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ENT –Hanna Meteorological Report

Analysis of Annual Wind Roses and Precipitation within about 50 Miles of the Pilgrim Nuclear Power Station, and Use of CALMET to Calculate the Annual Distribution of Trajectories from the Pilgrim Station

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1. Introduction

1.1 Overview of Purpose of Study

The main purpose of the study is to evaluate whether the use of the 2001 Pilgrim Meteorological Tower wind observations and the 2001 Plymouth Municipal Airport precipitation data as inputs to MACCS2/ATMOS in the SAMA analysis are a satisfactory representation of the annual 2001 wind field and precipitation conditions over the SAMA geographic domain (a 50 mile radius around the Pilgrim Station). The MACCS2/ATMOS model system is described by Jow et al. (1990), Chanin et al. (1990), Chanin and Young (1998) and USDOE (2004). First, the annual wind roses, wind speeds, and precipitation for 2001 from other weather observing sites in the domain are analyzed to determine if they are similar to the Pilgrim annual wind rose and wind speed and the Plymouth annual precipitation. This part of the study also assesses the similarity of the 2001 wind direction and precipitation observations used in the SAMA analysis to other years at the Pilgrim Station and at the Plymouth Municipal Airport. Second, the EPA's CALMET wind field model (IWAQM 1998, Scire et al. 2000a and b) is used to develop a CALMET wind field for each hour of 2001 in order to perform a trajectory analysis for the 50 mile region surrounding the Pilgrim Station. The CALMET wind field model is applied to all hours of 2001 using wind inputs from many weather observing sites on the domain, generating wind fields that vary in space across the domain and from hour to hour. These wind fields are then used to calculate trajectories originating at the Pilgrim Station during each hour of 2001 and determine where each trajectory passes across arcs at certain distances from the plant (out to a maximum of 50 miles).

Because the SAMA analysis concerns effects that are summed or integrated over a full year and over an area within a 50 mile radius around the Pilgrim Station, the analysis in this report focuses on annual summaries of meteorological variables and on potential wind trajectories (paths) over the entire 50 mile-radius geographic domain.

The term "representativeness" is often used in this report. It is widely used by meteorologists to assess the degree of similarity in weather from site to site across a region. For example, Hanna and Chang (1992) use the word "representativeness" in the title of their published paper concerning analysis of wind observations from 13 anemometers in an area with dimensions of about 6 miles (10 km).

1.2 Methodology and Data Acquired

To investigate whether the Pilgrim Station annual wind direction distributions (wind rose) and annual wind speeds are representative of the 50-mile radius geographic area being modeled in the SAMA, we searched for other wind observations in the area. The primary source is NOAA's National Climatic Data Center (NCDC), which archives meteorological data from all "official" sites in the U.S. (and in the world). These sites are generally operated by government agencies and their Quality Assurance/Quality

Control (QA/QC) procedures follow established, accepted guidelines for collecting and recording quality data. Most of these sites are at airports, but some are in special locations (such as Blue Hill Observatory in East Milton, Massachusetts).

We reviewed the NCDC on-line lists of available official sites, and called the NCDC representatives to follow up in cases there were special circumstances. We obtained data from all official sites within or just outside of the 50 mile radius circle. Note that the Boston Metropolitan area is located approximately at a distance of about 20 to 70 miles north to northwest of the Pilgrim Station. For the annual wind rose and wind speed analysis, we did not use sites where there was less than 50 % data capture in the year 2001. In addition to the land sites, we also investigated over-water wind observations measured at buoy locations. These data were obtained from three locations from the NOAA's National Buoy Data Center (NBDC). Hourly meteorological observations were obtained for 2001 from the Boston Approach Buoy, which is in the Atlantic Ocean about 28 miles north of the Pilgrim Station and is about 15 miles east of Boston Logan airport. This is an "official" NOAA site. The other two NOAA buoys whose data were acquired are much farther (100 or more miles) from the Pilgrim Station. The wind rose for the Boston Approach Buoy was generated from the hourly observations of winds and was compared with the wind roses from the land sites. All three buoys were used in the CALMET modeling analysis.

We have the Pilgrim Station hourly meteorological data and the Plymouth Municipal Airport hourly precipitation data on hand for 2001, since they were used in the SAMA analysis. The wind data from the 33 ft level and the temperature difference between the 220 ft and 33 ft levels of the so-called "upper" meteorological tower were the primary Pilgrim Station inputs. The upper meteorological tower is located about 600 ft from the coast. The Pilgrim Station wind data were used in both the wind rose and wind speed comparisons and the CALMET trajectory calculations.

Because much of this report deals with wind roses and trajectories, it is useful to explain the directions and sectors used in meteorological wind analyses. Figure 1 is a diagram showing the 16 basic wind direction sectors, their names (N, NNE etc., which follow standard compass terminology) and the angles (directions in degrees) that they represent. Note that a wind towards the North has angle 0°, towards the East has angle 90°, towards the South has angle 180°, and towards the West has angle 270°. The 16 wind direction sectors are each 22.5° wide, and Figure 1 shows the wind directions marking the dividing line between wind direction sectors. The diagram is set up so the radius of the colored circle is 50 miles, the same as the SAMA domain, and circles at radial distances of 10, 20, 30, and 40 miles are also indicated. The wind and trajectory roses will use the same direction sectors as in Figure 1.

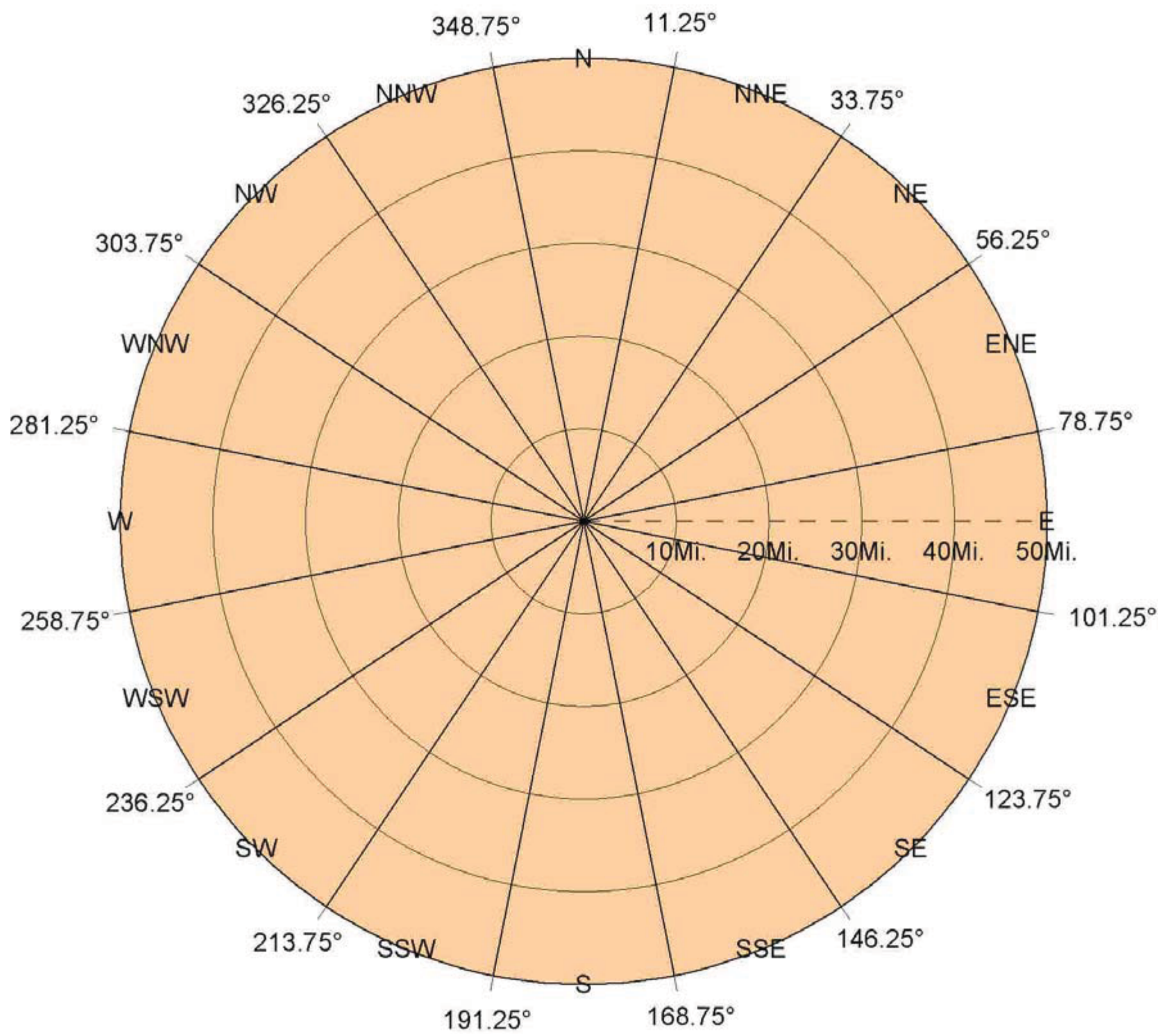


Figure 1. Angles assumed for standard meteorological wind direction sectors.

Table 1 contains a listing of the sites (besides Pilgrim) where near-surface land or over-water weather data were obtained from NCDC, NBDC, and other sources, and indicates whether the site was used in a) the wind rose (and also the wind speed) comparative analysis (18 sites), and/or b) the CALMET wind field and trajectory analysis (26 sites). The first column gives the site ID, where available, and the second column gives the airport call letters of the International Civil Aviation Organization (ICAO), for the NCDC sites where wind roses were produced. In the table, N/A in the "Data Obtained From" column indicates a site where data were not available for 2001. In the Wind Rose Analysis column, a superscript 1, i.e., "[1]", indicates sites that are outside of the 50 mile circle, for which wind rose comparisons were not performed. A superscript 2, i.e., "[2]", indicates a site for which a wind rose comparison was not performed because it is close to a site already included in the wind rose comparison. A superscript 3, i.e., "[3]", indicates sites where 50 % or less of the hourly data are available for the year. These latter sites were not used in the wind rose comparative analysis, since that looks at annual frequencies of wind directions, and these sites were missing data for more than an entire season. However, they were used in the CALMET wind field and trajectory analysis, since that represents a comprehensive analysis of many wind sites.

Another source of near-surface wind data is the Wind Energy Program of the Renewable Energy Trust of the Massachusetts Technical Collaborative. The web site containing those wind data is www.masstech.org/renewableenergy/winddata.html and their address is Renewable Energy Research Laboratory, University of Massachusetts, Amherst, MA 01003. The anemometers are typically placed on an existing tower (such as a TV or radio tower) at heights of about 20 to 100 m (66 to 328 ft) above ground level, and are used for wind energy planning. For example, when decisions are being made on where to place wind turbines, it is useful to have wind observations in the local areas at the approximate height of the hub of the propeller. No data are available from 2001, but there are a few sites close to the Pilgrim Station and/or along the coast towards Boston (Kingston, Scituate and Quincy) that have wind data available for 2006-2007. We reviewed the list of available sites and investigated their local terrain, and then acquired 10 minute wind data from the three sites mentioned. The Kingston site is 8.5 miles west-northwest of the Pilgrim Station and is one mile west of the coast. The Scituate site is 19 miles north-northwest of the Pilgrim Station and 0.7 miles west of the coastline (but only 0.1 mile north of an extensive marsh/salt flat area). The Quincy site is 30.2 mi northwest of the Pilgrim Station and is 2.8 mi west-southwest of the coast. We generated annual wind roses for the three sites using the 10 minute wind data for comparison to the annual Pilgrim wind rose.

We also searched the list of special coastal sites operated by WeatherFlow, a company that provides data to subscribers primarily for use by sailors and windsurfers. Data from Duxbury (only 8.5 mi north-northwest of the Pilgrim Station and right on the coast) for 2001 were available and were acquired from Mr. Jay Titlow of WeatherFlow. He provided 5 minute wind data for 2001. However, the wind directions are given for only the 8 major directions (N, NE, E etc.) rather than for the 16 major directions (N, NNE, NE, ENE etc) used for all of the other sites. Therefore, we generated an annual wind rose from the Duxbury data for comparison to the Pilgrim annual wind rose but did not use the

Duxbury wind data in the CALMET wind field generation, due to their much lower resolution.

For use in the CALMET wind field and trajectory analysis, we considered and acquired certified upper air meteorological observations for 2001 from NCDC from Chatham, Massachusetts, Gray, Maine, Albany, NY and Brookhaven, NY. These are the closest sites where upper air (radiosonde) observations are available. Upon review of the station locations relative to our CALMET modeling domain, it was decided that both Albany and Brookhaven were much farther away and the use of just the Chatham and Gray locations were sufficient to adequately cover the domain. Chatham and Gray are the Massachusetts Department of Environmental Protection (MA DEP) recommended upper air sites for use in air quality modeling in eastern Massachusetts to fulfill EPA requirements. Balloon soundings are taken each day at 0700 and 1900 EST at these sites. Wind, temperature, relative humidity, and pressure are observed as the balloon rises and are reported at standard heights such as 1000 m (3280 ft) and 2000 m (6560 ft) as well as at heights where inversion bases and other significant phenomena occur.

In addition to the hourly meteorological data from 2001 from the Pilgrim Station, reports summarizing observations from the same site for the years 1999, 2000, and 2001 were acquired (Duke Engineering and Services, 1999, 2000, 2001). The titles of the reports are "Pilgrim Station Meteorological Data Joint Frequency Distributions: First, Second, Third, and Fourth Quarters". The Pilgrim Station also sent us the hourly meteorological observations for 1996 through 2000, which were used to construct annual wind roses from 1996-2000 to compare with the 2001 Pilgrim annual wind rose.

Precipitation observations were obtained from NCDC for 1995-2009 for nine sites: Plymouth (8 mi to the WSW of Pilgrim), Boston Logan (37 mi to the NNW of Pilgrim), Taunton (23 mi to the W of Pilgrim), Brockton (27 mi to the WNW of Pilgrim), East Wareham (13 mi to the S of Pilgrim), Hingham (25 mi to the NNW of Pilgrim), Middleboro (14 mi to the WSW of Pilgrim), New Bedford (27 mi to the SW of Pilgrim), and Rochester (19 mi to the SW of Pilgrim). The Plymouth Municipal Airport data were acquired because the 2001 precipitation data from that site were used in the SAMA analysis. The other eight sites were chosen because they are spread over the SAMA domain. We used these data to evaluate the representativeness of the 2001 Plymouth airport precipitation data to other years and to other weather observing stations within the region. Figure 2 shows the locations of the precipitation sites.

Table 1. Meteorological surface station site summary (besides Pilgrim).

Station ID	ICAO ID	Station Name	State	Direct. from Pilgrim	Dist. from Pil (mi)	Data obtained From	Wind Rose Analysis	CALMET Modeling
725059	KBED	LAUR G HANSCOM	MA	NW	49.9	NCDC	Yes	Yes
725060	KFMH	OTIS ANGB	MA	S	20.7	NCDC	Yes	Yes
725063 (14756)		NANTUCKET MEM	MA	SSE	55.2	NCDC	No[1]	Yes
725064	KPYM	PLYMOUTH MUNIC	MA	WSW	8.0	NCDC	Yes	Yes
725065	KEWB	NEW BEDFORD RGN	MA	SW	27.0	NCDC	Yes	Yes
725066	KMVY	MARTHAS VINE	MA	S	37.8	NCDC	Yes	Yes
725067	KHYA	BARNSTABLE MUNI	MA	SE	25.0	NCDC	Yes	Yes
725068	KTAN	TAUNTON MUNI APT	MA	WSW	23.0	NCDC	Yes	Yes
725069	KCQX	CHATHAM MUN APT	MA	ESE	35.2	NCDC	Yes	Yes
725073		PROVINCETN(AWOS)	MA	ENE	20.6	NCDC	No[3]	Yes
725090 (14739)	KBOS	BOSTON/LOGAN INTL	MA	NNW	36.6	NCDC	Yes	Yes
725094		MARSHFIELD APT	MA	NNW	11.8	N/A	No	No
725098	KOWD	NORWOOD MEM	MA	NW	34.9	NCDC	Yes	Yes
744907 (14753)	KMQE	E MILTON BLUE HILL	MA	NW	33.1	NCDC	Yes	Yes
994140		BUZZARDS BAY	MA	S	11.8	N/A	No	No
744904		LAWRENCE MUNI	MA	NNW	59.8	NCDC	No[1]	Yes
725088		BEVERLY MUNI	MA	N	47.1	NCDC	No[2]	Yes
722256		G HARLOW FLD	MA	NNW	11.8	N/A	No	No
725070 (14765)	KPVD	PROVIDENCE/GREEN STATE AIRPORT	RI	WSW	46.6	NCDC	Yes	Yes
997278		PROVIDENCE	RI	W	43.3	N/A	No[2]	No
725074		QUONSET STATE	RI	SW	49.7	NCDC	No[3]	Yes
725079	KUUU	NEWPORT	RI	SW	46.1	NCDC	Yes	Yes
998004		NARRAG BAY RES	RI	SW	55.0	N/A	No	No
725054		PAWTUCKET (AWOS)	RI	W	47.3	NCDC	No[2]	Yes
999999 (54796)		CRN KINGSTON	RI	SW	58.6	NCDC	No[2]	Yes
725058		BLOCK ISLAND	RI	SW	74.1	NCDC	No[1]	Yes
743946		NASHUA/BOIRE FLD	NH	NW	74.9	NCDC	No[1]	Yes
743945		MANCHESTER	NH	NW	79.9	NCDC	No[1]	Yes
44013	No ID	16 NM E of Boston	MA	N	28.7	NBDC	Yes	Yes
44007		12 NM SE of Portland	ME	N	111.6	NBDC	No[1]	Yes
44005		78 NM E of Portsmouth	NH	N	106.2	NBDC	No[1]	Yes
	No ID	KINGSTON	MA	WNW	8.5	RERL	Yes	No
	No ID	QUINCY - QUARRY	MA	NW	30.2	RERL	Yes	No
	No ID	SCITUATE	MA	NNW	19.1	RERL	Yes	No
	No ID	DUXBURY	MA	NNW	8.5	Weather-flow	Yes	No

N/A – data not available for year. [1]site outside of 50 mi circle. [2]site nearby another site. [3]site with less than 50 % of hours available in 2001.

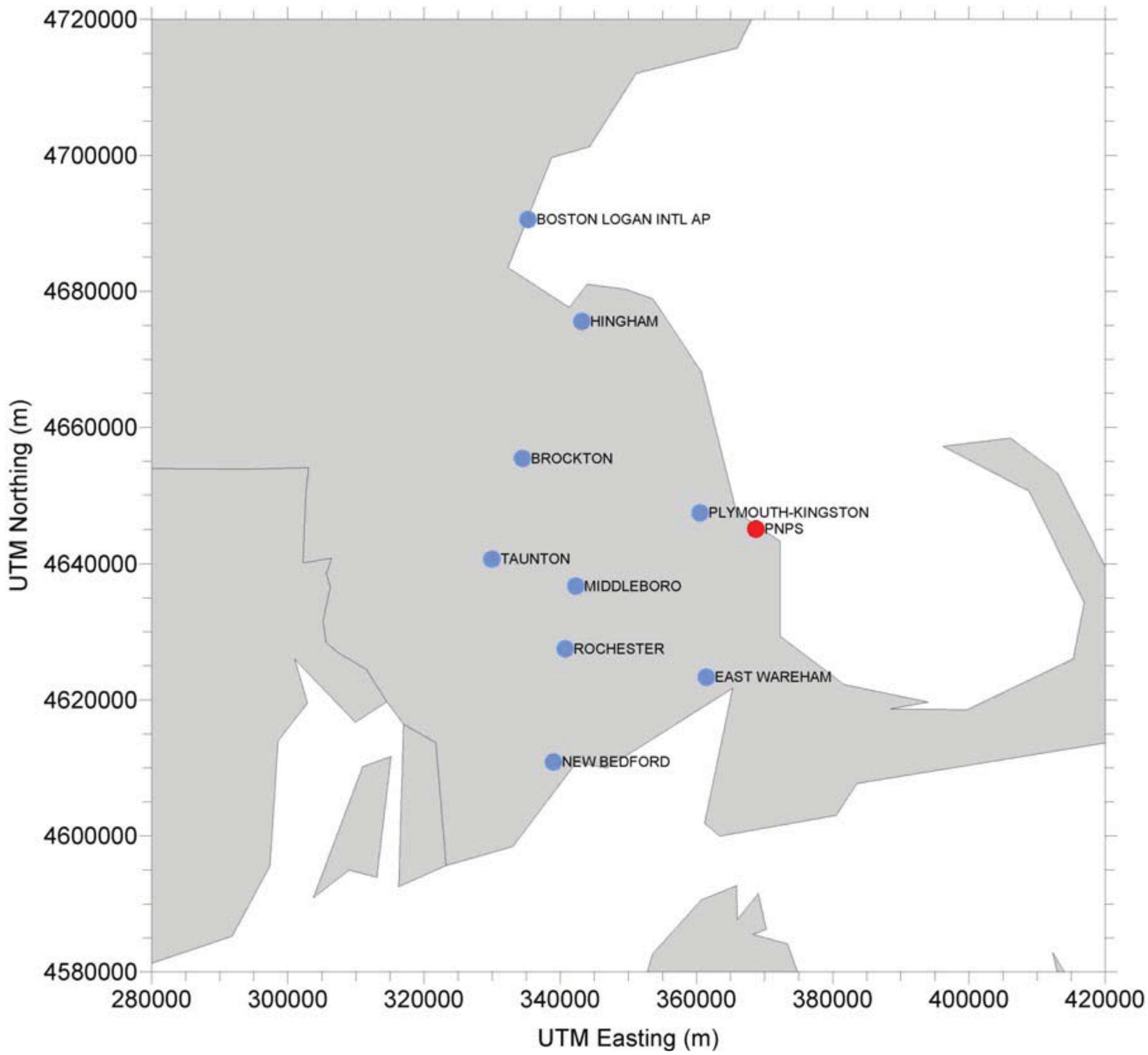


Figure 2. Sites whose annual precipitation observations are compared.

Because Pilgrim Watch raised the issue of the effects of sea and land breezes and other causes of time and space variations in wind fields, we devised a method to evaluate whether the annual wind rose used for the SAMA analysis – the wind rose for 2001 from the 33 ft (10 m) level of the Pilgrim Station met tower – was consistent with the effective annual wind rose that would reflect variable flow vectors in the 50-mile radius domain. Our methodology is to use the EPA's CALMET diagnostic wind model (Scire et al., 2000a, 2000b) to determine spatially variable wind fields for each hour of the year 2001. The input winds used by CALMET were from official sites throughout a 200 km by 200 km (124 mile by 124 mile) square that is centered on the Pilgrim Station. The 200 km (124 mile) square was used so that there would be winds available for interpolation at the edges and beyond the 50 mile radius circle. The resulting hourly wind fields and their variation in time across a 124 mi square area represent influences of many types of physical phenomena such as sea and land breezes, terrain effects, fronts, scattered convective clouds, and other variabilities across such a large domain and such a long period of time.

Given the hourly CALMET-generated wind fields for the entire year of 2001, we developed software to start a hypothetical trajectory from the Pilgrim Station at the beginning of each hour, and follow each trajectory until it passed the 50 mile circle. We then evaluated these trajectories for each of the 8756 available hours of wind data from the region. In general, the local wind field and hence the trajectory are most strongly influenced by the nearest local wind observations, although the calculated CALMET wind field combines the influences of all wind observations on the domain. Sometimes it took several hours for the trajectory to reach 50 miles. We counted the angular position where each trajectory passed the circles of radius 1, 2, …10, 20, 30, 40 and 50 miles, as shown on Figure 1. These distances are those that were used in the SAMA analysis. Thus at each radius, over a year there would be 8756 instances where trajectories passed each of the circles. Each angle for a given trajectory crossing was then assigned to one of the sixteen 22 ½ ° wind direction sectors seen in Figure 1. Then for each radial circle of 1, 2, …10, 20, 30, 40 and 50 miles, annual frequencies were determined for each of the 16 wind direction sectors for comparison with the observed Pilgrim 33 ft wind rose. However, since the flow trajectories are blowing with the wind, the annual wind trajectory rose is for "directions towards". This contrasts with the usual meteorological convention for a wind rose, which indicates "direction from". Therefore, to better allow comparisons we converted all wind roses to "direction towards" formats. This format is used in the remainder of this analysis and in the five Appendices.

The trajectory roses are compared with the Pilgrim wind rose (used for the SAMA analysis) by means of visual and quantitative comparisons.

2. Description of CALMET Model and Specialized Trajectory Software

The trajectory analysis employed the CALMET model, which is the meteorological model in the U.S. EPA's CALPUFF modeling system (IWAQM 1998, Scire et al. 2000a, 2000b). The purpose of choosing a model like CALMET is to attempt to more fully treat the effects of time and space variations of winds on plume transport. CALMET is a diagnostic meteorological model that produces three-dimensional (two horizontal directions and the vertical direction) wind fields, resulting in spatially varying gridded meteorological fields for each hour. Specialized software was developed for the estimation of trajectories using CALMET wind fields as input. The trajectory analysis consisted of two steps:

1) Computation of the location of the trajectory for each hour, and
2) Determination, at each of the downwind distance arcs, of the frequency that the trajectories crossed within each of the 22 ½ direction sectors.

The CALPUFF transport and dispersion model and its diagnostic meteorological model, CALMET, are in the class of models called Lagrangian puff models, since they can follow a puff of pollutant material moving around the geographic domain, which usually is a rectangular area with side dimensions of about 100 or 200 km (62 or 124 mi). Wendell (1972) developed one of the first Lagrangian puff models for the DOE and NRC. Ramsdell (1994) developed a Lagrangian puff model called RATCHET for use in calculating dispersion for the Hanford Environmental Dose Reconstruction (HEDR) project. Chang et al. (2003) evaluated CALPUFF and two other Lagrangian puff models using field experiment data from two field sites with domain sizes of about 50 km (31 miles) by 50 km (31 miles) in complex terrain, showing that they all generally agreed with the concentration observations within plus and minus a factor of two.

CALMET produces a different wind vector plot for each hour, where a wind vector on the plots shown later is shaped like an arrow, and is characterized by a wind speed and by a wind direction. Wind vectors are output at horizontal intervals of 4 km (2.5 mi) and at vertical intervals of about 100 m (328 ft), as described in a later subsection. The trajectories are calculated by starting a trajectory at a prescribed elevation at the beginning of each hour at the Pilgrim Station. The trajectory follows the vector wind field (perhaps slightly curved) for that hour for a distance equal to velocity times one hour (or 3600 seconds), where velocity is the wind speed in mi/hr or m/s, respectively. For the next hour, there is a new wind vector field and the trajectory is moved with that wind field at the location of the trajectory. And so on.

Because the wind speed usually increases with height, the trajectories at higher elevations move faster. Even so, the wind speeds are usually not strong enough to move the trajectory 50 miles in an hour. Therefore, at any given hour, there may be several trajectories still on the domain.

2.1 CALMET Model Selection

For this analysis, the latest release of the EPA's CALMET Meteorological Model, (Version 5.8, Level 070623), was used to develop a three dimensional wind field out to 100 km (about 62 miles) from the Pilgrim Station. CALMET is part of the CALPUFF modeling system recommend by the EPA for mesoscale to long range transport modeling (i.e., for distances roughly in the range from about 10 to 300 km (6.2 to 186 mi)).

CALMET simulates vertical variations of winds and can also simulate the effects of time-varying and space-varying meteorological conditions. Usually CALPUFF is used to simulate short-term (one hour to one day) worst case conditions at a specific location, since the EPA regulations generally concern that type of problem.

The EPA recommends their AERMOD dispersion model (Cimorelli et al., 2005) for use at short distances and CALPUFF for use at mesoscale and larger distances, but does not have a specific recommendation for the distance range where users should "switch" from AERMOD to CALPUFF. There is much overlap in actual applications.

2.2 CALMET Modeling Domain

The CALMET modeling domain was defined with dimensions 200 km by 200 km (about 124 miles by 124 miles), centered on the Pilgrim on-site meteorological tower. This domain ensures that there is a sufficient buffer zone of at least 12 miles from the 50 mile (80.5 km) radius of interest around Pilgrim Station to the edge of the modeling domain. The buffer zone allows for winds to be predicted beyond the SAMA area of interest (50 miles) so the domain does not just end abruptly in case the wind patterns have significant curvature. A grid resolution of 4 km (2.5 miles) (the standard size used in CALMET for this type of geographic domain) was used to capture the variations in terrain elevations and varying land uses in the area. Figure 3 shows the modeling domain in relation to the Pilgrim Station location, the 50 mile radius, and the 4 km grid lines. It is seen that the 4 km (2.5 miles) resolution is able to capture most of the coastal features such as bays and peninsulas. Seven vertical layers were used to resolve the mixed layer of the atmosphere, with a finer resolution near the surface and coarser resolution aloft. The seven vertical levels were located at heights of: 10, 35, 100, 200, 500, 1125, and 2000 m (33, 115, 328, 656, 1640, 3690, and 6560 ft). The 10 m (33 ft) height is the level at which most observing stations measure the winds. The trajectory analysis is of interest at 100 m (328 ft), 200 m (656 ft) and 500 m (1640 ft). The 500 m (1640 ft) level is approximately half the value of the presumed mixing height, 1000 m (3280 ft) in the Pilgrim SAMA analysis. A plume that is fully mixed from the ground surface to the presumed mixing height of 1000 m would have a mean height of 500 m.

2.3 CALMET Meteorological Modeling

2.3.1 Preparation of Meteorological Data Bases for CALMET

Hourly surface observations of wind speed and direction, temperature, cloud cover, ceiling height, station pressure, and relative humidity data are required inputs to CALMET. CALMET also requires twice daily upper air observations of vertical profiles of pressure, temperature, and wind speed and direction. All available hourly data were obtained within or close to the region of our modeling domain. Twenty-five surface stations and three buoy stations, plus two NWS upper air stations were used for this analysis. Certified versions of the hourly surface and upper air data were obtained from the National Climatic Data Center (NCDC).

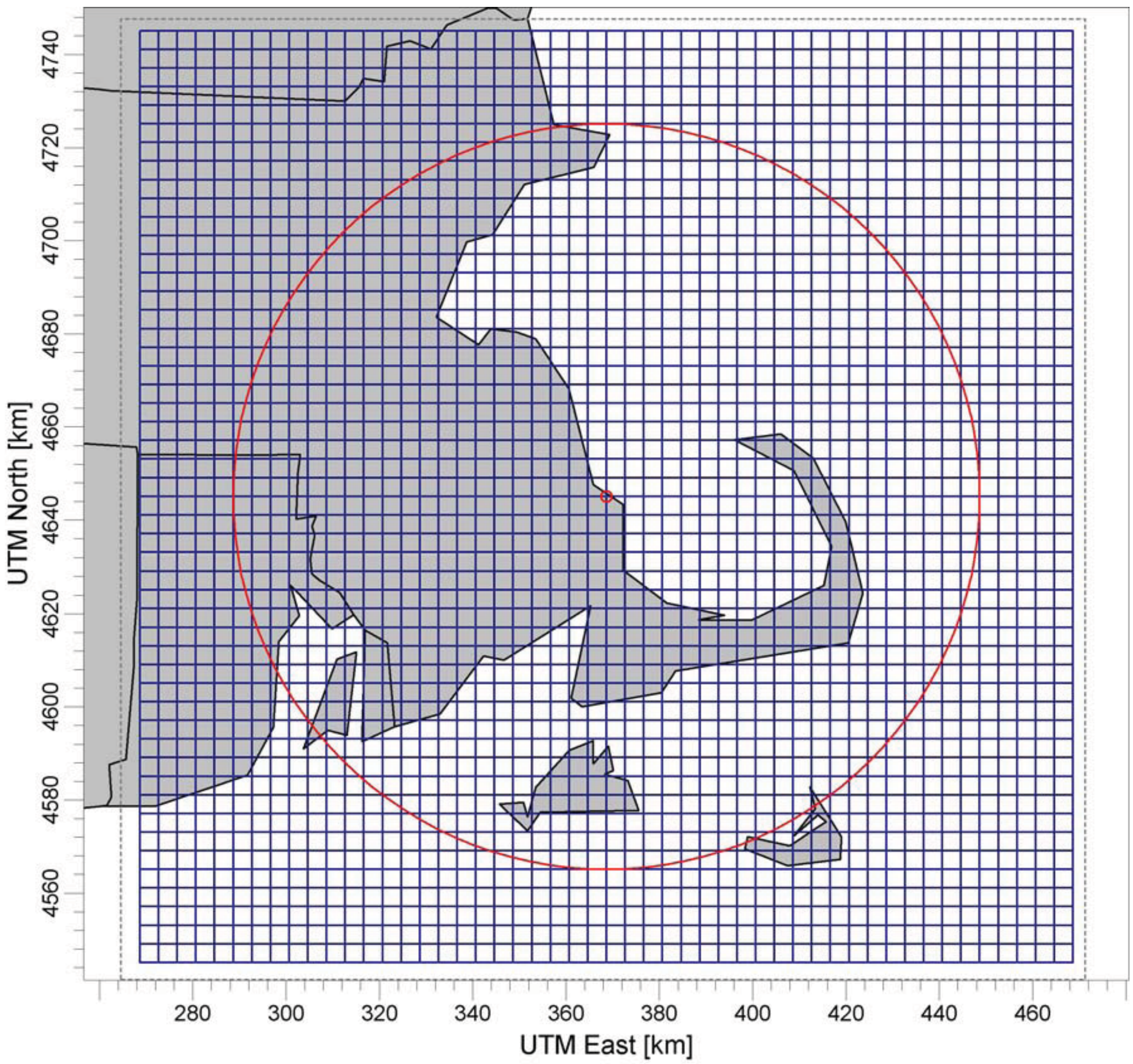


Figure 3. CALMET modeling domain with 4 km (2.5 mi) grid spacing. The Pilgrim Station and the 50 mile radius circle around the Pilgrim Station are indicated in red.

Earlier, Table 1 listed the surface weather stations used in the various types of analyses in this report, and included a column noting whether that location was used in the CALMET modeling. Table 2 below lists just the meteorological stations used in the CALMET analysis, and adds the upper air stations. Figure 4 shows the modeling domain and the locations of the meteorological observing stations used in the CALMET modeling. Note that sites S1 and S2 are the 220 ft and 33 ft levels, respectively, of the Pilgrim Station upper meteorological tower and therefore would be collocated on Figure 4. Consequently only S1 is shown on the figure.

To prepare the hourly surface observation data from NCDC for input to CALMET, the CALMET pre-processor, SMERGE, was used. SMERGE combines data from multiple stations into one input file for CALMET. The NCDC format data file contains more information for each hour than CALMET requires, such as parameters like present weather conditions. The SMERGE program needed to be updated to properly read and skip the parameters unnecessary for the CALMET analysis.

2.3.2 Preparation of Geophysical Data Bases for CALMET

Terrain Data

Gridded terrain elevations for the modeling domain were prepared using the United States Geological Survey (USGS) digital elevation models (DEM). DEM data are provided in 7.5 minute format derived from the USGS 1:24,000 scale topographic maps or 1 degree DEM files covering one (1) degree by one (1) degree blocks of latitude and longitude. These data are derived from the USGS 1:250,000 scale topographic maps.

The CALMET modeling domain around the Pilgrim Station encompasses a range of terrain elevations, from large expanses of open ocean to relatively flat coastal locations to the rolling terrain (at heights up to about 300 m or 984 ft) of central Massachusetts and Northwestern Rhode Island. One reason for selecting a horizontal grid spacing resolution of 4 km (2.5 miles) for the CALMET analysis was to adequately represent the variations of the coastline. The eastern portion of the CALMET domain is obviously over the Atlantic Ocean, which is seen in Figure 3 to occupy a little more than half of the entire 200 km by 200 km (124 mi by 124 mi) domain. The spacing of the terrain data in the 7.5 minute DEM file is approximately every 30 m (98.4 ft). Terrain elevations found within a particular CALMET grid cell are averaged to produce a mean elevation at each grid point, and the resulting terrain elevations of the modeling domain are shown in Figure 5.

