway Valley, Jackass Flats, and Crater Flats. Temperature inversions of a few degrees Celsius were found between 2 m-agl and about 30 m-agl, with an isothermal layer extending upward beyond 100 m-agl. Speeds reached 3 to 5 m/s at 10 m-agl in well-developed drainage winds, with lesser speeds above the near-surface drainage layer in the isothermal layer.

Near-surface smoke releases in western Midway Valley near Site 1 took diverse pathways out of Midway Valley during basically nocturnal drainage wind periods. Some paths were toward the gap between Alice Hill and Fran Ridge near Site 7; the smoke occasionally was found near the surface, and at other times it stayed aloft at least a few tens of meters. At other times, the smoke remained nearly horizontal, leaving Midway Valley over low portions of Fran Ridge to the east, or through the saddle in the southern portion of Midway Valley near Site 8. Wind data and smoke release observations indicated that the northeasterly wind airflow across the top of Yucca Mountain continued toward the southwest through Crater Flat toward Amargosa Valley, rather than toward the west in the direction of Beatty, Nevada.

The winds from the surface to a few hundred meters above ground level in Crater Flat were similar to those observed in southern Jackass Flats. Winds in the first few tens of meters above ground level tended to follow the surface topography features, in a layer of a surface-based temperature inversion with isothermal conditions aloft. Winds aloft in Crater Flat on the study nights were from the northeast. Shallow layers of southerly airflow were observed between the surface northerly and aloft northeasterly flow.

A recent second study performed by R/EFPD staff focused on the depth and structure of the stable layers in western Midway Valley and along the eastern slope of Yucca Mountain. Three temporary meteorological stations with wind sensors at 2.5 m-agl operated for a 43-day period in March and April 1997. For locations of these stations see Figure 3-42.

Site 101 was on the top of Exile Hill, overlooking (toward the east) the north portal area of the Exploratory Studies Facility, at an elevation of 1160 m-msl; this location is one km north of Site 1. This hilltop faces the mouth of Drill Hole Wash to the west-northwest.

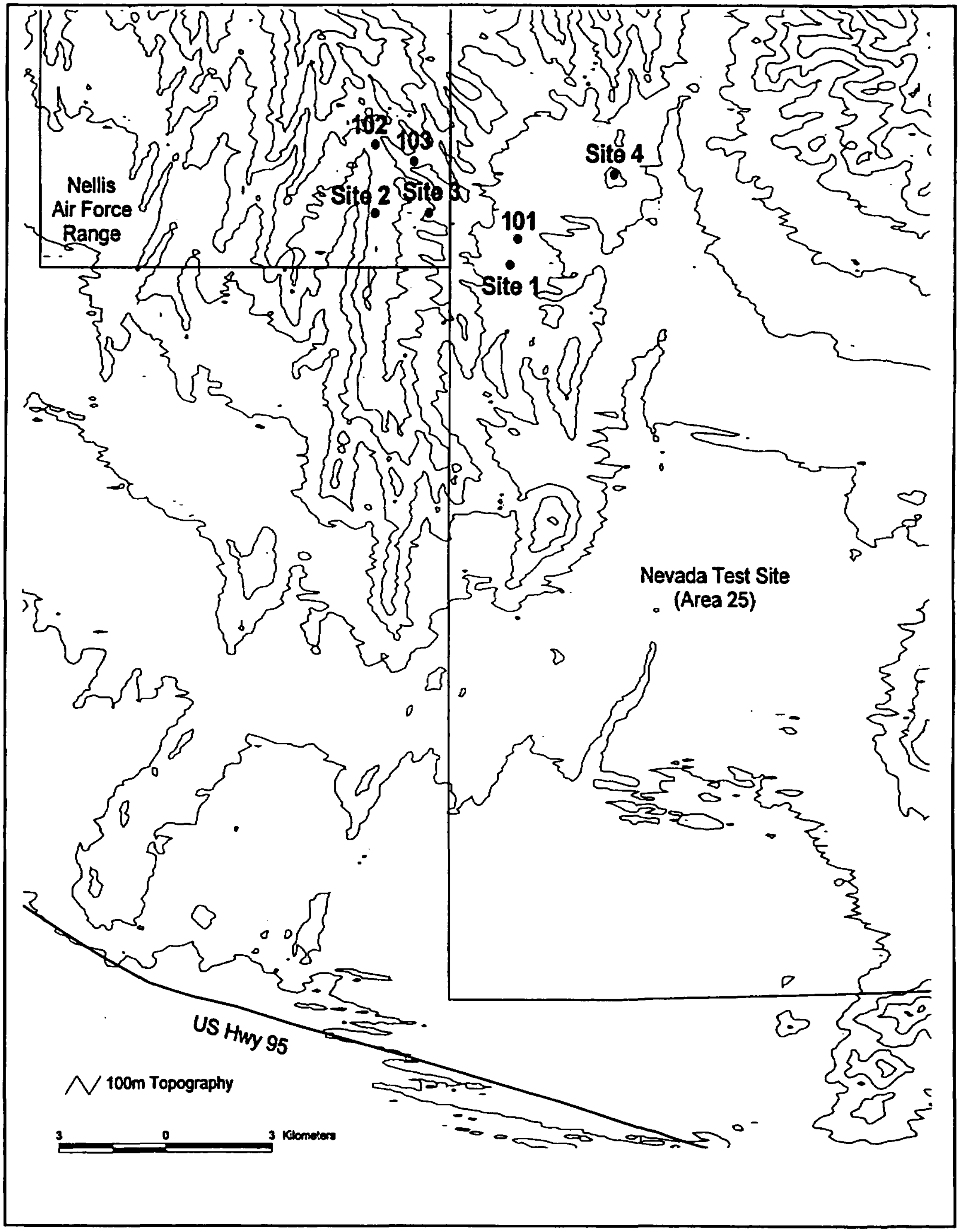


Figure 3-42. Temporary Meteorological Monitoring Site Locations

Site 102 was on the far northern end of the Yucca Mountain ridge top, at an elevation of 1480 m-msl. This location is 1.7 km north of Site 2; it overlooks Drill Hole Wash to the east.

Site 103 was on an exposed hillside in Drill Hole Wash at an elevation of 1355 m-msl; the hillside protrudes toward the southeast as part of a minor ridge line along the eastern slope of Yucca Mountain. The site is 3.6 km northwest of Site 1.

Figures 3-43 and 3-44 show the wind roses from the three temporary sites and Sites 1 through 4 for the nighttime hours during the 43-day period. The wind roses from Sites 1 through 4 are similar to those from all seasons; there were more periods of strong wind speeds than usually occur. Site 2 experienced more northerly winds than typically occur, and fewer easterly winds. The wind rose figures show the following specific features.

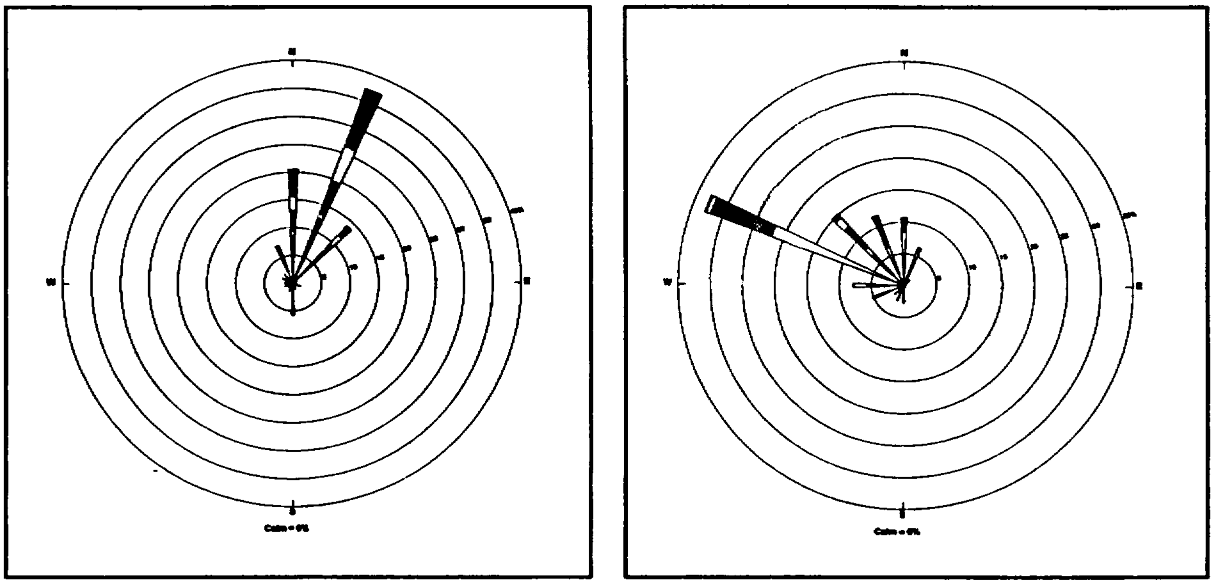
The nighttime winds at Site 101 were from the WNW, which is a downslope wind direction from Drill Hole Wash, at speeds less than 3.3 m/s during 32 percent of the hours. The winds were between WNW and N during over 70 percent of the hours. The N and NNE winds through Midway Valley occurred during only 17 percent of the hours. The winds were southerly during only about 5 percent of the hours. The wind data from Site 101 on top of Exile Hill resemble the wind data from the 10-m level, at Site 1 given the different directions toward the mouth of Drill Hole Wash at the two sites. The speeds were less at Site 101 than at Site 1.

The nighttime winds on the north end of Yucca Mountain (Site 102) were from NNW through ENE during almost 60 percent of the time. The northerly winds correspond to airflow from nearby higher terrain to the north; the northeasterly winds appear to be from distant higher terrain northeast of Midway Valley, and may correspond to the northeasterly winds frequently observed at night on top of Alice Hill at Site 4. The winds were southerly during less than 15 percent of the hours. While the Site 2 winds were northerly more than typically occur, the ENE and E winds still occurred a significant amount of the time.

The nighttime winds on the hillside in Drill Hole Wash (Site 103) were from the downslope wind directions NNW through N during almost 47 percent of the hours. These directions correspond to both local drainage winds down the hillside and the apparent overlying airflow indicated by the winds on the north end of the ridge at Site 102. The winds were from the NNE and E during over 10 percent of the hours; these periods appear to correspond to northerly and northeasterly airflow through Midway Valley reaching this location. The winds were southerly during less than 10 percent of the hours. By comparison, the winds at Site 3 in the bottom of Coyote Wash remained downslope from the WNW and NW, with only five percent of the hours having southeasterly winds.

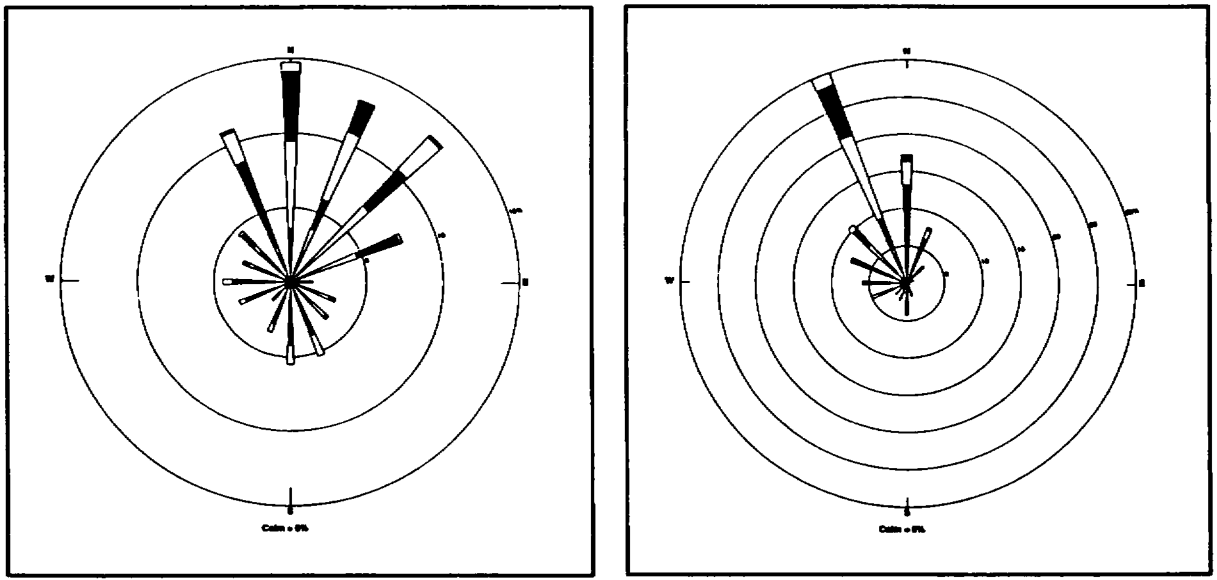
Two study nights of intensive measurements using the Tethersonde® system at Site 1 during the same period as the temporary stations operated provided examples of different airflow conditions occurring in layers with transitions over periods less than one hour.