Land Use Data

Gridded land use data for the CALMET modeling domain were prepared using the United States Geological Survey (USGS) Composite Theme Grid (CTG) land use data. The data are provided in files covering one (1) degree by one (1) degree blocks of latitude and longitude with a resolution of 200 m (656 ft). For each grid cell in the modeling domain, the fractional proportion for each land use category is determined and is used to generate land use - weighted values of surface and vegetation properties. This information was used to determine the dominant land use category for each grid cell for input into CALMET. The 37 USGS land use categories are mapped into the 14

Table 2. Meteorological Observing Stations used in CALMET Modeling

Hourly Over Land Surface Observation Stations

Number	Station ID	Location	Latitude	Longitude	Distance to Pilgrim (miles)
S1	220	Pilgrim (220 ft)	41.946N	70.584W	0.0
S2	33	Pilgrim (33 ft)	41.946N	70.584W	0.0
S3	744904	Lawrence Municipal Airport, MA	42.717N	71.117W	59.8
S4	725090	Boston Logan International Airport, MA	42.367N	71.017W	36.6
S5	725088	Beverly Municipal Airport, MA	42.583N	70.917W	47.1
S6	725070	Providence Green State Airport, RI	41.717N	71.433W	46.6
S7	725054	Pawtucket, RI	41.917N	71.5W	47.3
S8	725098	Norwood Memorial Airport, MA	42.183N	71.183W	34.9
S9	725059	Hanscom Field, MA	42.46N	71.27W	49.9
S10	725066	Martha's Vineyard, MA	41.4N	70.617W	37.8
S11	725079	Newport, RI	41.533N	71.283W	46.1
S12	725060	Otis ANGB, MA	41.65N	70.52W	20.7
S13	725067	Barnstable Municipal Airport, MA	41.67N	70.27W	25.0
S14	725065	New Bedford Regional Airport, MA	41.667N	70.95W	27.0
S15	725069	Chatham Municipal Airport, MA	41.683N	70W	35.2
S16	725068	Taunton Municipal Airport, MA	41.867N	71.017W	23.0
S17	725064	Plymouth Municipal Airport, MA	41.917N	70.733W	8.0
S18	725073	Provincetown, MA	42.067N	70.217W	20.6
S19	725058	Block Island, RI	41.17N	71.57W	74.1
S20	743945	Manchester, NH	42.92N	71.43W	79.9
S21	725063	Nantucket Memorial Airport, MA	41.25N	70.06W	55.2
S22	744907	East Milton, MA	42.217N	71.117W	33.1
S23	743946	Nashua Boire Field, NH	42.78N	71.52W	74.9
S24	725074	Quonset State Airport, RI	41.59N	71.42W	49.7
S25	999999	Kingston, RI	41.491N	71.541W	58.6

Buoy Observation Stations

Number	Station ID	Location	Latitude	Longitude	Distance to Pilgrim (miles)
O1	44013	16 NM E of Boston	42.354N	70.691W	28.7
O2	44007	12 NM SE of Portland	43.531N	70.144W	111.6
O3	44005	78 NM E of Portsmouth	42.896N	68.949W	106.2

Twice Daily Upper Air Observation Stations

Number	Station ID	Location	Latitude	Longitude	Distance to Pilgrim (miles)
U1	14684	Chatham, MA	41.667N	69.950W	38.0
U2	54762	Gray, ME	43.900N	70.250W	135.9

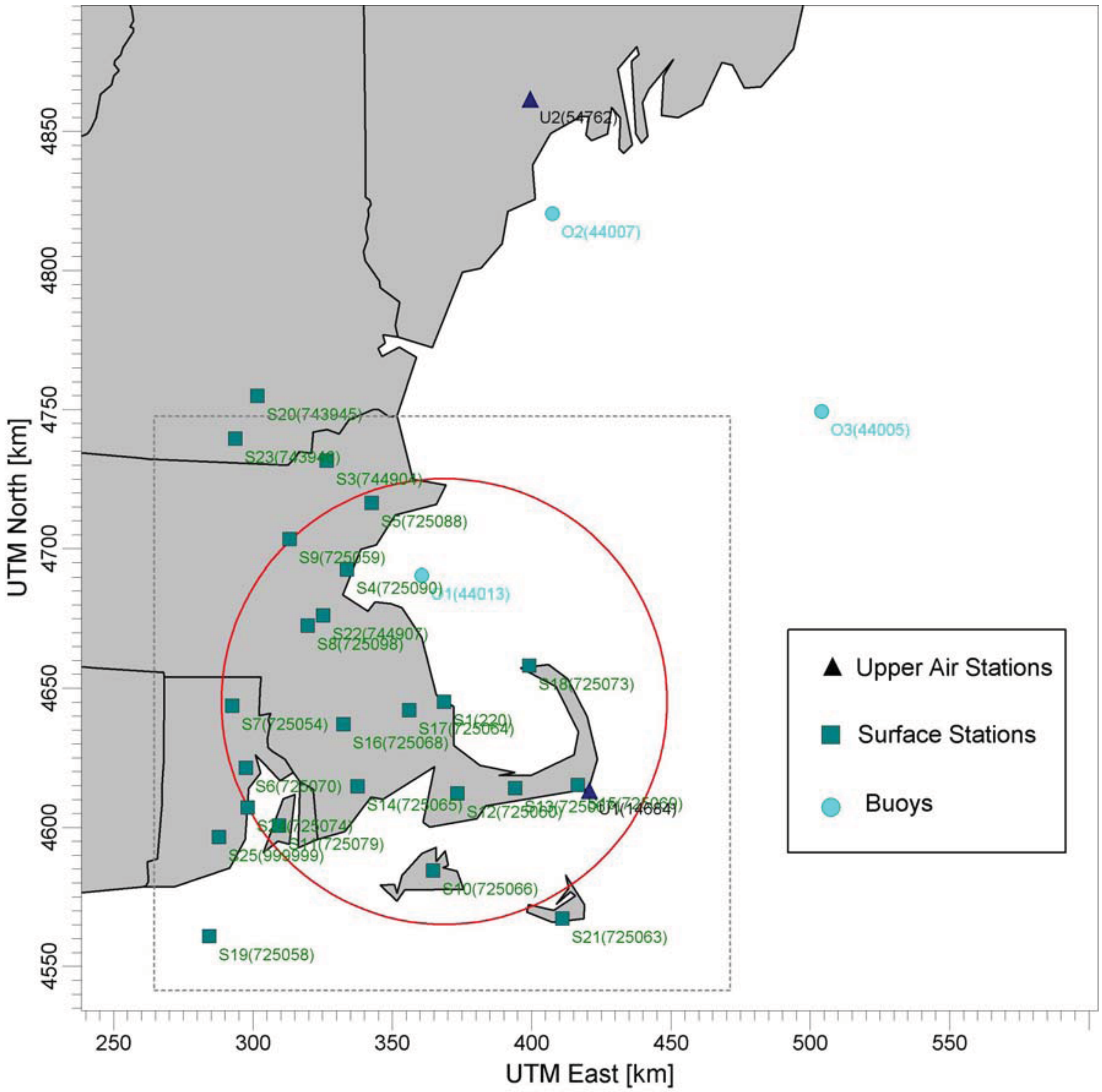


Figure 4. Locations of meteorological stations used in CALMET modeling and listed in Table 2. Land surface, buoy and upper air station locations are shown. The 50 mi radius circle around the Pilgrim Station (S1 on the map) is shown in red.

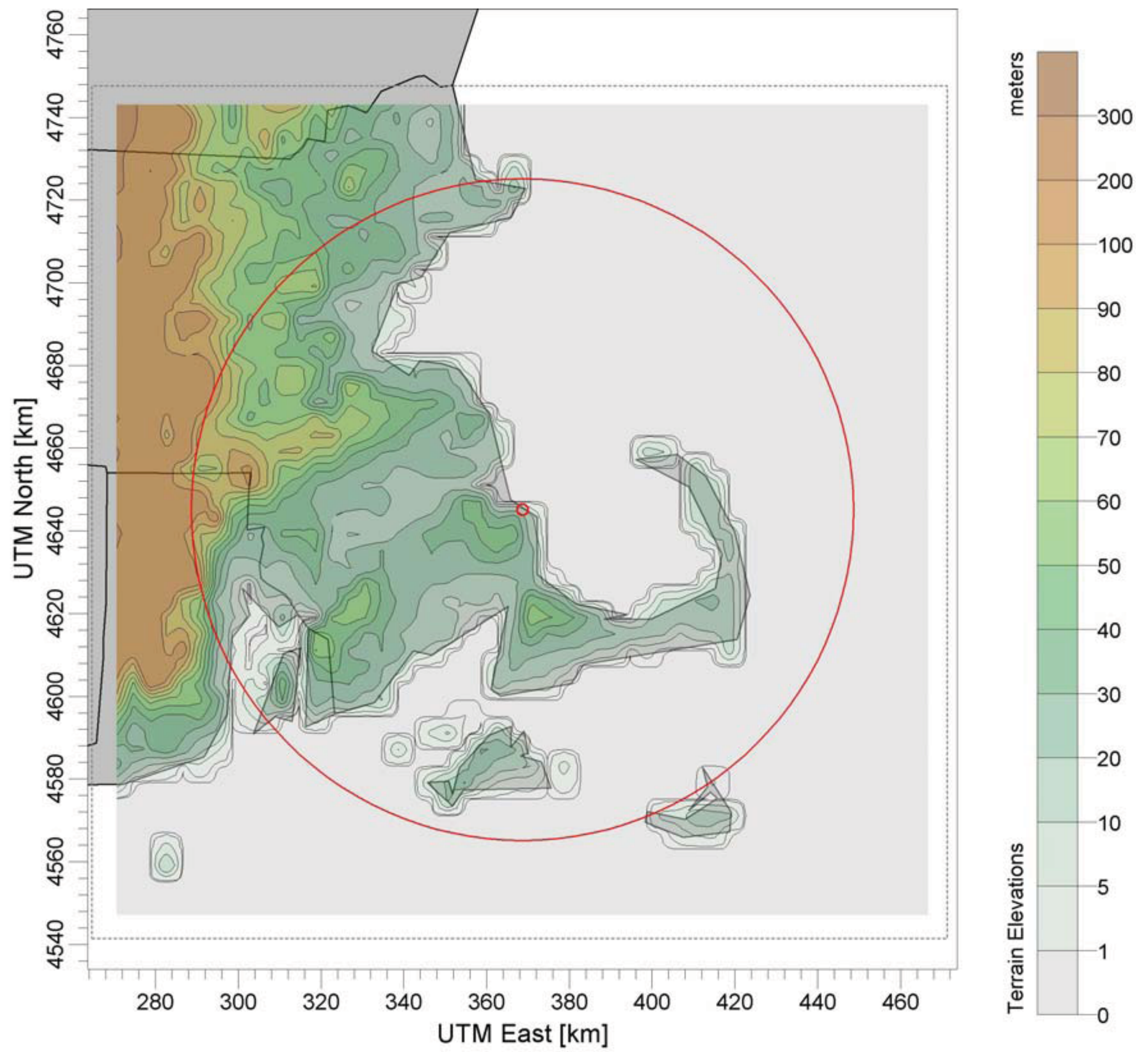


Figure 5. Terrain elevations in the CALMET modeling domain. The Pilgrim Station and the 50 mi radius circle around the Pilgrim Station are shown in red.

categories used by CALMET. Figure 6 shows the dominant land use categories for each CALMET grid cell in the modeling domain.

2.3.3 CALMET Meteorological Model Options

The CALMET model options that have been used follow the EPA recommended model settings for use of the CALMET model (EPA, 2009a, EPA 2009b). There are some options that are dependent on the particular model application. The values that are used specifically for this application are discussed below.

Before incorporating the many surface wind observations, CALMET starts with an initial three-dimensional wind field based on the Chatham upper air observations, taken by a rising radiosonde balloon. The Chatham observations are adjusted to reflect the effects of the CALMET fine-scale (4 km or 2.5 mi) terrain, which may slightly bend the winds in certain parts of the domain to partially account for flow around hills, for channeling down valleys, and for thermally-driven upslope winds during the day and downslope winds during the night. The resulting adjusted initial wind field is called the "Step 1" wind field. The thermally driven slope flows are estimated at this stage as a function of the local terrain slope and the height of the nearest hill crest (defined as the highest peak within a particular radius, TERRAD, around each grid point). TERRAD is an input into CALMET, and is assumed here to be 15 km (9.32 mi) as recommended by the EPA.

Surface observations are next incorporated into the Step 1 wind field to produce the final wind field. Both surface and upper air observations are integrated as part of the objective analysis. The interpolation formula for the observations uses an $\exp(-(R/R_{scale})^2)$ weighting factor, where R is distance from the observation and R_{scale} is a scaling distance, which is based on physical reasoning and experience. R_{scale} is on the order of 10 km (6.2 mi). Thus, at locations very close to a particular observation site, the CALMET-calculated wind is nearly the same as the observed wind at that site. As another example, if the wind is desired at a location that is equal distance (say 5 km or 3.1 mi) from four observing sites to the N, S, E and W, the wind at that location will be equally influenced by all four sites.

A radius of influence, RMAX, is defined for CALMET and assumes that, at distances beyond RMAX from the observing site, that site has no effect on the calculated winds. For this analysis, a 100 km (62 mi) radius of influence was assumed for the surface observations (RMAX1) and a 200 km (124 mi) radius of influence was used for both the upper air and over water observations (RMAX2, RMAX3).

The weighting factor defined above is applied to the observations and to the Step 1 field winds within the radius of influence. CALMET variables, R1 and R2, are defined as a scaling distance that represents the distance at which the observation and the Step 1 wind field are weighted equally. A value of R1 = 50 km (31 mi) was assumed for the surface layer and R2 = 100 km (62 mi) was used for the upper air (layers aloft) (R2) in this analysis.

The values selected for R1 and R2 can be considered to be measures of the spatial representativeness of the surface observation stations. Most of the surface observation stations in this application are located in areas of relatively flat terrain. The values of R1 and R2 chosen allow the surface observations to be given more weight within 50 km (31 mi). At 50 km (31 mi) the Step 1 wind field and surface observations are equally weighted, and beyond 50 km (31 mi), the Step 1 wind field dominates.

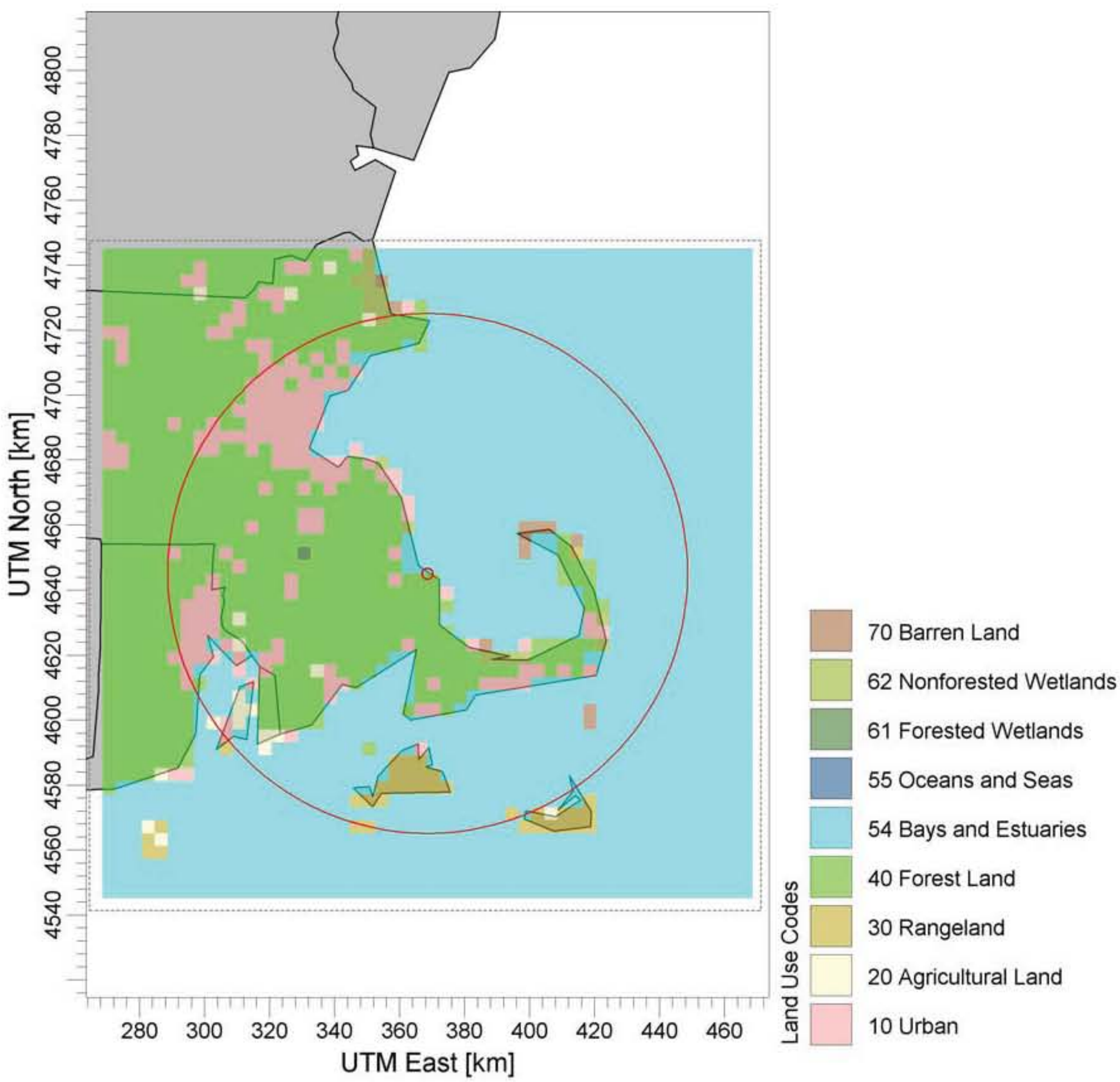


Figure 6. Land use categories in the CALMET modeling domain. The Pilgrim Station and the 50 mi radius circle around the Pilgrim Station are shown in red.

2.3.4 Examples of CALMET Meteorological Modeling Results

Initially we attempted to run CALMET as a single computer run for all 8756 hours of NCDC-provided meteorological data for 2001. When running the subsequent software to compute trajectories, we found that it was taking too much computer time and was slowing down because of the large file sizes that were generated by CALMET for the full year. Consequently, we broke down the CALMET runs into 12 separate computer runs (i.e., one for each month of 2001). This resulted in a much smaller CALMET output files and then a shorter overall computer run time for the trajectory software.

Each month was run for an extra day, in order to have an overlap so that the subsequent software for calculating trajectories would not miss any hours for those trajectories started on the last few hours of each month. For example, a trajectory started at the Pilgrim Station at 2200 (10 pm) on January 31 may not pass the 50 mi (81 km) radius of the domain until 0400 (4 am) on February 1.

The CALMET simulation began on hour 1 of January 1, 2001 and ran through hour 19 of December 31, 2001. The calculation stops on hour 19 because the data for 2001 are available only through midnight Greenwich universal time, which is hour 1900 EST.

As an example of the type of hourly wind information that is produced by CALMET, Figure 7 is a vector plot of the surface wind field generated by the model for 0900 on March 6, 2001, illustrating the high winds with steady wind directions over the domain during a “Nor’easter” storm that occurred that day. As a different example, Figure 8 presents a vector plot illustrating the CALMET model’s handling of a light wind period at 1500 on May 4, 2001. Note that the wind directions in Figure 8 are more variable than those in Figure 7. This is a typical result, since periods with light winds tend to have more variability.

2.4 Development of Trajectory Analysis Software

The CALMET wind fields were used to calculate hypothetical trajectories on the SAMA domain. The trajectory is the path of a small non-buoyant inert parcel of air “released” from the Pilgrim Station at the beginning of each hour, and moved by the hourly wind field produced by the CALMET model. The trajectory follows the wind at its current location and at a specific height. Since we needed software able to calculate trajectories from the CALMET-produced hourly wind fields, we first searched for commercially-available software. However, none was available that would calculate thousands of hours of trajectories. Consequently, we developed two software programs for the trajectory analyses. The first, COMPTRAJ, reads the three-dimensional wind field produced by CALMET and computes the trajectory location for each hour. As mentioned above, each trajectory starts at the location of the Pilgrim meteorological tower and is followed until it passes the 50 mile (80 km) radius circle. COMPTRAJ computes the location of the trajectory based on the horizontal winds at the grid cell of its current location and hour, coupled with the winds for the next hour.

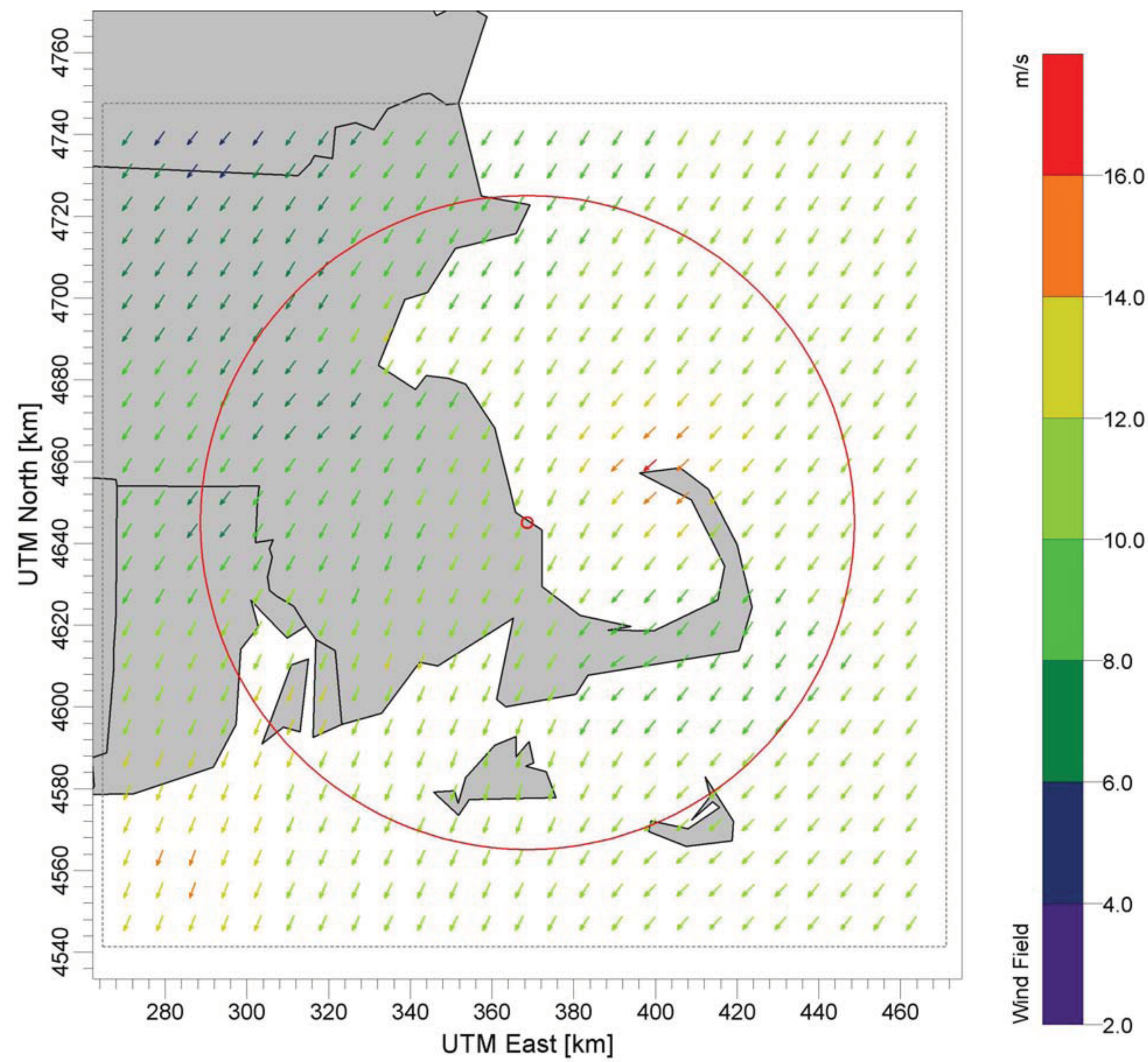


Figure 7. CALMET Wind Vectors at 10 m (33 ft) at 0900 on March 6, 2001. The direction of the wind is shown by the direction the vector or "arrow" is moving, and the speed of the wind is indicated by the color of the arrow, with the scale shown on the legend. Strong northeast winds are occurring, with speeds up to 16 m/s (36 mi/hr) on the tip of Cape Cod. The Pilgrim Station and the 50 mi radius circle around the Pilgrim Station are shown in red.

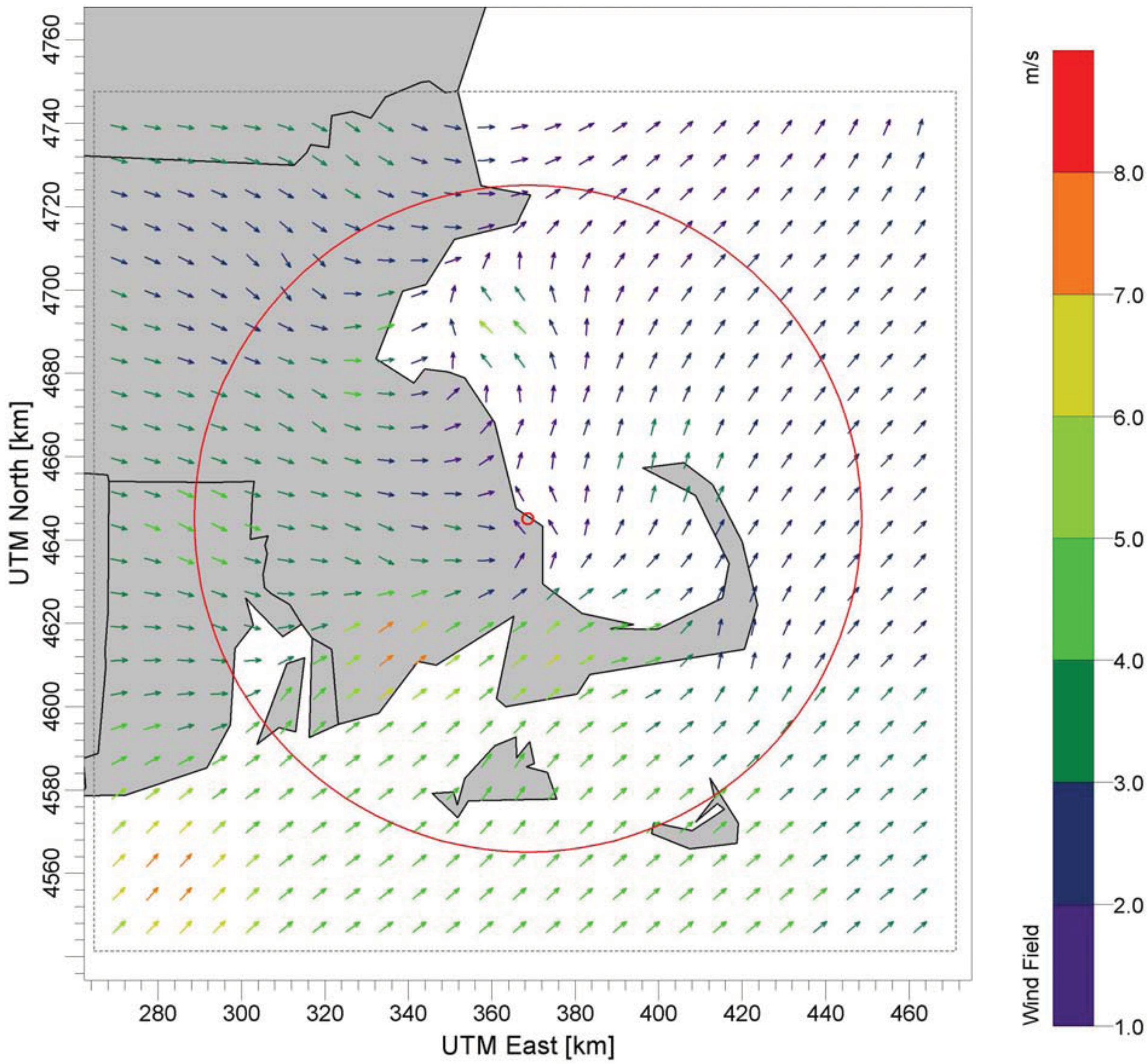


Figure 8. CALMET Wind Vectors at 10 m at 1500 on May 4, 2001. The direction of the wind is shown by the direction the vector or "arrow" is moving, and the speed of the wind is indicated by the color of the arrow, with the scale shown on the legend. The Pilgrim Station and the 50 mi radius circle around the Pilgrim Station are shown in red.

The calculated trajectory starts at a specific height above ground and remains at that height. We decided to calculate trajectories from the Pilgrim Station at three heights: 100, 200, and 500 m (328, 656, and 1640 ft). The rationale for these choices is straightforward. 100 m (328 ft) was chosen because that is the approximate average height of a pollutant cloud at a distance of 1 km (0.62 mi) from the Pilgrim Station. 500 m (1640 ft) is chosen because that is the approximate average height of a pollutant cloud at large distances (beyond about 10 km or 6.2 mi) after the cloud has mixed vertically between the surface and the mixed layer height, which averages about 1000 m (3280 ft) in the eastern U.S. and therefore also near the Pilgrim Station. We note that the inputs of mixing height for the SAMA analysis average about 1000 m (3280 ft) over the year. 200 m (656 ft) is chosen as a value in between the 100 m (328 ft) and 500 m (1640 ft) trajectory heights.

The second program, TRAJFREQ, reads the coordinates of the trajectory for each hour (produced by COMPTRAJ) and determines whether the trajectory has crossed a specified radial distance arc. These radial distance arcs are centered on the Pilgrim meteorological tower and are at the following downwind distances: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 20, 30, 40, and 50 miles. These correspond to distances used in the SAMA analysis. If the trajectory crosses one of these arcs, the direction (angle location) of the crossing is noted and saved by the software. The angle locations are measured in meteorological convention (see Figure 1), where 0º corresponds to traveling north, 90º corresponds to traveling east, 180º corresponds to traveling south, and 270º corresponds to traveling west. As with the wind roses, the angle locations are then assigned to one of 16 standard sectors of 22 1/2 º each. The full year of 8756 trajectory angle locations on each distance arc is then analyzed to calculate the fractional occurrence of trajectory crossings in each 22 ½ direction sector at each distance. This allows the "trajectory roses" to be plotted and compared easily with the 2001 Pilgrim site 33' wind rose plot.

Each of the new programs described above was carefully quality checked to be free of errors. This was done by having a "debug" version of each program that would write out the contents of each variable after specific actions by the code so that the progression of the software could be hand checked and compared with real data. This enabled hand checking and confirmation of the CALMET binary output files against the real data. For example, after the wind data were read from the CALMET binary output file, they were written out in the debug mode so the programmer could make sure the data were read in correctly. The CALMET gridded wind speed and wind direction binary outputs at the vertical level of interest were similarly written out in the debug mode and hand checked as were the trajectory calculations, along with the process of interpolating the trajectory locations. Sample calculations were hand checked in this way for each of the variable outputs to ensure the correct functioning of the program.

3. Results of Data Representativeness Studies

In meteorology, the term "representative" means that a certain meteorological observation at a specific location and for a specific time period is "within the normal expected range" of observations at other nearby locations and times. The word "representativeness" is the condition associated with being representative. An example of a wind representativeness study is given by Hanna and Chang (1992) for a set of 13 research-grade anemometers installed on an L-shaped pattern in a relatively flat plain, with the arms of the "L" having lengths of 10 km (6 miles). Typical variabilities in hourly-averaged wind speeds are observed to be 2 to 3 mph (0.9 to 1.3 m/s).

Annual precipitation has a relative (i.e., %) variability that is larger in areas with small annual precipitation. Because the New England area has moderate annual precipitation (about 40 to 50 inches), the year-to-year variability is also moderate – about plus or minus 10 inches each year.

For the Pilgrim Station SAMA analysis, the hourly observations of wind and temperature difference from 2001 at the Pilgrim Station upper meteorological tower were used as inputs. Winds were used from the 33 ft (10 m) level. Temperature differences between the 33 ft (10 m) and 220 ft (67 m) levels were used. Precipitation observations from the nearby Plymouth Municipal Airport were also used as inputs to the SAMA analysis.

3.1 Representativeness of 2001 Pilgrim Station Annual Wind Rose Compared with Other Years at the Pilgrim Station

The study first considered whether the 2001 wind rose from the 33 ft (10 m) level of the Pilgrim tower (used in the SAMA analysis) is representative of other years. To investigate this, we used the 1999, 2000, and 2001 Pilgrim meteorological reports (Duke, 1999, 2000, 2001), and the 1996-2001 hourly meteorological data files. These were the six most accessible years for the historical period up through 2001, and show no major variations.

The wind roses were generated using the hourly observation files. We converted each wind rose so that it indicates direction the wind is blowing towards (consistent with the MACCS2 convention) rather than direction the wind is blowing from (the normal meteorological convention that is used in most wind roses and is used in the reports).

When the eye looks at the six annual wind rose plots from the Pilgrim Station, shown in Appendix A, they "look visually" similar. That is, the relative occurrence of high and low values at a particular direction from year to year is similar across all six years. The dominant directions for all years are the directions toward the north and east.

In Table 3, the wind roses for the six years at the Pilgrim Station are compared quantitatively. The numbers that are entered in the table are percentages. In addition, the right hand side of Table 3 lists the average and the range of the six numbers for each of the 16 wind rose direction sectors. More than half of the time, the percentage that the wind is blowing towards any of the direction sectors varies by less than 1 % from year to year, and has a maximum variation of 3 % for the sectors towards the NNE. The colors red and green are used in Table 3 to indicate which year had the largest and smallest percentages, respectively, for that direction. The "scores" are summarized for each year at the bottom of the table. It is seen that the number of times that a year has the maximum or minimum over the 16 sectors varies somewhat from year to year, and that there is no year that stands out as a major outlier. The numbers for the year 2001 are within the range of statistical expectation. In fact, out of the six years, 2001 has the fewest cases of having a maximum or minimum.

It is concluded that the annual wind rose from 2001 at the Pilgrim Station is representative of other years.

3.2 Representativeness of 2001 Pilgrim Station Annual Wind Rose Compared with Other Sites in the Area

The annual wind roses from several sites in the 50-mile radius around the Pilgrim Station were compared to determine whether the 2001 annual Pilgrim 33 ft (10 m) wind rose used in the SAMA analysis was representative of other sites in the area. Table 1 listed the 18 sites (in addition to the Pilgrim site) used in the wind rose analysis, and Figure 9 shows their locations. These sites were chosen after a comprehensive survey of sites with available wind data. We use all of the available sites except a few near the edge of the SAMA domain that are located close to other sites. A combination of visual and quantitative comparisons is used in the analysis.

As described earlier, the wind roses were converted from the usual meteorological convention where a west wind is from the west, to the SAMA convention where a west wind is a wind towards the west. Thus in the following figures presenting annual wind roses, a “petal” towards the north represents a wind blowing towards the north. Appendix B contains the complete set of wind roses from the 18 sites and from the Pilgrim 33 ft and 220 ft levels.

Note that all of the wind rose plots in this report include identification of the percentage of calms, as well as the percentage of winds in the 16 sectors. The percentage of calms ranges from 0.51% at the Pilgrim 33 ft level to 10 to 15% for some of the regional airports. A calm is defined using the known minimum threshold of the wind vane or anemometer used for the observation at each site. The Pilgrim site has less calms because it uses a sonic anemometer, which can measure accurately down to speeds less than 0.5 m/s (1.2 mph). The regional airport anemometers have more calms because their minimum believable (accurate) speeds are about 1 to 1.5 m/s (about 2 to 3 mph). The frequencies in the wind rose plots are consequently less in some sectors than the frequencies listed in Tables 3 -7 due to this difference in treating calms. For the tables, we have normalized the frequencies so that they add to 100 %. This is done by distributing the calms around the circle using the wind direction distributions in the wind roses.

Table 3 - Comparison of the percentages for the 16 directions (towards) in the annual wind rose from the 33 ft (10 m) level of the Pilgrim upper meteorological tower for the year 2001 (used in the SAMA) with percentages from that location for 1996 through 2001. The next to last column gives the average over the six years and the last column gives the range. Red color indicates that number is the highest and green color indicates that it is the smallest over the six years. At the bottom of the table, the numbers of times highest (red) and times lowest (green) for each year are listed.