Winds at Site 1 between 1800 Pacific Standard Time (PST) on March 24 through 0600 PST on March 25, 1997 were mostly from the WNW at 10 m-agl, with speeds generally 2 to 4 m/s. The 60 m-agl winds were generally northerly, with speeds only 1 to 3 m/s. One short duration period



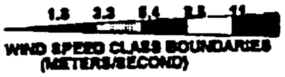
(a) Site 4

(b) Site 101



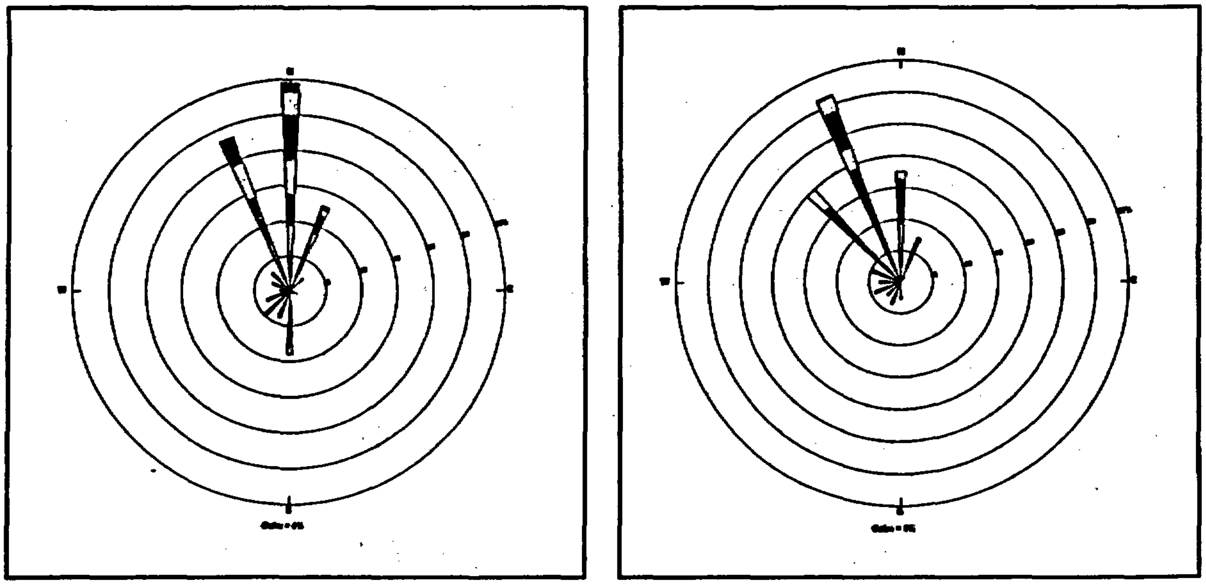
(c) Site 102

(d) Site 103



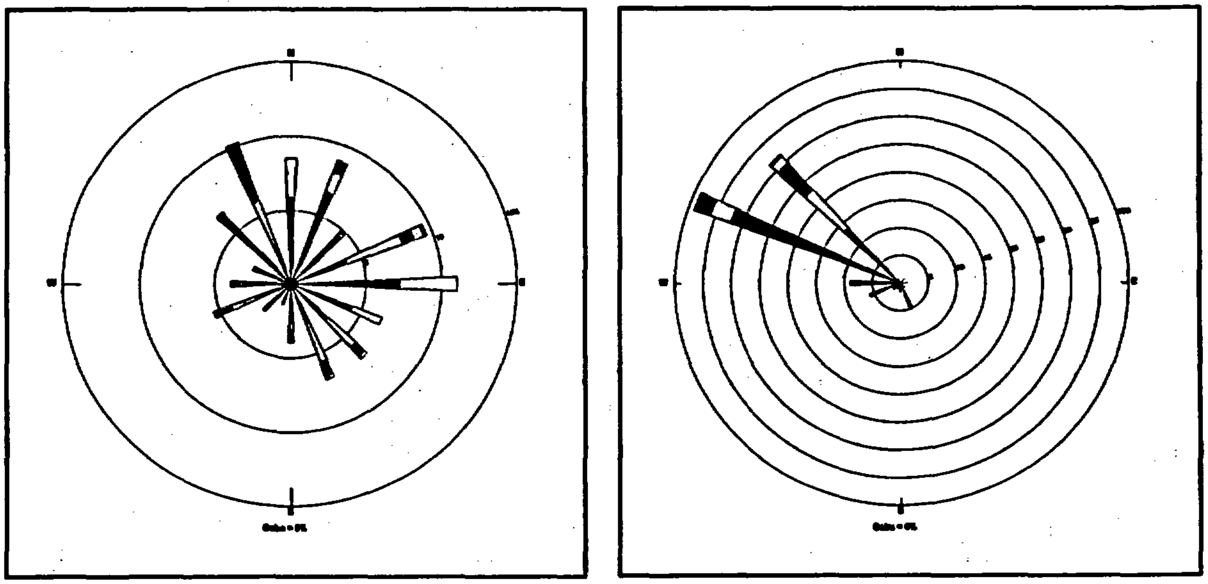
Note: The diagram is the frequency of occurrence for each wind direction from which the wind is blowing.

Figure 3-43. Julian Days 78 - 121 Nighttime Hours Wind Rose Plots For Sites 4, 101, 102, and 103



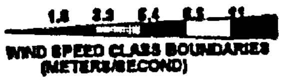
(a) Site 1-60m

(b) Site 1-10m



(c) Site 2

(d) Site 3



Note: The diagram is the frequency of occurrence for each wind direction from which the wind is blowing.

Figure 3-44. Julian Days 78 - 121 Nighttime Hours Wind Rose Plots For Sites 1, 2, and 3 with southerly winds was noted at 60 m-agl near midnight. The directions occurring at Site 101 were similar to those from the 10-m level, with speeds between one and two meters per second.

The winds on the ridge-top during the same period were from the W and SW from 1800 PST through about 2000 PST, when the transition to SE and E winds began. By 0100 PST, the winds at Site 2 were steadily from the ENE, and at Site 102 from the NNE to E. One short period of winds from the south was noted at Site 102 near midnight.

The two sites on the eastern slope of Yucca Mountain (3 and 103) showed consistent downslope winds during this period, with few exceptions. The winds at Site 3 in Coyote Wash remained quite steady from the WNW, except for two brief periods of SW winds near 2000 PST and near midnight. The winds on the hillside in Drill Hole Wash at Site 103 were most often from the north or northwest; one brief period near 2100 PST indicated easterly winds, and the short period of southerly winds near midnight was seen at this site.

The wind and temperature data aloft in Midway Valley taken by the Tethersonde® system at Site 1 during this night showed conditions more complex than observed at the surface-based meteorological stations. A shallow temperature inversion of about 3°C from the surface to less than 20 m-agl persisted during most of the observations. Isothermal conditions were typically observed aloft to over 100 m-agl, and slowly decreasing temperatures above the isothermal layer. The temperature tended to remain constant for long periods, as long as the wind conditions remained steady. Temperature changes of a few degrees Celsius were noted with major changes in wind direction.

The winds during the same night (late March 24 through early March 25, 1997) remained generally from the west to northwest near the surface, comparing closely with data from the meteorological stations. Aloft, the wind data showed complex layers and transitions in time involving winds from all directions at various times. For example, early evening southwesterly winds soon changed to northwesterly drainage-type winds near 50 m-agl, with later transition to east and northeasterly winds at about 100 and 200 m-agl, and southeasterly to southerly flow above 300 m-agl.

The other night of the special study period began with north and northwesterly winds with speeds greater than 6 m/s at Site 1, which precluded operating the Tethersonde® system until about 0300 PST. The remainder of the night had periods of westerly and southerly winds at Site 1 with speeds between about 1 and 3 m/s. A surface-based temperature inversion remained the rest of the night up to at least 60 m-agl. Data from the meteorological stations and the Tethersonde® system showed periods of southerly airflow between about 100 and 200 m-agl (at Site 1) in Midway Valley, with northwesterly flow at lower levels and northerly and northeasterly winds at higher levels. This southerly airflow was replaced for about an hour with northerly winds at Site 1, but this did not occur at Alice Hill. This apparently indicates a relatively narrow and shallow layer of southerly winds occurring through Midway Valley, which override the surface-based drainage wind layer and are beneath northeasterly and northerly winds aloft.

3.4 LINKAGE TO REGIONAL AIRFLOW

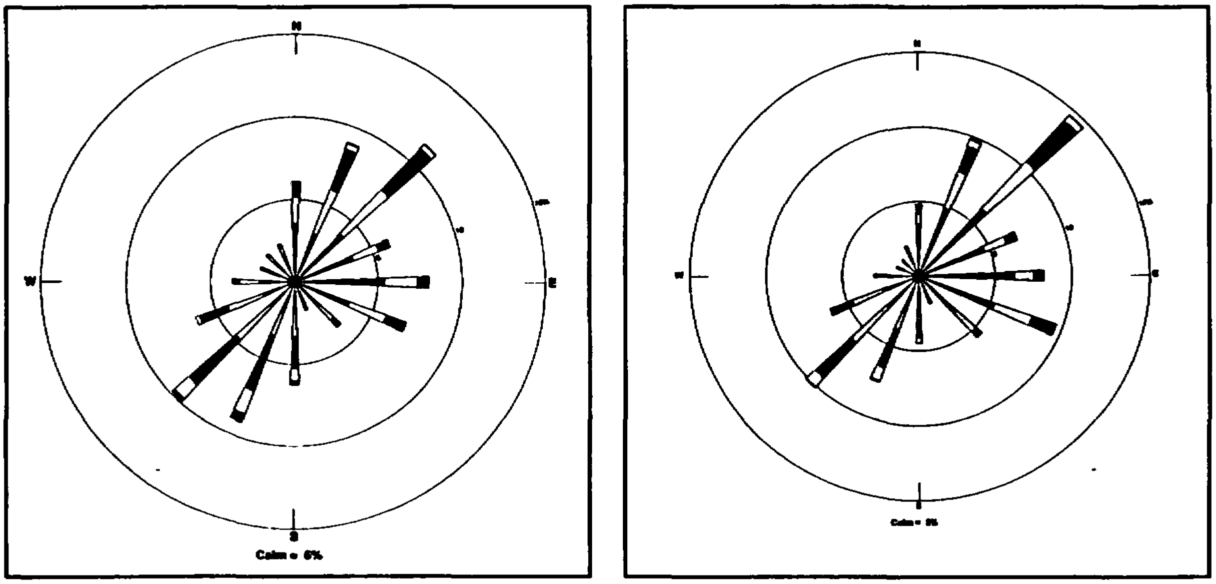
The preceding airflow and stability discussions show evidence of airflow that occurs from directions different from those associated with the slope wind mechanisms, or from the same directions but with notably greater wind speeds than are typical with slope winds. These conditions are caused by regional scale weather systems that overpower, or enhance, the local airflow mechanisms. Based on analyses of R/EFPD data and studies previously cited reported in the literature, the most important factors appear to be cloud cover and wind speeds resulting from pressure gradients associated with the weather systems. Both factors tend to minimize the slope flows by altering the surface heating and cooling mechanisms.

The limited information available from the intensive study periods performed by YMP near Yucca Mountain and by NOAA in Jackass Flats indicate that airflow within the valleys defined by surrounding terrain within a few kilometers is at least channeled, if not totally controlled by, the topographically-related wind mechanisms. These results are similar to those evident in areas and studies such as the western Colorado deep valleys (Orgill et al.1992, Gudiksen et al. 1992), the southern Colorado Rocky Mountains (Banta and Cotton 1981), the Colorado front range Rocky Mountains (Bossert et al. 1989, Coulter and Gudiksen 1995), and the Tennessee River Valley (Whiteman and Doran 1993).

Further indications of the transition to regional airflow are evident in comparisons of different levels of winds aloft data taken at Desert Rock Airport during the twice-daily routine rawinsonde ascents. The ascent times are 0400 and 1600 PST, which provide observations of both well-developed nighttime and daytime conditions. Winds aloft data are reported for the "mandatory" pressure levels, such as 850 and 700 millibars (mb), and for intermediate levels depending on wind, temperature, and humidity profile characteristics. The Desert Rock surface data described in this section are based on observations made at hourly intervals, so caution is needed in comparing the surface data with the data taken aloft.

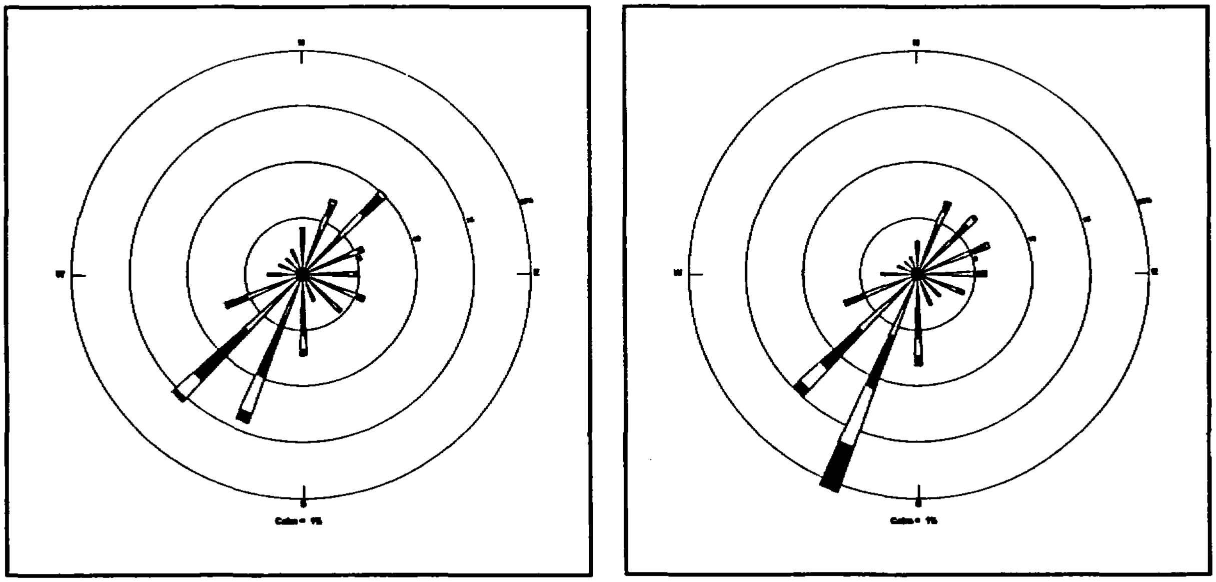
Further indications of the transition to regional airflow are evident in comparisons of different levels of winds aloft data taken at Desert Rock Airport during the twice-daily routine rawinsonde ascents. The ascent times are 0400 PST (0000Z) and 1600 PST (1200Z), which provide observations of both well-developed nighttime and daytime conditions. The Desert Rock surface data are based on observations made at hourly intervals. Winds aloft data are reported for the "mandatory" pressure levels (e.g. 850 and 700 mb), and for intermediate levels depending on wind, temperature, and humidity profile characteristics. Winds aloft summaries in this section include data from a 10 mb range around the intermediate levels identified, such as 890 ±5 mb.

The winds aloft and surface data were summarized by three time periods: daytime, nighttime, and all hours. The daytime period includes all daytime surface data, and the 1600 PST rawinsonde ascent for the winds aloft data. The nighttime period includes the surface data and the 0400 PST rawinsonde data. Wind roses summarizing data from the surface and the 900, 890 and 850 mb pressure levels are shown in Figures 3-45 through 3-47. The pressure levels correspond to approximately near-surface, 80, and 460 meters above ground level (m-agl) in the standard atmosphere. The actual heights of the pressure surfaces can vary depending on weather conditions, but the standard heights are reasonably close for discussion and summary purposes. The elevation



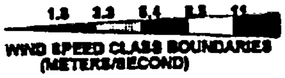
(a) Surface all hours

(b) 900mb all hours



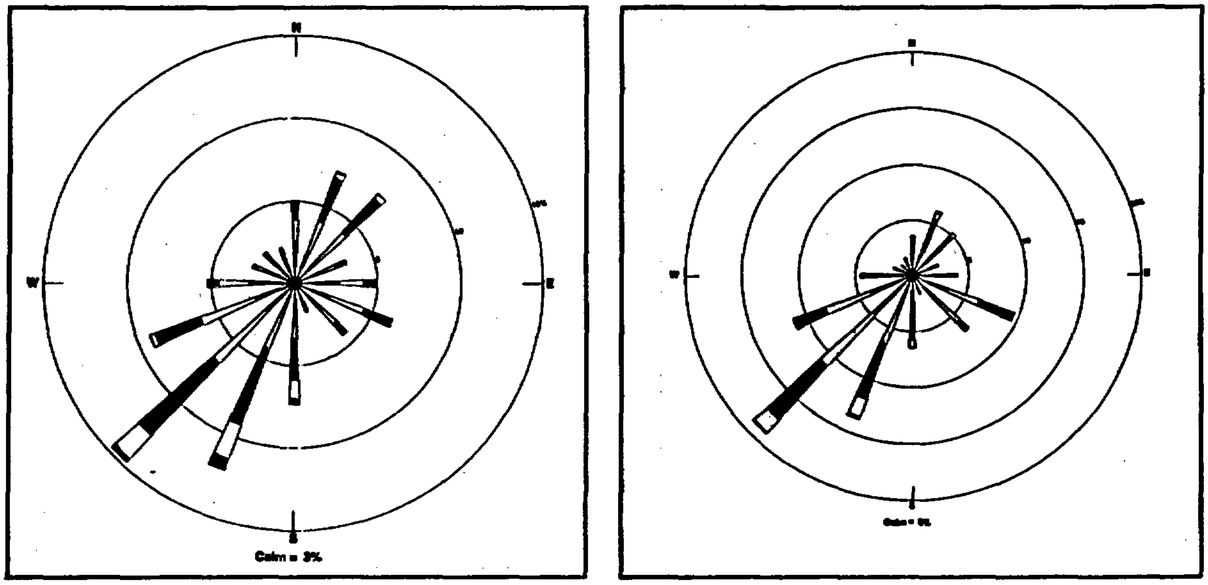
(c) 890mb all hours

(d) 850mb all hours



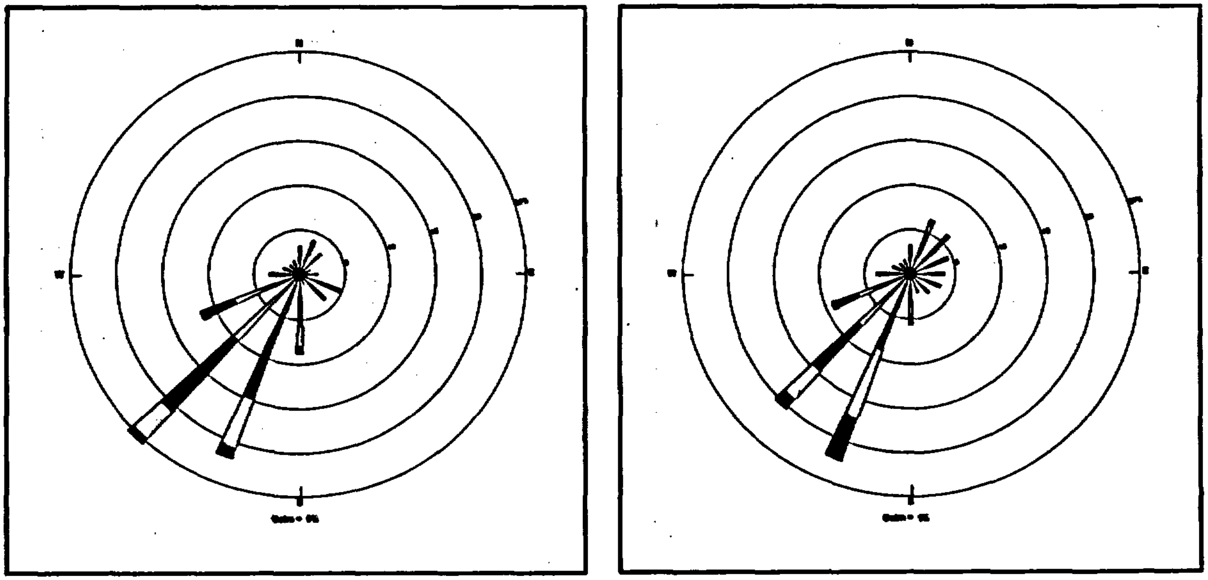
Note: The diagram is the frequency of occurrence for each wind direction from which the wind is blowing.

Figure 3-45. Desert Rock All Hours Wind Rose Plots for Surface, 900mb, 890mb, and 850mb



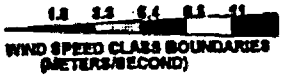
(a) Surface day

(b) 900mb day



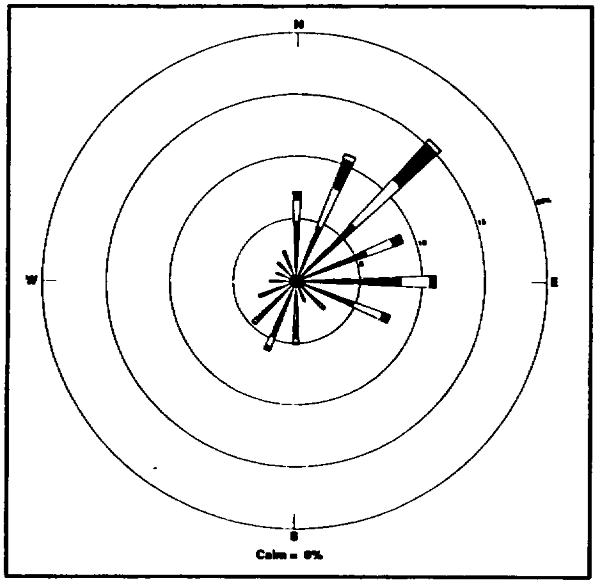
(c) 890mb day

(d) 850mb day



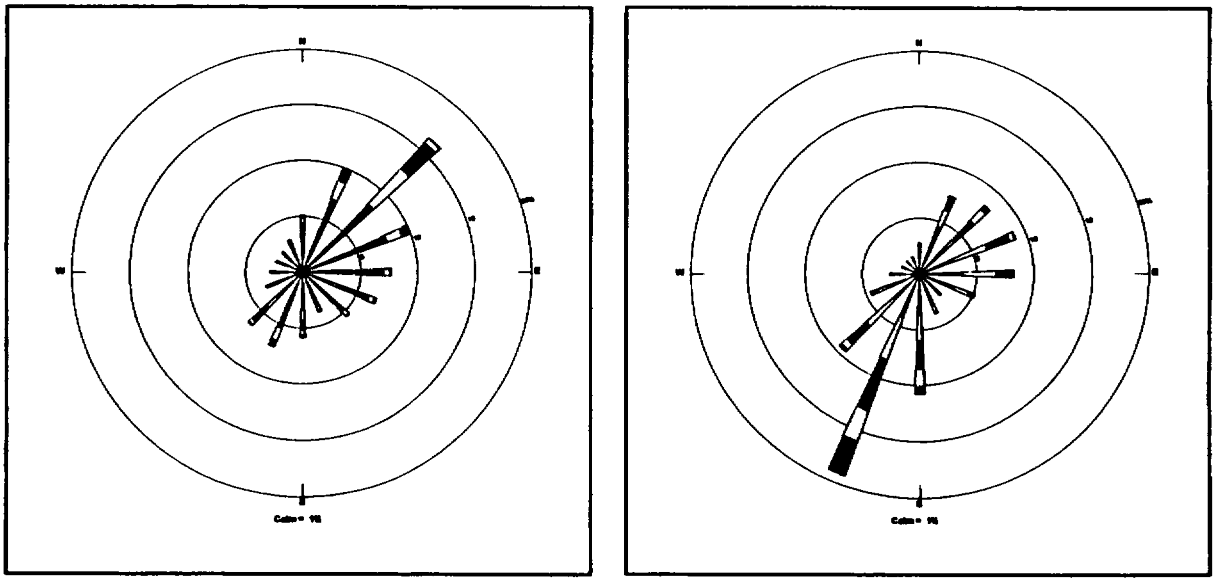
Note: The diagram is the frequency of occurrence for each wind direction from which the wind is blowing.

Figure 3-46. Desert Rock Daytime Hours Wind Rose Plots for Surface, 900mb, 890mb, and 850mb



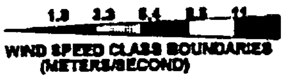
(a) Surface night

(b) 900mb night



(c) 890mb night

(d) 850mb night



Note: The diagram is the frequency of occurrence for each wind direction from which the wind is blowing.

Figure 3-47. Desert Rock Nighttime Hours Wind Rose Plots for Surface, 900mb, 890mb, and 850mb of Desert Rock upper air station is 1000 meters above mean sea level (m-msl), which corresponds to 898.7 mb in the standard atmosphere. R/EFPD Site 2 on the ridge-top of Yucca Mountain is at 1478 m-msl, which is approximately the elevation of the 850 mb pressure level.

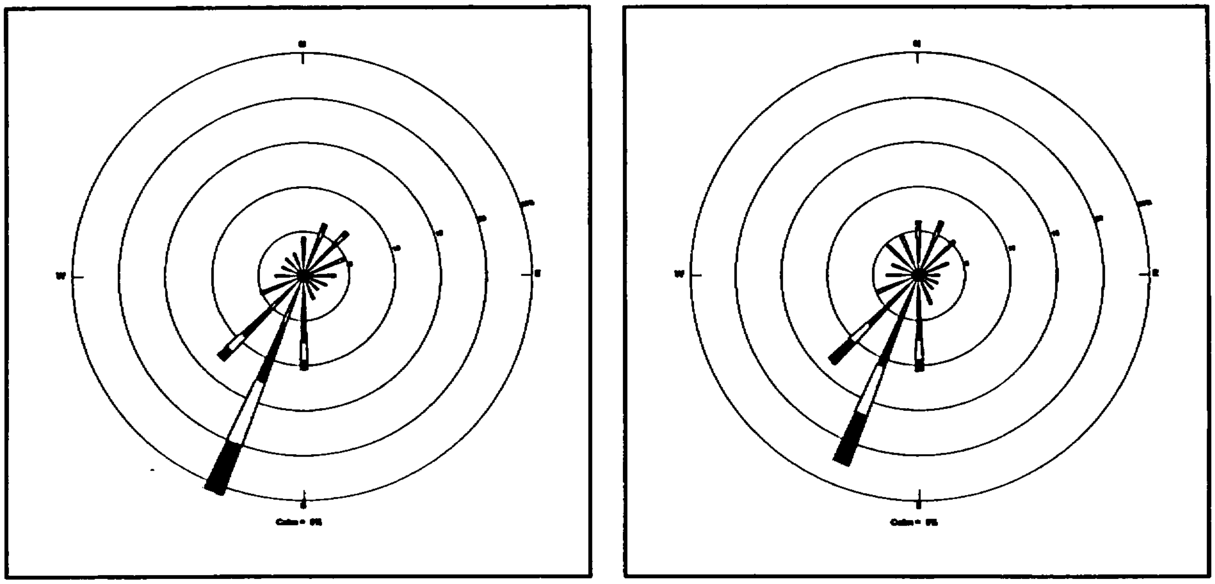
The surface wind rose from all hours in Figure 3-45 shows winds approximately evenly split between the S through WSW directions and N through ENE during about 64 percent of the time. The dominant directions were SW and NE, followed by NNE and SSW. Winds were from the E and ESE directions an additional 15 percent of the time. The diurnal surface wind roses, displayed in Figures 3-46 and 3-47, show that the southwesterly winds occur most often in the daytime hours, and the winds at night are mostly from the N through ESE directions. These primary directions are aligned with the most direct pathway to and from Amargosa Valley, and follow the daytime-upslope and nighttime-downslope pattern seen at the R/EFPD and ARL/SORD sites in Jackass Flats and Midway Valley.