	Pilgrim Upper Tower 33 ft						Avg of	Range of
Direction	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**10 years**	**10 years**
						(SAMA)		
N	9.6%	8.3%	8.0%	**10.0%**	**7.3%**	**8.8%**	**8.7%**	**7.3% to 10.0%**
NNE	15.5%	**14.0%**	**17.1%**	14.1%	14.8%	**16.1%**	**15.3%**	**14.0% to 17.1%**
NE	11.8%	**13.0%**	**10.5%**	11.0%	11.4%	**12.1%**	**11.6%**	**10.5% to 13.0%**
ENE	**8.9%**	**10.8%**	9.1%	9.4%	10.2%	**10.1%**	**9.7%**	**8.9% to 10.8%**
E	9.6%	**11.6%**	9.6%	9.4%	9.7%	**9.3%**	**9.9%**	**9.3% to 11.6%**
ESE	6.2%	6.5%	6.4%	**6.0%**	**6.7%**	**6.5%**	**6.4%**	**6.0% to 6.7%**
SE	4.5%	**4.2%**	5.3%	**5.5%**	5.4%	**4.5%**	**4.9%**	**4.2% to 5.5%**
SSE	**3.5%**	**2.5%**	2.9%	3.2%	3.1%	**3.1%**	**3.1%**	**2.5% to 3.5%**
S	3.2%	**2.0%**	2.5%	2.3%	**4.4%**	**3.7%**	**3.0%**	**2.0% to 4.4%**
SSW	4.6%	5.1%	5.3%	**4.3%**	**5.5%**	**5.2%**	**5.0%**	**4.3% to 5.5%**
SW	**3.7%**	4.9%	**5.4%**	3.8%	4.8%	**3.8%**	**4.4%**	**3.7% to 5.4%**
WSW	4.4%	**3.4%**	4.5%	**5.1%**	4.3%	**3.6%**	**4.2%**	**3.4% to 5.1%**
W	4.3%	3.8%	4.3%	4.3%	**4.5%**	**3.6%**	**4.1%**	**3.6% to 4.5%**
WNW	**2.4%**	3.6%	2.8%	**3.8%**	3.1%	**3.2%**	**3.2%**	**2.4% to 3.8%**
NW	3.3%	2.9%	3.4%	**3.8%**	**2.3%**	**3.7%**	**3.2%**	**2.3% to 3.8%**
NNW	**4.5%**	3.5%	3.0%	3.8%	**2.5%**	**2.6%**	**3.3%**	**2.5% to 4.5%**
times highest	2	3	2	5	4	**0**		
times lowest	3	5	1	2	3	**2**		

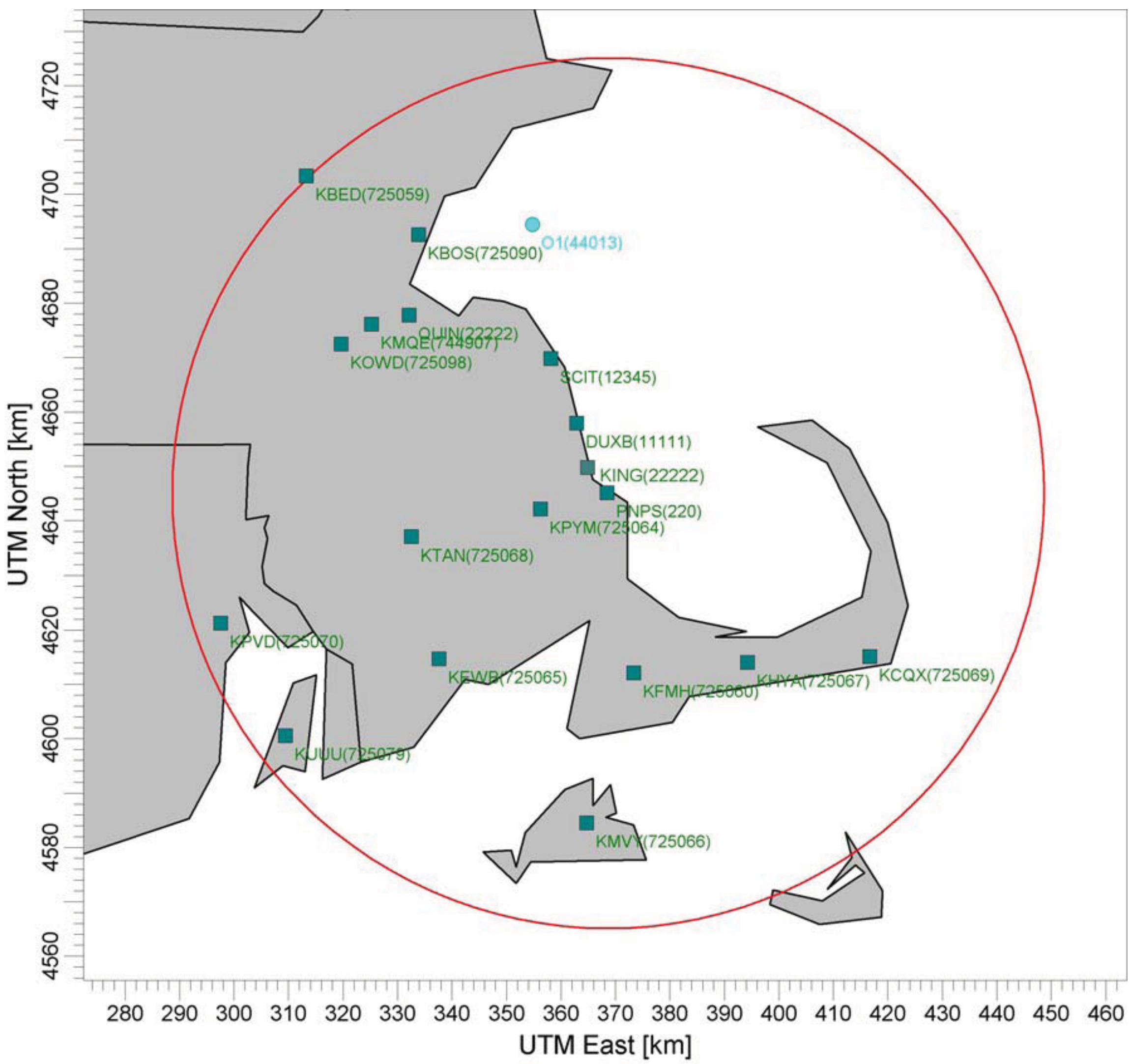


Figure 9. Weather stations used in the wind rose comparisons. The 50 mi radius circle around the Pilgrim Station (marked as PNPS) is shown in red. See Table 1 for a listing of site names and other details.

Figure 10 shows one example of a wind rose comparison from Appendix B. In this example, the Pilgrim Station 33 foot (10 m) wind rose is compared with that from the Plymouth Municipal Airport, which is the closest of the 18 sites to the Pilgrim Station. Each plot in Appendix B has a similar format to that seen in Figure 10, showing the annual 2001 wind rose for the Pilgrim 33' level (the left panel in each figure) and the wind rose from another site on the right hand side. Two wind roses are on a page to make visual comparisons easier. It is easy for the eye to "see" that the pairs of wind roses in Figure 10 and in Appendix B "look" similar. They all have predominate winds blowing towards the eastern sector, and far fewer winds blowing towards the western sector. A few of the wind roses have some specific directions with relatively low frequencies (such as Providence TF Green towards the west and Newport State Airport towards the northeast), but our investigation of local topography did not reveal any scientific reasons for these low frequencies. The wind rose from the Boston Approach Lighted Buoy is obviously more exposed than the on-land coastal sites and shows a more uniform distribution of frequencies, although still retaining the dominant flow towards the east and the minimum flow towards sectors in the southwest quadrant. The wind rose from the East Milton Blue Hill Observatory, which is well exposed on the highest hill on the Massachusetts coast, indicates slightly more winds towards the southeast, more reflecting the upper air flow. None of the wind roses from these other official weather sites in the region, however, show significant changes in their predominant wind direction distributions from the 2001 Pilgrim wind rose that would suggest different weather patterns that would significantly affect the SAMA analysis.

A quantitative comparison of the Pilgrim wind rose and the 18 other wind roses in Appendix B is given in Table 4. Because the sites had varying frequencies of calms and missing data, it was necessary to normalize the direction sector distributions so that the frequencies sum to 100% at each site. This was done by assuming that the calm and missing hours would have wind direction distributions the same as the other hours at that site. Because the Duxbury site reported wind directions in eight rather than in 16 sectors, the Duxbury frequencies for a 45 degree sector were equally divided among the two imbedded 22 ½ degree sectors. There are 13 NCDC sites from 2001, one buoy, three Mass Energy sites (Kingston, Quincy and Scituate) from 2006-2007, and the Duxbury site from 2001. The Mass Energy sites were not operating in 2001. In Table 4, the minimum frequency for each direction sector is green and the maximum is red. The range of the frequencies for the non-Pilgrim sites is shown. It is seen that 13 of the non-Pilgrim sites have one to four "maxima" or "minima". The Pilgrim 33 ft site has one sector with a minimum, for winds blowing towards the SE. For the other 15 wind direction sectors, the Pilgrim 33 ft percentage is within the range of the others.

Just as found in the qualitative comparisons of the wind roses, the quantitative comparisons in Table 4 occasionally indicate anomalies in the frequencies for certain 22 ½ ° wind direction sectors, such as the relatively low values at Newport for directions towards the ENE and E. Because these slight anomalies are expected to even out when summed over several adjacent sectors, and because the SAMA concerns integrated impacts to populated areas, we summed the frequencies of wind directions towards the S clockwise through the NNW for each site. This 180° hemisphere sector represents winds blowing towards the west, where nearly all of the population is located. Table 5 lists the

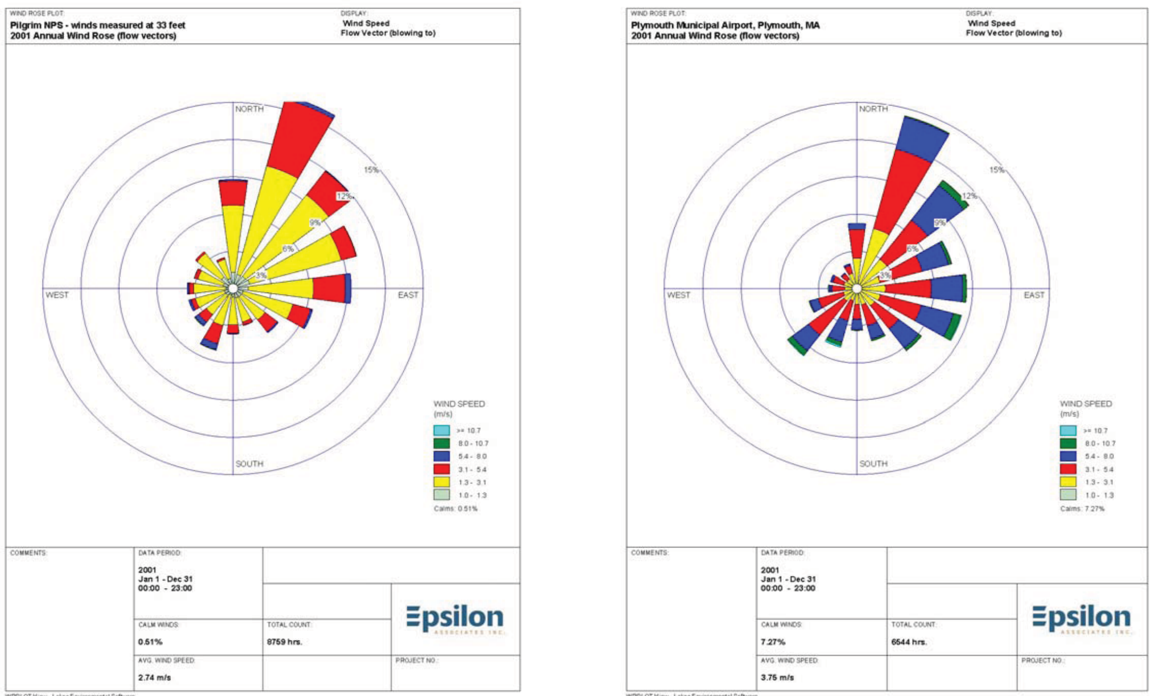


Figure 10. Annual wind roses for Pilgrim 33' (10 m) met tower level (left) and for Plymouth (right). The percentage of winds blowing towards the indicated direction are shown.

Table 4. Annual wind direction frequencies, expressed as direction the wind is blowing towards, for 22 ½° wind direction sectors for the 33 ft (10 m) level of the Pilgrim meteorological tower, and for 18 other sites in the 50-mile radius SAMA geographic domain around Pilgrim. All are for 2001 except the Kingston, Quincy, and Scituate sites are for 2006-2007. Green is the minimum and red is the maximum at a given wind direction for all sites. The range of the non-Pilgrim sites is included.

Wind Direction blowing towards	Compass direction	Pilgrim 33 ft	Range of non-Pilgrim sites	Average of non-Pilgrim sites	Hanscom	Otis	Plymouth	New Bedford	Martha's Vineyard	Barn-stable	Taunton	Chatham	Boston Logan	Norwood	East Milton	Provi-dence	Newport	Kingston MA	Quincy	Scituate	Duxbury	Boston Approach Buoy
348.75 - 11.25	**N**	8.8%	2.5 to 11.2%	5.7%	3.5%	4.7%	5.7%	4.5%	4.6%	2.6%	5.8%	10.5%	4.2%	5.0%	7.9%	6.6%	**11.2%**	3.9%	5.8%	**2.5%**	5.5%	8.0%
11.25 - 33.75	**NNE**	16.1%	4.1 to 22.0%	9.9%	7.1%	8.5%	15.5%	8.1%	9.4%	5.9%	13.0%	**22.0%**	7.7%	9.8%	10.0%	7.1%	14.3%	7.5%	12.3%	**4.1%**	5.5%	9.5%
33.75 - 56.25	**NE**	12.0%	3.3 to 17.1%	12.1%	12.9%	**17.1%**	11.8%	16.3%	16.7%	15.0%	13.0%	10.2%	12.1%	10.3%	9.3%	8.7%	**3.3%**	16.3%	11.1%	12.0%	11.5%	10.2%
56.25 - 78.75	**ENE**	10.1%	2.4 to 13.6%	8.9%	10.7%	9.4%	8.2%	7.8%	7.5%	**13.6%**	7.7%	6.3%	7.2%	9.1%	8.2%	7.7%	**2.4%**	9.4%	12.0%	12.1%	11.6%	8.8%
78.75 - 101.25	**E**	9.3%	6.5 to 14.5%	9.5%	11.6%	8.3%	9.2%	8.7%	8.6%	8.1%	9.5%	**6.5%**	10.1%	9.9%	9.0%	10.7%	7.1%	10.1%	**14.5%**	10.3%	10.1%	8.4%
101.25 - 123.75	**ESE**	6.5%	6.2 to 11.0%	9.1%	9.4%	9.1%	9.1%	8.1%	7.3%	7.1%	9.8%	**6.2%**	12.1%	9.4%	**11.0%**	9.6%	9.7%	9.1%	9.6%	10.5%	10.1%	6.4%
123.75 - 146.25	**SE**	**4.5%**	5.2 to 11.7%	8.2%	9.4%	7.1%	6.8%	8.0%	8.3%	6.6%	7.8%	5.2%	9.2%	9.8%	**11.7%**	9.8%	10.4%	8.5%	6.2%	10.0%	**5.2%**	6.8%
146.25 - 168.75	**SSE**	3.1%	2.6 to 8.7%	5.5%	7.8%	3.7%	4.7%	5.9%	5.9%	5.8%	5.5%	2.7%	5.1%	**8.7%**	5.9%	7.1%	7.2%	5.2%	**2.6%**	5.4%	5.2%	4.5%
168.75 - 191.25	**S**	3.7%	2.3 to 8.3%	5.2%	5.2%	4.8%	3.7%	6.6%	6.3%	**8.3%**	4.4%	4.7%	4.6%	5.6%	3.1%	7.1%	8.1%	4.4%	**2.3%**	5.8%	5.4%	3.4%
191.25 - 213.75	**SSW**	5.2%	3.3 to 8.4%	5.2%	3.6%	6.9%	5.3%	6.0%	5.0%	**8.4%**	4.9%	6.5%	4.0%	3.6%	3.4%	6.0%	5.1%	4.9%	**3.3%**	7.2%	5.3%	4.7%
213.75 - 236.25	**SW**	3.8%	3.2 to 6.3%	4.8%	4.1%	4.7%	7.3%	4.2%	4.5%	**6.3%**	3.5%	4.0%	3.7%	**3.2%**	5.5%	5.5%	**3.2%**	5.0%	6.1%	5.4%	5.5%	4.4%
236.25 - 258.75	**WSW**	3.6%	2.1 to 6.6%	3.6%	4.0%	2.3%	4.2%	**2.1%**	4.2%	2.9%	2.4%	3.0%	4.1%	6.2%	3.7%	2.8%	2.4%	**6.6%**	4.2%	2.4%	5.4%	2.5%
258.75 - 281.25	**W**	3.6%	1.2 to 4.6%	2.9%	3.1%	2.3%	2.4%	2.3%	3.6%	1.7%	1.7%	2.7%	**4.6%**	**4.6%**	2.8%	**1.2%**	3.2%	4.4%	2.7%	2.8%	3.5%	3.5%
281.25 - 303.75	**WNW**	3.2%	1.3 to 4.4%	2.7%	2.7%	3.6%	2.3%	3.5%	1.7%	1.9%	2.4%	2.6%	4.4%	2.0%	1.7%	**1.3%**	3.6%	1.9%	1.6%	3.3%	3.5%	**4.4%**
303.75 - 326.25	**NW**	3.7%	1.2 to 7.7%	3.3%	2.6%	4.2%	1.7%	4.3%	3.5%	2.8%	4.2%	2.8%	4.7%	1.4%	3.0%	2.2%	3.5%	**1.2%**	2.4%	3.6%	3.3%	**7.7%**
326.25 - 348.75	**NNW**	2.6%	1.6 to 6.7%	3.5%	2.3%	3.2%	2.2%	3.4%	3.0%	3.1%	4.3%	4.0%	2.2%	**1.6%**	3.8%	6.3%	5.4%	1.7%	3.3%	2.6%	3.4%	**6.7%**
	times hi	0			0	1	0	0	0	4	0	1	1	2	2	0	1	1	1	0	0	3
	times low	1			0	0	0	1	0	0	0	2	0	2	0	2	3	1	3	2	0	0

Table 5. Same format as Table 4, except the percentages listed are for the 180° sector including the directions S clockwise through NNW (i.e., winds blowing towards the western sector where most of the population is located).

Pilgrim 33 ft	Range of non-Pilgrim sites	Average of non-Pilgrim sites	Hanscom	Otis	Plymouth	New Bedford	Martha's Vineyard	Barn-stable	Taunton	Chatham	Boston Logan	Norwood	East Milton	Provi-dence	Newport	Kingston MA	Quincy	Scituate	Duxbury	Boston Approach Buoy
29.5%	25.8 to 37.4%	31.2%	27.5%	32.0%	29.0%	32.6%	31.8%	35.4%	27.8%	30.4%	32.2%	28.0%	27.0%	32.6%	34.5%	30.0%	25.8%	33.1%	35.3%	37.4%

frequencies in the western 180° sector for the same 19 sites as shown in Table 4. As expected from the known dominance of winds towards the east in all wind roses, the summed frequency towards the western half of the circle are all less than 50 %, with an average of 31.2% and a range from 25.8% (Quincy) to 37.4% (Boston Approach Buoy). The Pilgrim 33 ft value is 29.5%, slightly below the average and well within the range.

Thus the statistical behavior of all sites is similar, and the Pilgrim site frequencies are within the range of the other sites for all 16 sectors. It is concluded that the Pilgrim 33 ft (10 m) annual wind rose for 2001 is representative of the annual wind roses from other sites in the SAMA domain.

3.3. Representativeness of 2001 Pilgrim Station Annual Average Wind Speed Compared with Other Sites in the Area

Atmospheric transport and dispersion models such as MACCS2/ATMOS use the observed wind speed as an input. In all dispersion models, the wind speed, u, is a diluting factor that appears in the denominator of the equation for estimating the concentration, C. If the wind is blowing past a sampling point on one day at a speed that is a certain % larger than that on the previous day, then there is a volume of air available for dilution that is that certain % larger. Therefore concentration, C, is approximately inversely proportional to wind speed u due solely to the dilution effect (that is, $C \approx A/u$, where A is all other factors in the equation). When u doubles, C decreases by approximately one-half. When u increases by 5 %, C decreases by approximately 5 %. This dilution effect occurs independently of the dispersion effect.

The plotted annual wind roses in this report contain the annual average wind speed listed in a block near the bottom. However, the software used to prepare those wind roses does not include the observed calm hours in the calculation of the average wind speed. The average annual wind speeds discussed in the remainder of this section have been calculated so that the calm hours are included. Table 6 contains the 2001 average annual wind speeds at the Pilgrim Station 33 ft (10 m) level (used in the MACCS2/ATMOS runs) and at the 18 non-Pilgrim Station sites used in the wind rose comparison and indicated in Table 1. Figure 9, presented earlier, contains a map with the site locations shown. The sites in Table 6 are ordered such that those closer to the Pilgrim Station are at the top and those farther away are at the bottom.

It is seen that the Pilgrim Station annual average wind speed, at 2.73 m/s, is the smallest of the group by about 0.06 m/s (the Norwood annual average wind speed is 2.79 m/s). The average of the 18 "non-Pilgrim" annual wind speeds is 3.79 m/s and the range is from 2.79 m/s at Norwood to 5.62 m/s at East Milton Blue Hill Observatory. However, it is easy to explain this because the Pilgrim site is in an area of fields and trees whereas all of the other sites are in flat open airport environments, on tall towers in open areas (the Mass Energy sites), on a hilltop (East Milton Blue Hill Observatory), on the beach (Duxbury) or surrounded by open ocean (Boston Approach Buoy).

Table 6. Average annual wind speed listed for weather sites in the SAMA domain and used in the wind rose comparisons. The MA Energy sites, with measurements on tall towers, have had their wind speeds adjusted to an equivalent 10 m height using the logarithmic wind speed profile formula with surface roughness length of 0.1 m.

Site	Height of anemometer	Annual wind speed (m/s)	Speed adjusted to 10 m	Terrain
Pilgrim Station	33 ft (10 m)	2.73		Field, woods
Plymouth Muni Airport	33 ft (10 m)	3.48		Flat open
Kingston MA En tower	164 ft (50 m)	5.54	4.11	Top of sealed landfill
Duxbury	33 ft (10 m)	3.61		Beach edge
Taunton Muni Airport	33 ft (10 m)	2.98		Flat open
Otis Air Nat Guard	33 ft (10 m)	4.30		Flat open
Scituate MA En tower	128 ft (39 m)	4.40	3.38	Flat near marsh
Barnstable Muni Airport	33 ft (10 m)	4.04		Flat open
Boston Approach Buoy	16 ft (5 m)	5.15	5.48	Open ocean
Quincy MA En tower	220 ft (67 m)	5.18	3.67	Small open hill
Chatham Muni Airport	33 ft (10 m)	3.68		Flat open
East Milton Blue Hill Observatory	33 ft (10 m) at top of hill	5.62		Large hill 635 ft (194 m)
Norwood Mem Airport	33 ft (10 m)	2.79		Flat open
New Bedford Airport	33 ft (10 m)	3.67		Flat open
Boston Logan Airport	22 ft (6.7 m)	4.77	5.22	Flat open
Providence Green Airp	33 ft (10 m)	3.54		Flat open
Newport State Airport	33 ft (10 m)	3.16		Flat open
Hanscom Field Airport	33 ft (10 m)	3.35		Flat open
Martha's Vineyard Airp	33 ft (10 m)	4.36		Flat open

The 12 airport sites in the table are the most similar in respect to their surrounding terrain (i.e., flat open areas over a broad area at least one mile across) and their height of measurement (10 m for most). They have a median and mean wind speed of 3.68 m/s, and a range of 2.79 m/s (Norwood) to 4.77 m/s (Boston) (i.e., plus and minus about 25 or 30 %). The Duxbury site, on the beach 8.5 mi NNW of the Pilgrim Station, has a speed, 3.61 m/s, that is within in this range. When the three Mass Energy sites, with anemometers on tall towers in exposed locations, have their winds adjusted to the 10 m height of the airport sites, the adjusted speeds range from 3.38 m/s to 4.11 m/s, which are also in the range of the airport sites. The standard logarithmic wind profile formula is used to make this adjustment:

$$u(z) = (u^*/0.4)\ln(z/z_o) \qquad (1)$$

where z is height above ground, z_o is surface roughness length (assumed to be 0.1 m in the SAMA MACCS2/ATMOS runs), and u* is a scaling speed known as the friction velocity, which can be assumed constant with height in approximately the lowest 100 m of the atmosphere.

Assuming that z_1 and z_2 are the heights (less than about 100 m) of interest then equation (1) can be used to estimate the ratio of the wind speeds at the two heights:

$$u(z_1)/u(z_2) = \ln(z_1/z_o)/(\ln(z_2/z_o)) \qquad (2)$$

In our calculations for the three MA energy sites, z_o is assumed to equal 0.1 m, which is a reasonable value for typical open areas and was used in the SAMA. The lower height, z_1, is 10 m. The upper height, z_2, is 50 m for Kingston, 39 m for Scituate, and 67 m for Quincy.

Equation (2) was also used to estimate the wind speed at 10 m based on the wind speed observed at a height less than 10 m at the Boston Logan Airport (z = 6.7 m) and at the Boston Approach Buoy (z = 5 m). The surface roughness length, z_o, was assumed to equal 0.1 m at Logan Airport. The surface roughness length, z_o, for the Boston Approach Buoy was assumed to equal 0.0001 m, which is a standard value assumed for the open ocean.

The wind speed at the East Milton Blue Hill Observatory in Table 6 is relatively large, 5.62 m/s, which can be explained because the site is at the top of Blue Hill, whose elevation is 635 ft (194 m). The Blue Hill Observatory was set up in the late 19th century because of its exposed location on the highest hill along the New England coast south of Camden, Maine.

The Boston Approach Lighted Buoy is in the open ocean 15 miles east of Boston's Logan Airport. When its annual observed wind speed is extrapolated to 10 m, the resulting value of 5.48 m/s is slightly larger than the 5.22 m/s value obtained when the Boston Logan Airport observation is extrapolated to 10 m.

The logarithmic wind speed profile relation in equation (1) can also be used to estimate the "effective" wind speed at the 33 ft (10 m) height on the Pilgrim Station upper tower, assuming that the surface roughness length, z_o, for Pilgrim is the same as at the airport sites (about 0.1 m). To do this, we assume that the wind speed at a height of 100 m above the ground is the same with no dependence on surface roughness. This procedure is recommended by Britter and Hanna (2003) when the wind speed near the ground in the middle of a city must be estimated based on the observed wind speed at a height of 10 m at the airport on the outskirts of the city. If it is assumed that z_o = 1 m at the Pilgrim Station upper tower site, then applying equation (1) would yield an effective wind speed of 3.63 m/s if the roughness were similar to that at the airports. This wind speed is within the range of the observed airport annual wind speeds.

Thus, when the larger roughness around the Pilgrim Station upper tower is accounted for, the slightly smaller wind speeds at that site can be explained satisfactorily and are consistent with the other sites.

As explained in the first paragraph of this section, it is generally true that transport and dispersion models calculate larger concentrations for smaller wind speeds, for other conditions the same. Thus by using the Pilgrim Station observed wind speed at 33 ft (10 m), with annual average of 2.73 m/s, the SAMA calculations are conservative, since average wind speeds are slightly larger at the other 18 wind observing sites in the domain.

3.4 Representativeness of the 2001 Plymouth Municipal Airport Annual Average Precipitation in Space and Time

Figure 11 contains the results of comparisons of annual precipitation totals for 1995-2009 for nine sites: Plymouth (8 mi to the WSW of Pilgrim), Boston Logan (37 mi to the NNW of Pilgrim), Taunton (23 mi to the WSW of Pilgrim), Brockton (27 mi to the WNW of Pilgrim), East Wareham (13 mi to the S of Pilgrim), Hingham (25 mi to the NNW of Pilgrim), Middleboro (14 mi to the WSW of Pilgrim), New Bedford (27 mi to the SW of Pilgrim), and Rochester (19 mi to the SW of Pilgrim)). These nine sites, shown in Figure 2, were chosen because they are spread over the SAMA domain.

Note that the annual precipitation range is from about 30 inches to about 70 inches for all of the sites and years on Figure 11. The plot shows two major results:

1) The 2001 precipitation for Plymouth (used for the SAMA) is close to the middle of the annual precipitation for Plymouth for the other years between 1995 and 2009. Note that two Plymouth years are missing. This is because if there is more than one month of data missing, the whole year is reported as missing.

2) The 2001 precipitation for Plymouth is also close to the middle of the annual precipitation for the other eight sites for 2001.

Thus we can conclude that the annual precipitation from Plymouth for 2001 is not an outlier in time or in space. It is representative of the 2001 annual precipitation for the SAMA area, and it is representative of the 15-year time period.

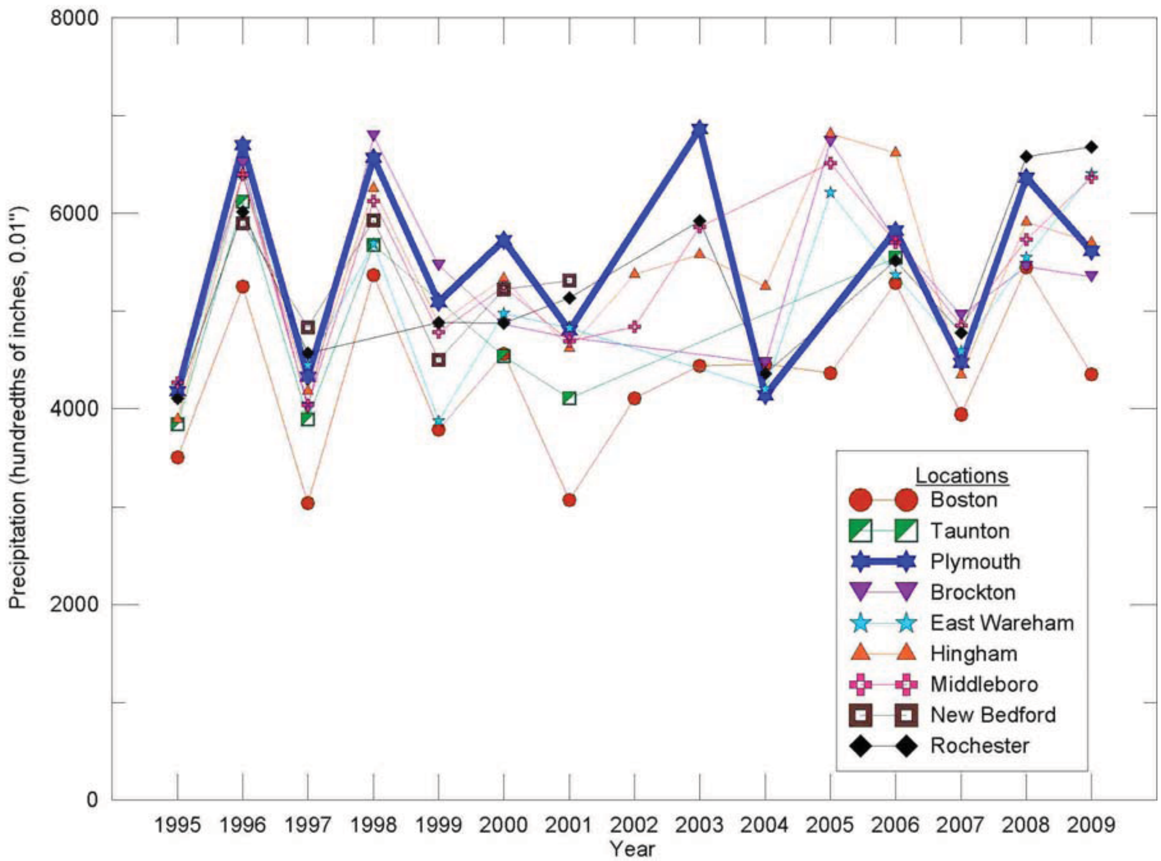


Figure 11. Annual precipitation observed at Plymouth airport and at eight other weather stations in the SAMA geographic domain for 1995-2009. Note that some sites have missing years due to incomplete data records.

4. Results of Trajectory Analysis, including Trajectory Roses

4.1 Trajectory Analysis Methodology

As stated in Section 2, the trajectory calculations were conducted at three elevations, 100, 200, and 500 m (328, 656, and 1640 ft). The computer program COMPTRAJ was run on each monthly file of CALMET (as discussed above, this was done to reduce the run time of the COMPTRAJ software). However, trajectories released from the Pilgrim site during the last few hours of a given month may still be on the geographic domain during the first few hours of the following month. As the COMPTRAJ monthly trajectory output files were combined to create an annual file, these overlap data were accounted for only once. Then the TRAJFREQ program was run to count the frequency of occurrence of trajectory crossings for each 22 ½° direction sector at each of the downwind distances.

The Golden Software application GRAPHER was used to graphically display the trajectory frequency distributions in standard wind rose format. A plot was created for each of the 14 downwind distances (1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 20, 30, 40, and 50 miles) at each of the three trajectory elevations.

4.2 Trajectory Analysis Results

Full sets of the CALMET trajectory frequency roses at 100 m (328 ft) are presented in Appendix C, at 200 m (656 ft) in Appendix D and at 500 m (1640 ft) in Appendix E. A few specific results are described below.

Figure 12 (right panel) shows the annual trajectory frequency rose at the 100 m (328 ft) height at a downwind distance of 1 mi (1.6 km). This shows how often the hourly trajectory will be located within particular wind direction sectors (22½° wide, as illustrated in Figure 1) as the trajectory crosses the 1 mile (1.6 km) arc. Keep in mind that each trajectory was computed based on spatially and time-varying winds simulated by CALMET. The left panel of Figure 12 shows the wind rose plot (expressed as direction towards) for 2001 for the 33 ft (10 m) level wind measurements from the Pilgrim meteorological tower. Note that the wind rose plots, such as in this figure, list the percent of calms in a block at the bottom (0.51 % for the 2001 Pilgrim 33 ft wind direction data) and therefore the percentages on the wind direction rose petals do not include the calms. The annual trajectory frequency rose and the wind rose in the right and left panels are clearly very similar, suggesting that, over a year, the wind direction distributions measured at Pilgrim are representative of the surrounding area within the 1 mile (1.6 km) radius. This is expected, since CALMET applies a fairly high weighting to the local (closest) station at a relatively low elevation (100 m (328 ft) in this example) and at a distance of only 1 mile (1.6 km) from that station.

A more relevant comparison for the SAMA analysis is at the largest circle with 50 mile (80.5 km) radius, for trajectories at an elevation of 500 m (1640 ft). The 500 m level is appropriate for larger distances, where most of the population in the SAMA domain is located. At downwind distances greater than approximately 6 miles (10 km), the plume is likely to be well-mixed from the surface to the typical mixing height of 1000 m (3280 ft). The right panel of Figure 13 shows the annual trajectory frequency rose for the 500 m (1640 ft) level at that distance. In agreement with what was found in Figure 12, this trajectory rose is very similar to the Pilgrim meteorological tower wind rose, plotted in the left panel. Some differences arise because the CALMET derived wind fields are more influenced by the upper air observations (from Gray and Chatham) and by observations from the other surface sites. It is clear however, that short term differences in observed winds have minimal effect on the annual wind direction frequencies.

The visual comparisons of annual trajectory roses for the three levels and the 14 distance arcs versus the annual wind rose from the Pilgrim 33 ft (10 m) meteorological tower in Appendices C, D, and E suggest that the Pilgrim wind rose used in the SAMA analysis is similar to (i.e., representative of) the calculated trajectory roses. In particular, for the dominant winds towards the east in this geographic area, most of the trajectories pass over the water. The fractions of wind directions blowing towards the more populated areas to the northwest and west are small for both the trajectory roses and the Pilgrim 33 ft (10 m) rose.

Earlier, when determining the representativeness of the Pilgrim 33 ft (10 m) annual wind rose compared to annual wind roses from many other sites in the geographic domain, we carried out a quantitative comparison by determining the ranges of fractions of occurrence in each of the 16 wind direction sectors. We showed that the Pilgrim fractions were within the reasonable range of the other sites. We have performed similar quantitative comparisons for the CALMET trajectory roses to the Pilgrim wind rose.

Table 7 contains a quantitative comparison of the 2001 annual wind direction frequencies that were presented in the two panels of Figure 13. Percentages have been rounded to the nearest 0.1%. In this table, the calms were distributed into the Pilgrim 33 ft wind rose percentages, so that these percentages agree with those in earlier tables. The table first lists the wind direction sectors in terms of standard compass directions. The second and third columns list the percentages that were written on the wind direction petals in Figure 13, for the CALMET trajectory analysis (500 m elevation trajectories, at a distance of 50 miles from the Pilgrim Station), and for the 33 ft level of the Pilgrim meteorological tower (including calms). The final column lists the difference between the CALMET trajectory and the Pilgrim 33 ft percentages for each direction sector. The root mean square (RMS) difference (i.e., the standard deviation) of the 16 numbers is 1.5% and the mean absolute difference is 1.3%. No sector difference is larger than 2.6 %. For the "western" 180 degree half circle (from S through NNW), where most of the land and population are located, there is only a 0.7 % difference in total percentage (30.1% for the CALMET trajectories and 29.4% for the Pilgrim 33 ft level). Thus it can be concluded from Table 7 that there is minimal difference between the 2001 annual wind roses from the CALMET trajectories (500 m level and 50 mile distance) and the 33 ft Pilgrim observation. This CALMET trajectory level and distance is very relevant for the SAMA analysis, since the bulk of the population is at distances greater than 20 miles.

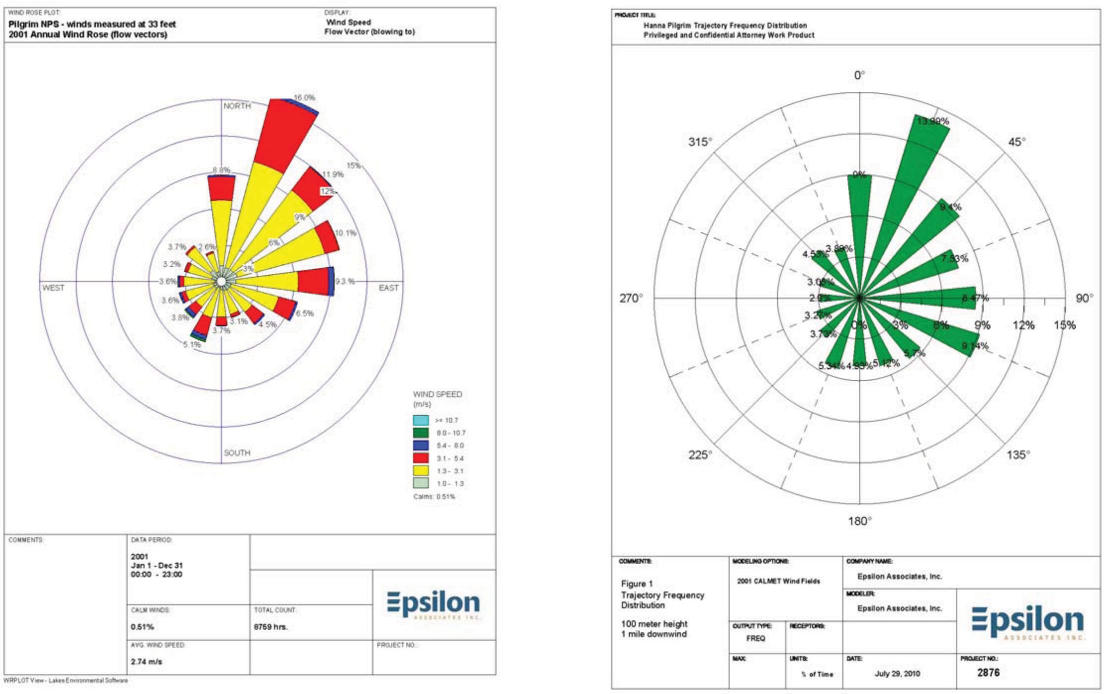
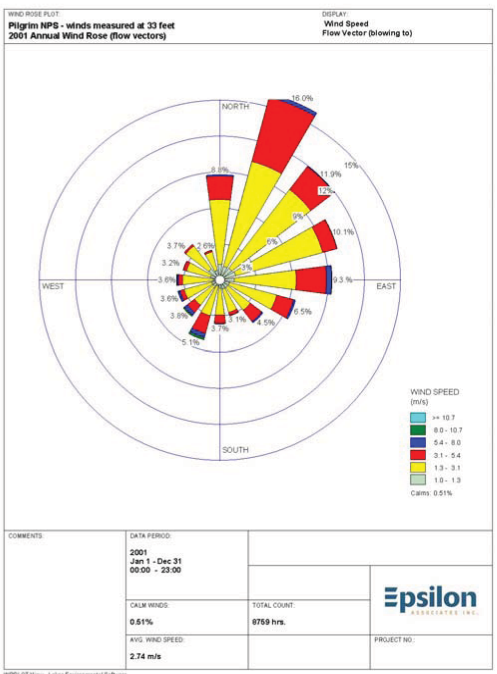


Figure 12. CALMET-generated trajectory rose at 100 m (328 ft) height and 1 mile (1.6 km) distance (right panel). Pilgrim 33 ft (10 m) annual wind rose, with calms not included in the direction petals (left panel).