The wind roses made from wind data taken near the 900 mb level, which are very near the surface, are similar to those made from the surface data. The wind rose for the nighttime period shows strong dominance of winds from the northeasterly downslope direction; about 45 percent of the hours had winds from the NNE through ENE directions. The daytime wind rose shows dominance of the southwesterly directions during over 50 percent of the observations, though the ESE, SE and NNE, NE directions account for over 25 percent of the data.

The wind roses made from wind data taken near the 890 mb level, which is approximately 80 m-agl, show important differences from those taken from the 900 mb level. The nighttime wind rose still shows dominance of the northeasterly winds, but winds were from the S through SW during about 20 percent of the hours, compared to approximately 5 percent of the observations at the near-surface levels. The daytime wind rose for the 890 mb level shows strong dominance of winds from the S through WSW during about 67 percent of the observations.

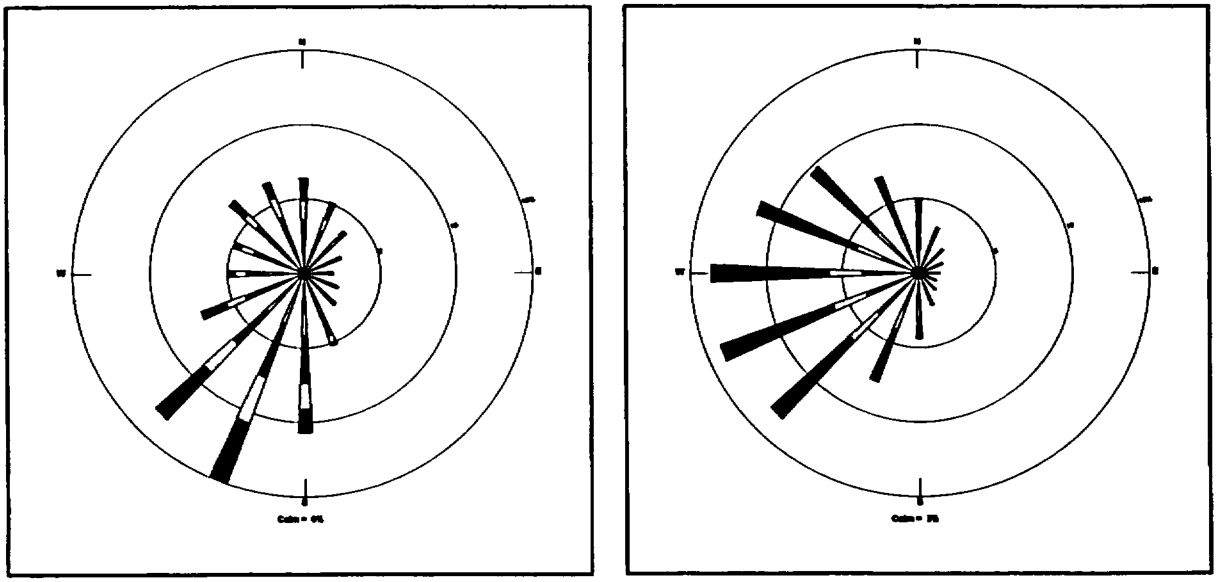
The next pressure level with a representative number of observations is the mandatory 850 mb level, which is about 460 m-agl at Desert Rock, and is approximately the same as the ridge-top of Yucca Mountain. The 850 mb wind rose shows notable differences from those at the lower levels. The strong dominance of northeasterly winds seen at the lower levels during nighttime hours does not occur at this level, though about 30 percent of the observations were from the NNE through E directions. The dominant directions were S through SW, with nearly 40 percent of the observations. Only about 10 percent of the observations were from the W through N directions. The most prevalent daytime directions were from the SSW through WSW, with about 50 percent of the observations. About 17 percent of the daytime observations were from the NNE through ENE directions, and about 10 percent from the W through N directions.

Wind roses from higher levels are also included in Figures 3-48 through 3-50, to show the progression of wind patterns aloft with increasing heights above ground level. A representative amount of wind data from two intermediate levels between the 850 and 700 mb mandatory pressure levels were summarized. The 800 and 750 and 700 mb pressure levels correspond to 950, 1460, and 2010 m-agl at Desert Rock. Recall that Desert Rock is 1000 m-msl.



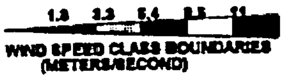
(a) 800mb all hours

(b) 750mb all hours



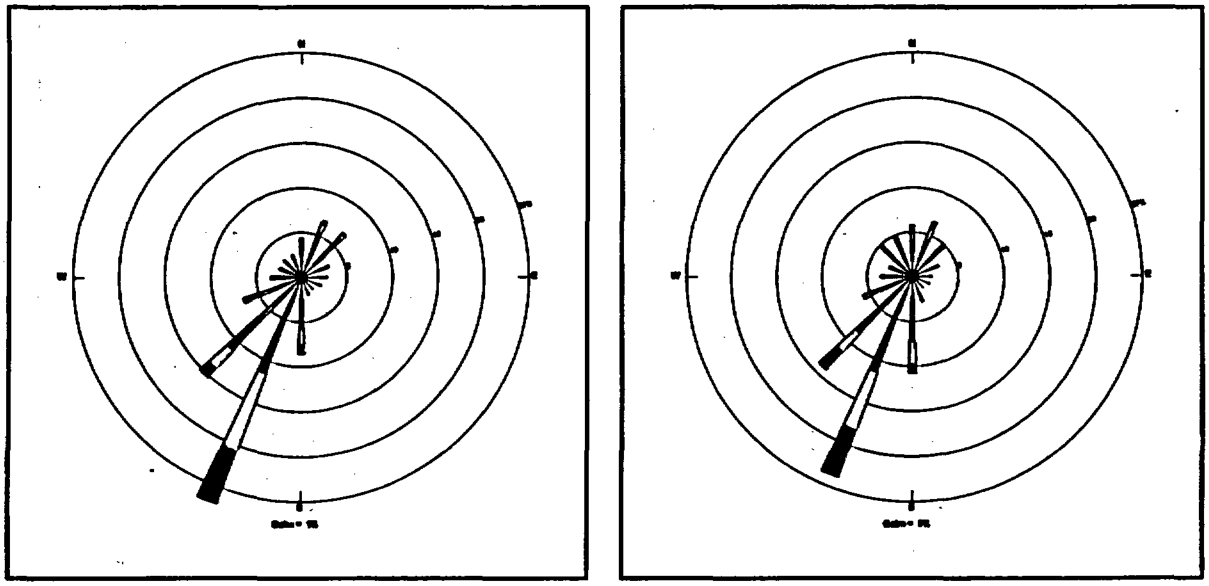
(c) 700mb all hours

(d) 500mb all hours



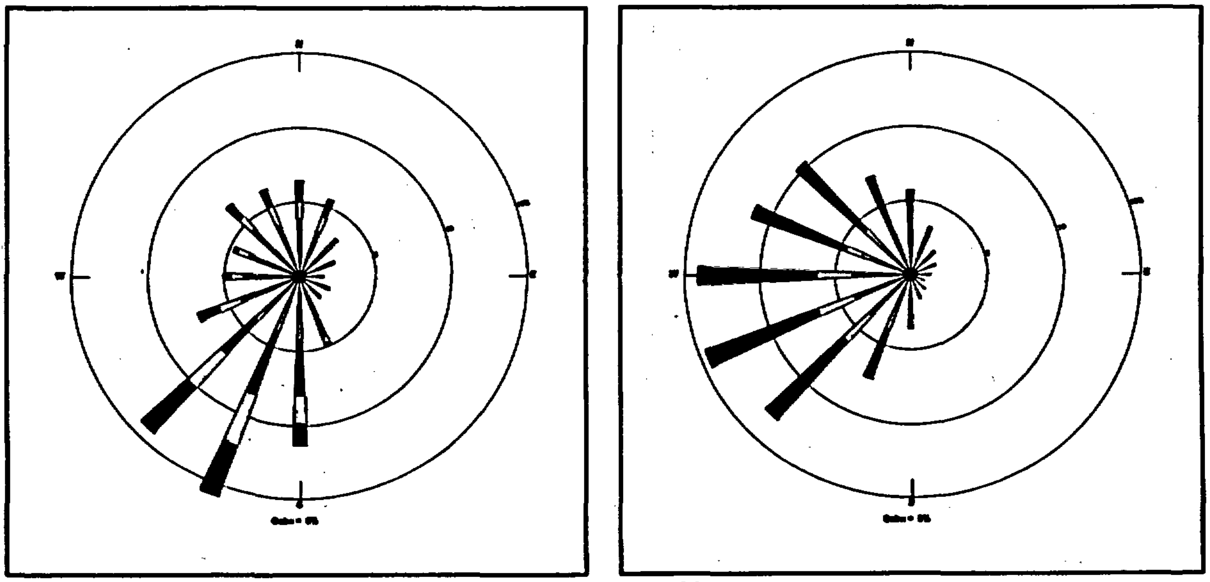
Note: The diagram is the frequency of occurrence for each wind direction from which the wind is blowing.

Figure 3-48. Desert Rock All Hours Wind Rose Plots for 800mb, 750mb, 700mb, and 500mb



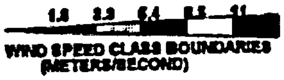
(a) 800mb day

(b) 750mb day



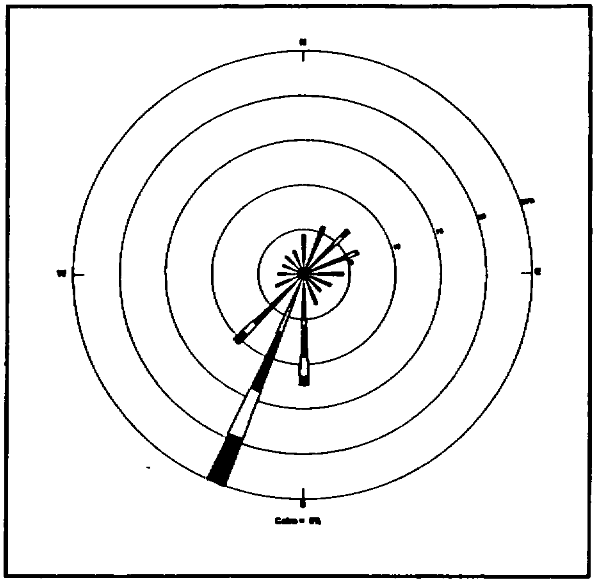
(c) 700mb day

(d) 500mb day



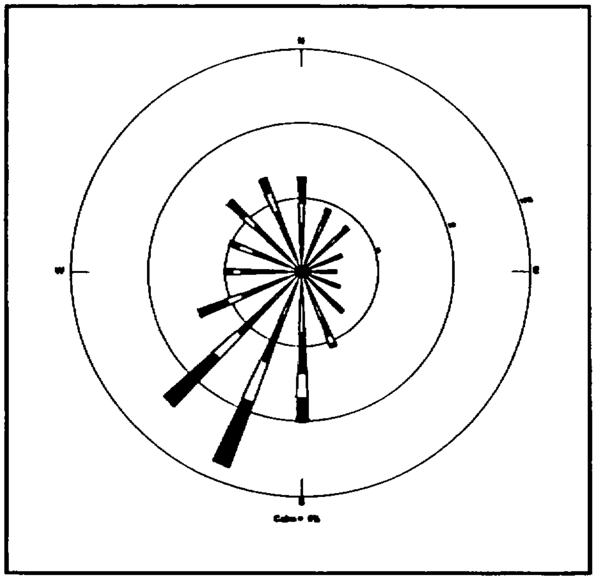
Note: The diagram is the frequency of occurrence for each wind direction from which the wind is blowing.

Figure 3-49. Desert Rock Daytime Hours Wind Rose Plots for 800mb, 750mb, 700mb, and 500mb



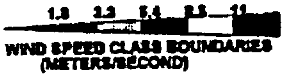
(a) 800mb night

(b) 750mb night



(c) 700mb night

(d) 500mb night



Note: The diagram is the frequency of occurrence for each wind direction from which the wind is blowing.

Figure 3-50. Desert Rock Nighttime Hours Wind Rose Plots for 800mb, 750mb, 700mb, and 500mb

The wind roses for the 800 mb level are similar to the 850 mb level, with a slight shift in the southwesterly winds at 850 mb toward the southerly direction at 800 mb. The daytime and nighttime wind roses at the 800 mb level are similar to each other, though some differences are evident.

By the 750 mb level, the southwesterly airflow still dominates the occurrences. The northeasterly winds observed at lower levels were shifted toward the north, with directions spread between NW and NE. The easterly winds seen at lower levels do not occur at the higher levels. The wind roses from the 700 mb level show the two dominant directions converging toward the west. The dominant directions at this level are about 45 percent of the winds from S through WSW, and about 25 percent from the NW through N. Only about 12 percent of the winds were from the NE through SE directions at 700 mb. The wind roses from the highest pressure level are for the 500 mb level. These wind roses show strong dominance from the west and southwest; over 75 percent of the winds were from the SSW through NNW directions. Very few occurrences at 500 mb were from the easterly directions.

In summary, the winds aloft data from Desert Rock show that the nighttime frequent northeasterly airflow is usually limited to layers within about 100 m-agl. Winds from these directions in the next few higher hundred meters above ground level occur about one-half as often as winds at the surface. Southwesterly airflow occurred frequently at night above the near-surface northeasterly layer. Daytime winds are typically southwesterly at all levels. Northwesterly winds seldom occurred at any of the levels up through 850 mb. The differences between daytime and nighttime wind summaries decreased with increasing height above ground level. Wind at the higher levels converged toward westerly, with very few occurrences of easterly winds.

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4. REGIONAL AIRFLOW

Regional scale airflow patterns were investigated by examining wind data taken at surface stations around Nevada, southern California and southern Utah. The surface data provide some indications of regional airflow, though topographic channeling influences the local wind patterns at the stations enough to preclude extrapolating the wind summaries to long-range air trajectories based on these data alone. Winds aloft data taken from the twice-daily routine upper-air observations Desert Rock Airport (DRA) located near Mercury, Nevada in the southern portion of the Nevada Test Site were also used in the analysis. Desert Rock is along a potential air pathway between Yucca Mountain and metropolitan Las Vegas, Nevada.

4.1 WEATHER PATTERNS

The winter upper-air pattern is determined by the position of the Aleutian Low and its associated trough. The Aleutian Low is normally centered in the Gulf of Alaska with the associated trough oriented north-south off-shore along the Pacific Coast. The normal storm track for the West Coast of the United States is toward the northeast along the Northern California coast through British Columbia. This normal storm track location leaves the southern Nevada region under the upper-air ridge and generally free from frontal passages. The lack of frontal passages and the cold air at the surface allows the formation of the Great Basin High, which is the common name for the surface-based high pressure area located in the central Nevada area (Houghton et al.1975).

The weak pressure gradients and frequently clear skies occurring with the Great Basin High correspond to relatively slow regional-scale wind speeds and significant diurnal differences in ground surface heating and cooling. This combination of slow speeds and the diurnal surface heating cycle allow the topographic airflow mechanisms described in Section 3 to dominate regional and local airflow patterns. This pattern is normally characterized by mountain-valley circulation patterns. Frequently during this season the upper level Aleutian Low or its associated trough will migrate eastward or southeastward. When this happens, the Great Basin High is destroyed. The surface wind pattern resembles that associated with typical frontal passages. The surface winds are generally from the southwest to west preceding the frontal passage and change rapidly to the north following the frontal passage. The winds associated with the frontal passages usually overpower or enhance the topographically-induced mountain-valley wind patterns, depending on the orientation of the topography and the wind direction associated with the frontal passage.

The summer upper-air pattern is dominated by the positions of the North Pacific and Bermuda ridges. The North Pacific ridge dominates the Yucca Mountain region for the Summer. This ridge normally prevents any frontal passages from transiting the region. This lack of frontal passages and high surface air temperatures lead to the development of the Southwest Thermal Low. This daytime-only regional flow is strongly modified by topographically induced diurnal wind circulations. When the western extension of the Bermuda ridge approaches the region, the surface winds tend to come from the South to Southeast. This flow, and the associated moisture transported from the Gulf of Mexico, is termed as the Southwest Monsoon. This flow generally affects the region late in the summer for a brief time and usually only affects the eastern portion of the region.

4.2 WIND SUMMARIES

Regional stations reporting airways wind data were selected to analyze regional wind patterns. Stations selected included those from Nevada and those few stations in California and Utah near the Yucca Mountain area. The stations considered are shown in Figure 2-2, and have locations listed in Table 2-2. Three of the stations (Bishop, China Lake, and Milford) recorded observations only during the day, so data from these stations were included in the daytime-only plots, but not the all-hours plots.

Joint-frequency distributions and wind rose plots of the wind data were made for seven cases: all hours, and for daytime and nighttime hours during each climatological season. A review of the wind roses confirmed expectations based on results from the YMP results and climatological literature that Great Basin wind characteristics follow diurnal and seasonal patterns. The seasonal analyses showed two distinct seasons, winter and summer. Spring and fall are transitions between these two extreme seasons.

The summarized wind data from all hours at the regional meteorological stations were plotted as wind roses at the station locations shown in the regional map in Figure 2-2. Separate wind roses are shown for all hours and all seasons in Figure 4-1, summer daytime and summer nighttime hours in Figures 4-2 and 4-3, and winter daytime and winter nighttime in Figures 4-4 and 4-5.

Stations situated in terrain with the dominant downslope direction coincident with wind directions associated with typical large scale weather systems show one prevailing wind direction. Examples include Cedar City in southern Utah, Ely airport in east-central Nevada, and the Daggett airport southwest of Yucca Mountain. Most of the other stations show a more even distribution of wind occurrences, such as Desert Rock and Las Vegas.

There is greater wind direction variability in winter than summer. These differences seem to correspond to the greater number of frontal passages through northern and central Nevada in winter than in summer and enhancement of one or the other mechanism driving the topographical wind as discussed in Section 3. For example, more cold air in the winter can enhance the downslope portion of the wind while suppressing some of the upslope wind. The reverse would be true for the summer. Frontal passage periods can have wind forces strong enough to override the upslope and downslope topographic mechanisms.

4.3 COINCIDENT WIND OCCURRENCES

The wind summaries presented in Section 3 address the overall occurrences of winds at various locations and heights above ground level. Atmospheric transport over long distances requires the coincidence of certain wind occurrences that could show preferential transport of airborne material along a given pathway. In order to address coincidence of certain wind occurrences, wind speed and direction joint-frequency distributions were created for stations along the potential pathway between Yucca Mountain and Las Vegas. The stations used in this analysis are shown in Figure 4-6.