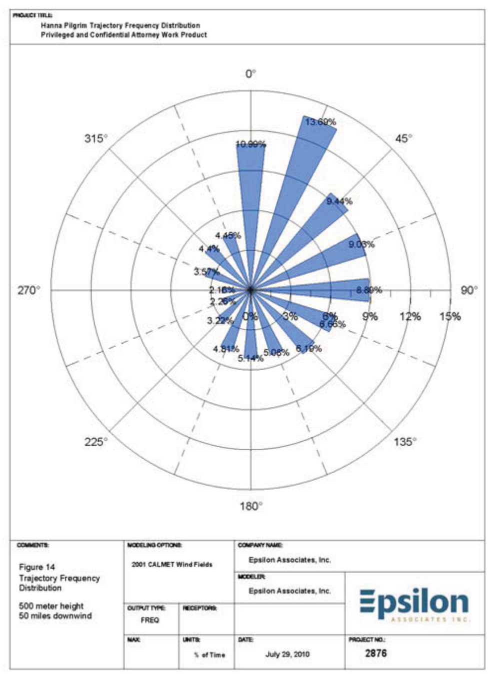


Figure 13. CALMET-generated trajectory rose at 500 m (1640 ft) height and 50 miles (80.5 km) distance (right panel). Pilgrim 33 ft (10 m) annual wind rose, with calms not included in the direction petals (left panel).

Table 7. Comparison of annual 2001 wind direction frequencies from the CALMET trajectory analysis (500 m elevation trajectories, at a distance of 50 miles from the Pilgrim Station), with wind direction frequencies from the 33 ft level of the Pilgrim meteorological tower (used in the SAMA analysis), where calms have been included in the direction petals.

Wind Direction (blowing towards) Compass Direction	CALMET Trajectory 500 m (1640 ft) 50 mile Distance	Pilgrim 33 ft	Difference
N	11.0%	8.8%	2.2%
NNE	13.7%	16.1%	-2.4%
NE	9.4%	12.0%	-2.6%
ENE	9.0%	10.1%	-1.1%
E	8.9%	9.3%	-0.4%
ESE	6.7%	6.5%	0.2%
SE	6.2%	4.5%	1.7%
SSE	5.1%	3.1%	2.0%
S	5.1%	3.7%	1.4%
SSW	4.8%	5.2%	-0.4%
SW	3.2%	3.8%	-0.6%
WSW	2.3%	3.6%	-1.3%
W	2.2%	3.6%	-1.4%
WNW	3.6%	3.2%	0.4%
NW	4.4%	3.7%	0.7%
NNW	4.5%	2.6%	1.9%

5. Conclusions

We used several approaches to investigate whether the Pilgrim 33 ft (10 m) wind direction observations were representative of the 50 mi (80.5 km) radius geographic area of concern to the SAMA calculation. We showed that the annual Pilgrim wind rose from 2001 is representative of data available from other years prior to and including 2001 at that site and is representative of the 18 other sites with weather data in the SAMA geographic area for 2001.

The average annual wind speeds were compared from the same 18 sites (plus Pilgrim 33 ft) used in the wind rose comparisons. The observations are at a variety of heights and the surface roughness varies from site to site. While the wind direction is fairly constant with height and has little dependence on surface roughness, the wind speed increases significantly with height above ground, and varies with the surface roughness (i.e., land use). Most of the wind observation heights (including nearly all airports) are 10 m. For the sites with heights different from 10 m, we used a standard wind profile equation to estimate the effective wind speed that would occur at 10 m. We used the same equation to estimate the effective wind speed at the Pilgrim Station 33 ft (10 m) level if the surface roughness were the same as the other sites instead of the fields and forests surrounding the Pilgrim Station. The effective wind speeds are within the range of the wind speeds at the other sites.

It was also shown that the annual average precipitation observations for 2001 from the Plymouth Municipal Airport (used as input for the SAMA) were representative of other years (1995-2009) at that site and were representative of other weather sites in the SAMA domain.

The EPA's widely-used CALMET diagnostic meteorological model was used to produce spatial varying and time varying (hourly) wind fields over the 50-mile radius geographic domain, using observed 2001 meteorological variables from many surface sites and two upper air (radiosonde balloon) sites in the domain. The CALMET wind fields were used to calculate the paths of hypothetical trajectories of parcels released hourly from the Pilgrim Station at elevations of 100, 200, and 500 m (328, 656, and 1640 ft). The angle at which each trajectory path crossed the circles with radius 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 20, 30, 40, and 50 miles was determined and used to produce "trajectory roses" with frequencies for each 22½° sector (just like the wind roses). The radial distances listed above correspond to distances used in the SAMA analysis. It was found that, on an annual basis, the trajectory roses are very similar to the Pilgrim 33 ft (10 m) wind rose. Thus it is concluded that, for the SAMA analysis, which involves summing the dose and economic effects over a full year and over the entire 50 mile (80.5 km) radius domain, the Pilgrim 33 ft (10 m) meteorological observations for 2001 are representative of annual wind direction observations from other sites in the area, and are also representative (over the entire year 2001) of the paths of trajectories influenced by local variations in winds.

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Scire, J.S., D.G. Strimaitis, and R.J. Yamartino, 2000b: A Users Guide for the CALMET Meteorological Model (Version 5).
http://www.src.com/calpuff/download/CALMET_UsersGuide.pdf

Wendell, L.L., 1972: Mesoscale wind fields and transport estimates determined from a network of towers. *Mon. Wea. Rev*. **100**, 565-578.

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Appendix A Annual Wind Roses at Pilgrim Station

This appendix contains plots of annual wind roses for six years of hourly wind observations at the Pilgrim Station. These wind roses are from the 33 ft level of the Pilgrim Station upper meteorological tower for 1996 through 2001. The 2001 data were used in the SAMA modeling. The wind roses were generated using the hourly observation files.

The percentage of calms is given in a block at the bottom of each plot. The average wind speed is also given in a block at the bottom, and is calculated after excluding hours with calms. Table 6 in the main report contains annual averaged wind speeds for the Pilgrim 33 ft level and from 18 other sites, where the average has been calculated including the calm hours.

The wind rose plots are presented in the following order:

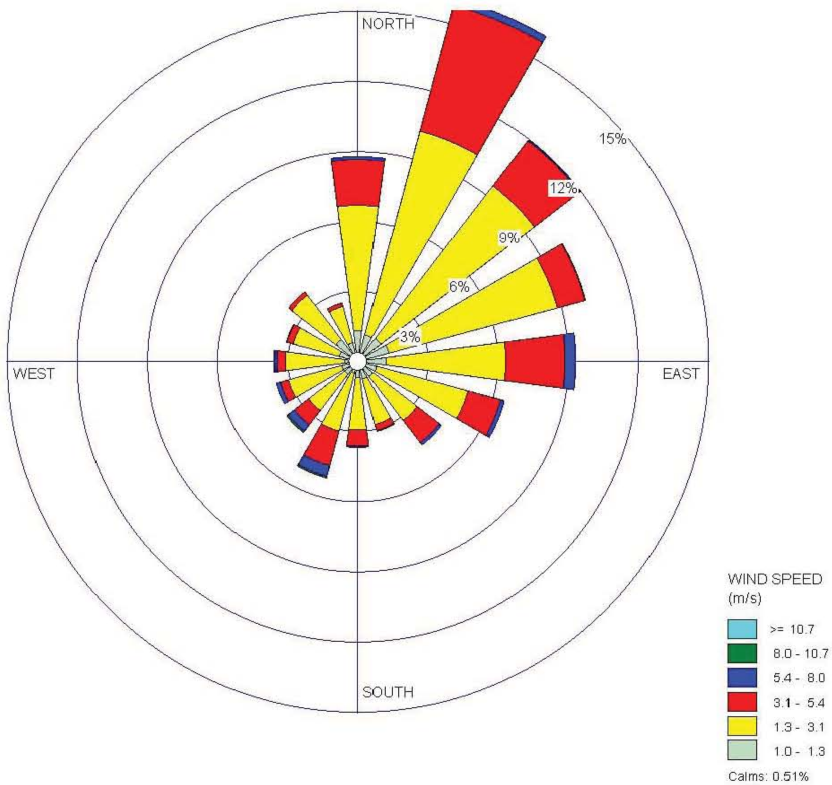
Pilgrim 33 ft – 2001
Pilgrim 33 ft – 1996
Pilgrim 33 ft – 1997
Pilgrim 33 ft – 1998
Pilgrim 33 ft – 1999
Pilgrim 33 ft – 2000

WIND ROSE PLOT:

Pilgrim NPS - winds measured at 33 feet
2001 Annual Wind Rose (flow vectors)

DISPLAY:

Wind Speed
Flow Vector (blowing to)



COMMENTS:

DATA PERIOD:

2001
Jan 1 - Dec 31
00:00 - 23:00

CALM WINDS:

0.51%

TOTAL COUNT:

8759 hrs.

Epsilon ASSOCIATES INC.

AVG. WIND SPEED:

2.74 m/s

PROJECT NO.:

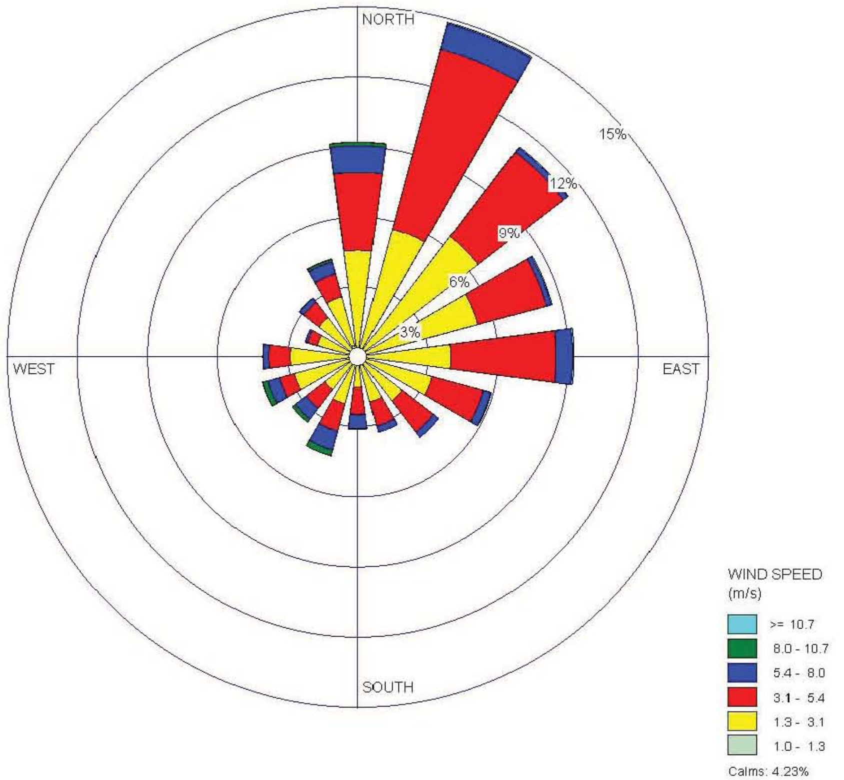
WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:

Pilgrim NPS - winds measured at 33 feet
1996 Annual Wind Rose (flow vectors)

DISPLAY:

Wind Speed
Flow Vector (blowing to)



COMMENTS:	DATA PERIOD:		
	1996 **Jan 1 - Dec 31** **00:00 - 23:00**		
	CALM WINDS: **4.23%**	TOTAL COUNT: **8660 hrs.**	**Epsilon** ASSOCIATES INC.
	AVG. WIND SPEED: **3.89 m/s**		PROJECT NO.:

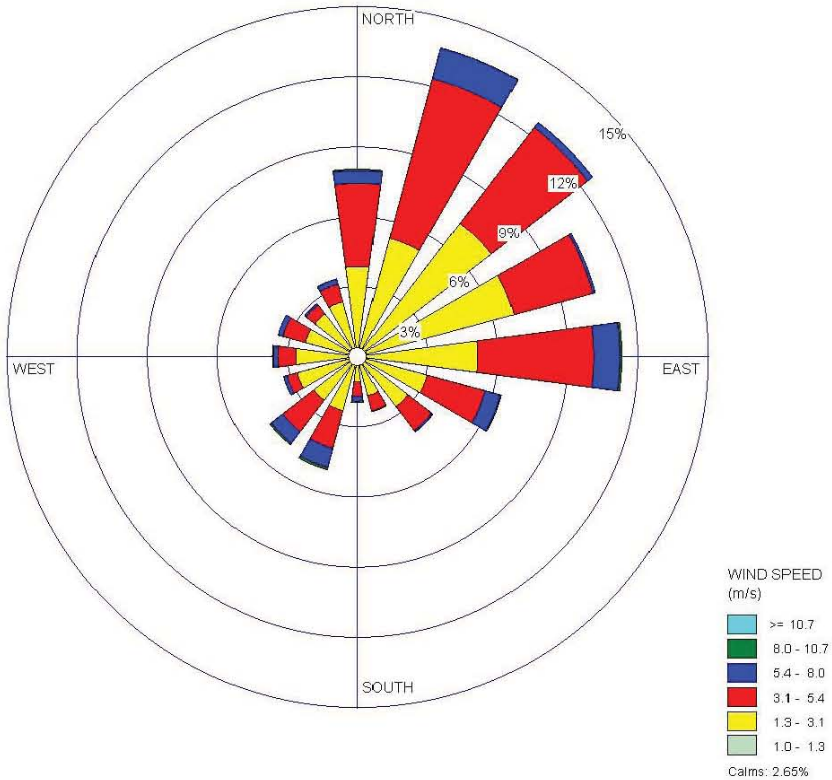
WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:

Pilgrim NPS - winds measured at 33 feet
1997 Annual Wind Rose (flow vectors)

DISPLAY:

Wind Speed
Flow Vector (blowing to)



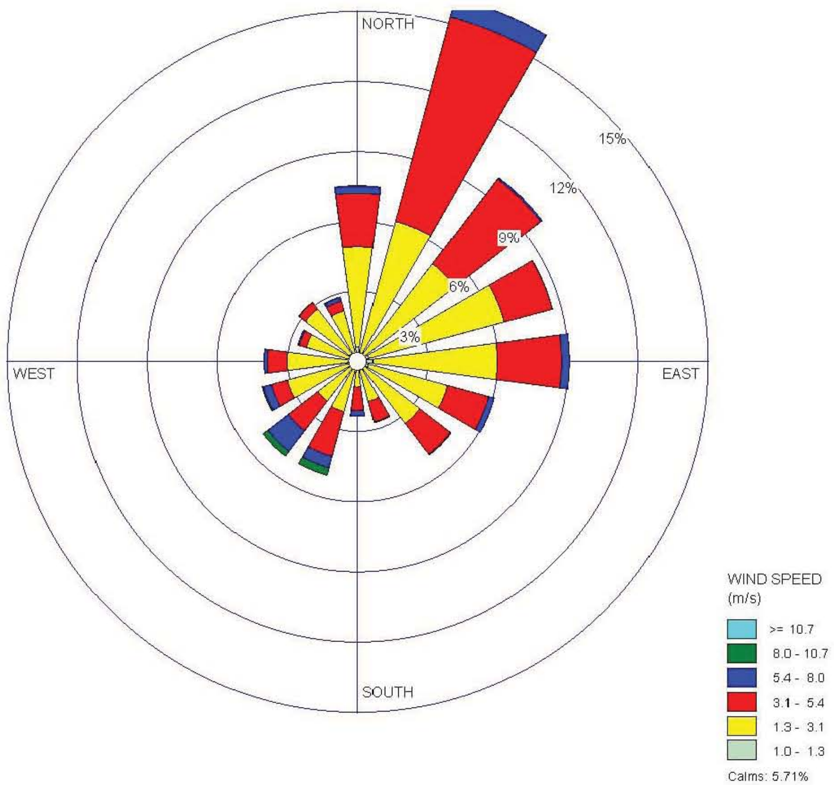
COMMENTS:	DATA PERIOD:		
	1997 **Jan 1 - Dec 31** **00:00 - 23:00**		Epsilon ASSOCIATES INC.
	CALM WINDS: **2.65%**	TOTAL COUNT: **8216 hrs.**	
	AVG. WIND SPEED: **3.28 m/s**		PROJECT NO.:

WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:

Pilgrim NPS - winds measured at 33 feet
1998 Annual Wind Rose (flow vectors)

DISPLAY:
Wind Speed
Flow Vector (blowing to)



COMMENTS:

DATA PERIOD:
1998
Jan 1 - Dec 31
00:00 - 23:00

Epsilon ASSOCIATES INC.

CALM WINDS:
5.71%

TOTAL COUNT:
8498 hrs.

AVG. WIND SPEED:
2.77 m/s

PROJECT NO.:

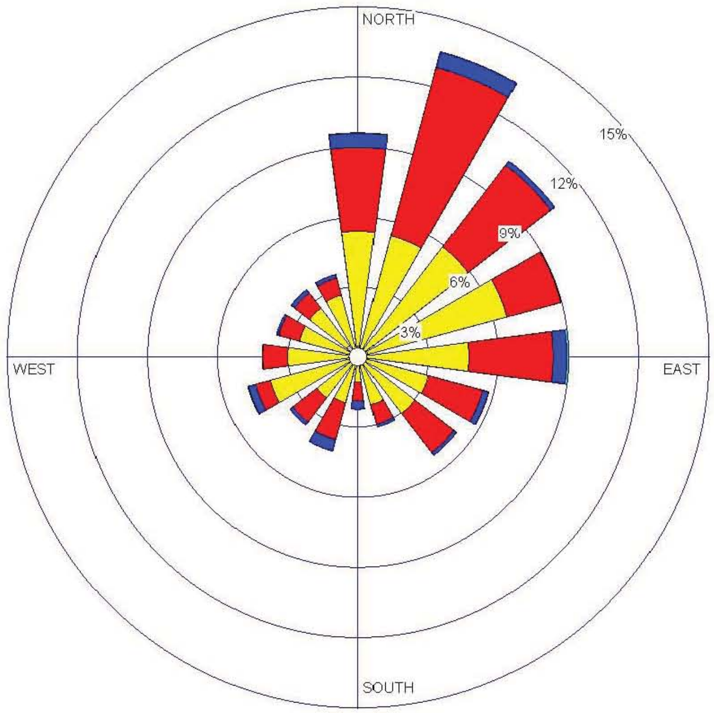
WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:

Pilgrim NPS - winds measured at 33 feet
1999 Annual Wind Rose (flow vectors)

DISPLAY:

Wind Speed
Flow Vector (blowing to)



WIND SPEED
(m/s)

- >= 10.7
- 8.0 - 10.7
- 5.4 - 8.0
- 3.1 - 5.4
- 1.3 - 3.1
- 1.0 - 1.3

Calms: 4.29%

COMMENTS:

DATA PERIOD:

1999
Jan 1 - Dec 31
00:00 - 23:00

CALM WINDS:

4.29%

TOTAL COUNT:

8384 hrs.

AVG. WIND SPEED:

3.26 m/s

Epsilon
ASSOCIATES INC.

PROJECT NO.:

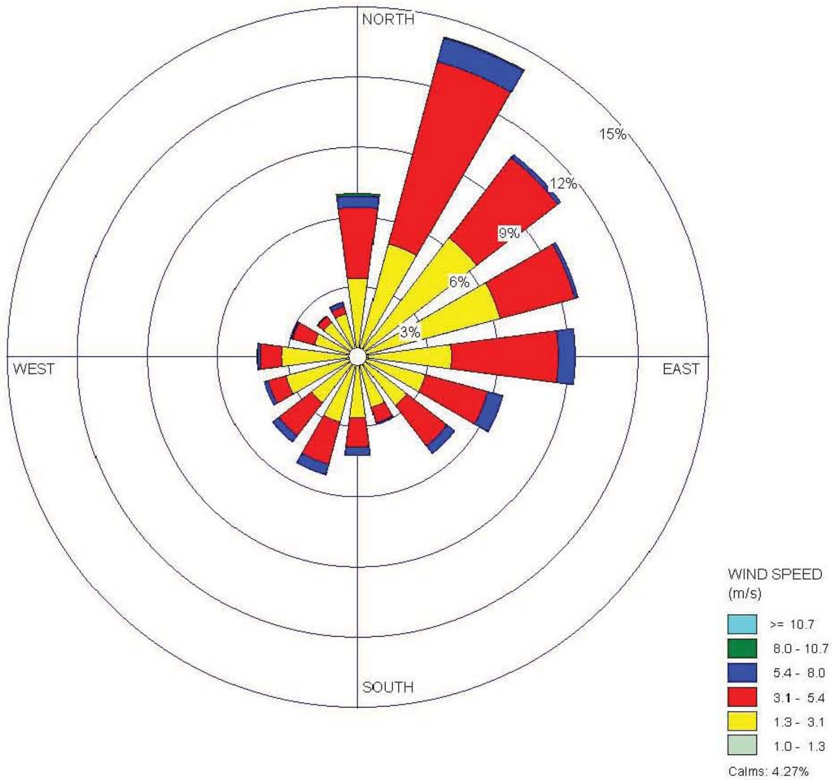
WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:

Pilgrim NPS - winds measured at 33 feet
2000 Annual Wind Rose (flow vectors)

DISPLAY:

Wind Speed
Flow Vector (blowing to)



COMMENTS:	DATA PERIOD: **2000** **Jan 1 - Dec 31** **00:00 - 23:00**		
	CALM WINDS: **4.27%**	TOTAL COUNT: **8389 hrs.**	Epsilon ASSOCIATES INC.
	AVG. WIND SPEED: **2.92 m/s**		PROJECT NO.:

WRPLOT View - Lakes Environmental Software

Appendix B Annual Wind Roses

This appendix contains plots of all of the annual wind roses that were compared in the study of spatial variations across the SAMA domain for 2001. These wind roses include those from the 33 ft and 220 ft levels of the Pilgrim Station upper meteorological tower, and those from 18 other weather observing sites in the domain.

Table B-1 lists all of the meteorological sites (in addition to the Pilgrim site) which were used in the wind rose analysis, and also those which were used in the CALMET trajectory study. This table is the same as Table 1 in the main report.

Figure B-1 is a map of the area showing the locations of the wind rose sites. This is the same as Figure 9 in the main report.

The percentage of calms is given in a block at the bottom of each plot. The average wind speed is also given in a block at the bottom, and is calculated after excluding hours with calms. Table 6 in the main report contains annual averaged wind speeds for the Pilgrim 33 ft level and for the 18 other sites, where the average has been calculated including the calm hours.

Subsequent pages in this Appendix contain the individual annual wind roses for 2001 in the following order, where dates are given only for the three MA Energy sites where 2001 data were not available:

Pilgrim 33 ft
Pilgrim 220 ft
Bedford Hanscom Field
Otis
Plymouth
New Bedford
Martha's Vineyard
Barnstable
Taunton
Chatham
Boston Logan
Norwood
East Milton Blue Hill
Providence TF Green
Newport
Boston Approach Buoy
Kingston (12 July 2005 – 11 July 2006)
Quincy (1 Sept 2006 – 16 Aug 2007)
Scituate (1 Aug 2006 – 31 July 2007)
Duxbury

Table B-1. Meteorological surface station site summary (besides Pilgrim).
This table is the same as Table 1 in the main report.

Station ID	Station Name	State	Direct. from Pilgrim	Dist. from Pilgrim (mi)	Data Obtained From	Wind Rose Analysis	CALMET Modeling
725059	LAURENCE G HANSCOM	MA	NW	49.9	NCDC	Yes	Yes
725060	OTIS ANGB	MA	S	20.7	NCDC	Yes	Yes
725063 (14756)	NANTUCKET MEM	MA	SSE	55.2	NCDC	No[1]	Yes
725064	PLYMOUTH MUNICIPAL	MA	WSW	8.0	NCDC	Yes	Yes
725065	NEW BEDFORD RGNL	MA	SW	27.0	NCDC	Yes	Yes
725066	MARTHAS VINEYARD	MA	S	37.8	NCDC	Yes	Yes
725067	BARNSTABLE MUNI BOA	MA	SE	25.0	NCDC	Yes	Yes
725068	TAUNTON MUNI ARPT	MA	WSW	23.0	NCDC	Yes	Yes
725069	CHATHAM MUNI ARPT	MA	ESE	35.2	NCDC	Yes	Yes
725073	PROVINCETOWN (AWOS)	MA	ENE	20.6	NCDC	No[3]	Yes
725090 (14739)	BOSTON/LOGAN INTL	MA	NNW	36.6	NCDC	Yes	Yes
725094	MARSHFIELD AIRPORT	MA	NNW	11.8	N/A	No	No
725098	NORWOOD MEMORIAL	MA	NW	34.9	NCDC	Yes	Yes
744907 (14753)	EAST MILTON (BLUE HILL OB.)	MA	NW	33.1	NCDC	Yes	Yes
994140	BUZZARDS BAY	MA	S	11.8	N/A	No	No
744904	LAWRENCE MUNI	MA	NNW	59.8	NCDC	No[1]	Yes
725088	BEVERLY MUNI	MA	N	47.1	NCDC	No[2]	Yes
722256	GEORGE HARLOW FLD	MA	NNW	11.8	N/A	No	No
725070 (14765)	PROVIDENCE/GREEN STATE AIRPORT	RI	WSW	46.6	NCDC	Yes	Yes
997278	PROVIDENCE	RI	W	43.3	N/A	No[2]	No
725074	QUONSET STATE	RI	SW	49.7	NCDC	No[3]	Yes
725079	NEWPORT	RI	SW	46.1	NCDC	Yes	Yes
998004	NARRAGANSETT BAY RES	RI	SW	55.0	N/A	No	No
725054	PAWTUCKET (AWOS)	RI	W	47.3	NCDC	No[2]	Yes
999999 (54796)	CRN KINGSTON	RI	SW	58.6	NCDC	No[2]	Yes
725058	BLOCK ISLAND	RI	SW	74.1	NCDC	No[1]	Yes
743946	NASHUA/BOIRE FIELD	NH	NW	74.9	NCDC	No[1]	Yes
743945	MANCHESTER	NH	NW	79.9	NCDC	No[1]	Yes
44013	16 NM E of Boston	MA	N	28.7	NBDC	Yes	Yes
44007	12 NM SE of Portland	ME	N	111.6	NBDC	No[1]	Yes
44005	78 NM E of Portsmouth	NH	N	106.2	NBDC	No[1]	Yes
	KINGSTON	MA	WNW	8.5	RERL	Yes	No
	QUINCY - QUARRY HILL	MA	NW	30.2	RERL	Yes	No
	SCITUATE	MA	NNW	19.1	RERL	Yes	No
	DUXBURY	MA	NNW	8.5	Weather-flow	Yes	No

N/A – data not available for year. [1] site outside of 50 mi circle. [2]site nearby another site. [3]site with less than 50 % of hours available in 2001.

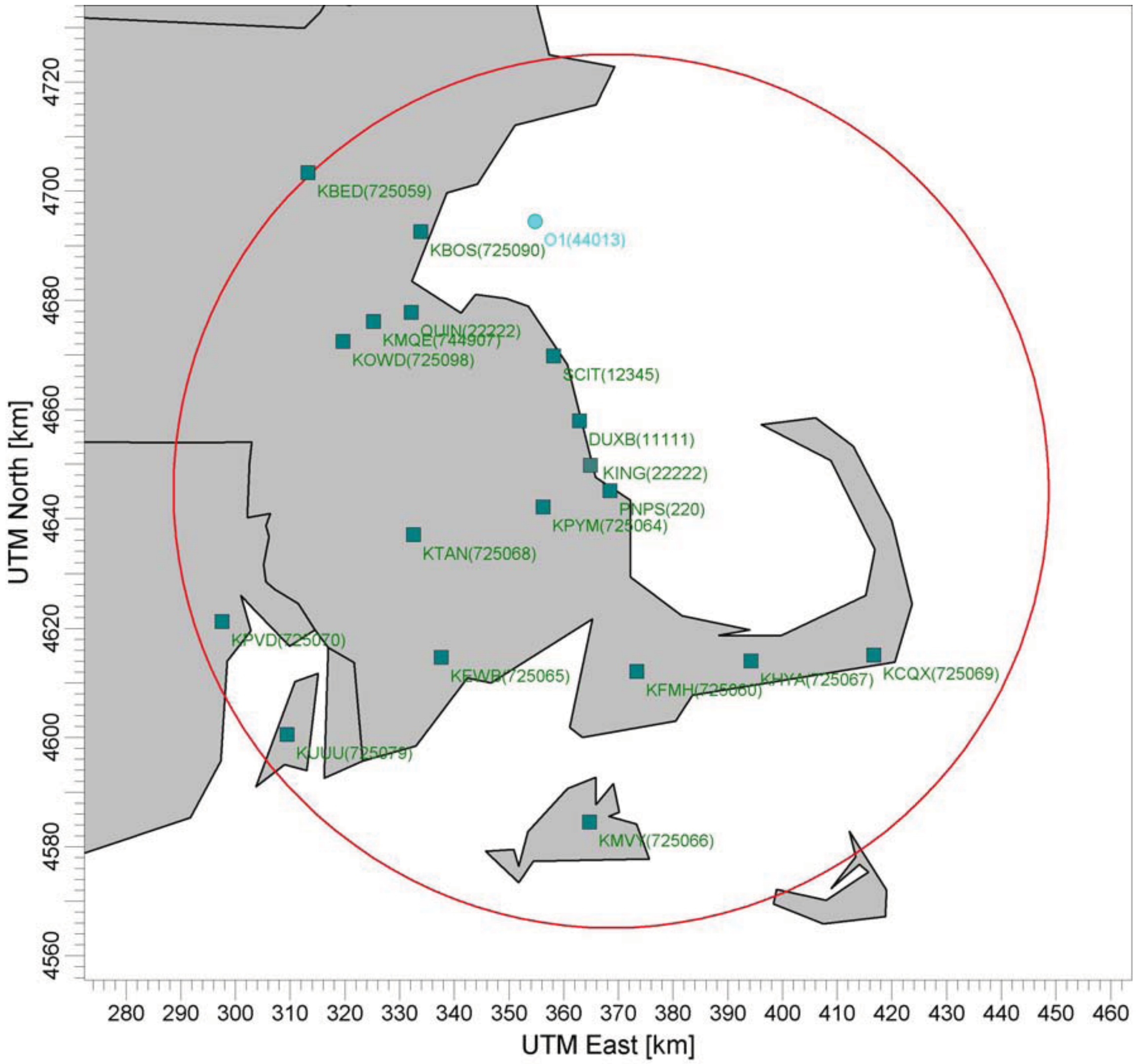
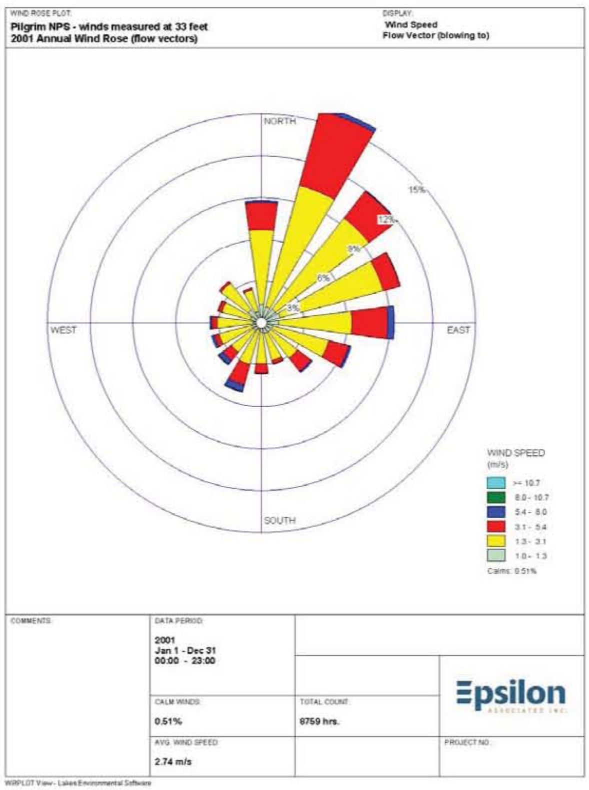
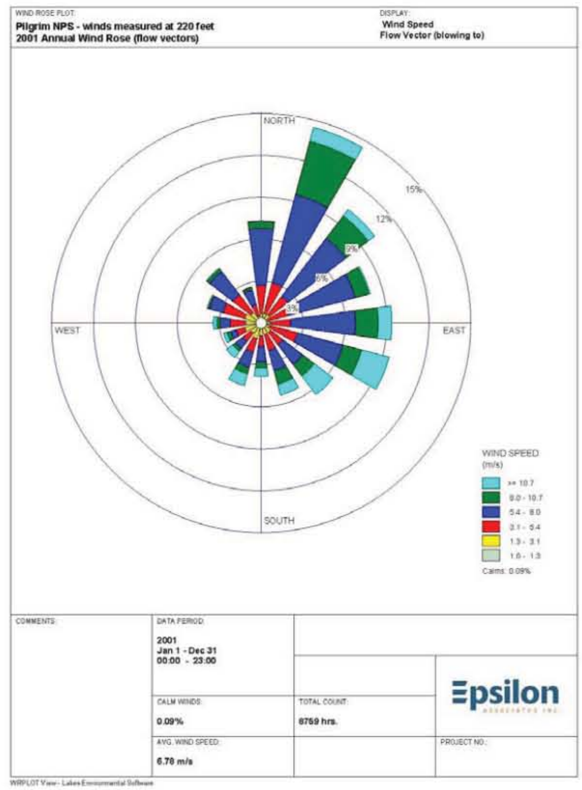
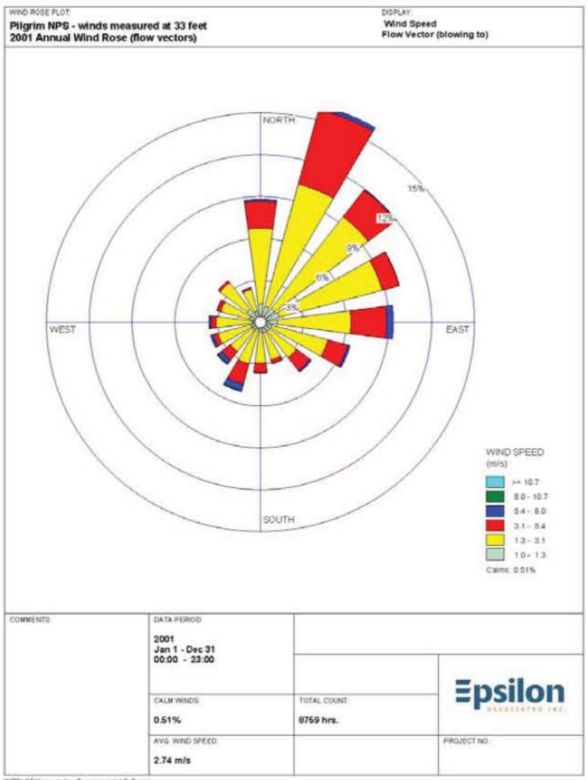


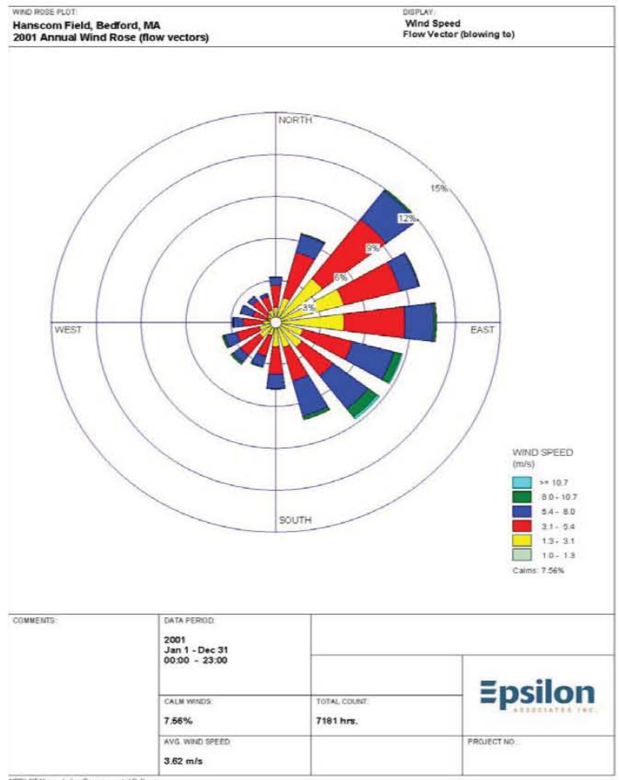
Figure B-1. Weather stations used in the wind rose comparisons. See Table B-1 for a listing of site names and other details. This figure is the same as Figure 9 in the main report.