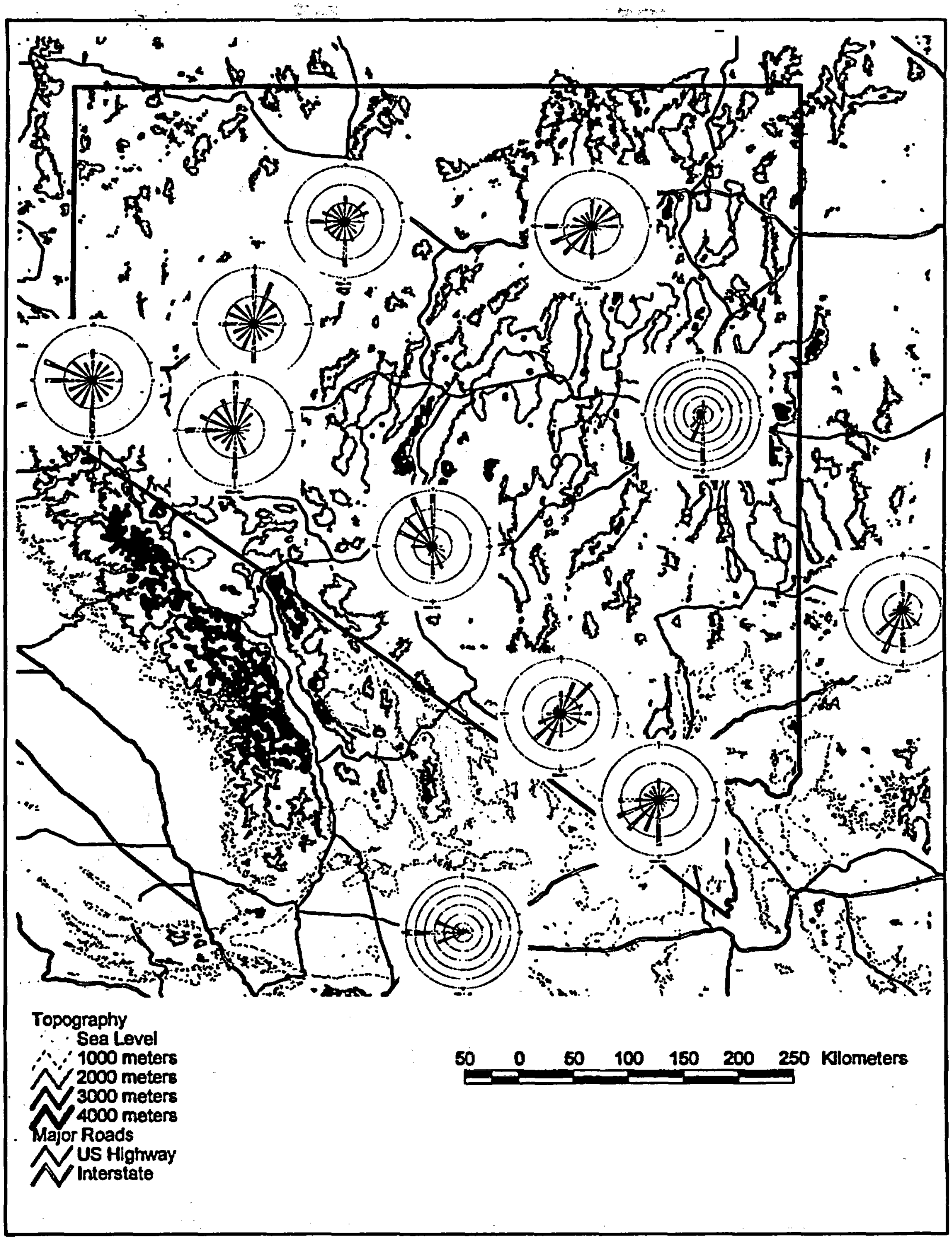


Figure 4-1. All Hours Wind Rose Plots

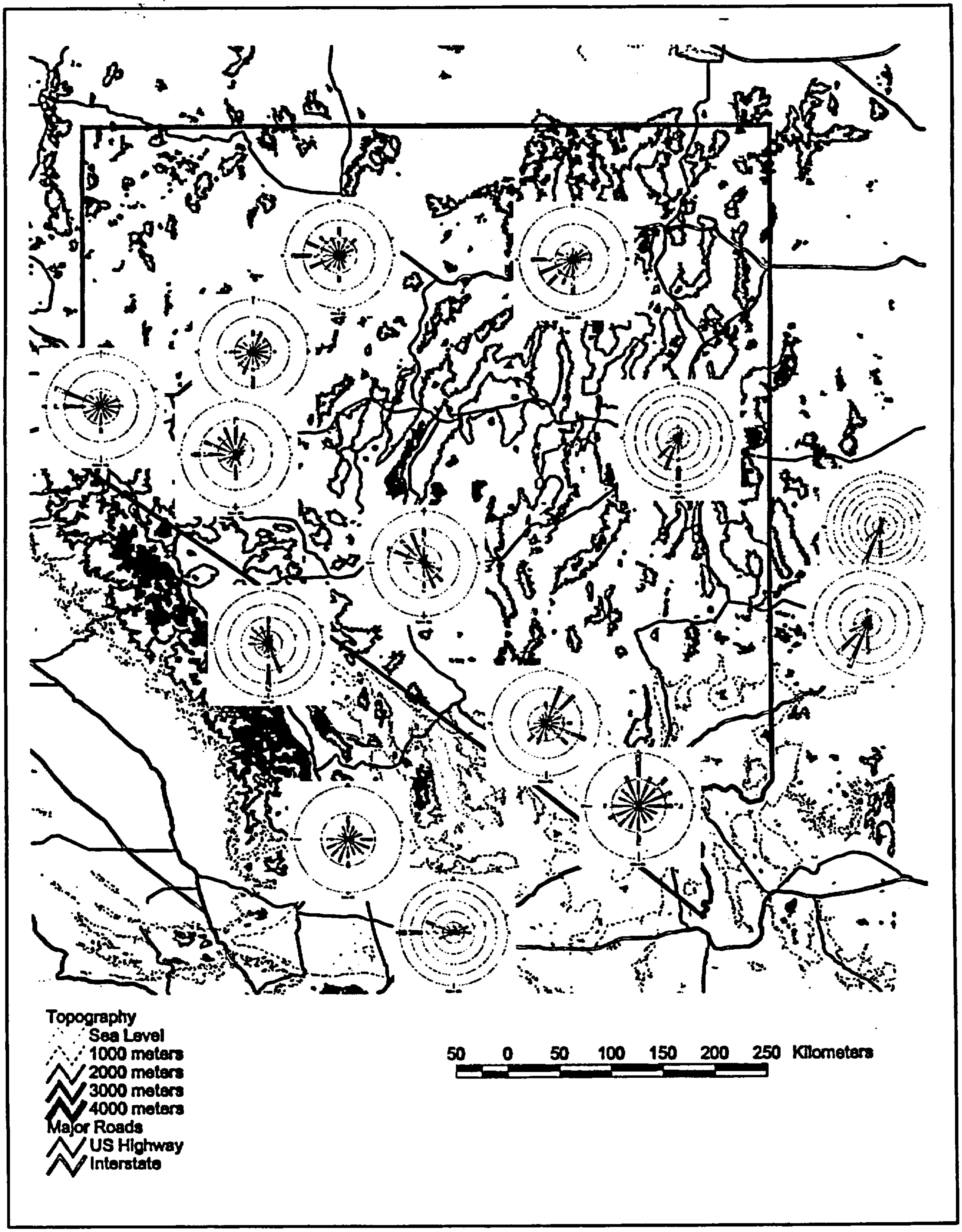


Figure 4-2. Summer Daytime Hours Wind Rose Plots

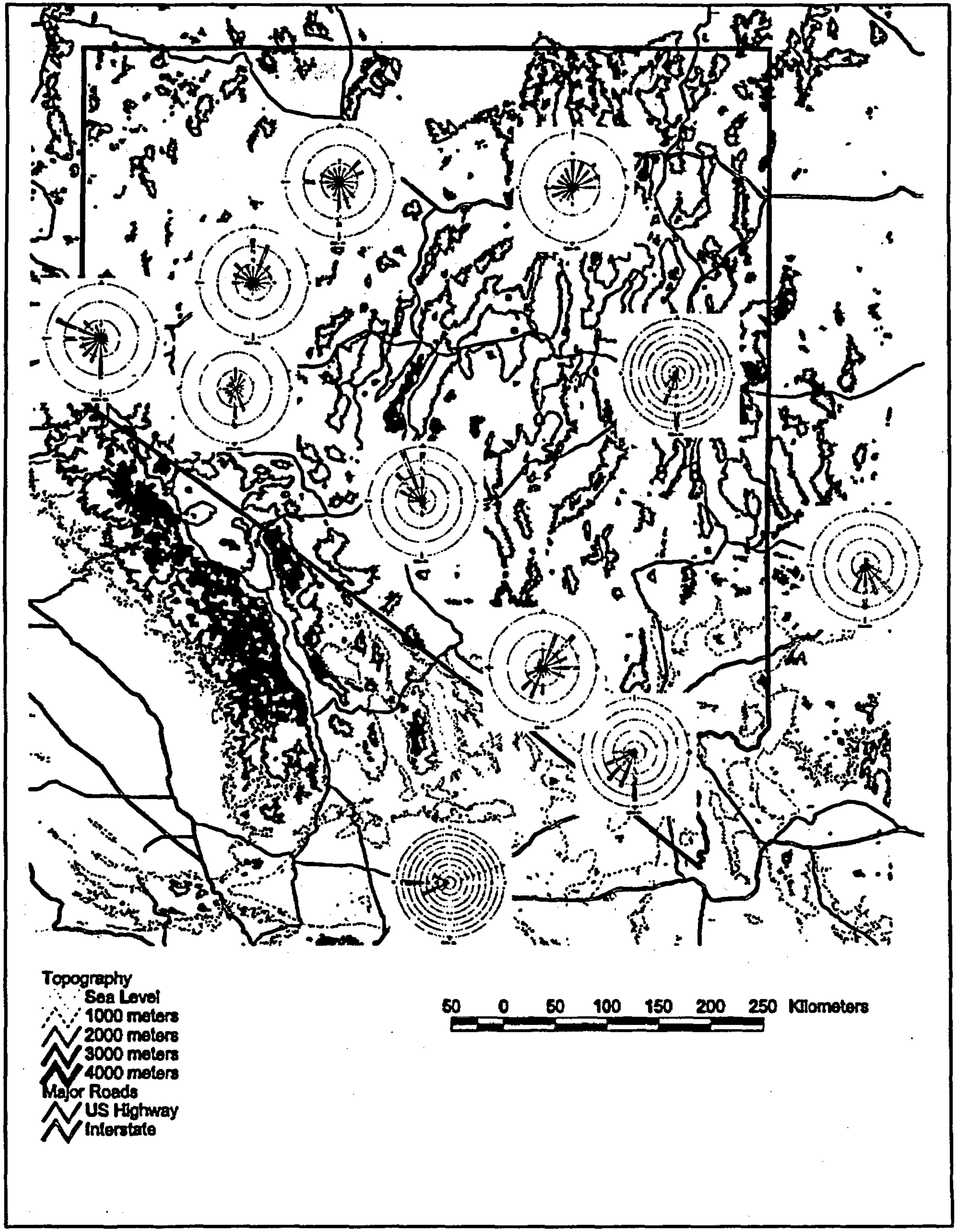


Figure 4-3. Summer Nighttime Hours Wind Rose Plots

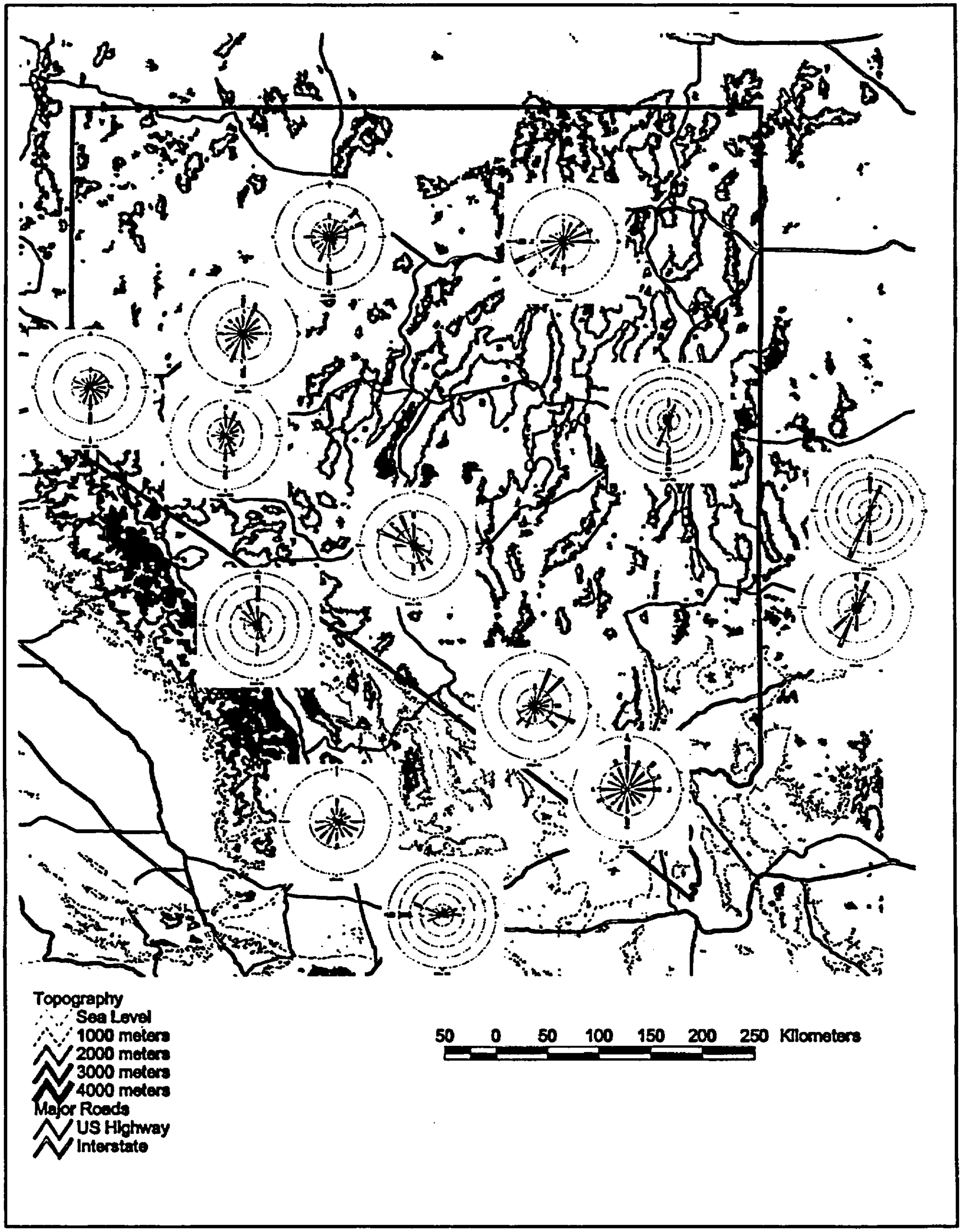


Figure 4-4. Winter Daytime Hours Wind Rose Plots

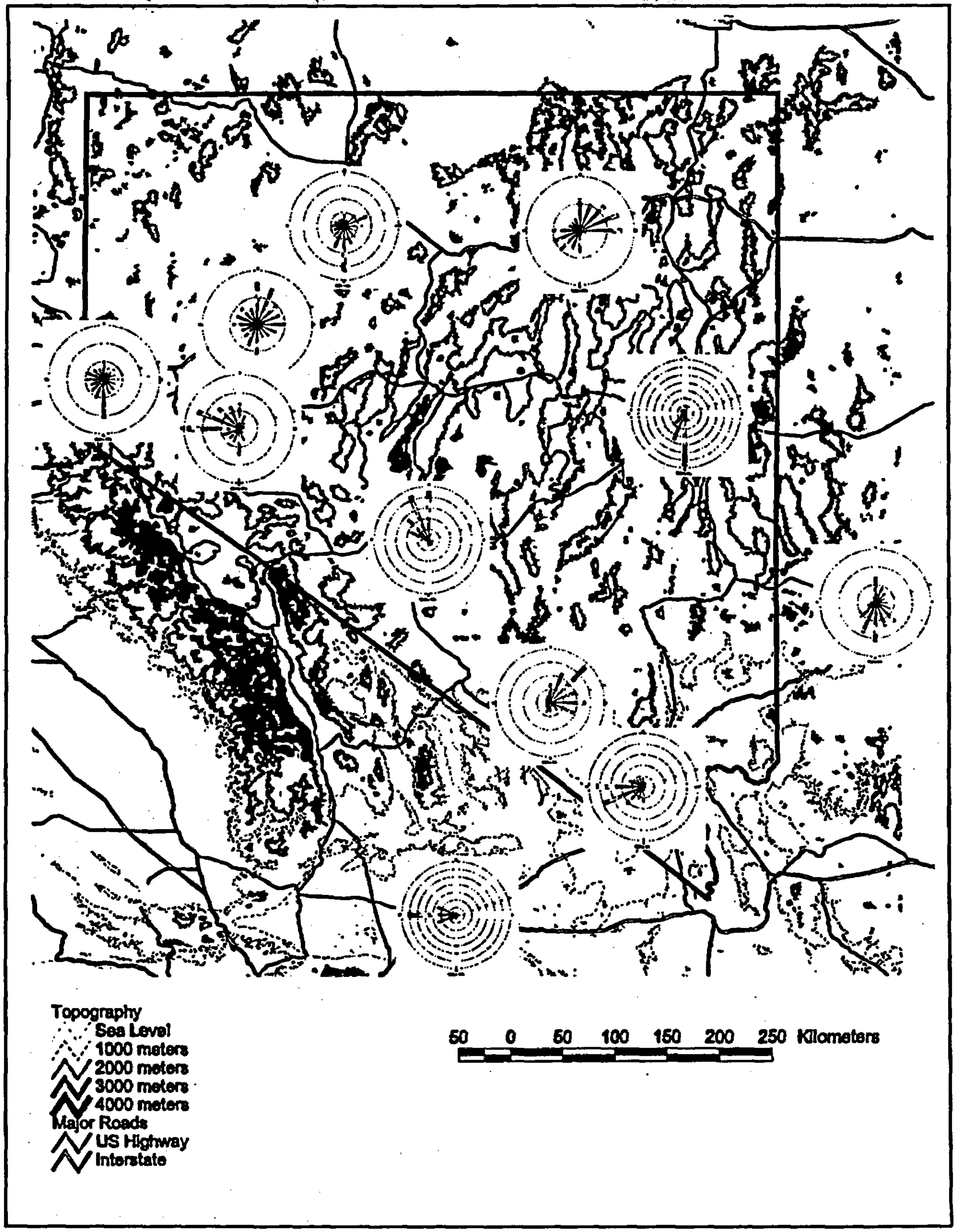


Figure 4-5. Winter Nighttime Hours Wind Rose Plots

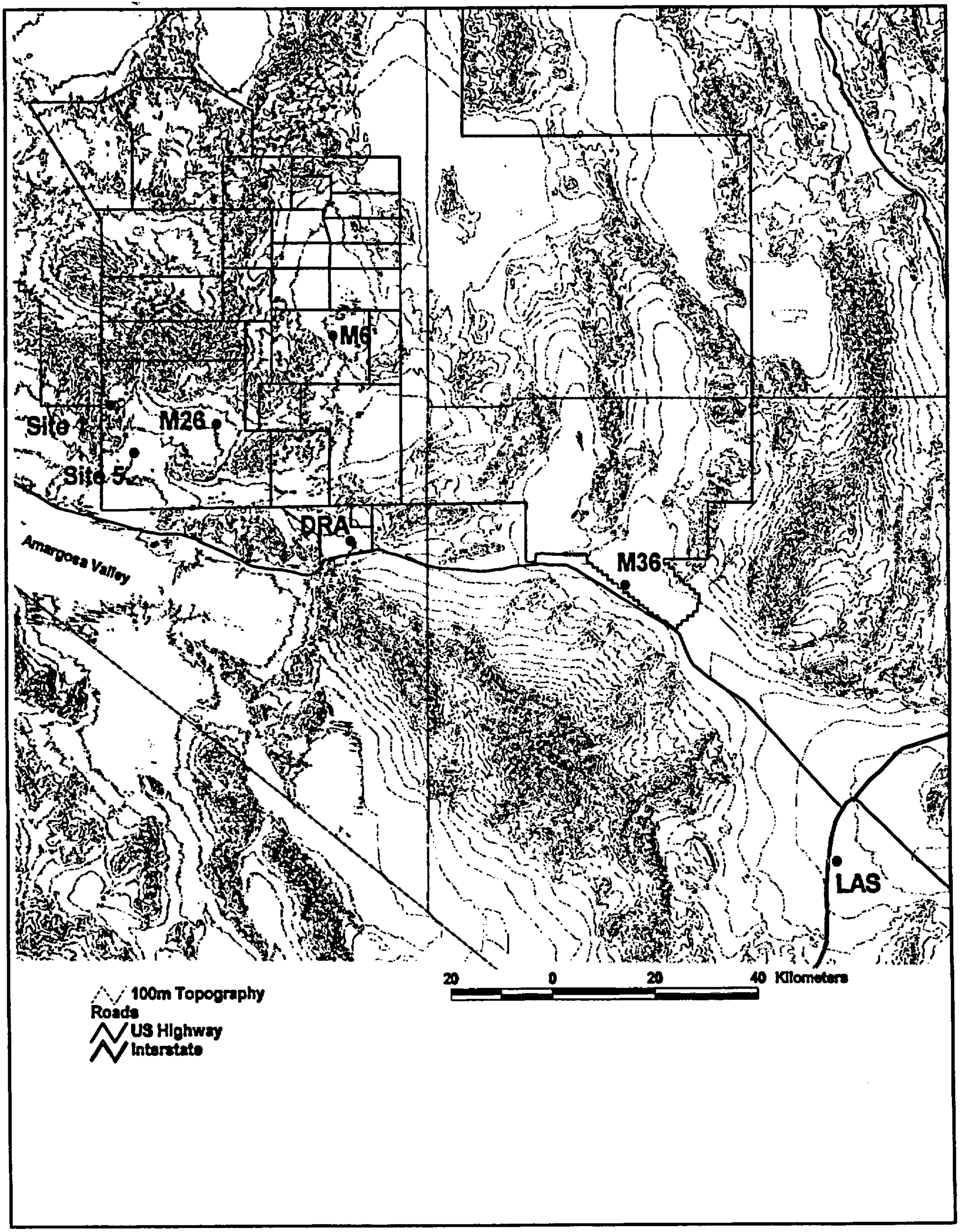


Figure 4-6. Locations of Coincident Wind Sites

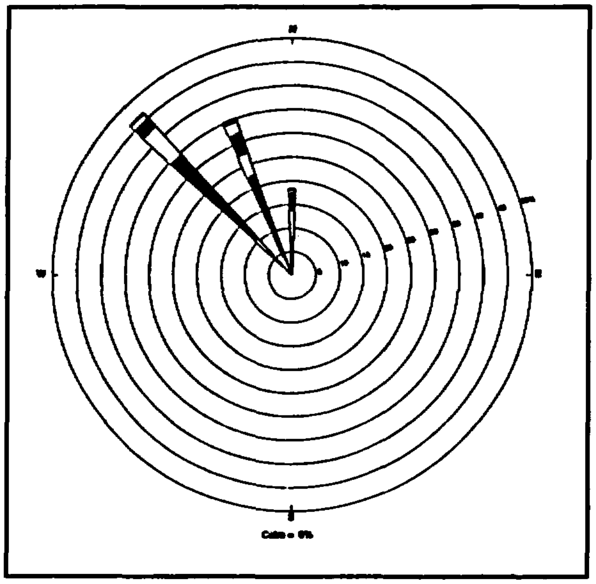
The coincident wind analysis was performed for two conditions. The first was under nighttime conditions when airborne material would be emitted into downvalley airflow. The hours with wind directions from the NW through N directions at the 10-m level at Site 1 were identified as representative of the condition. The second condition analyzed was for the same wind directions, but with speeds at least 5.4 m/s. These wind directions were chosen for their high frequency of occurrence, and because these directions could be the first step in transporting airborne material toward Las Vegas. The air pathway for these directions takes material out of Midway Valley, where it typically flows toward the south through Jackass Flats and on to Amargosa Valley.

For both starting conditions, the next step was to create a wind joint-frequency distribution of wind data from Site 5 from the hours meeting the initial criterion at Site 1. Site 5 was chosen for the analysis as the next site along the potential pathway (see Figure 4-6); it is in Jackass Flats along Fortymile Wash, between Midway Valley and Amargosa Valley. Then, the hours with wind directions at Site 5 from the NNW through NNE directions were identified as potentially occurring with airborne material being transported from the area near Site 1 at least through lower Jackass Flats heading toward Amargosa Valley. The hours meeting the wind direction criterion at Site 5 were then selected to create wind joint-frequency distributions at Desert Rock Airport, MEDA Station 36 (located near Indian Springs), and the Las Vegas airport.

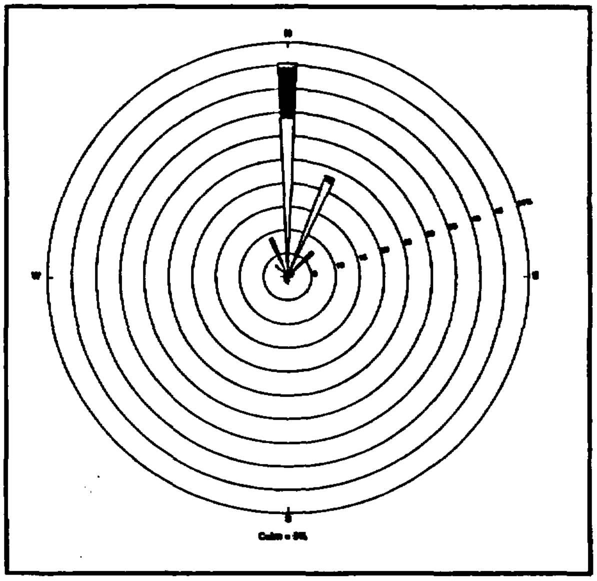
The wind rose figures made from the wind summaries from Sites 1 and 5 are shown in Figure 4-7. The first wind rose for both wind speed conditions analyzed is the occurrences of winds from the NW through N at Site 1. Winds at Site 1 met the direction criteria for all wind speeds during about 37 percent of all hours, and the criteria for speeds at least 5.4 m/s during about 6 percent of all hours. Continuing to the direction criterion at Site 5, about 28 percent of all hours remained in the analysis for the all speeds at Site 1 condition. Only 4.5 percent of all hours remained when the criteria at Site 1 included speeds at least 5.4 m/s. The wind rose figures for Site 5 show winds mostly from the N and NNE for the all wind speed condition, and mostly from the NNW and N for the wind speeds at least 5.4 m/s.

The wind roses for the all speeds condition for the last three stations (Desert Rock, MEDA36, and Las Vegas Airport) are shown in Figure 4-8. The winds at Desert Rock were from the N through ESE directions about 72 percent of the hours; 20 percent were from the NE direction alone. Since many of the selected hours at Site 1 represent stable, downvalley airflow, the northeasterly winds at Desert Rock were anticipated because this direction corresponds to the downvalley winds at this location.

Continuing with the condition of all wind speeds case, the winds at the MEDA36 station were from the W through N directions during about 45 percent of the hours of the analysis, primarily from the WNW and NW directions. Winds were from the south during nearly 20 percent of the hours, and were spread among the other directions between SE and WSW for most of the remaining hours. The southerly winds were typically with speeds less than 3.3 m/s, indicating the regular occurrence of downslope winds from the Spring Mountains to the south. The wind summary for Las Vegas showed nearly 40 percent of the hours from the W and WSW, and another 25 percent from the S through SW directions. Less than 20 percent of the hours had winds from the WNW through NNW directions.



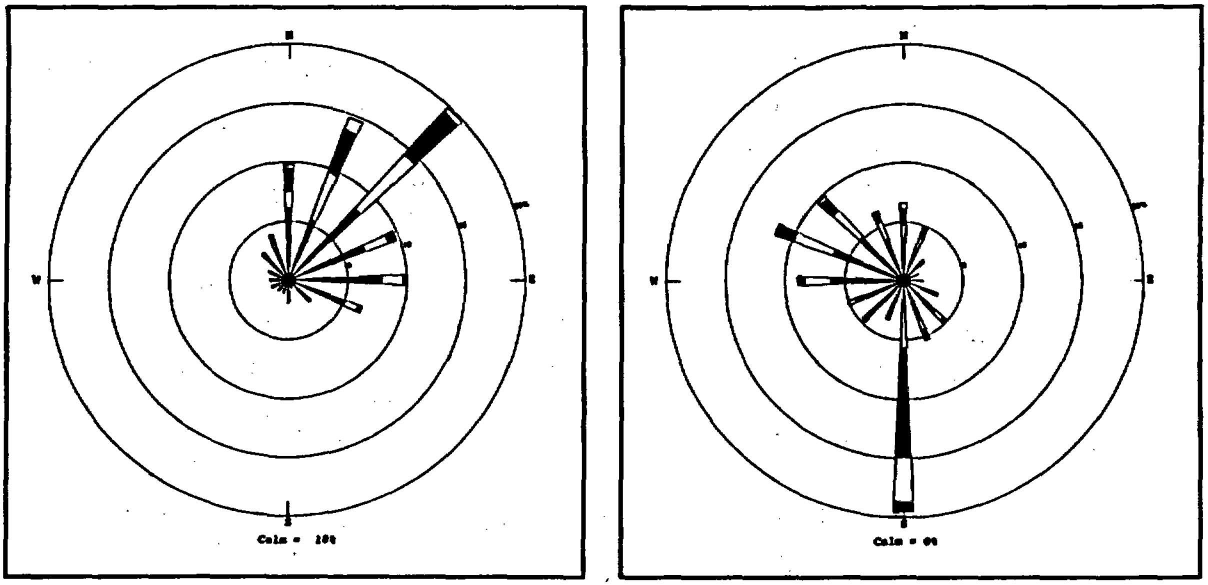
(a) Site 1



(b) Site 5

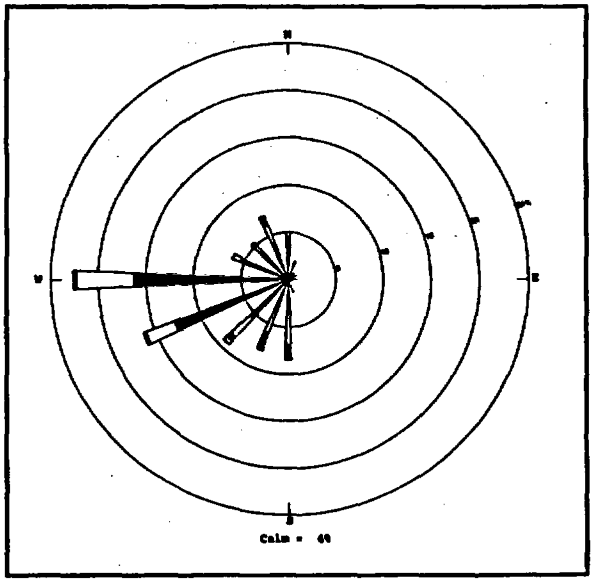
Note: The diagram is the frequency of occurrence for each wind direction from which the wind is blowing.

Figure 4-7. Coincident Wind Roses For Sites 1 and 5 Using All Nighttime Hours

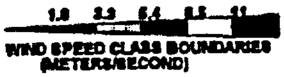


(a) Desert Rock, NV

(b) MEDA36



(C) Las Vegas, NV

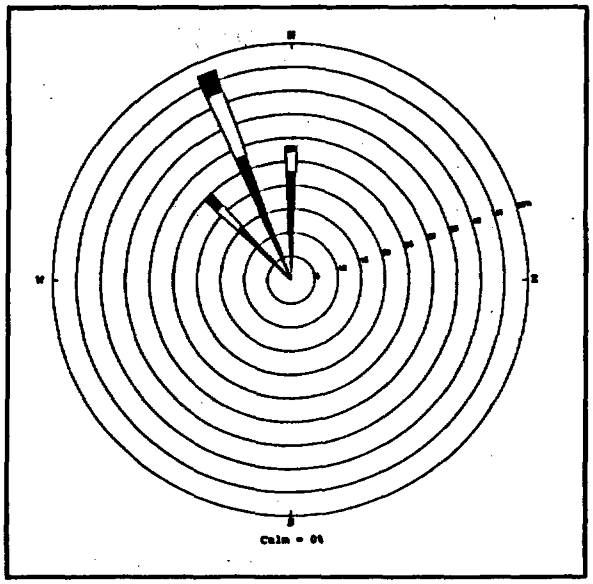


Note: The diagram is the frequency of occurrence for each wind direction from which the wind is blowing.