WIND ROSE PLOT:
Pilgrim NPS - winds measured at 33 feet
2001 Annual Wind Rose (flow vectors)
DISPLAY:
Wind Speed
Flow Vector (blowing to)
NORTH
WEST
EAST
SOUTH
3%
6%
9%
12%
15%
WIND SPEED
(m/s)
>= 10.7
8.0 - 10.7
5.4 - 8.0
3.1 - 5.4
1.3 - 3.1
1.0 - 1.3
Calms: 0.51%
COMMENTS:
DATA PERIOD:
2001
Jan 1 - Dec 31
00:00 - 23:00
CALM WINDS:
0.51%
TOTAL COUNT:
8759 hrs.
AVG. WIND SPEED:
2.74 m/s
PROJECT NO.:
WRPLOT View - Lakes Environmental Software

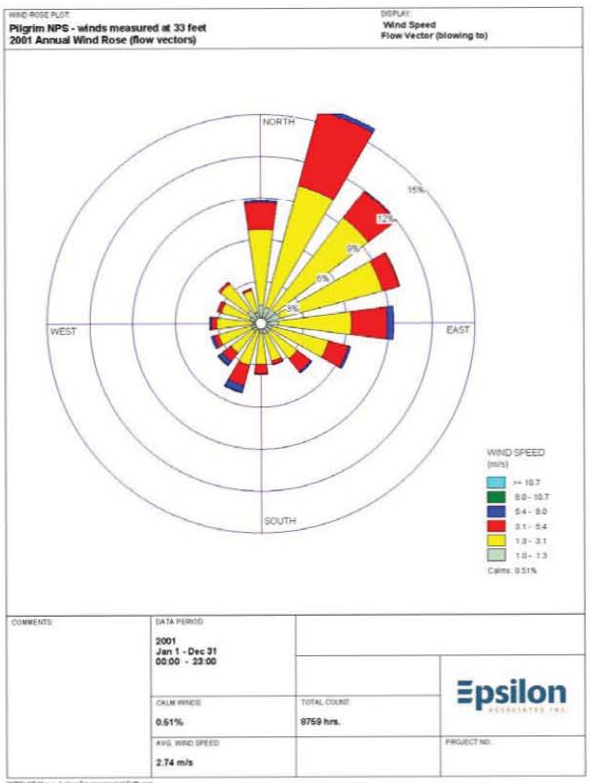

WIND ROSE PLOT:
Pilgrim NPS - winds measured at 220 feet
2001 Annual Wind Rose (flow vectors)
DISPLAY:
Wind Speed
Flow Vector (blowing to)
NORTH
WEST
EAST
SOUTH
3%
6%
9%
12%
15%
WIND SPEED
(m/s)
>= 10.7
8.0 - 10.7
5.4 - 8.0
3.1 - 5.4
1.3 - 3.1
1.0 - 1.3
Calms: 0.09%
COMMENTS:
DATA PERIOD:
2001
Jan 1 - Dec 31
00:00 - 23:00
CALM WINDS:
0.09%
TOTAL COUNT:
8759 hrs.
AVG. WIND SPEED:
6.78 m/s
PROJECT NO.:
WRPLOT View - Lakes Environmental Software

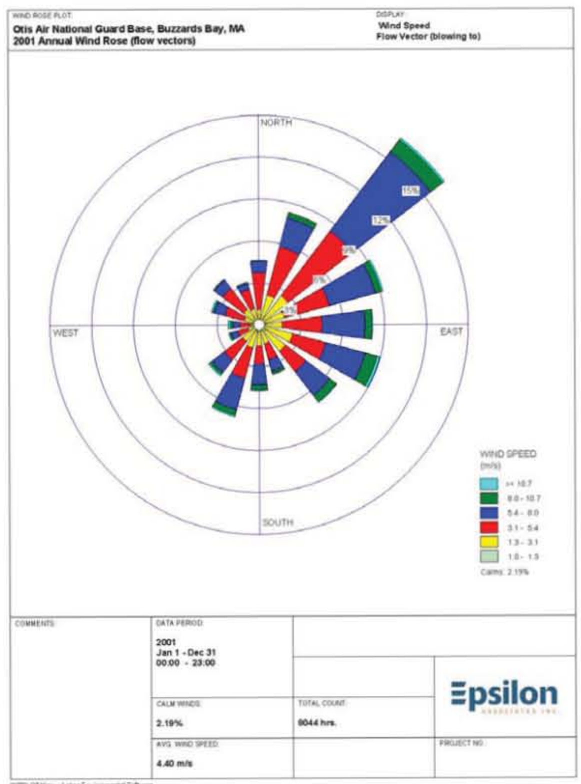


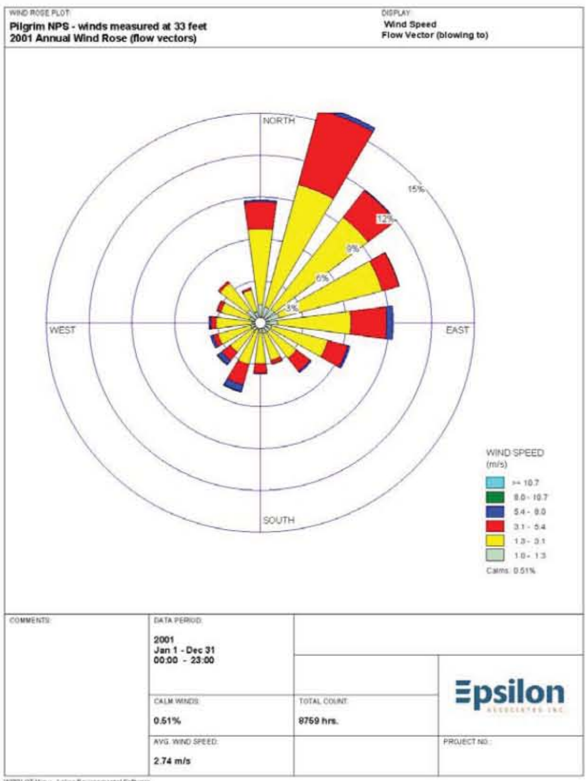
WRPLOT View - Lakes Environmental Software

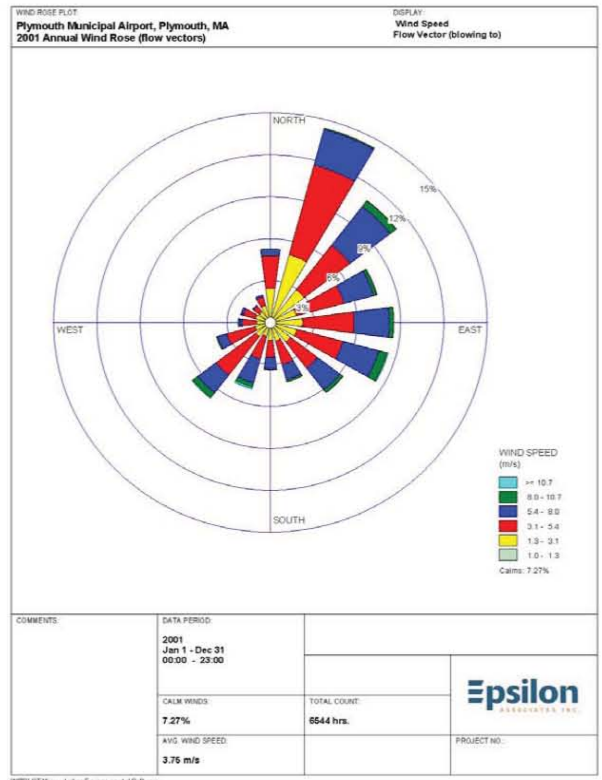


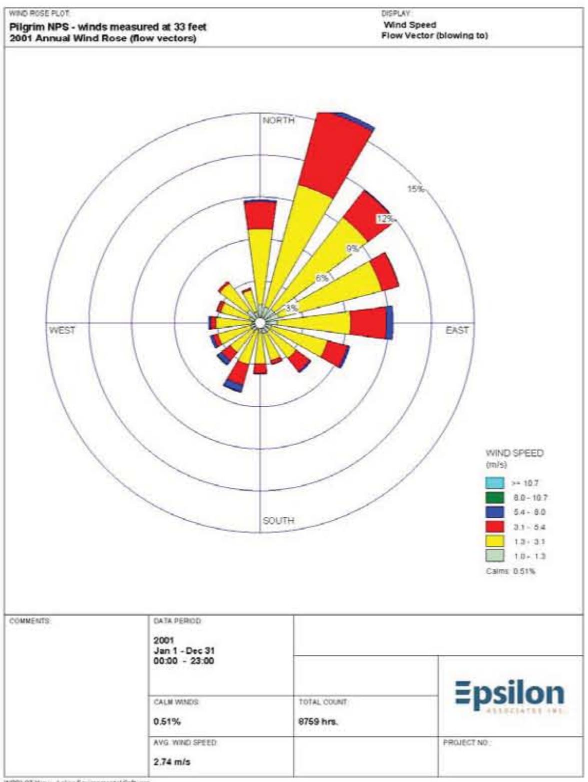
WRPLOT View - Lakes Environmental Software

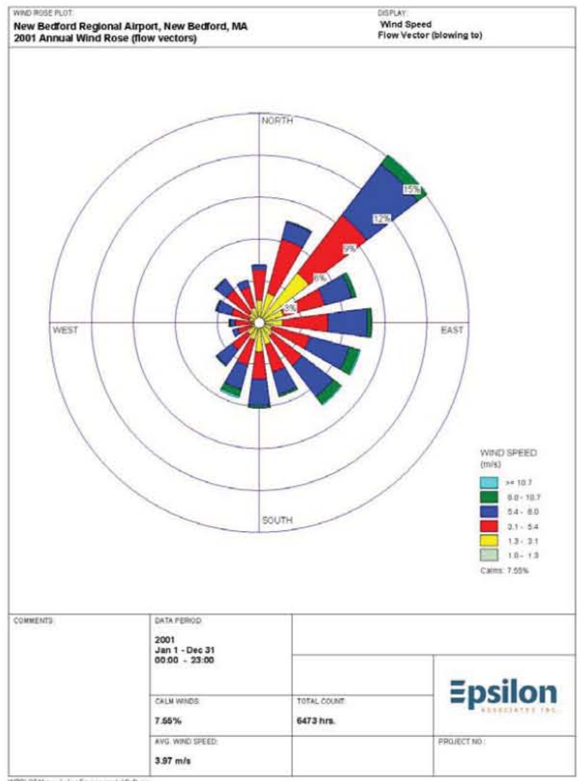

WIND ROSE PLOT:
Pilgrim NPS - winds measured at 33 feet
2001 Annual Wind Rose (flow vectors)
DISPLAY:
Wind Speed
Flow Vector (blowing to)
NORTH
WEST
EAST
SOUTH
15%
12%
9%
6%
3%
WIND SPEED
(m/s)
>= 10.7
8.0 - 10.7
5.4 - 8.0
3.1 - 5.4
1.3 - 3.1
1.0 - 1.3
Calms: 0.51%
COMMENTS:
DATA PERIOD:
2001
Jan 1 - Dec 31
00:00 - 23:00
CALM WINDS:
0.51%
TOTAL COUNT:
8759 hrs.
AVG. WIND SPEED:
2.74 m/s
PROJECT NO.:
WRPLOT View - Lakes Environmental Software

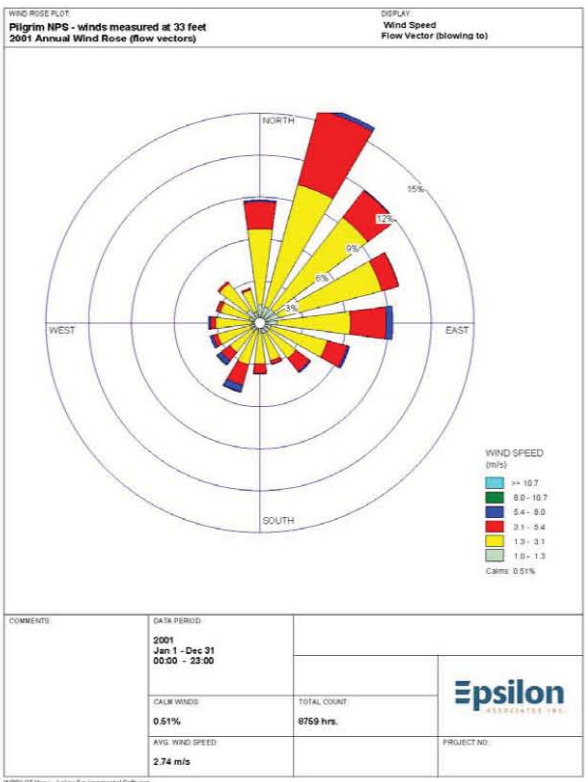

WIND ROSE PLOT:
Otis Air National Guard Base, Buzzards Bay, MA
2001 Annual Wind Rose (flow vectors)
DISPLAY:
Wind Speed
Flow Vector (blowing to)
NORTH
WEST
EAST
SOUTH
15%
12%
9%
6%
3%
WIND SPEED
(m/s)
>= 10.7
8.0 - 10.7
5.4 - 8.0
3.1 - 5.4
1.3 - 3.1
Calms: 2.19%
COMMENTS:
DATA PERIOD:
2001
Jan 1 - Dec 31
00:00 - 23:00
CALM WINDS:
2.19%
TOTAL COUNT:
8044 hrs.
AVG. WIND SPEED:
4.40 m/s
PROJECT NO.:
WRPLOT View - Lakes Environmental Software

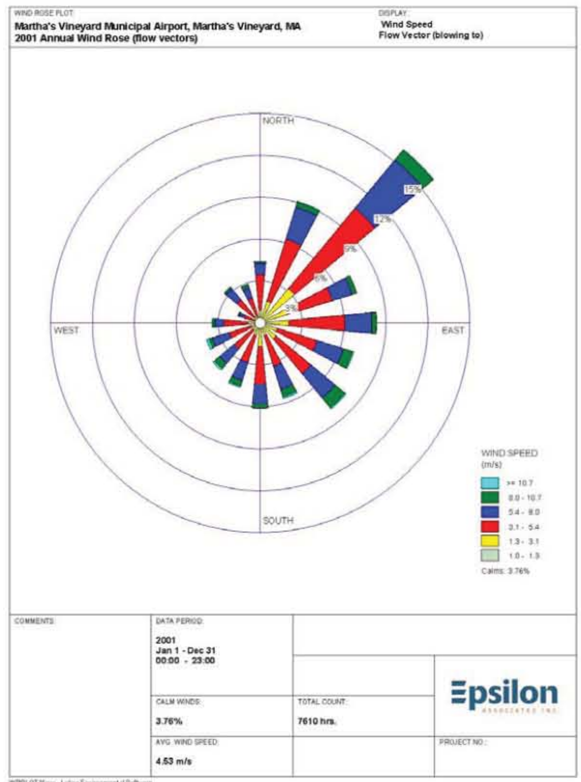

WIND ROSE PLOT:
Pilgrim NPS - winds measured at 33 feet
2001 Annual Wind Rose (flow vectors)
DISPLAY:
Wind Speed
Flow Vector (blowing to)
NORTH
WEST
EAST
SOUTH
3%
6%
9%
12%
15%
WIND SPEED
(m/s)
>= 10.7
8.0 - 10.7
5.4 - 8.0
3.1 - 5.4
1.3 - 3.1
1.0 - 1.3
Calms: 0.51%
COMMENTS:
DATA PERIOD:
2001
Jan 1 - Dec 31
00:00 - 23:00
CALM WINDS:
0.51%
TOTAL COUNT:
8759 hrs.
AVG. WIND SPEED:
2.74 m/s
PROJECT NO.:
WRPLOT View - Lakes Environmental Software

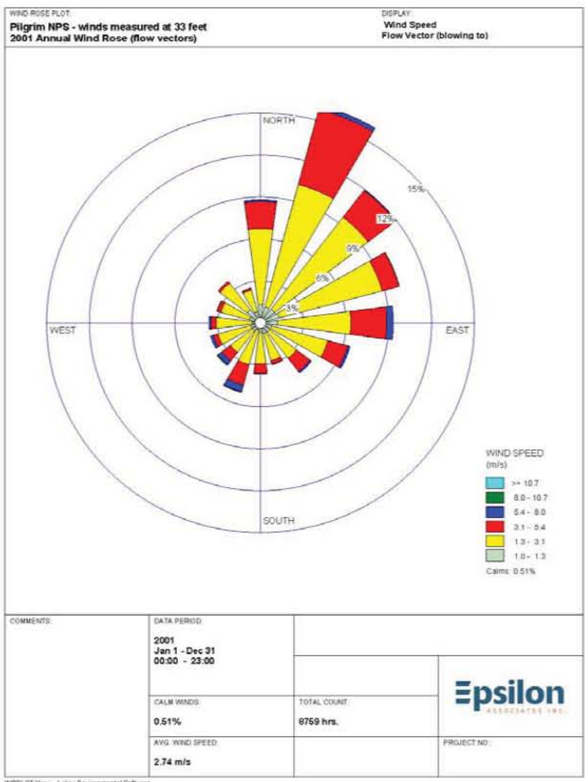

WIND ROSE PLOT:
Plymouth Municipal Airport, Plymouth, MA
2001 Annual Wind Rose (flow vectors)
DISPLAY:
Wind Speed
Flow Vector (blowing to)
NORTH
WEST
EAST
SOUTH
3%
6%
9%
12%
15%
WIND SPEED
(m/s)
>= 10.7
8.0 - 10.7
5.4 - 8.0
3.1 - 5.4
1.3 - 3.1
1.0 - 1.3
Calms: 7.27%
COMMENTS:
DATA PERIOD:
2001
Jan 1 - Dec 31
00:00 - 23:00
CALM WINDS:
7.27%
TOTAL COUNT:
6544 hrs.
AVG. WIND SPEED:
3.76 m/s
PROJECT NO.:
WRPLOT View - Lakes Environmental Software

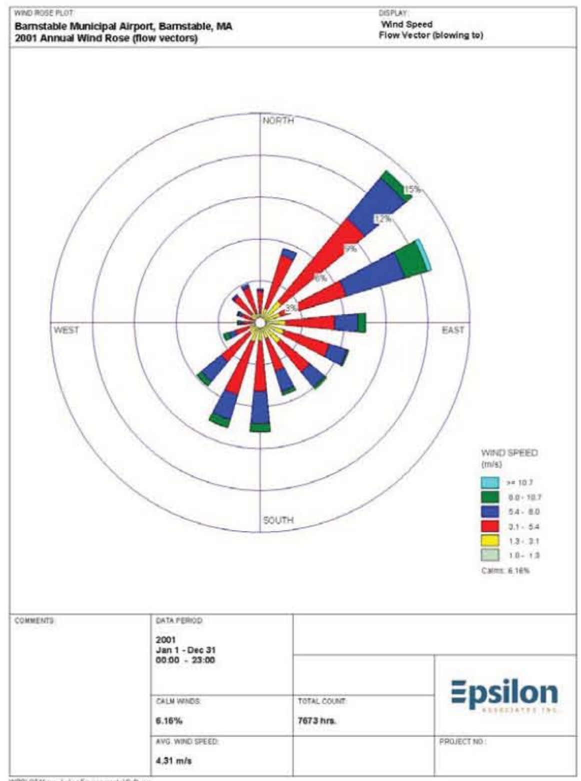

WIND ROSE PLOT:
Pilgrim NPS - winds measured at 33 feet
2001 Annual Wind Rose (flow vectors)
DISPLAY:
Wind Speed
Flow Vector (blowing to)
NORTH
WEST
EAST
SOUTH
3%
6%
9%
12%
15%
WIND SPEED
(m/s)
>= 10.7
8.0 - 10.7
5.4 - 8.0
3.1 - 5.4
1.3 - 3.1
1.0 - 1.3
Calms: 0.51%
COMMENTS:
DATA PERIOD:
2001
Jan 1 - Dec 31
00:00 - 23:00
CALM WINDS:
0.51%
TOTAL COUNT:
8759 hrs.
AVG. WIND SPEED:
2.74 m/s
PROJECT NO.:
WRPLOT View - Lakes Environmental Software

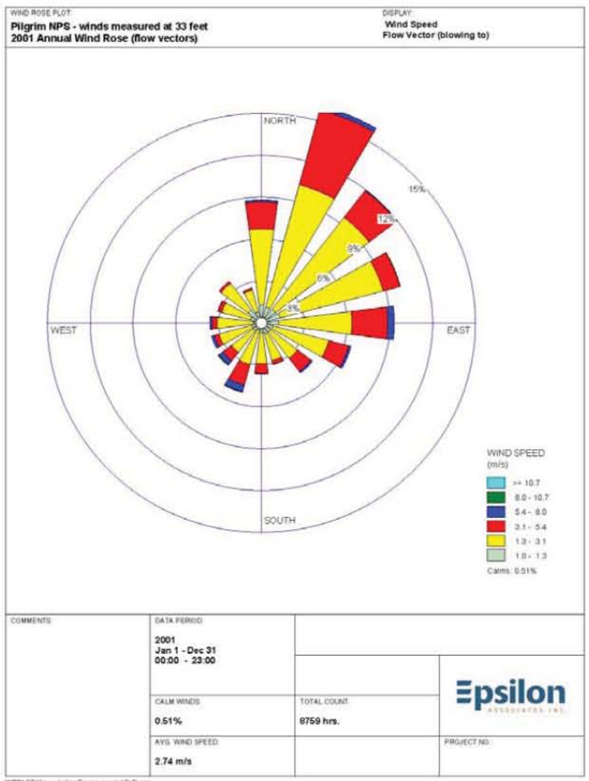

WIND ROSE PLOT:
New Bedford Regional Airport, New Bedford, MA
2001 Annual Wind Rose (flow vectors)
DISPLAY:
Wind Speed
Flow Vector (blowing to)
NORTH
WEST
EAST
SOUTH
3%
6%
9%
12%
15%
WIND SPEED
(m/s)
>= 10.7
8.0 - 10.7
5.4 - 8.0
3.1 - 5.4
1.3 - 3.1
1.0 - 1.3
Calms: 7.55%
COMMENTS:
DATA PERIOD:
2001
Jan 1 - Dec 31
00:00 - 23:00
CALM WINDS:
7.55%
TOTAL COUNT:
6473 hrs.
AVG. WIND SPEED:
3.97 m/s
PROJECT NO.:
WRPLOT View - Lakes Environmental Software


WIND ROSE PLOT:
Pilgrim NPS - winds measured at 33 feet
2001 Annual Wind Rose (flow vectors)
DISPLAY:
Wind Speed
Flow Vector (blowing to)
NORTH
WEST
EAST
SOUTH
15%
12%
9%
6%
3%
WIND SPEED
(m/s)
>= 10.7
8.0 - 10.7
5.4 - 8.0
3.1 - 5.4
1.3 - 3.1
1.0 - 1.3
Calms: 0.51%
COMMENTS:
DATA PERIOD:
2001
Jan 1 - Dec 31
00:00 - 23:00
CALM WINDS:
0.51%
TOTAL COUNT:
8759 hrs.
AVG. WIND SPEED:
2.74 m/s
Epsilon
PROJECT NO.:
WRPLOT View - Lakes Environmental Software

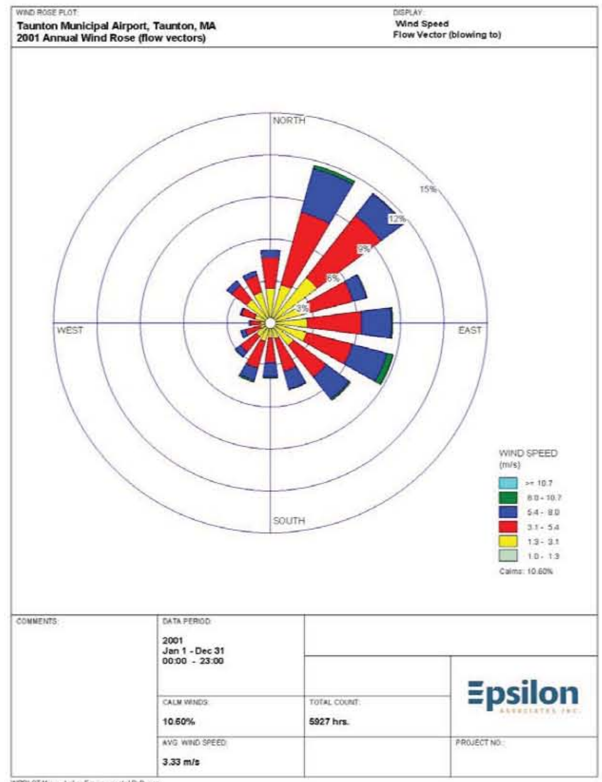

WIND ROSE PLOT:
Martha's Vineyard Municipal Airport, Martha's Vineyard, MA
2001 Annual Wind Rose (flow vectors)
DISPLAY:
Wind Speed
Flow Vector (blowing to)
NORTH
WEST
EAST
SOUTH
15%
12%
9%
6%
3%
WIND SPEED
(m/s)
>= 10.7
8.0 - 10.7
5.4 - 8.0
3.1 - 5.4
1.3 - 3.1
1.0 - 1.3
Calms: 3.76%
COMMENTS:
DATA PERIOD:
2001
Jan 1 - Dec 31
00:00 - 23:00
CALM WINDS:
3.76%
TOTAL COUNT:
7610 hrs.
AVG. WIND SPEED:
4.53 m/s
Epsilon
PROJECT NO.:
WRPLOT View - Lakes Environmental Software


WIND ROSE PLOT:
Pilgrim NPS - winds measured at 33 feet
2001 Annual Wind Rose (flow vectors)
DISPLAY:
Wind Speed
Flow Vector (blowing to)
NORTH
WEST
EAST
SOUTH
3%
6%
9%
12%
15%
WIND SPEED
(m/s)
>= 10.7
8.0 - 10.7
5.4 - 8.0
3.1 - 5.4
1.3 - 3.1
1.0 - 1.3
Calms: 0.51%
COMMENTS:
DATA PERIOD:
2001
Jan 1 - Dec 31
00:00 - 23:00
CALM WINDS:
0.51%
TOTAL COUNT:
8759 hrs.
AVG. WIND SPEED:
2.74 m/s
PROJECT NO.:
WRPLOT View - Lakes Environmental Software

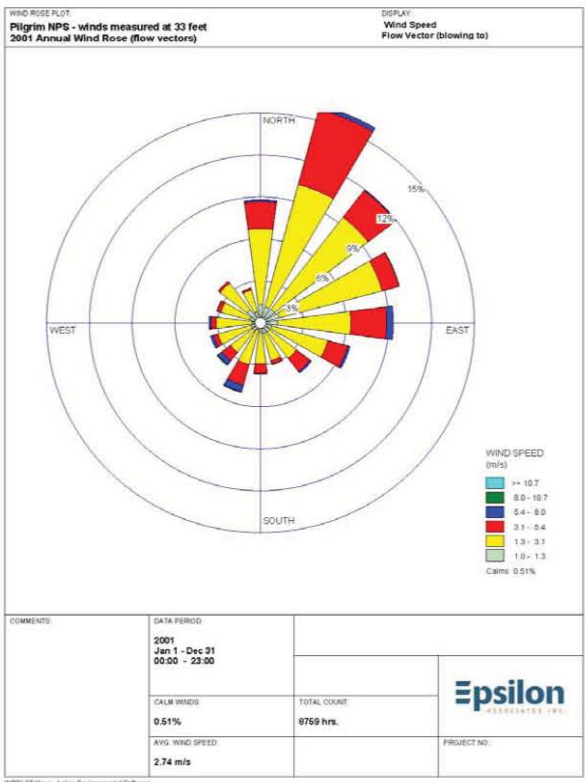

WIND ROSE PLOT:
Barnstable Municipal Airport, Barnstable, MA
2001 Annual Wind Rose (flow vectors)
DISPLAY:
Wind Speed
Flow Vector (blowing to)
NORTH
WEST
EAST
SOUTH
3%
6%
9%
12%
15%
WIND SPEED
(m/s)
>= 10.7
8.0 - 10.7
5.4 - 8.0
3.1 - 5.4
1.3 - 3.1
1.0 - 1.3
Calms: 6.16%
COMMENTS:
DATA PERIOD:
2001
Jan 1 - Dec 31
00:00 - 23:00
CALM WINDS:
6.16%
TOTAL COUNT:
7673 hrs.
AVG. WIND SPEED:
4.31 m/s
PROJECT NO.:
WRPLOT View - Lakes Environmental Software

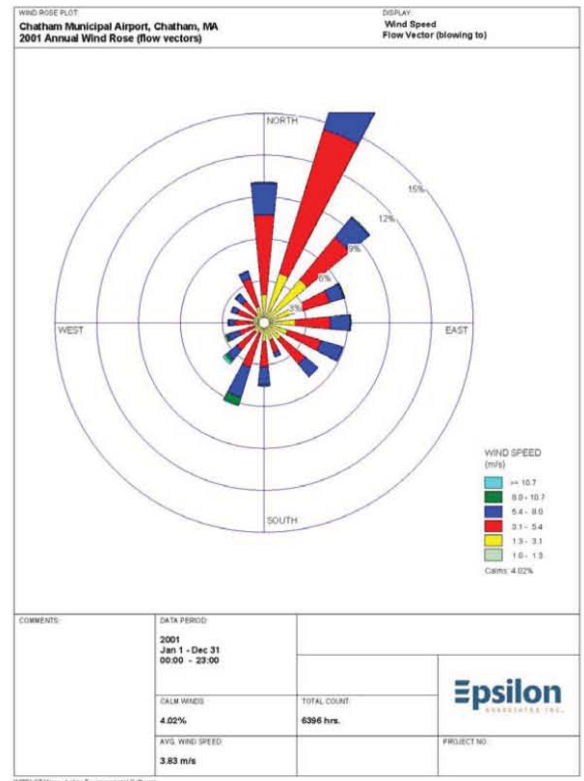


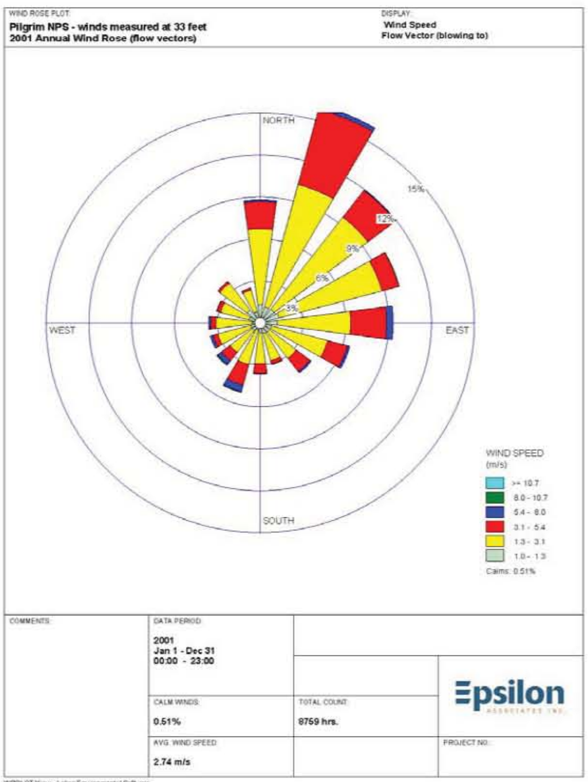
WIND ROSE PLOT:
Pilgrim NPS - winds measured at 33 feet
2001 Annual Wind Rose (flow vectors)
DISPLAY:
Wind Speed
Flow Vector (blowing to)
NORTH
WEST
EAST
SOUTH
15%
12%
9%
6%
3%
WIND SPEED
(m/s)
>= 10.7
8.0 - 10.7
5.4 - 8.0
3.1 - 5.4
1.3 - 3.1
1.0 - 1.3
Calms: 0.51%
COMMENTS:
DATA PERIOD:
2001
Jan 1 - Dec 31
00:00 - 23:00
CALM WINDS:
0.51%
TOTAL COUNT:
8759 hrs.
AVG. WIND SPEED:
2.74 m/s
PROJECT NO.:
Epsilon
ASSOCIATES INC.
WRPLOT View - Lakes Environmental Software

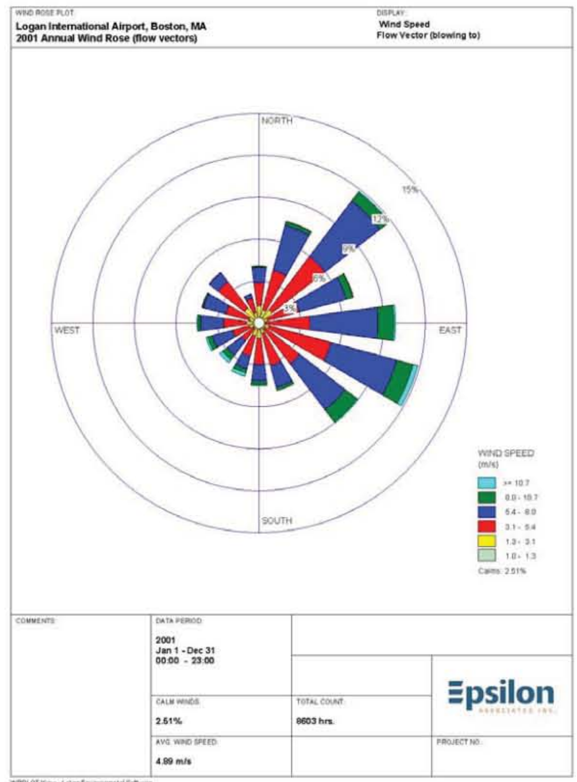


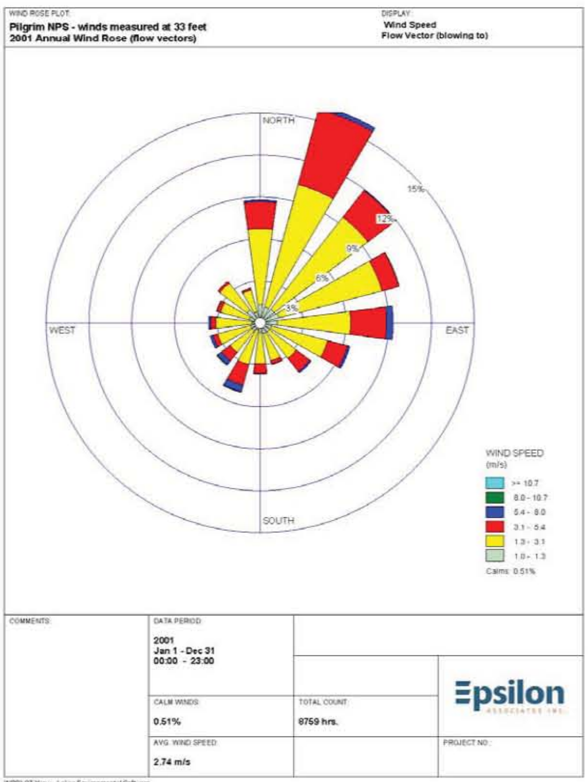
WIND ROSE PLOT:
Taunton Municipal Airport, Taunton, MA
2001 Annual Wind Rose (flow vectors)
DISPLAY:
Wind Speed
Flow Vector (blowing to)
NORTH
WEST
EAST
SOUTH
15%
12%
9%
6%
3%
WIND SPEED
(m/s)
>= 10.7
8.0 - 10.7
5.4 - 8.0
3.1 - 5.4
1.3 - 3.1
1.0 - 1.3
Calms: 10.60%
COMMENTS:
DATA PERIOD:
2001
Jan 1 - Dec 31
00:00 - 23:00
CALM WINDS:
10.60%
TOTAL COUNT:
5927 hrs.
AVG. WIND SPEED:
3.33 m/s
PROJECT NO.:
Epsilon
ASSOCIATES INC.
WRPLOT View - Lakes Environmental Software

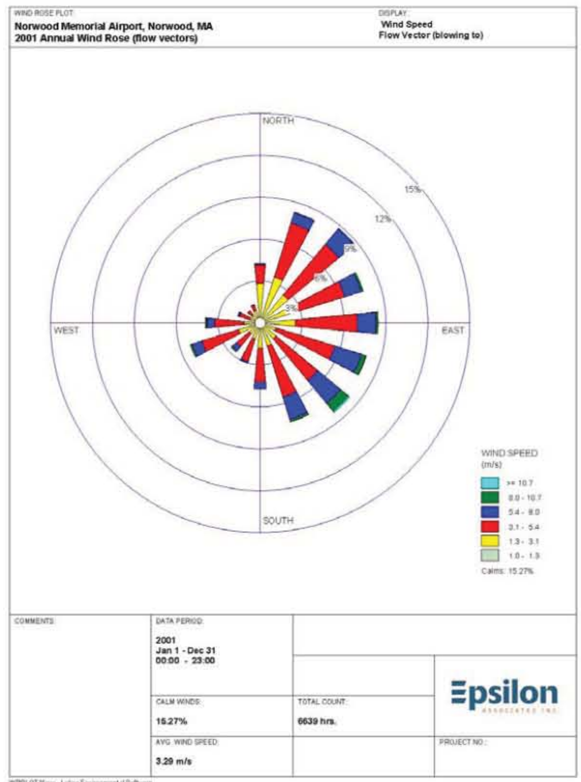

WIND ROSE PLOT:
Pilgrim NPS - winds measured at 33 feet
2001 Annual Wind Rose (flow vectors)
DISPLAY:
Wind Speed
Flow Vector (blowing to)
NORTH
WEST
EAST
SOUTH
3%
6%
9%
12%
15%
WIND SPEED
(m/s)
>= 10.7
8.0 - 10.7
5.4 - 8.0
3.1 - 5.4
1.3 - 3.1
1.0 - 1.3
Calms: 0.51%
COMMENTS:
DATA PERIOD:
2001
Jan 1 - Dec 31
00:00 - 23:00
CALM WINDS:
0.51%
TOTAL COUNT:
8759 hrs.
AVG. WIND SPEED:
2.74 m/s
PROJECT NO.:
WRPLOT View - Lakes Environmental Software