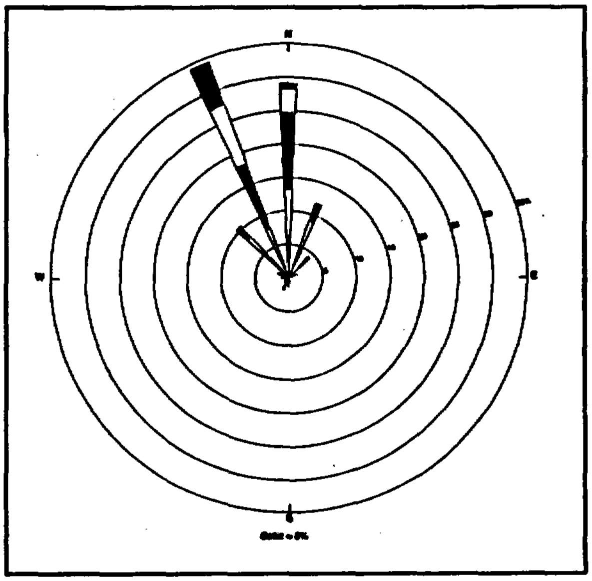
Figure 4-8. Coincident Wind Roses For Desert Rock, MEDA36, and Las Vegas Using All Nighttime Hours

The two wind rose plots for Sites 1 and 5 for the case of Site 1 wind speeds at least 5.4 m/s are shown in Figure 4-9. The winds at Site 5 were from the NNW through NNE directions during about 75 percent of those times. The plots of wind data from the corresponding hours at Desert Rock, MEDA36 and Las Vegas are shown in Figure 4-10. Winds at Desert Rock were from the N through NE during over 60 percent of the time that the Site 5 winds were from the NNW through NNE, and from the NW and NNW during only about 13 percent of the times. This indicates that airflow traveling southward through Jackass Flats is most likely to continue on toward the south, rather than turning toward the east on a potential pathway toward Las Vegas. The winds at MEDA36 station were from WNW or NW during about 40 percent of the hours, and from W through NNE during over 80 percent of the hours. On the other hand, over 10 percent of MEDA36 winds were with winds from the south. These may be associated with pre-frontal periods when the front had passed the Midway Valley area, but had not yet arrived in the Indian Springs area. Finally, the Las Vegas wind rose shows over 60 percent of the hours occurring with winds from the NW through N.

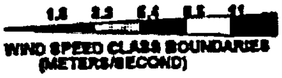
To summarize the coincident wind analyses, the apparent air pathway continued downslope into and through Jackass Flats toward Amargosa Valley. Material near the surface in this area appears to continue through Amargosa Valley, possibly joined by near-surface downslope flow entering the northeast portion of Amargosa Valley from the Desert Rock area, particularly during the lower wind speed, drainage-type wind periods. The likelihood of near-surface airflow turning to the east in Amargosa Valley and heading toward and into Las Vegas is very low. Material that might be airborne near Indian Springs could be brought into the Las Vegas area, particularly when wind speeds are greater than 5.4 m/s at Site 1. An example of an occurrence associated with an airborne release from underground nuclear testing in Yucca Flat during strong northwesterly airflow showed that the material traveled through the Indian Springs area, and across the west side of Las Vegas (NOAA 1985).



(a) Site 1

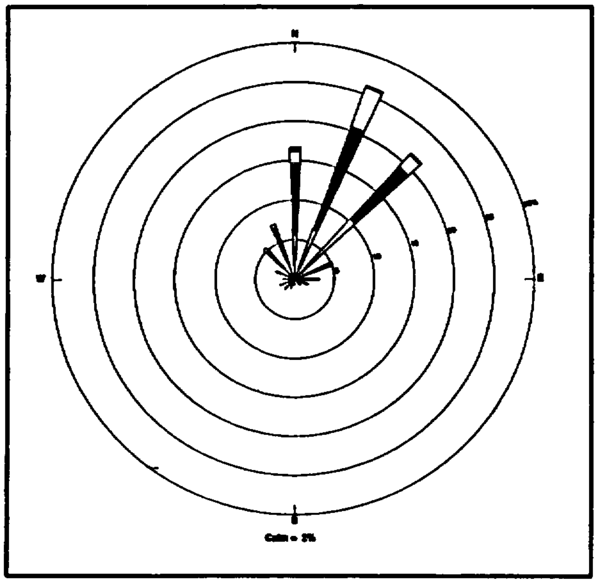


(b) Site 5

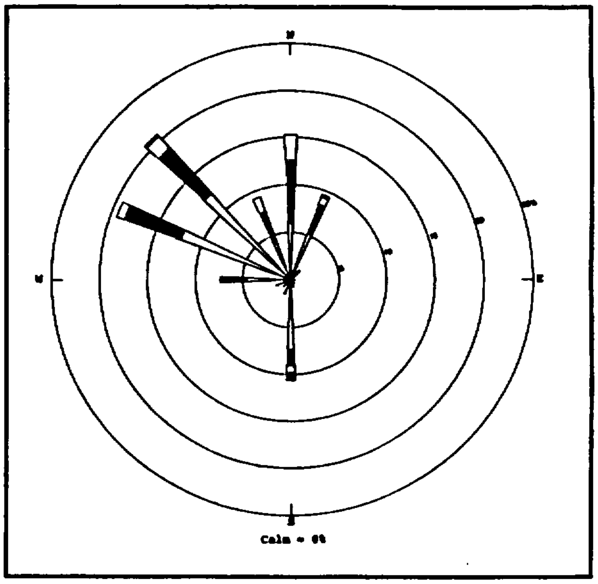


Note: The diagram is the frequency of occurrence for each wind direction from which the wind is blowing.

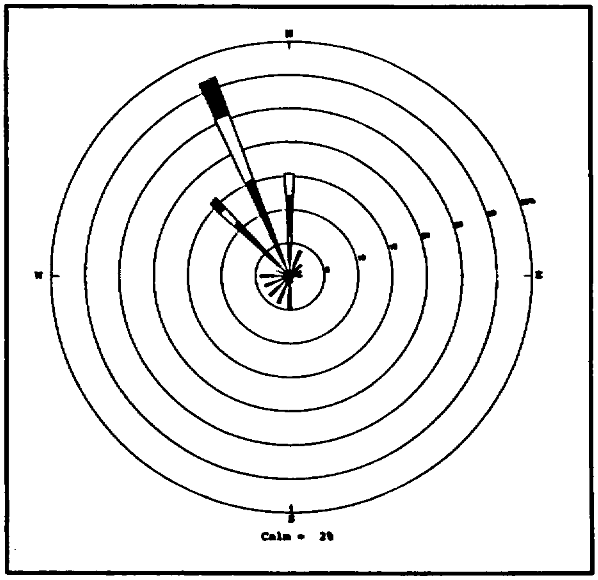
Figure 4-9. Coincident Wind Roses For Sites 1 and 5 Using Nighttime Hours With Wind Speeds At Least 5.4 m/s



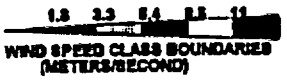
(a) Desert Rock, NV



(c) MEDA36



(b) Las Vegas, NV



Note: The diagram is the frequency of occurrence for each wind direction from which the wind is blowing.

Figure 4-10. Coincident Wind Roses For Desert Rock, MEDA36, and Las Vegas Using Nighttime Hours With Wind Speeds At Least 5.4 m/s

5. CONCLUSIONS

The results of the analyses of local and regional wind and airflow data show that winds in valley areas near Yucca Mountain are usually channeled by local topography. The wind directions are aligned with the local terrain valley axis, particularly at night during stable conditions. Wind patterns also have a strong diurnal cycle of daytime winds from the south and nighttime winds from the north. Directions opposite the typical diurnal cycle occasionally occur during the influence of regional scale weather systems that overpower the topographic mechanisms. Wind speeds are frequently in the 1.8 to 5.4 meters per second (m/s) range.

Nighttime conditions are usually very stable up to a few hundred meters above the ground, with a complex structure of decoupled layers responding to various topographic and weather pattern forces. The lowest layers are typically associated with downslope or downvalley "drainage" winds that tend to follow the hydrographic downhill gradient. Thus, nighttime airflow from Midway Valley is typically through Jackass Flats and into Amargosa Valley.

Unstable atmospheric stability conditions typically prevail during daytime hours. The first few hundred meters above ground level are well mixed, and the transport direction is usually toward the north. Strong vertical mixing occurs during unstable conditions, which tends to cause winds above the surface to be similar to the winds near the surface.

Further summaries of the local and regional wind patterns analyses follow. Recommendations based on the results follow the summaries.

5.1 LOCAL WIND PATTERNS

Results of the routine meteorological monitoring program and the intensive studies of specific airflow phenomena clearly point to the important significance of topography in controlling local airflow patterns. Topography channels airflow along the axes of terrain constraints ranging from narrow canyon sidewalls to broad valleys. Topography also creates upslope and downslope wind forces, which operate over scales ranging from narrow canyons to elevated terrain larger than tens of kilometers in area. The upslope and downslope wind forces tend to operate in a diurnal cycle due to the driving forces related to ground surface heating and cooling. The various topographic wind generating mechanisms operate during virtually all hours and weather conditions, so there are few occurrences of very slow wind speeds. The continued presence of air movement minimizes the potential for air stagnation periods when atmospheric dispersion potential is at its lowest.

Daytime atmospheric stability conditions are typically either neutral or unstable; both are conducive to greater atmospheric dispersion potential. Neutral and unstable airflow can be channeled by large scale topographic features, but to a lesser extent than occurs during stable conditions. Typical daytime conditions in and around Midway Valley and Jackass Flats include southerly airflow with speeds at least 3.3 m/s; the southerly directions are channeled along the washes that run generally northwest to southeast down the east side of Yucca Mountain. Ridge-top winds on Yucca Mountain are less channeled than those at the lower elevations in the valley and wash areas, so the winds are spread over a wider range from southeast through southwest. Some periods of northerly winds occur, frequently from the northeast more than the northwest.

Nighttime conditions are typically stable, or occasionally neutral when the wind speeds remain large enough to preclude establishing strong temperature inversion conditions. The air above valley floors and hillsides often has a temperature inversion in the first few tens of meters above ground level, with isothermal layers above. Stable conditions tend to reduce the overall atmospheric dispersion potential, and to complicate transport and dispersion analyses with overlying decoupled layers capable of significant variation in transport direction and mixing potential. The frequent downslope winds typically are from a northerly direction with significant channeling occurring, and wind speeds greater than 1.8 or even 3.3 m/s. These wind speeds help to improve the atmospheric dispersion potential during periods of low vertical mixing rates associated with thermally stable environments. Nighttime ridge-top winds on Yucca Mountain are less channeled than those at the lower elevations in the valley and wash areas. Easterly winds on Yucca Mountain at night may be partly due to downvalley airflow from higher terrain to the north and northeast. Another possible cause of the easterly winds is regional-scale weather systems.

Seasonal patterns in airflow are also seen on the local scale. The seasonal patterns are due in part to the annual cycle of relative amounts of daytime and nighttime, and part to regional airflow patterns controlled by mesoscale and synoptic scale weather patterns.

In summary, the nighttime airflow originating in Midway Valley and the east side of Yucca Mountain is typically toward the south through Jackass Flats and into the Amargosa Valley area. The airflow apparently does not turn toward the east in the direction of Las Vegas or Indian Springs. The typical daytime airflow is toward the north and northwest, away from any nearby populated area.

5.2 REGIONAL WIND PATTERNS

Lower level winds throughout the region appear to be controlled by the same topographic and mesoscale or synoptic scale weather system factors that influence the local wind patterns. Thus, the daytime winds are generally from the south and southwest. Nighttime winds are generally from the north, unless nearby topography creates a stronger downslope wind. Although the wind mechanisms are similar, wind patterns further distant than about 100 kilometers from Yucca Mountain show influences of other large scale topographic features and larger scale weather patterns.

The regional wind patterns tend to continue the airflow pathways seen in the local wind patterns. For airborne material potentially emitted in Midway Valley on the east side of Yucca Mountain, nighttime airflow would transport material to the south through Amargosa Valley. This material, and the material emitted during daytime hours, is typically transported toward the north during strong atmospheric mixing and dispersion conditions. There are no population centers within 100 kilometers to the north of Yucca Mountain.

5.3 RECOMMENDATIONS

The complexity of airflow patterns occurring near Yucca Mountain during the typical stable nighttime conditions that could bring airborne material toward the populated area in Amargosa Valley that was emitted in or near Midway Valley warrants continued monitoring and investigation of airflow patterns. Incomplete information about possible emission locations and source types raise the uncertainty of impact estimates made using current information. Better understanding of the complex airflow patterns aloft would be important if possible emissions were to occur from elevated stacks or from vents located in higher terrain on Yucca Mountain.

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6.2 PROCEDURES

QAP-2-0, *Conduct of Activities*. Rev. 3.

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