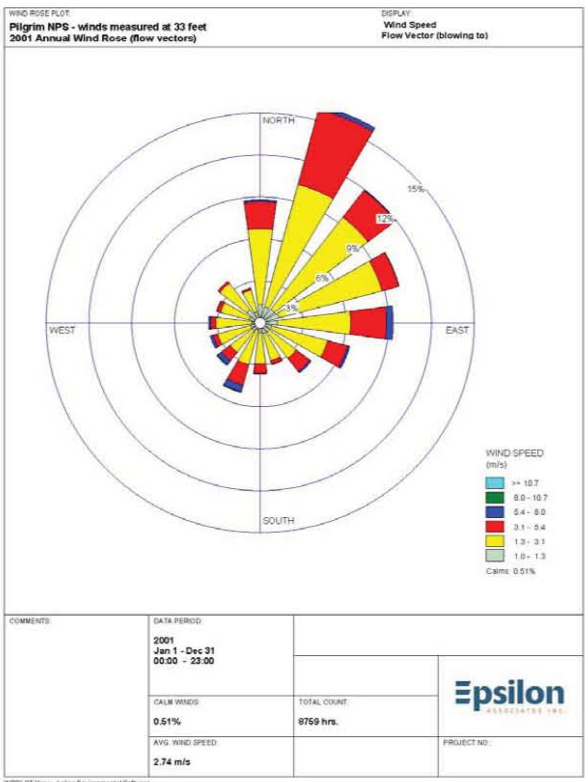

WIND ROSE PLOT:
Chatham Municipal Airport, Chatham, MA
2001 Annual Wind Rose (flow vectors)
DISPLAY:
Wind Speed
Flow Vector (blowing to)
NORTH
WEST
EAST
SOUTH
3%
6%
9%
12%
15%
WIND SPEED
(m/s)
>= 10.7
8.0 - 10.7
5.4 - 8.0
3.1 - 5.4
1.3 - 3.1
1.0 - 1.3
Calms: 4.02%
COMMENTS:
DATA PERIOD:
2001
Jan 1 - Dec 31
00:00 - 23:00
CALM WINDS:
4.02%
TOTAL COUNT:
6396 hrs.
AVG. WIND SPEED:
3.83 m/s
PROJECT NO.:
WRPLOT View - Lakes Environmental Software

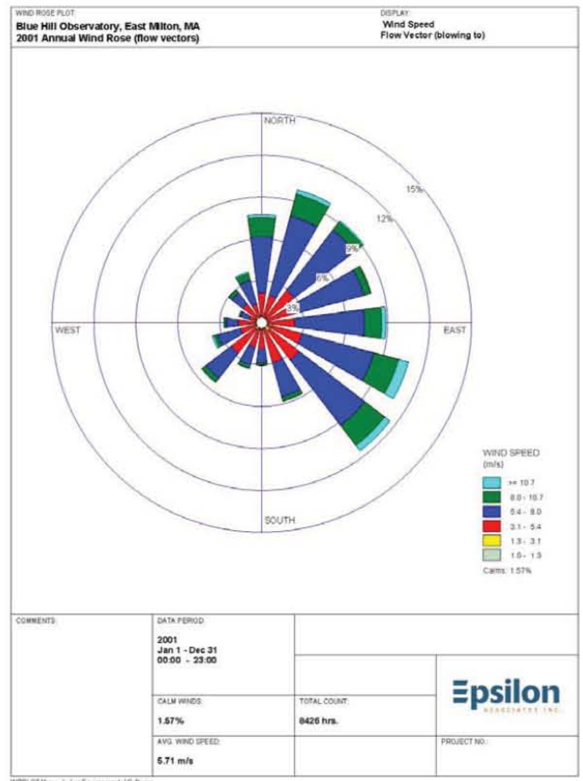

WIND ROSE PLOT:
Pilgrim NPS - winds measured at 33 feet
2001 Annual Wind Rose (flow vectors)
DISPLAY:
Wind Speed
Flow Vector (blowing to)
NORTH
SOUTH
WEST
EAST
3%
6%
9%
12%
15%
WIND SPEED (m/s)
>= 10.7
8.0 - 10.7
5.4 - 8.0
3.1 - 5.4
1.3 - 3.1
1.0 - 1.3
Calms: 0.51%
COMMENTS:
DATA PERIOD:
2001
Jan 1 - Dec 31
00:00 - 23:00
CALM WINDS:
0.51%
TOTAL COUNT:
8759 hrs.
AVG. WIND SPEED:
2.74 m/s
PROJECT NO.:
Epsilon
ASSOCIATES INC.
WRPLOT View - Lakes Environmental Software

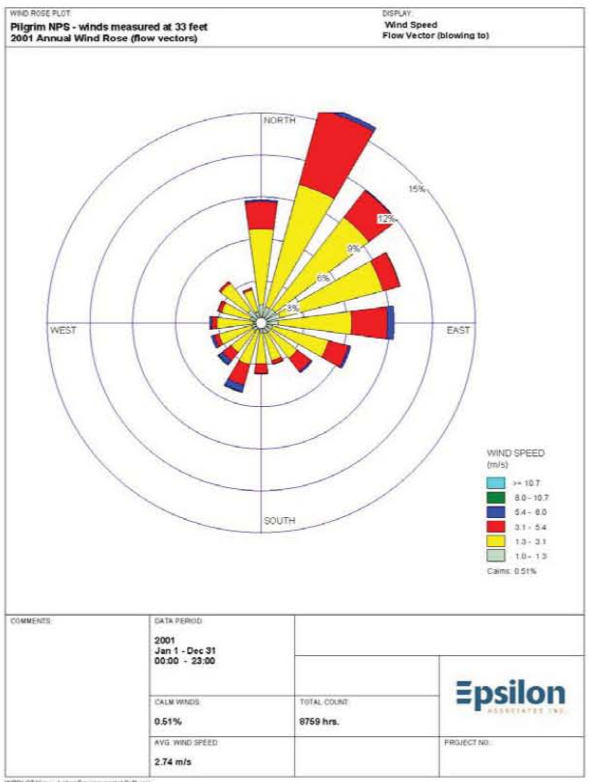

WIND ROSE PLOT:
Logan International Airport, Boston, MA
2001 Annual Wind Rose (flow vectors)
DISPLAY:
Wind Speed
Flow Vector (blowing to)
NORTH
SOUTH
WEST
EAST
3%
6%
9%
12%
15%
WIND SPEED (m/s)
>= 10.7
8.0 - 10.7
5.4 - 8.0
3.1 - 5.4
1.3 - 3.1
1.0 - 1.3
Calms: 2.51%
COMMENTS:
DATA PERIOD:
2001
Jan 1 - Dec 31
00:00 - 23:00
CALM WINDS:
2.51%
TOTAL COUNT:
8603 hrs.
AVG. WIND SPEED:
4.89 m/s
PROJECT NO.:
Epsilon
ASSOCIATES INC.
WRPLOT View - Lakes Environmental Software

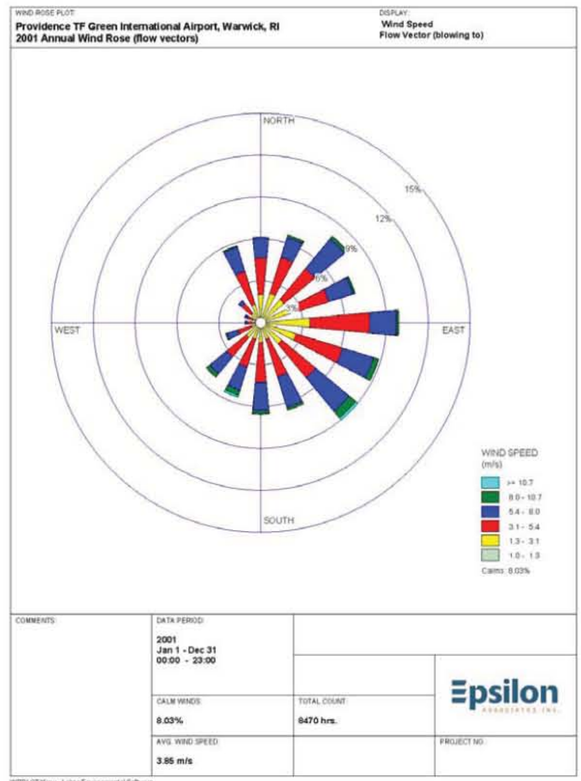

WIND ROSE PLOT:
Pilgrim NPS - winds measured at 33 feet
2001 Annual Wind Rose (flow vectors)
DISPLAY:
Wind Speed
Flow Vector (blowing to)
NORTH
15%
12%
9%
6%
3%
WEST
EAST
SOUTH
WIND SPEED
(m/s)
>= 10.7
8.0 - 10.7
5.4 - 8.0
3.1 - 5.4
1.3 - 3.1
1.0 - 1.3
Calms: 0.51%
COMMENTS:
DATA PERIOD:
2001
Jan 1 - Dec 31
00:00 - 23:00
CALM WINDS:
0.51%
TOTAL COUNT:
8759 hrs.
AVG. WIND SPEED:
2.74 m/s
PROJECT NO.:
WRPLOT View - Lakes Environmental Software

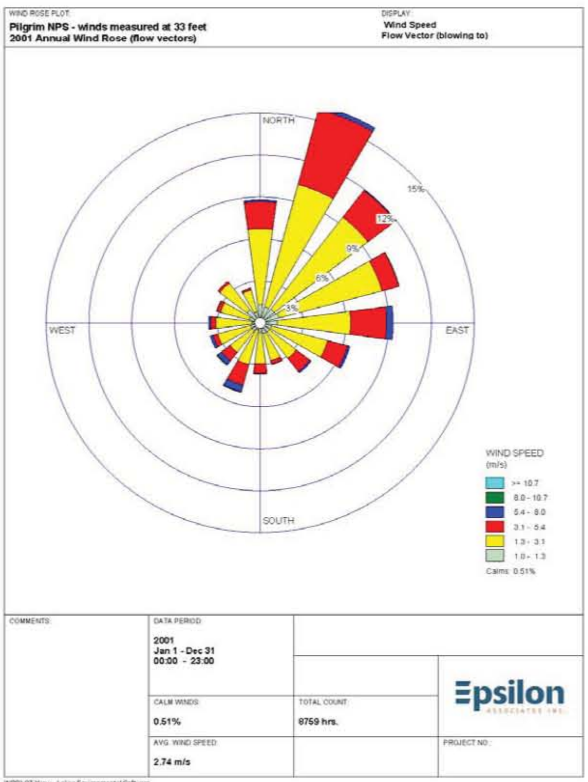

WIND ROSE PLOT:
Norwood Memorial Airport, Norwood, MA
2001 Annual Wind Rose (flow vectors)
DISPLAY:
Wind Speed
Flow Vector (blowing to)
NORTH
15%
12%
9%
6%
3%
WEST
EAST
SOUTH
WIND SPEED
(m/s)
>= 10.7
8.0 - 10.7
5.4 - 8.0
3.1 - 5.4
1.3 - 3.1
1.0 - 1.3
Calms: 15.27%
COMMENTS:
DATA PERIOD:
2001
Jan 1 - Dec 31
00:00 - 23:00
CALM WINDS:
15.27%
TOTAL COUNT:
6639 hrs.
AVG. WIND SPEED:
3.29 m/s
PROJECT NO.:
WRPLOT View - Lakes Environmental Software

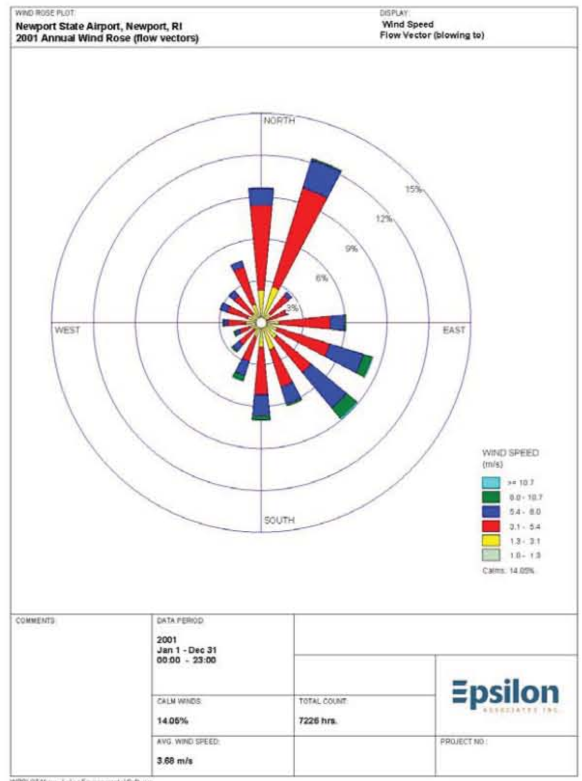

WIND ROSE PLOT:
Pilgrim NPS - winds measured at 33 feet
2001 Annual Wind Rose (flow vectors)
DISPLAY:
Wind Speed
Flow Vector (blowing to)
NORTH
SOUTH
WEST
EAST
3%
6%
9%
12%
15%
WIND SPEED
(m/s)
>= 10.7
8.0 - 10.7
5.4 - 8.0
3.1 - 5.4
1.3 - 3.1
1.0 - 1.3
Calms: 0.51%
COMMENTS:
DATA PERIOD:
2001
Jan 1 - Dec 31
00:00 - 23:00
CALM WINDS:
0.51%
TOTAL COUNT:
8759 hrs.
AVG. WIND SPEED:
2.74 m/s
PROJECT NO.:
WRPLOT View - Lakes Environmental Software

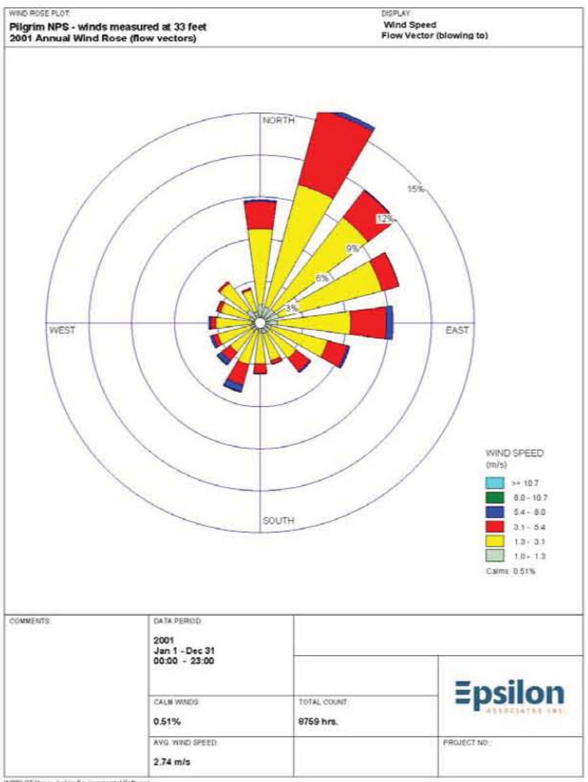

WIND ROSE PLOT:
Blue Hill Observatory, East Milton, MA
2001 Annual Wind Rose (flow vectors)
DISPLAY:
Wind Speed
Flow Vector (blowing to)
NORTH
SOUTH
WEST
EAST
3%
6%
9%
12%
15%
WIND SPEED
(m/s)
>= 10.7
8.0 - 10.7
5.4 - 8.0
3.1 - 5.4
1.3 - 3.1
1.0 - 1.3
Calms: 1.57%
COMMENTS:
DATA PERIOD:
2001
Jan 1 - Dec 31
00:00 - 23:00
CALM WINDS:
1.57%
TOTAL COUNT:
8426 hrs.
AVG. WIND SPEED:
5.71 m/s
PROJECT NO.:
WRPLOT View - Lakes Environmental Software

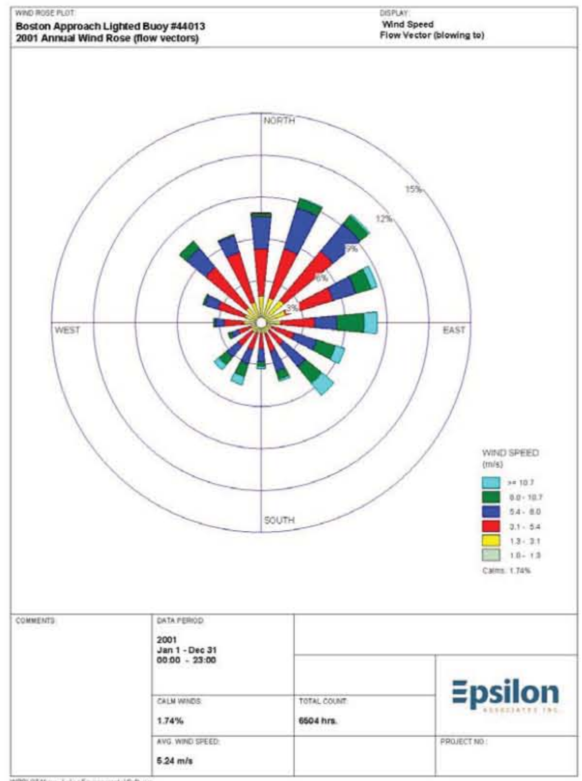

WIND ROSE PLOT:
Pilgrim NPS - winds measured at 33 feet
2001 Annual Wind Rose (flow vectors)
DISPLAY:
Wind Speed
Flow Vector (blowing to)
NORTH
WEST
EAST
SOUTH
15%
12%
9%
6%
3%
WIND SPEED
(m/s)
>= 10.7
8.0 - 10.7
5.4 - 8.0
3.1 - 5.4
1.3 - 3.1
1.0 - 1.3
Calms: 0.51%
COMMENTS:
DATA PERIOD:
2001
Jan 1 - Dec 31
00:00 - 23:00
CALM WINDS:
0.51%
TOTAL COUNT:
8759 hrs.
AVG. WIND SPEED:
2.74 m/s
PROJECT NO.:
WRPLOT View - Lakes Environmental Software

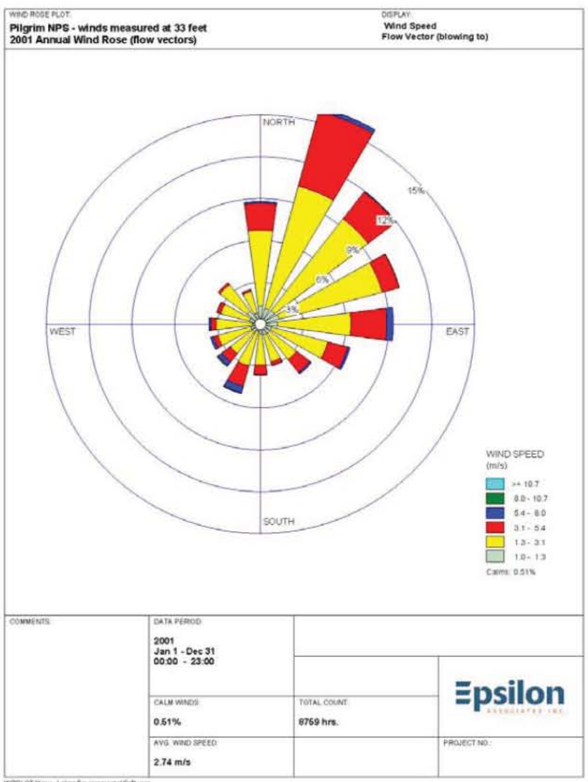

WIND ROSE PLOT:
Providence TF Green International Airport, Warwick, RI
2001 Annual Wind Rose (flow vectors)
DISPLAY:
Wind Speed
Flow Vector (blowing to)
NORTH
WEST
EAST
SOUTH
15%
12%
9%
6%
3%
WIND SPEED
(m/s)
>= 10.7
8.0 - 10.7
5.4 - 8.0
3.1 - 5.4
1.3 - 3.1
1.0 - 1.3
Calms: 8.03%
COMMENTS:
DATA PERIOD:
2001
Jan 1 - Dec 31
00:00 - 23:00
CALM WINDS:
8.03%
TOTAL COUNT:
8470 hrs.
AVG. WIND SPEED:
3.86 m/s
PROJECT NO.:
WRPLOT View - Lakes Environmental Software

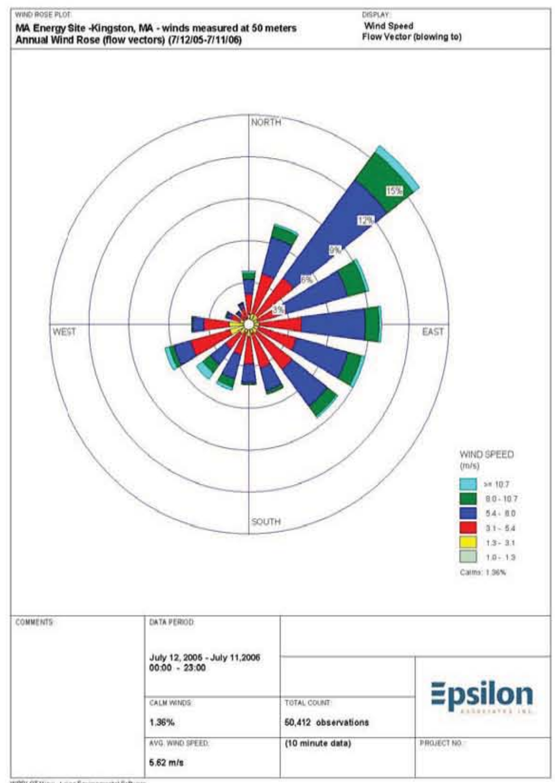

WIND ROSE PLOT:
Pilgrim NPS - winds measured at 33 feet
2001 Annual Wind Rose (flow vectors)
DISPLAY:
Wind Speed
Flow Vector (blowing to)
NORTH
SOUTH
WEST
EAST
3%
6%
9%
12%
15%
WIND SPEED
(m/s)
>= 10.7
8.0 - 10.7
5.4 - 8.0
3.1 - 5.4
1.3 - 3.1
1.0 - 1.3
Calms: 0.51%
COMMENTS:
DATA PERIOD:
2001
Jan 1 - Dec 31
00:00 - 23:00
CALM WINDS:
0.51%
TOTAL COUNT:
8759 hrs.
AVG. WIND SPEED:
2.74 m/s
PROJECT NO.:
WRPLOT View - Lakes Environmental Software

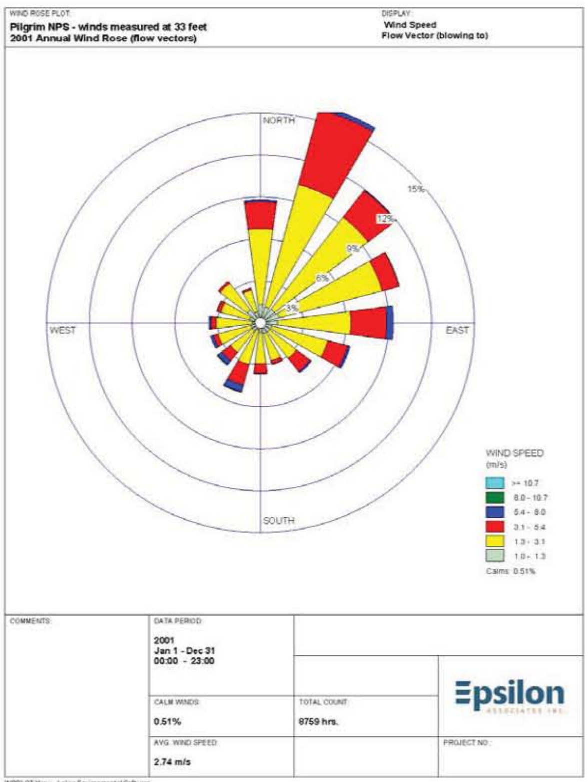

WIND ROSE PLOT:
Newport State Airport, Newport, RI
2001 Annual Wind Rose (flow vectors)
DISPLAY:
Wind Speed
Flow Vector (blowing to)
NORTH
SOUTH
WEST
EAST
3%
6%
9%
12%
15%
WIND SPEED
(m/s)
>= 10.7
8.0 - 10.7
5.4 - 8.0
3.1 - 5.4
1.3 - 3.1
1.0 - 1.3
Calms: 14.05%
COMMENTS:
DATA PERIOD:
2001
Jan 1 - Dec 31
00:00 - 23:00
CALM WINDS:
14.05%
TOTAL COUNT:
7226 hrs.
AVG. WIND SPEED:
3.68 m/s
PROJECT NO.:
WRPLOT View - Lakes Environmental Software

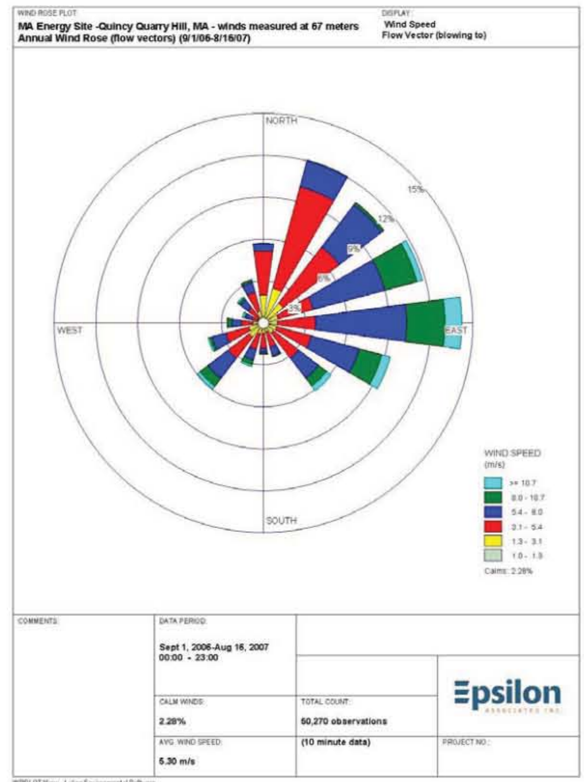

WIND ROSE PLOT:
Pilgrim NPS - winds measured at 33 feet
2001 Annual Wind Rose (flow vectors)
DISPLAY:
Wind Speed
Flow Vector (blowing to)
NORTH
WEST
EAST
SOUTH
3%
6%
9%
12%
15%
WIND SPEED
(m/s)
>= 10.7
8.0 - 10.7
5.4 - 8.0
3.1 - 5.4
1.3 - 3.1
1.0 - 1.3
Calms: 0.51%
COMMENTS:
DATA PERIOD:
2001
Jan 1 - Dec 31
00:00 - 23:00
CALM WINDS:
0.51%
TOTAL COUNT:
8759 hrs.
AVG. WIND SPEED:
2.74 m/s
PROJECT NO.:
Epsilon
WRPLOT View - Lakes Environmental Software

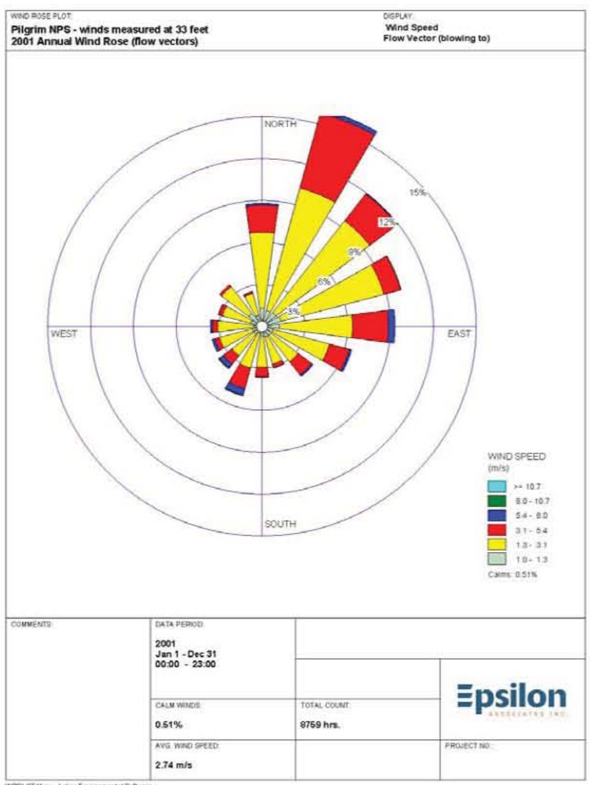

WIND ROSE PLOT:
Boston Approach Lighted Buoy #44013
2001 Annual Wind Rose (flow vectors)
DISPLAY:
Wind Speed
Flow Vector (blowing to)
NORTH
WEST
EAST
SOUTH
3%
6%
9%
12%
15%
WIND SPEED
(m/s)
>= 10.7
8.0 - 10.7
5.4 - 8.0
3.1 - 5.4
1.3 - 3.1
1.0 - 1.3
Calms: 1.74%
COMMENTS:
DATA PERIOD:
2001
Jan 1 - Dec 31
00:00 - 23:00
CALM WINDS:
1.74%
TOTAL COUNT:
6504 hrs.
AVG. WIND SPEED:
5.24 m/s
PROJECT NO.:
Epsilon
WRPLOT View - Lakes Environmental Software

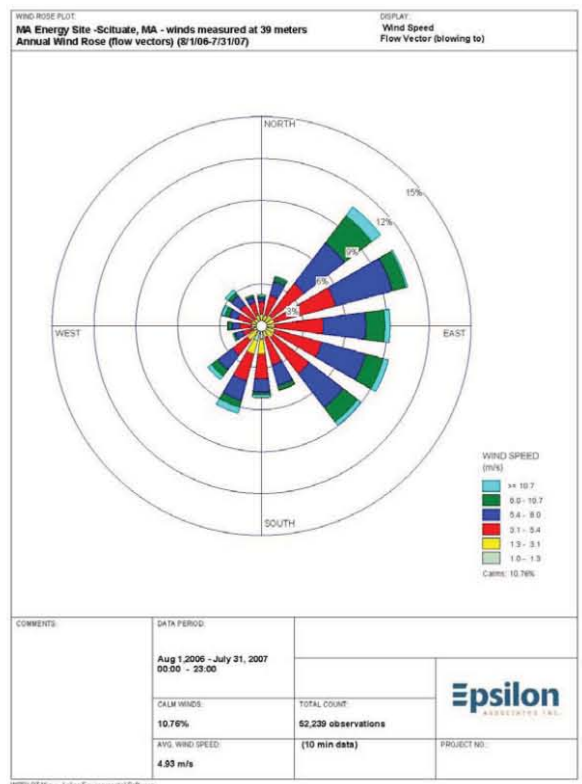

WIND ROSE PLOT:
Pilgrim NPS - winds measured at 33 feet
2001 Annual Wind Rose (flow vectors)
DISPLAY:
Wind Speed
Flow Vector (blowing to)
NORTH
WEST
EAST
SOUTH
3%
6%
9%
12%
15%
WIND SPEED
(m/s)
>= 10.7
8.0 - 10.7
5.4 - 8.0
3.1 - 5.4
1.3 - 3.1
1.0 - 1.3
Calms: 0.51%
COMMENTS:
DATA PERIOD:
2001
Jan 1 - Dec 31
00:00 - 23:00
CALM WINDS:
0.51%
TOTAL COUNT:
8759 hrs.
AVG. WIND SPEED:
2.74 m/s
PROJECT NO.:
Epsilon
WRPLOT View - Lakes Environmental Software

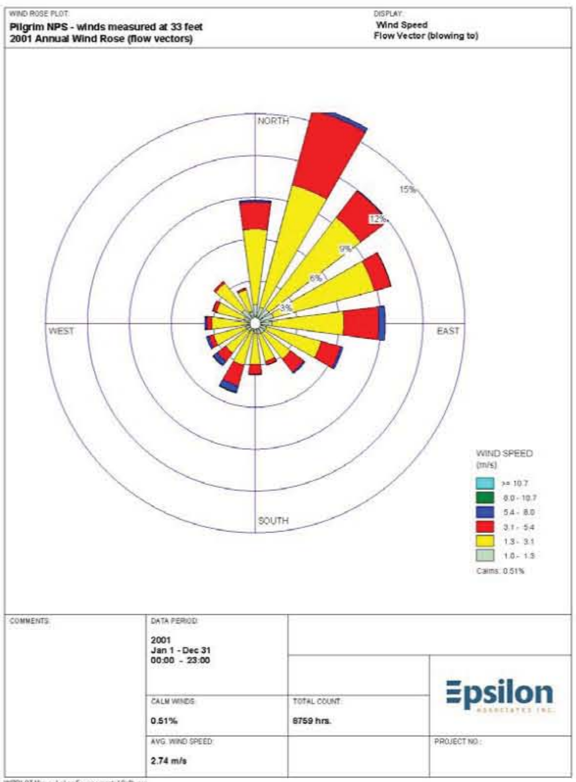

WIND ROSE PLOT:
MA Energy Site -Kingston, MA - winds measured at 50 meters
Annual Wind Rose (flow vectors) (7/12/05-7/11/06)
DISPLAY:
Wind Speed
Flow Vector (blowing to)
NORTH
WEST
EAST
SOUTH
3%
6%
9%
12%
15%
WIND SPEED
(m/s)
>= 10.7
8.0 - 10.7
5.4 - 8.0
3.1 - 5.4
1.3 - 3.1
1.0 - 1.3
Calms: 1.36%
COMMENTS:
DATA PERIOD:
July 12, 2005 - July 11,2006
00:00 - 23:00
CALM WINDS:
1.36%
TOTAL COUNT:
50,412 observations
(10 minute data)
AVG. WIND SPEED:
5.62 m/s
PROJECT NO.:
Epsilon
WRPLOT View - Lakes Environmental Software

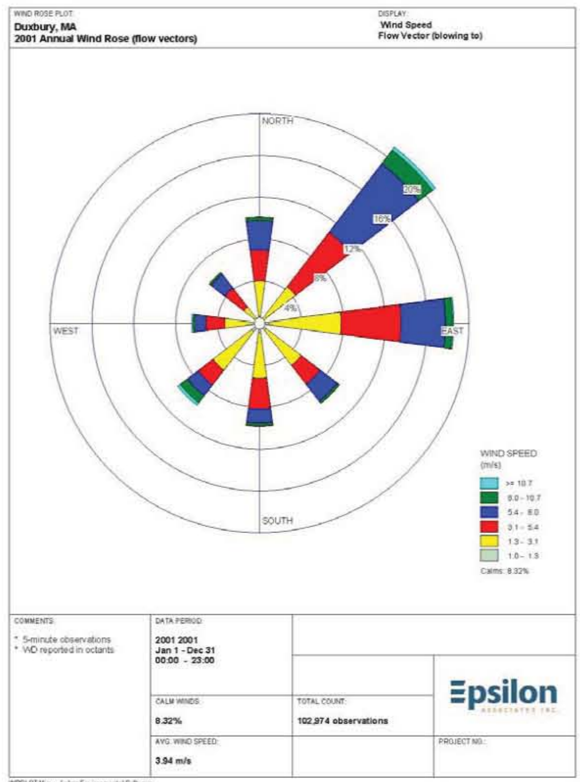

WIND ROSE PLOT:
Pilgrim NPS - winds measured at 33 feet
2001 Annual Wind Rose (flow vectors)
DISPLAY:
Wind Speed
Flow Vector (blowing to)
NORTH
WEST
EAST
SOUTH
15%
12%
9%
6%
3%
WIND SPEED
(m/s)
>= 10.7
8.0 - 10.7
5.4 - 8.0
3.1 - 5.4
1.3 - 3.1
1.0 - 1.3
Calms: 0.51%
COMMENTS:
DATA PERIOD:
2001
Jan 1 - Dec 31
00:00 - 23:00
CALM WINDS:
0.51%
TOTAL COUNT:
8759 hrs.
AVG. WIND SPEED:
2.74 m/s
PROJECT NO.:
WRPLOT View - Lakes Environmental Software


WIND ROSE PLOT:
MA Energy Site -Quincy Quarry Hill, MA - winds measured at 67 meters
Annual Wind Rose (flow vectors) (9/1/06-8/16/07)
DISPLAY:
Wind Speed
Flow Vector (blowing to)
NORTH
WEST
EAST
SOUTH
15%
12%
9%
6%
3%
WIND SPEED
(m/s)
>= 10.7
8.0 - 10.7
5.4 - 8.0
3.1 - 5.4
1.3 - 3.1
1.0 - 1.3
Calms: 2.28%
COMMENTS:
DATA PERIOD:
Sept 1, 2006-Aug 16, 2007
00:00 - 23:00
CALM WINDS:
2.28%
TOTAL COUNT:
50,270 observations
(10 minute data)
AVG. WIND SPEED:
5.30 m/s
PROJECT NO.:
WRPLOT View - Lakes Environmental Software


WIND ROSE PLOT:
Pilgrim NPS - winds measured at 33 feet
2001 Annual Wind Rose (flow vectors)
DISPLAY:
Wind Speed
Flow Vector (blowing to)
NORTH
SOUTH
WEST
EAST
3%
6%
9%
12%
15%
WIND SPEED
(m/s)
>= 10.7
8.0 - 10.7
5.4 - 8.0
3.1 - 5.4
1.3 - 3.1
1.0 - 1.3
Calms: 0.51%
COMMENTS:
DATA PERIOD:
2001
Jan 1 - Dec 31
00:00 - 23:00
CALM WINDS:
0.51%
TOTAL COUNT:
8759 hrs.
AVG. WIND SPEED:
2.74 m/s
PROJECT NO.:
Epsilon
ASSOCIATES INC.
WRPLOT View - Lakes Environmental Software


WIND ROSE PLOT:
MA Energy Site -Scituate, MA - winds measured at 39 meters
Annual Wind Rose (flow vectors) (8/1/06-7/31/07)
DISPLAY:
Wind Speed
Flow Vector (blowing to)
NORTH
SOUTH
WEST
EAST
3%
6%
9%
12%
15%
WIND SPEED
(m/s)
>= 10.7
8.0 - 10.7
5.4 - 8.0
3.1 - 5.4
1.3 - 3.1
1.0 - 1.3
Calms: 10.76%
COMMENTS:
DATA PERIOD:
Aug 1,2006 - July 31, 2007
00:00 - 23:00
CALM WINDS:
10.76%
TOTAL COUNT:
52,239 observations
(10 min data)
AVG. WIND SPEED:
4.93 m/s
PROJECT NO.:
Epsilon
ASSOCIATES INC.
WRPLOT View - Lakes Environmental Software


WIND ROSE PLOT:
Pilgrim NPS - winds measured at 33 feet
2001 Annual Wind Rose (flow vectors)
DISPLAY:
Wind Speed
Flow Vector (blowing to)
NORTH
WEST
EAST
SOUTH
15%
12%
9%
6%
3%
WIND SPEED
(m/s)
>= 10.7
8.0 - 10.7
5.4 - 8.0
3.1 - 5.4
1.3 - 3.1
1.0 - 1.3
Calms: 0.51%
COMMENTS:
DATA PERIOD:
2001
Jan 1 - Dec 31
00:00 - 23:00
CALM WINDS:
0.51%
TOTAL COUNT:
8759 hrs.
AVG. WIND SPEED:
2.74 m/s
PROJECT NO.:
WRPLOT View - Lakes Environmental Software


WIND ROSE PLOT:
Duxbury, MA
2001 Annual Wind Rose (flow vectors)
DISPLAY:
Wind Speed
Flow Vector (blowing to)
NORTH
WEST
EAST
SOUTH
20%
16%
12%
8%
4%
WIND SPEED
(m/s)
>= 10.7
8.0 - 10.7
5.4 - 8.0
3.1 - 5.4
1.3 - 3.1
1.0 - 1.3
Calms: 8.32%
COMMENTS:
* 5-minute observations
* WD reported in octants
DATA PERIOD:
2001 2001
Jan 1 - Dec 31
00:00 - 23:00
CALM WINDS:
8.32%
TOTAL COUNT:
102,974 observations
AVG. WIND SPEED:
3.94 m/s
PROJECT NO.:
WRPLOT View - Lakes Environmental Software

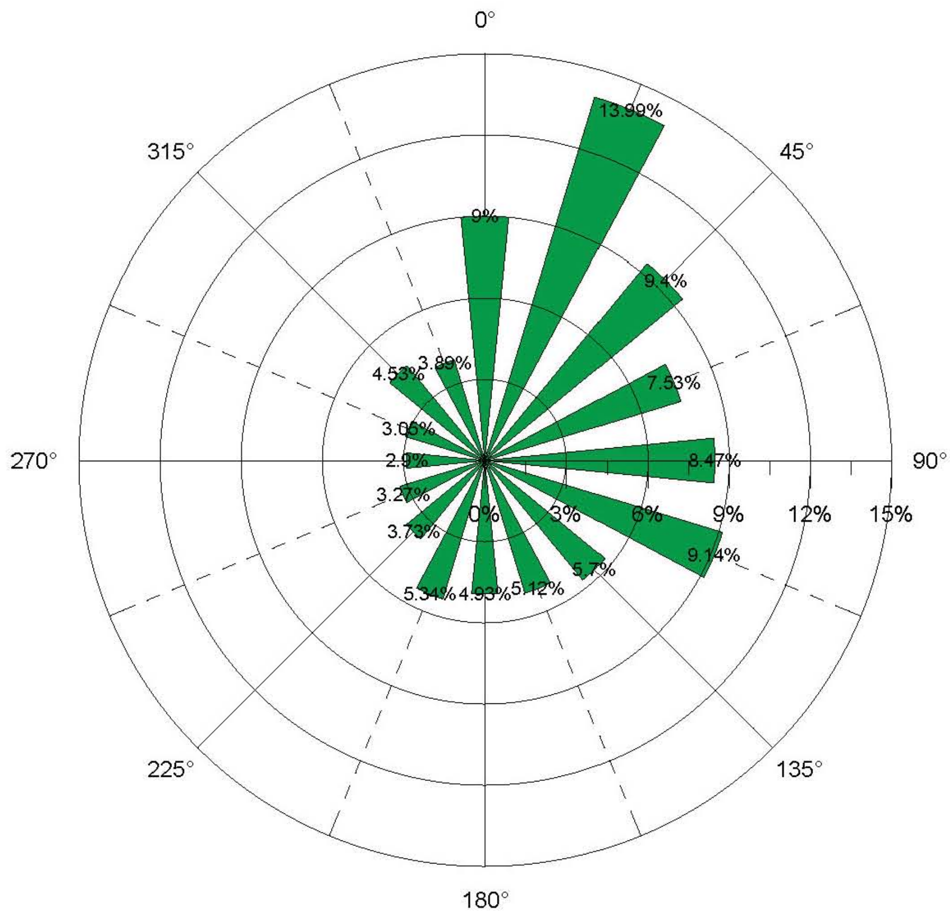
Appendix C
CALMET Trajectory Roses for 100 m Elevation

This appendix contains 14 plots containing trajectory roses for 2001, for trajectories initiated at the Pilgrim Station at an elevation of 100 m above the surface. The hourly wind fields that are used have been calculated by CALMET based on observations within a 124 by 124 mile domain.

Each plot is for a different downwind distance: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 20, 30, 40, and 50 miles.

PROJECT TITLE:

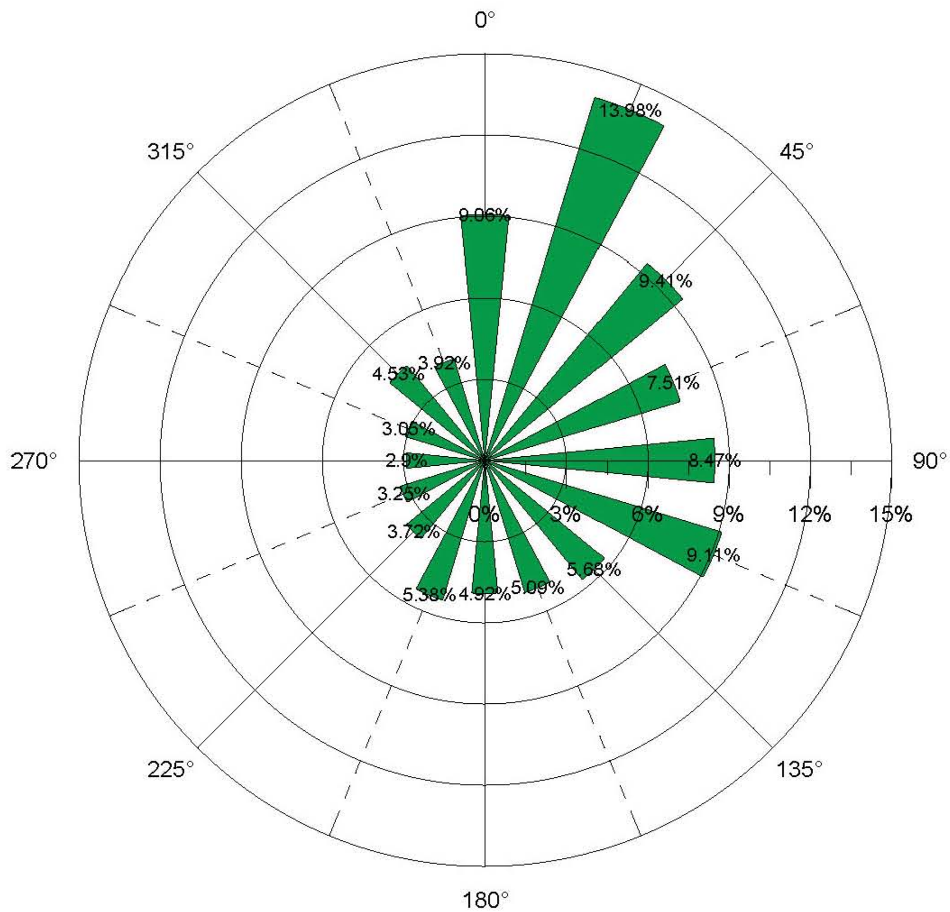
Hanna Pilgrim Trajectory Frequency Distribution
Privileged and Confidential Attorney Work Product



COMMENTS:	MODELING OPTIONS:		COMPANY NAME:	
Figure 1 Trajectory Frequency Distribution 100 meter height 1 mile downwind	2001 CALMET Wind Fields		Epsilon Associates, Inc.	
			MODELER: Epsilon Associates, Inc.	Epsilon ASSOCIATES INC.
	OUTPUT TYPE: FREQ	RECEPTORS:		
	MAX:	UNITS: % of Time	DATE: July 29, 2010	PROJECT NO.: 2876

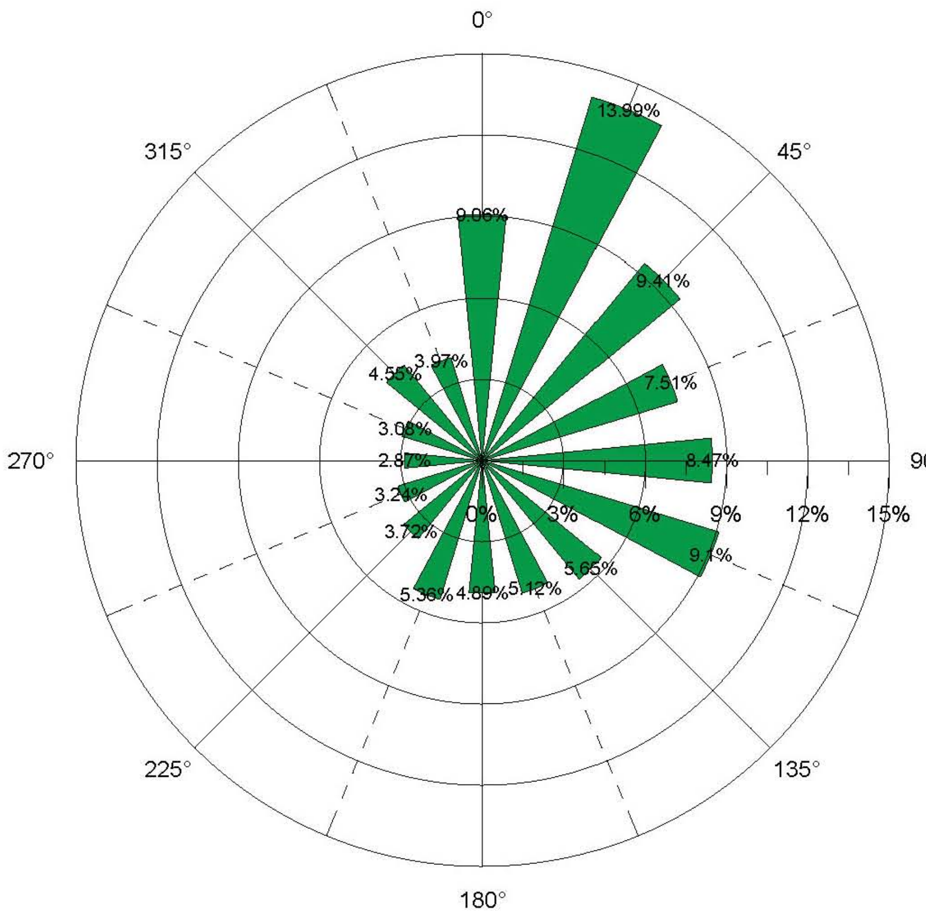
PROJECT TITLE:

Hanna Pilgrim Trajectory Frequency Distribution
Privileged and Confidential Attorney Work Product



COMMENTS: Figure 2 Trajectory Frequency Distribution 100 meter height 2 miles downwind	**MODELING OPTIONS:** 2001 CALMET Wind Fields		**COMPANY NAME:** Epsilon Associates, Inc.
			MODELER: Epsilon Associates, Inc.
	OUTPUT TYPE: FREQ	**RECEPTORS:**	Epsilon ASSOCIATES INC.
	MAX:	**UNITS:** % of Time	**DATE:** July 29, 2010 / **PROJECT NO.:** 2876

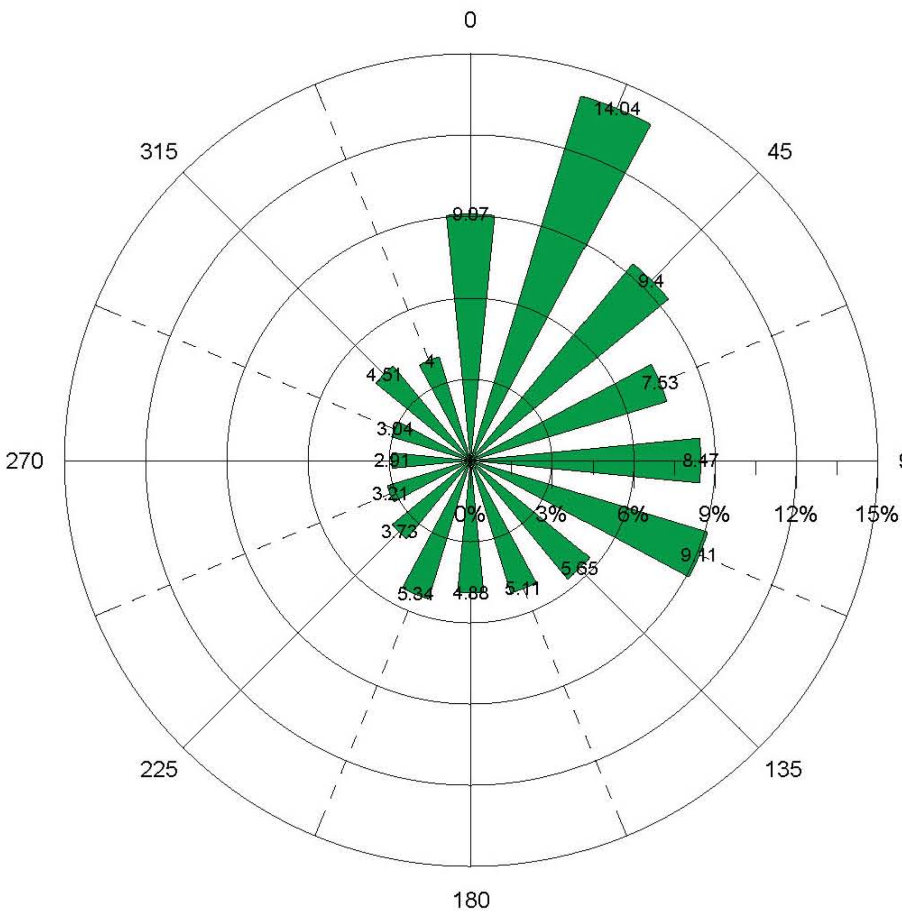
PROJECT TITLE:
Hanna Pilgrim Trajectory Frequency Distribution
Privileged and Confidential Attorney Work Product



COMMENTS:	MODELING OPTIONS:		COMPANY NAME:	
Figure 3 Trajectory Frequency Distribution 100 meter height 3 miles downwind	2001 CALMET Wind Fields		Epsilon Associates, Inc.	
			MODELER: Epsilon Associates, Inc.	Epsilon ASSOCIATES INC.
	OUTPUT TYPE: FREQ	RECEPTORS:		
	MAX:	UNITS: % of Time	DATE: July 29, 2010	PROJECT NO.: 2876

PROJECT TITLE:

Hanna Pilgrim Trajectory Frequency Distribution
Privileged and Confidential Attorney Work Product



COMMENTS:

Figure 4
Trajectory Frequency Distribution

100 meter height
4 miles downwind

MODELING OPTIONS: 2001 CALMET Wind Fields

COMPANY NAME: Epsilon Associates, Inc.

MODELER: Epsilon Associates, Inc.

OUTPUT TYPE: FREQ

RECEPTORS:

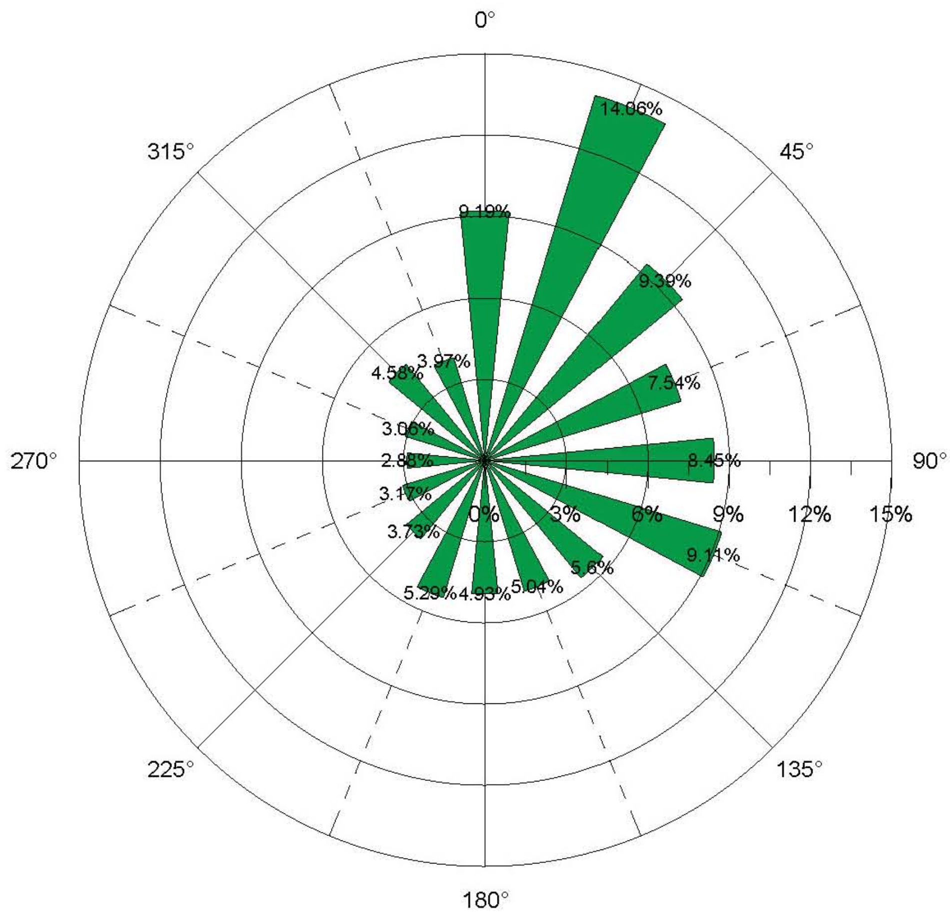
MAX:

UNITS: % of Time

DATE: July 29, 2010

PROJECT NO.: 2876

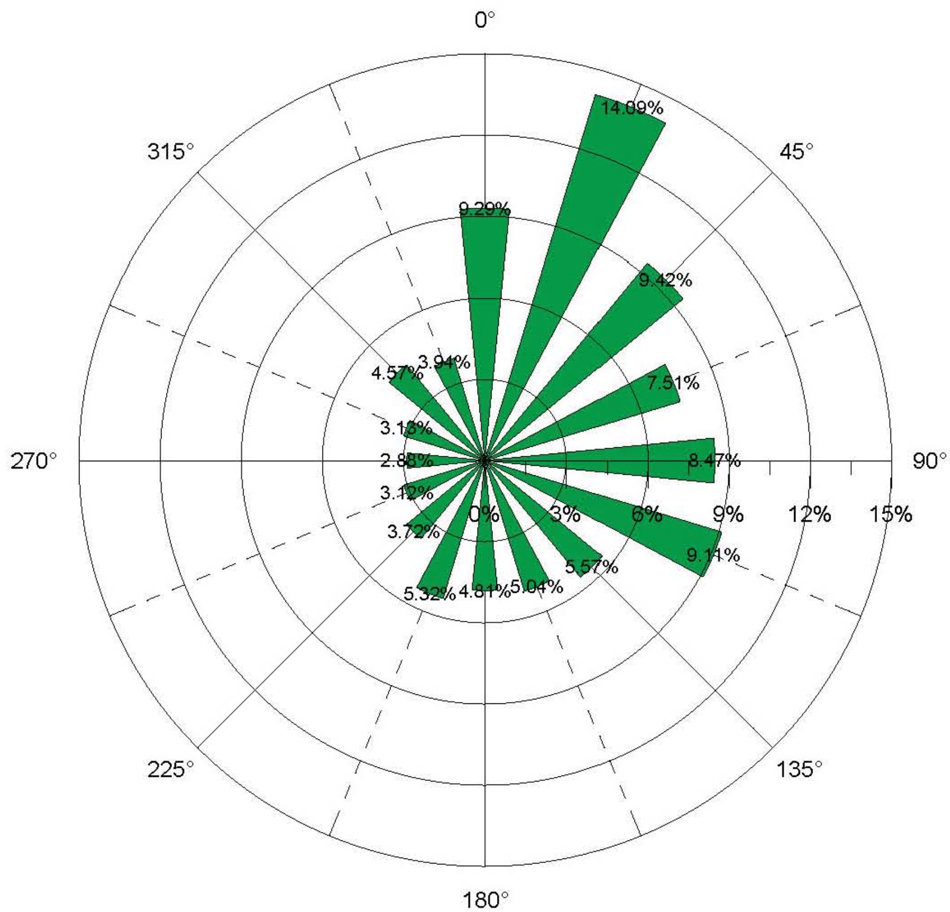
PROJECT TITLE:
Hanna Pilgrim Trajectory Frequency Distribution
Privileged and Confidential Attorney Work Product



COMMENTS:	MODELING OPTIONS:		COMPANY NAME:	
Figure 5 Trajectory Frequency Distribution 100 meter height 5 miles downwind	2001 CALMET Wind Fields		Epsilon Associates, Inc.	
			MODELER: Epsilon Associates, Inc.	Epsilon Associates Inc.
	OUTPUT TYPE: FREQ	RECEPTORS:		
	MAX:	UNITS: % of Time	DATE: July 29, 2010	PROJECT NO.: 2876

PROJECT TITLE:

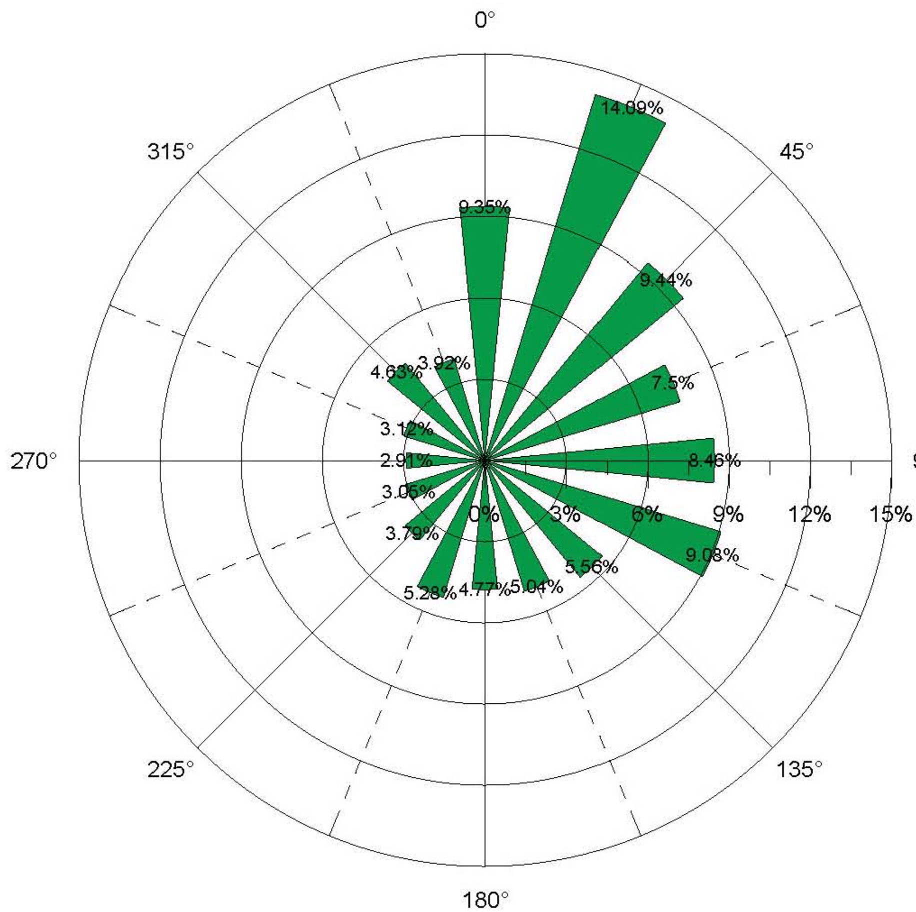
Hanna Pilgrim Trajectory Frequency Distribution
Privileged and Confidential Attorney Work Product



COMMENTS:	MODELING OPTIONS:		COMPANY NAME:	
Figure 6 Trajectory Frequency Distribution 100 meter height 6 miles downwind	2001 CALMET Wind Fields		Epsilon Associates, Inc.	
			MODELER: Epsilon Associates, Inc.	Epsilon ASSOCIATES INC.
	OUTPUT TYPE: FREQ	RECEPTORS:		
	MAX:	UNITS: % of Time	DATE: July 29, 2010	PROJECT NO.: 2876

PROJECT TITLE:

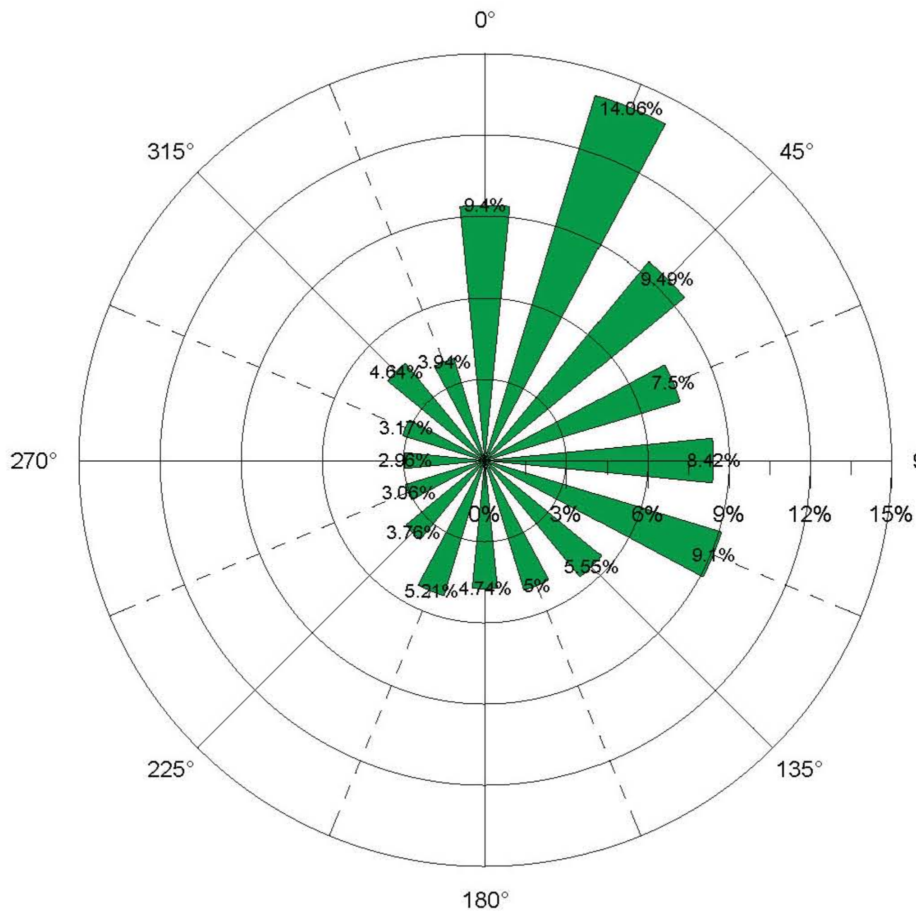
Hanna Pilgrim Trajectory Frequency Distribution
Privileged and Confidential Attorney Work Product



COMMENTS:	MODELING OPTIONS:		COMPANY NAME:	
Figure 7 Trajectory Frequency Distribution 100 meter height 7 miles downwind	2001 CALMET Wind Fields		Epsilon Associates, Inc.	
			MODELER: Epsilon Associates, Inc.	Epsilon Associates Inc.
	OUTPUT TYPE: FREQ	RECEPTORS:		
	MAX:	UNITS: % of Time	DATE: July 29, 2010	PROJECT NO.: 2876

PROJECT TITLE:

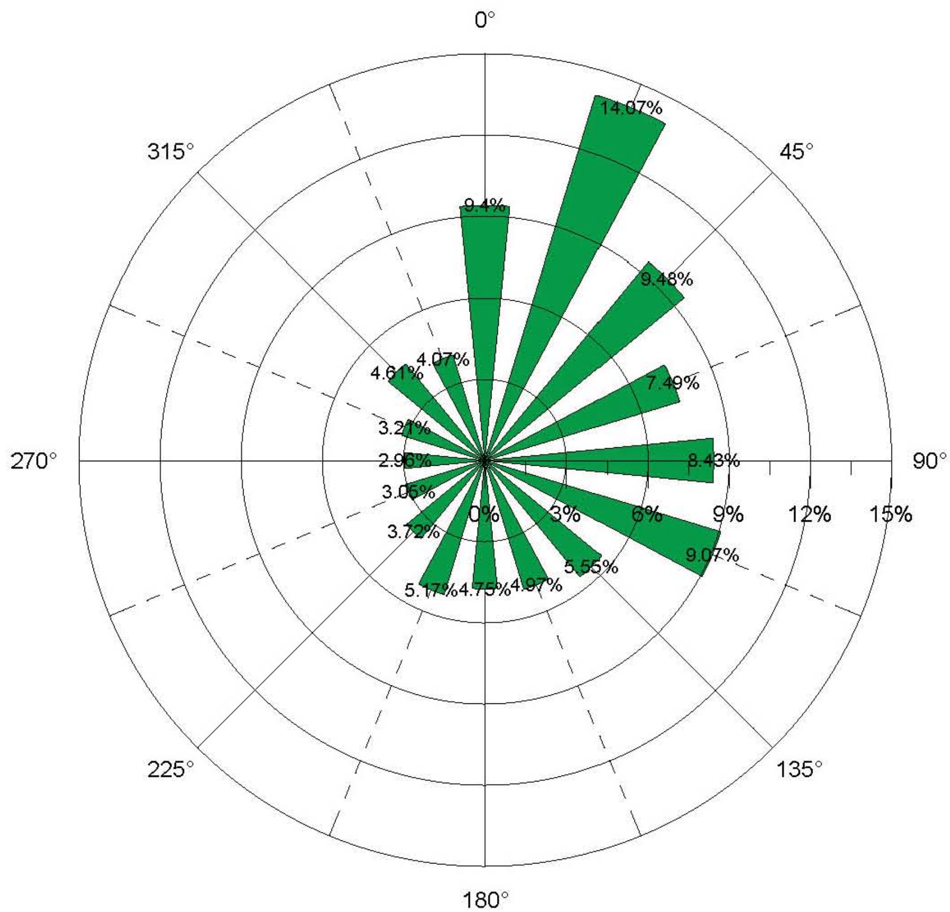
Hanna Pilgrim Trajectory Frequency Distribution
Privileged and Confidential Attorney Work Product



COMMENTS: Figure 8 Trajectory Frequency Distribution 100 meter height 8 miles downwind	**MODELING OPTIONS:** 2001 CALMET Wind Fields	**COMPANY NAME:** Epsilon Associates, Inc.	
		MODELER: Epsilon Associates, Inc.	Epsilon ASSOCIATES INC.
	OUTPUT TYPE: FREQ / **RECEPTORS:**		
	MAX: / **UNITS:** % of Time	**DATE:** July 29, 2010	**PROJECT NO.:** 2876

PROJECT TITLE:

Hanna Pilgrim Trajectory Frequency Distribution
Privileged and Confidential Attorney Work Product



COMMENTS:

Figure 9
Trajectory Frequency
Distribution

100 meter height
9 miles downwind

MODELING OPTIONS:

2001 CALMET Wind Fields

COMPANY NAME:

Epsilon Associates, Inc.

MODELER:

Epsilon Associates, Inc.

OUTPUT TYPE:

FREQ

RECEPTORS:

MAX:

UNITS:

% of Time

DATE:

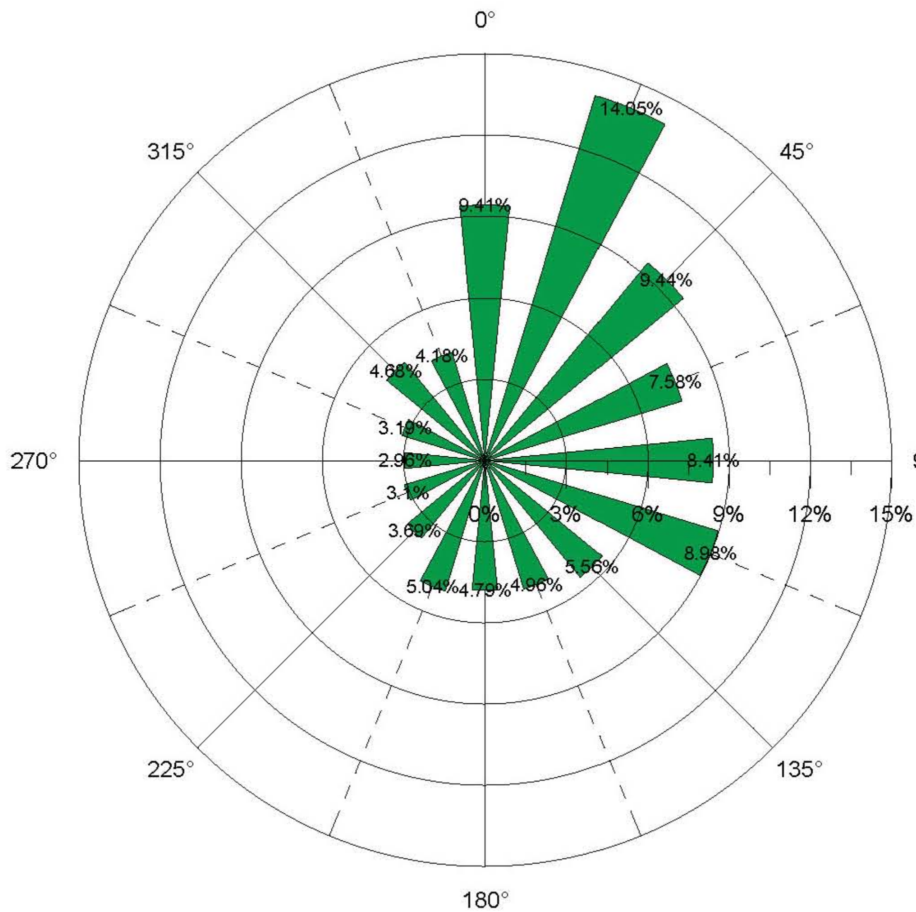
July 29, 2010

PROJECT NO.:

2876

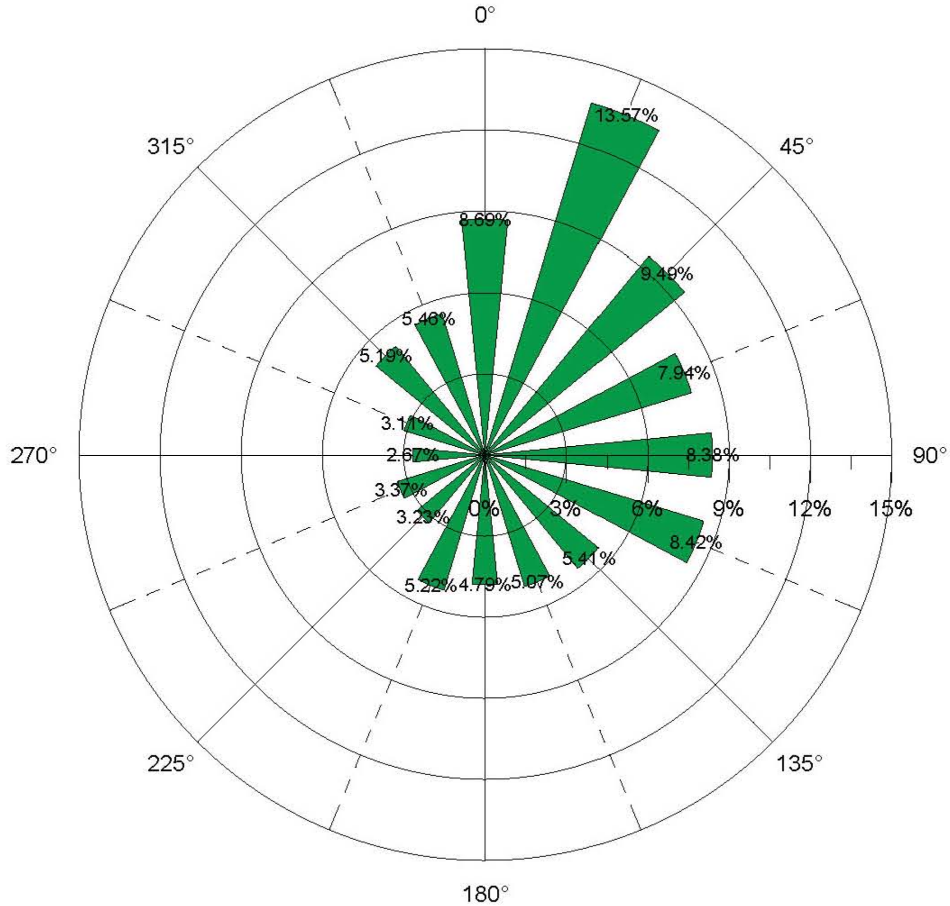
PROJECT TITLE:

Hanna Pilgrim Trajectory Frequency Distribution
Privileged and Confidential Attorney Work Product



COMMENTS:	MODELING OPTIONS:		COMPANY NAME:	
Figure 10 Trajectory Frequency Distribution 100 meter height 10 miles downwind	2001 CALMET Wind Fields		Epsilon Associates, Inc.	
			MODELER: Epsilon Associates, Inc.	Epsilon ASSOCIATES INC.
	OUTPUT TYPE: FREQ	RECEPTORS:		
	MAX:	UNITS: % of Time	DATE: July 29, 2010	PROJECT NO.: 2876

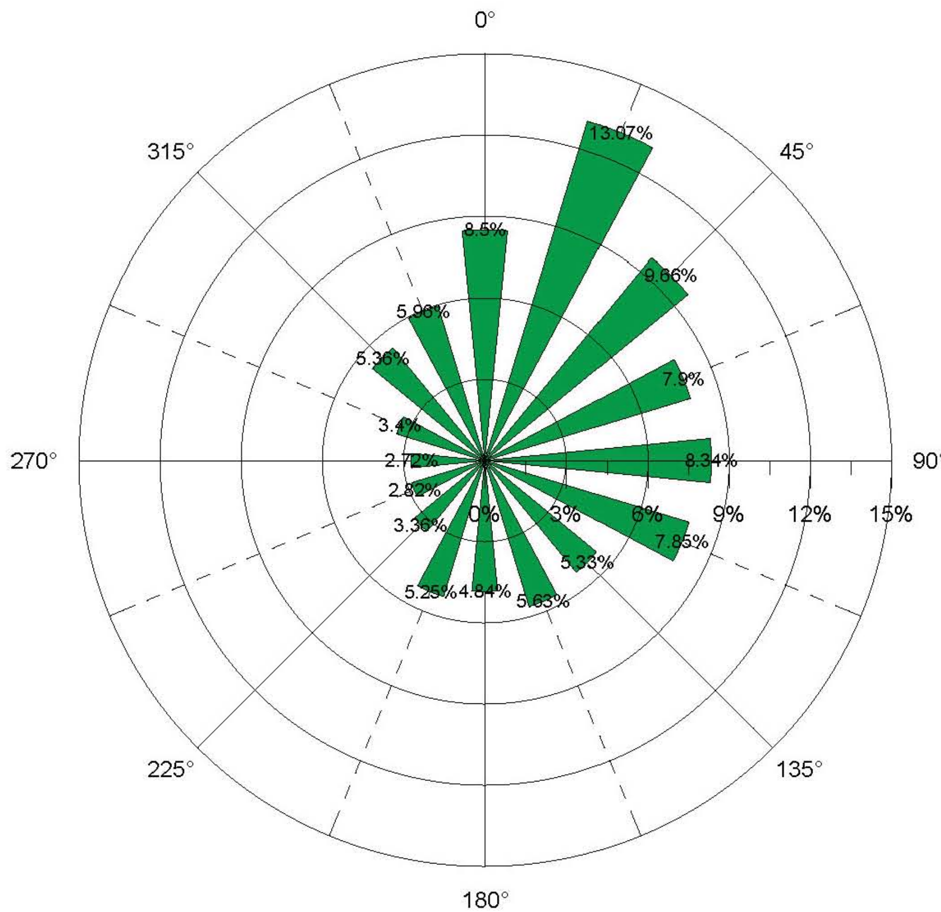
PROJECT TITLE:
Hanna Pilgrim Trajectory Frequency Distribution
Privileged and Confidential Attorney Work Product



COMMENTS:	MODELING OPTIONS:		COMPANY NAME:	
Figure 11 Trajectory Frequency Distribution 100 meter height 20 miles downwind	2001 CALMET Wind Fields		Epsilon Associates, Inc.	
			MODELER: Epsilon Associates, Inc.	Epsilon ASSOCIATES INC.
	OUTPUT TYPE: FREQ	RECEPTORS:		
	MAX:	UNITS: % of Time	DATE: July 29, 2010	PROJECT NO.: 2876

PROJECT TITLE:

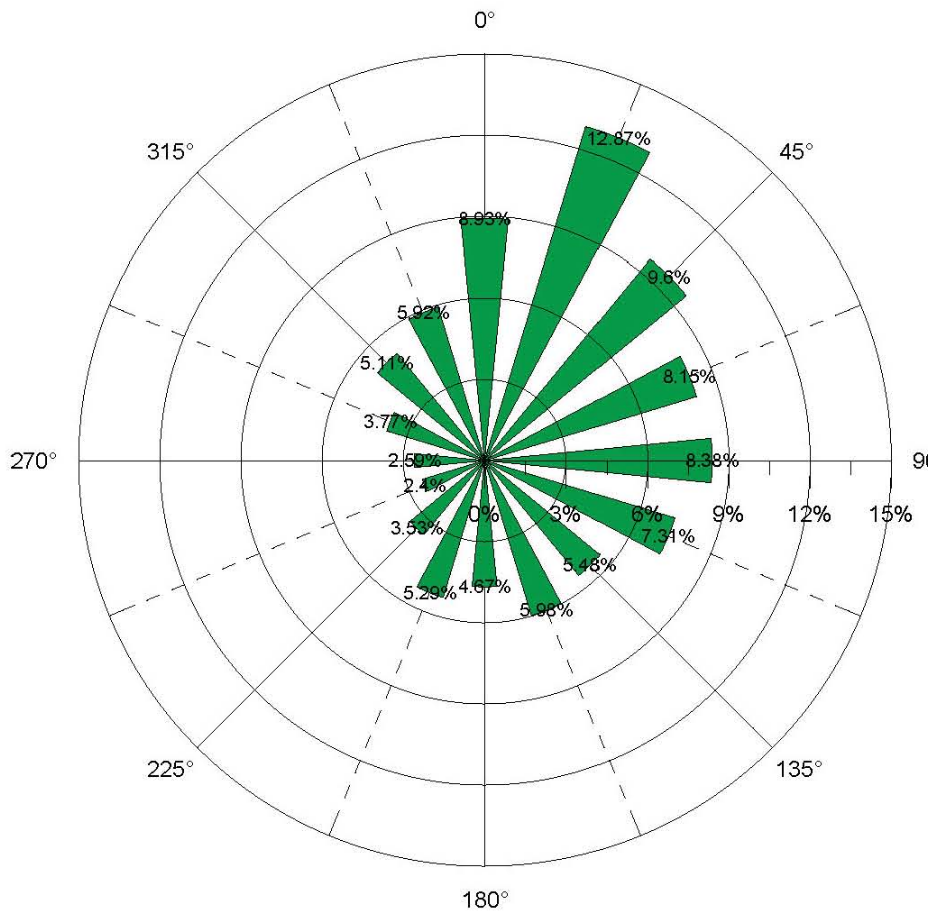
Hanna Pilgrim Trajectory Frequency Distribution
Privileged and Confidential Attorney Work Product



COMMENTS:	MODELING OPTIONS:		COMPANY NAME:	
Figure 12 Trajectory Frequency Distribution 100 meter height 30 miles downwind	2001 CALMET Wind Fields		Epsilon Associates, Inc.	
			MODELER: Epsilon Associates, Inc.	Epsilon Associates Inc.
	OUTPUT TYPE: FREQ	RECEPTORS:		
	MAX:	UNITS: % of Time	DATE: July 29, 2010	PROJECT NO.: 2876

PROJECT TITLE:

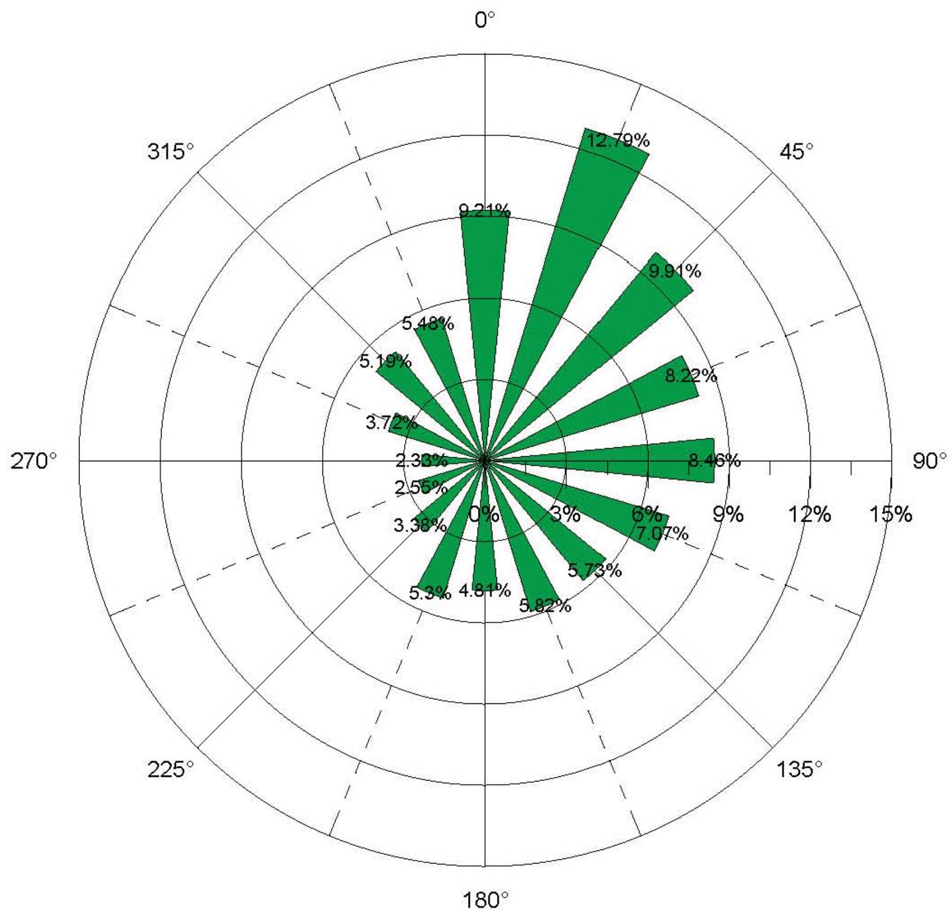
Hanna Pilgrim Trajectory Frequency Distribution
Privileged and Confidential Attorney Work Product



COMMENTS:	MODELING OPTIONS:		COMPANY NAME:	
Figure 13 Trajectory Frequency Distribution 100 meter height 40 miles downwind	2001 CALMET Wind Fields		Epsilon Associates, Inc.	
			MODELER: Epsilon Associates, Inc.	Epsilon ASSOCIATES INC.
	OUTPUT TYPE: FREQ	RECEPTORS:		
	MAX:	UNITS: % of Time	DATE: July 29, 2010	PROJECT NO.: 2876

PROJECT TITLE:

Hanna Pilgrim Trajectory Frequency Distribution
Privileged and Confidential Attorney Work Product



COMMENTS:	MODELING OPTIONS:		COMPANY NAME:	
Figure 14 Trajectory Frequency Distribution 100 meter height 50 miles downwind	2001 CALMET Wind Fields		Epsilon Associates, Inc.	
			MODELER: Epsilon Associates, Inc.	Epsilon ASSOCIATES INC.
	OUTPUT TYPE: FREQ	RECEPTORS:		
	MAX:	UNITS: % of Time	DATE: July 29, 2010	PROJECT NO.: 2876

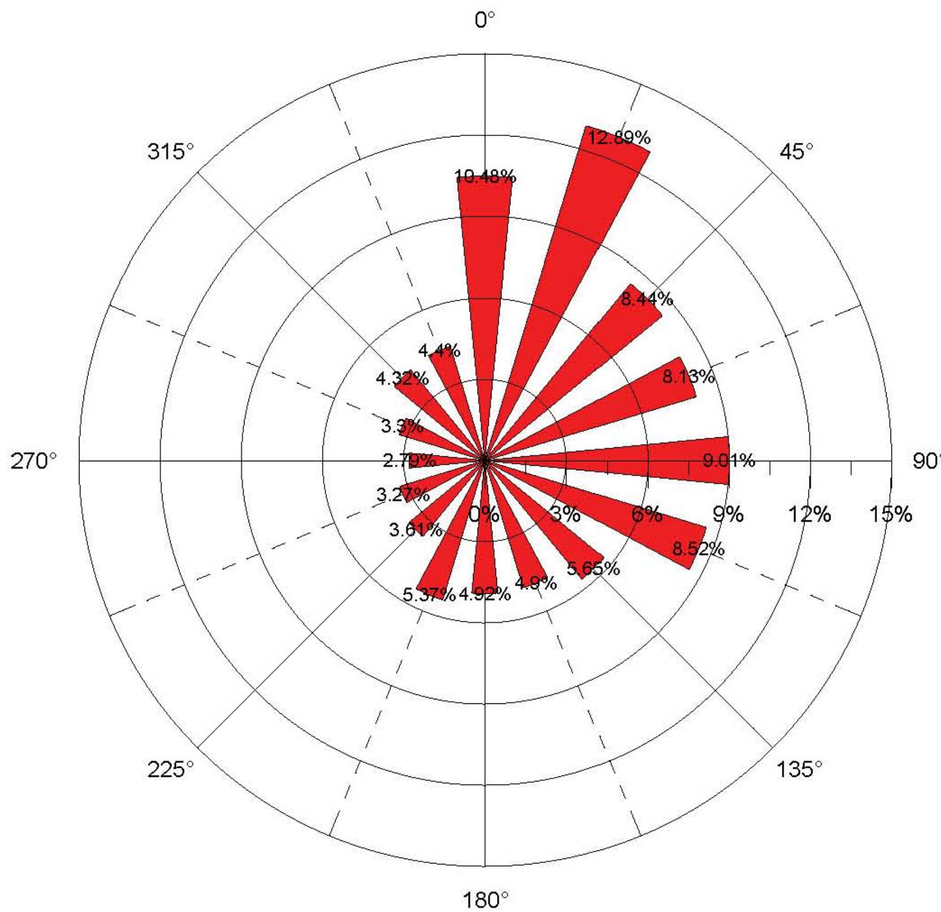
Appendix D
CALMET Trajectory Roses for 200 m Elevation

This appendix contains 14 plots containing trajectory roses for 2001, for trajectories initiated at the Pilgrim Station at an elevation of 200 m above the surface. The hourly wind fields that are used have been calculated by CALMET based on observations within a 124 by 124 mile domain.

Each plot is for a different downwind distance: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 20, 30, 40, and 50 miles.

PROJECT TITLE:

Hanna Pilgrim Trajectory Frequency Distribution
Privileged and Confidential Attorney Work Product



COMMENTS:

Figure 1
Trajectory Frequency Distribution

200 meter height
1 mile downwind

MODELING OPTIONS:

2001 CALMET Wind Fields

COMPANY NAME:

Epsilon Associates, Inc.

MODELER:

Epsilon Associates, Inc.

Epsilon ASSOCIATES INC.

OUTPUT TYPE:

FREQ

RECEPTORS:

MAX:

UNITS:

% of Time

DATE:

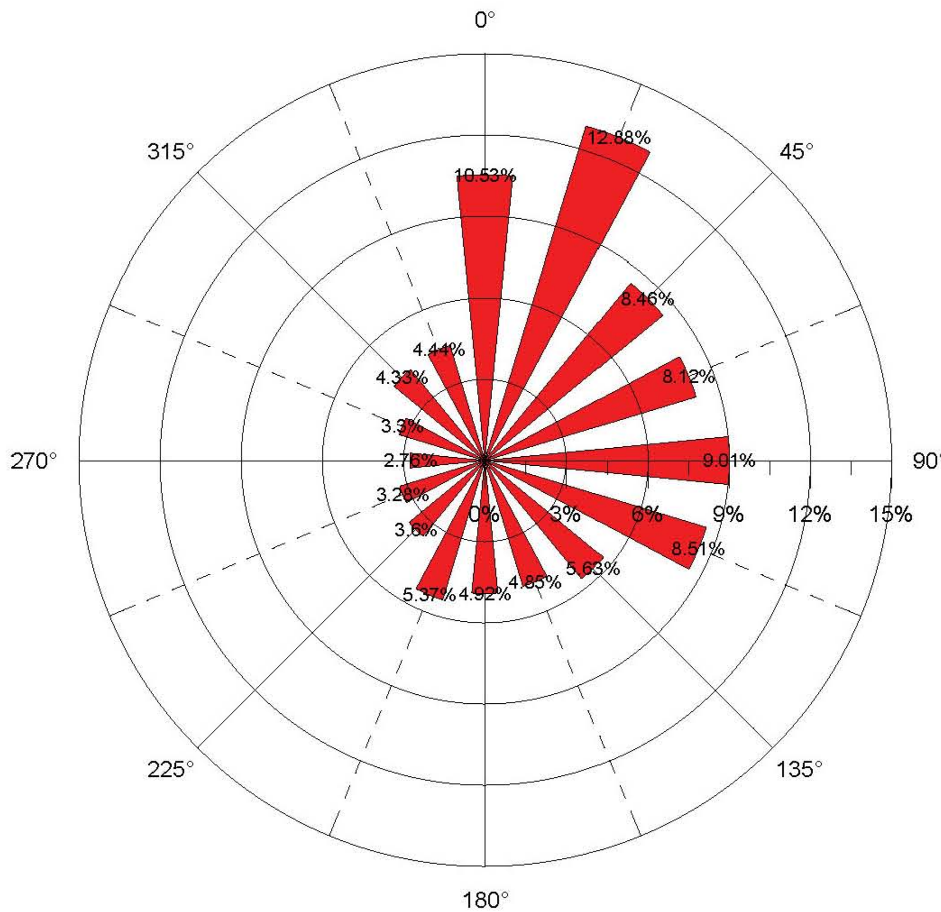
July 29, 2010

PROJECT NO.:

2876

PROJECT TITLE:

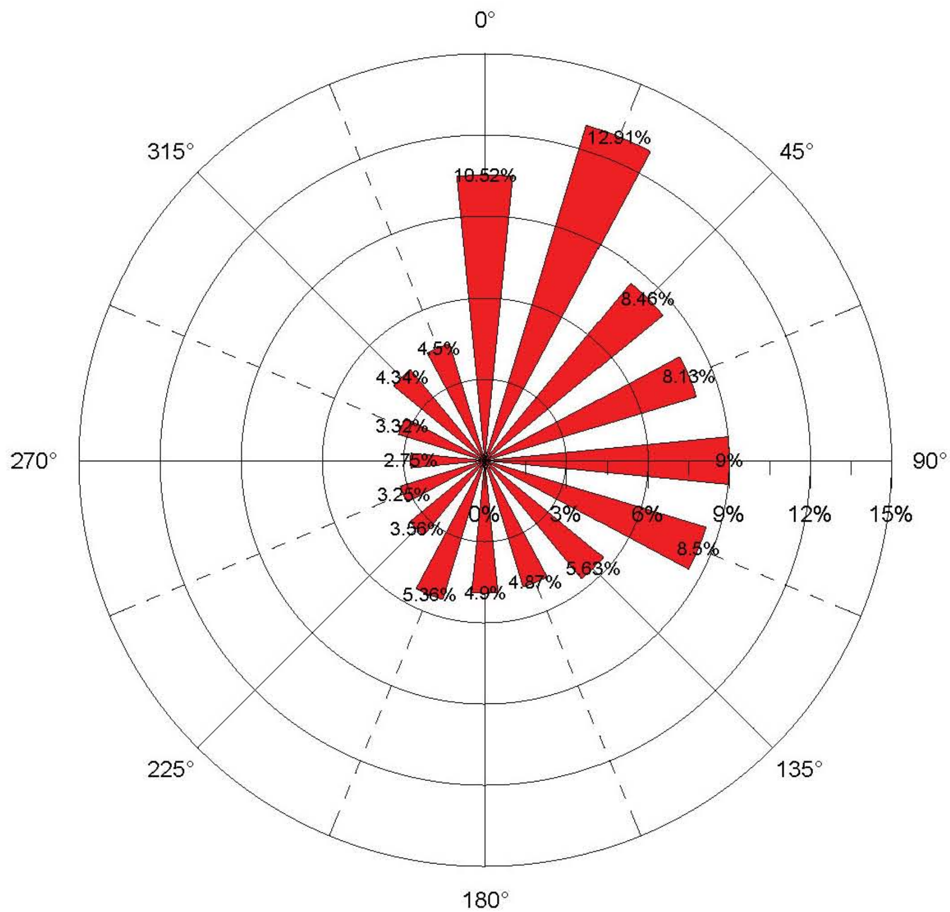
Hanna Pilgrim Trajectory Frequency Distribution
Privileged and Confidential Attorney Work Product



COMMENTS: Figure 2 Trajectory Frequency Distribution 200 meter height 2 miles downwind	**MODELING OPTIONS:** 2001 CALMET Wind Fields	**COMPANY NAME:** Epsilon Associates, Inc.	
		MODELER: Epsilon Associates, Inc.	Epsilon ASSOCIATES INC.
	OUTPUT TYPE: FREQ	**RECEPTORS:**	
	MAX:	**UNITS:** % of Time	**DATE:** July 29, 2010
			PROJECT NO.: 2876

PROJECT TITLE:

Hanna Pilgrim Trajectory Frequency Distribution
Privileged and Confidential Attorney Work Product



COMMENTS:

Figure 3
Trajectory Frequency
Distribution

200 meter height
3 miles downwind

MODELING OPTIONS:

2001 CALMET Wind Fields

COMPANY NAME:

Epsilon Associates, Inc.

MODELER:

Epsilon Associates, Inc.

Epsilon ASSOCIATES INC.

OUTPUT TYPE: FREQ

RECEPTORS:

MAX:

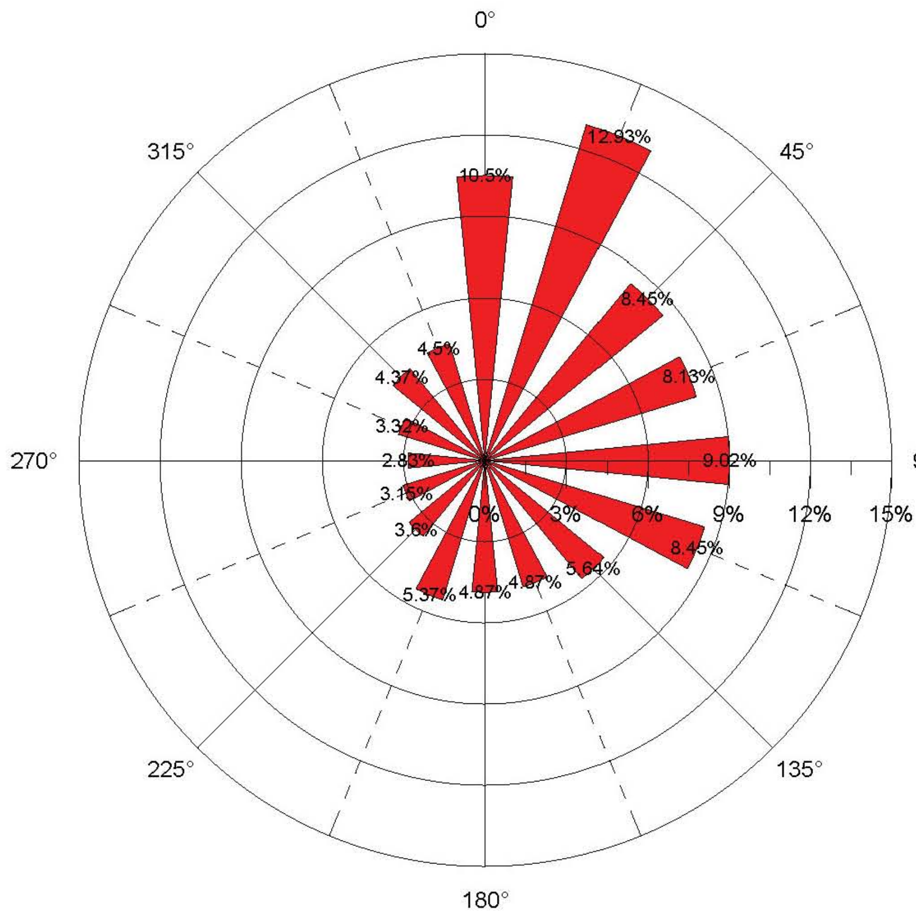
UNITS: % of Time

DATE: July 29, 2010

PROJECT NO.: 2876

PROJECT TITLE:

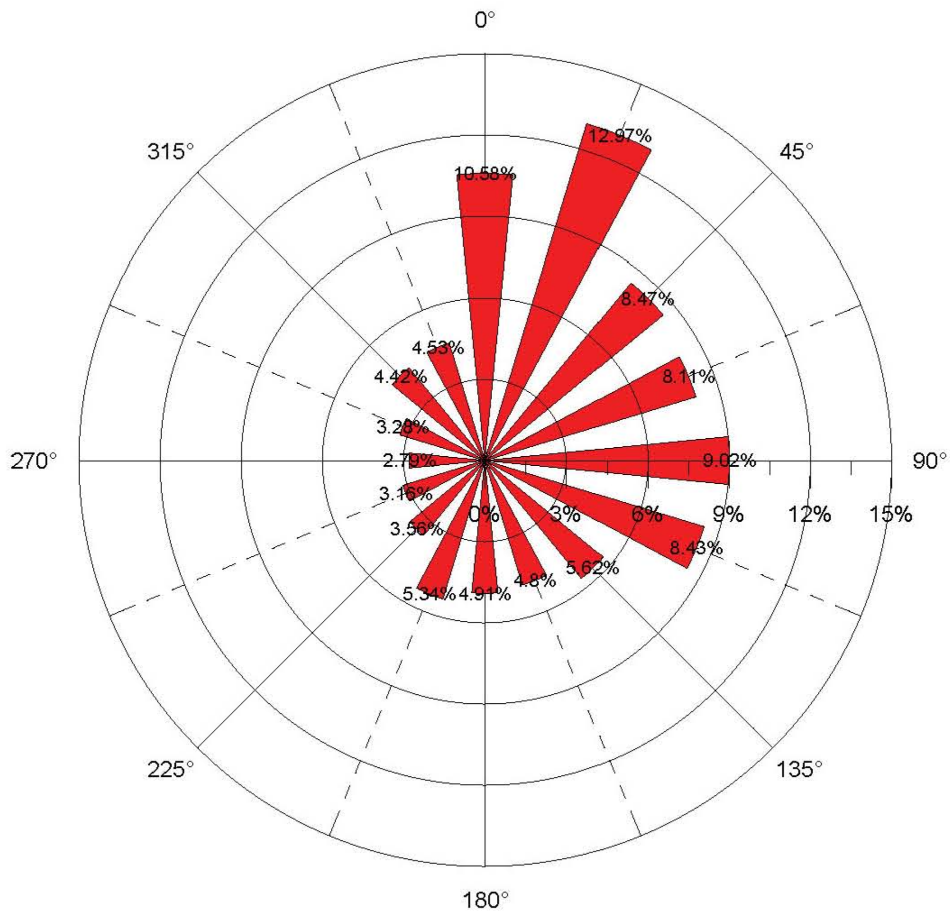
Hanna Pilgrim Trajectory Frequency Distribution
Privileged and Confidential Attorney Work Product



COMMENTS:	MODELING OPTIONS:		COMPANY NAME:	
Figure 4 Trajectory Frequency Distribution 200 meter height 4 miles downwind	2001 CALMET Wind Fields		Epsilon Associates, Inc.	
			MODELER: Epsilon Associates, Inc.	Epsilon ASSOCIATES INC.
	OUTPUT TYPE: FREQ	RECEPTORS:		
	MAX:	UNITS: % of Time	DATE: July 29, 2010	PROJECT NO.: 2876

PROJECT TITLE:

Hanna Pilgrim Trajectory Frequency Distribution
Privileged and Confidential Attorney Work Product



COMMENTS:

Figure 5
Trajectory Frequency Distribution

200 meter height
5 miles downwind

MODELING OPTIONS: 2001 CALMET Wind Fields

COMPANY NAME: Epsilon Associates, Inc.

MODELER: Epsilon Associates, Inc.

OUTPUT TYPE: FREQ

RECEPTORS:

MAX:

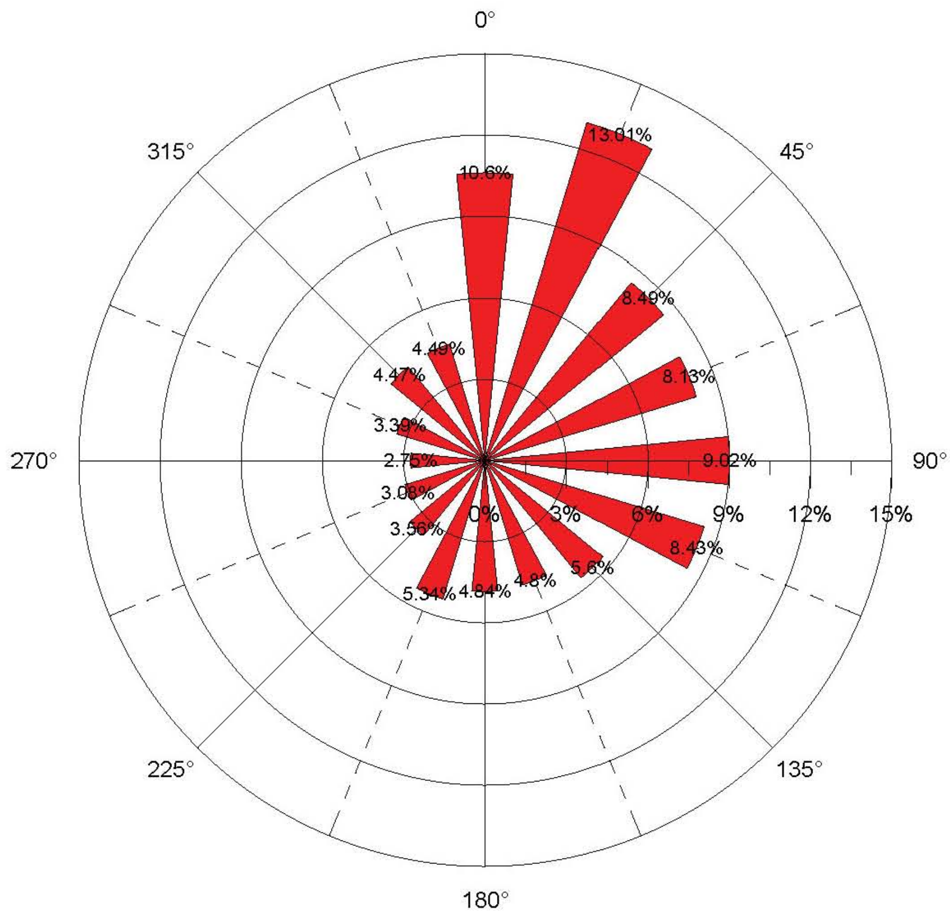
UNITS: % of Time

DATE: July 29, 2010

PROJECT NO.: 2876

PROJECT TITLE:

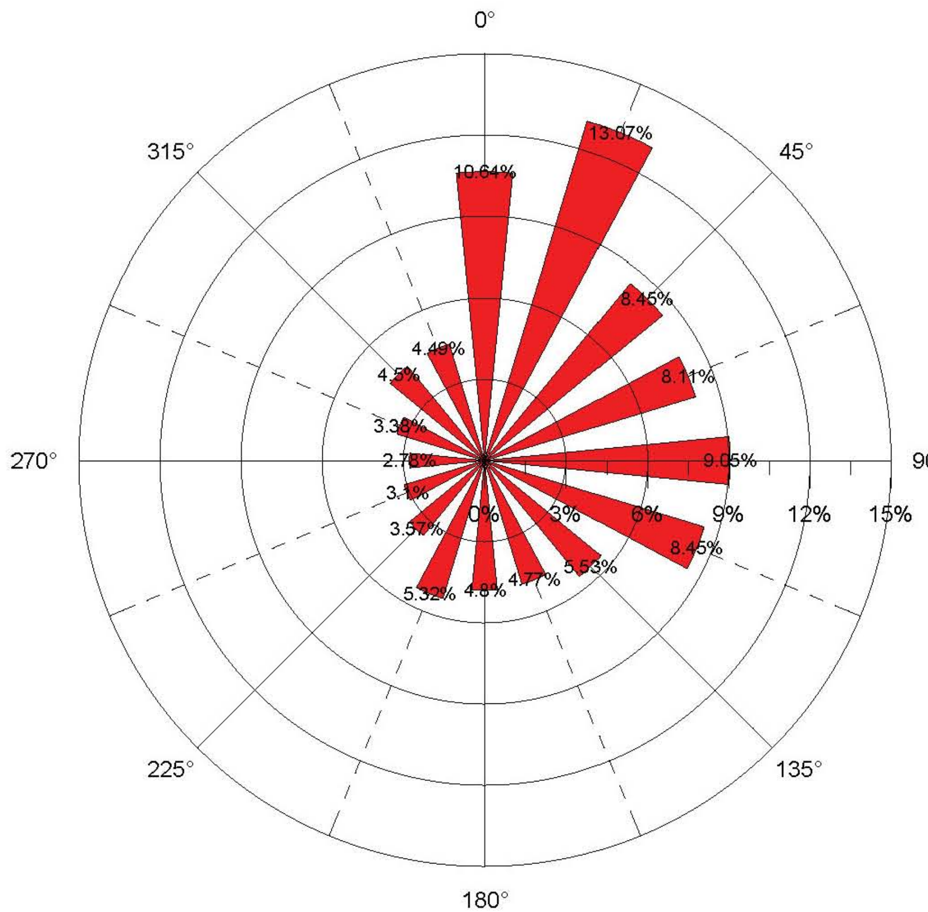
Hanna Pilgrim Trajectory Frequency Distribution
Privileged and Confidential Attorney Work Product



COMMENTS:	MODELING OPTIONS:		COMPANY NAME:	
Figure 6 Trajectory Frequency Distribution 200 meter height 6 miles downwind	2001 CALMET Wind Fields		Epsilon Associates, Inc.	
			MODELER: Epsilon Associates, Inc.	Epsilon ASSOCIATES INC.
	OUTPUT TYPE: FREQ	RECEPTORS:		
	MAX:	UNITS: % of Time	DATE: July 29, 2010	PROJECT NO.: 2876

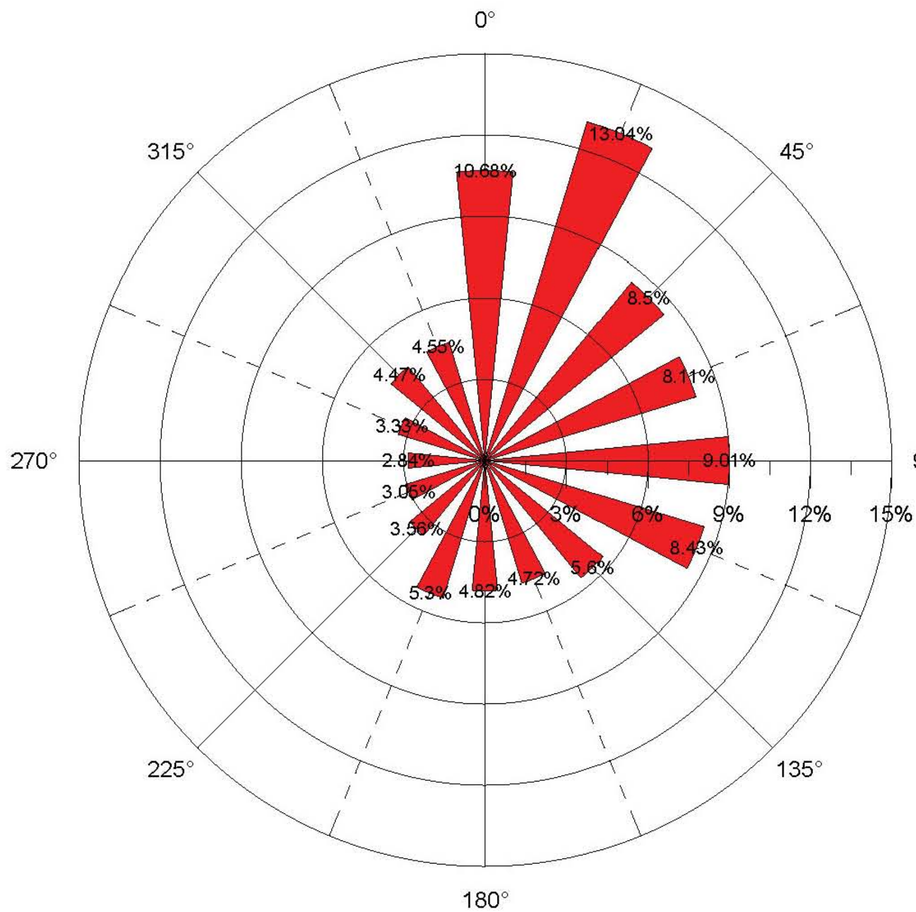
PROJECT TITLE:

Hanna Pilgrim Trajectory Frequency Distribution
Privileged and Confidential Attorney Work Product



COMMENTS:	MODELING OPTIONS:		COMPANY NAME:	
Figure 7 Trajectory Frequency Distribution 200 meter height 7 miles downwind	2001 CALMET Wind Fields		Epsilon Associates, Inc.	
			MODELER: Epsilon Associates, Inc.	Epsilon ASSOCIATES INC.
	OUTPUT TYPE: FREQ	RECEPTORS:		
	MAX:	UNITS: % of Time	DATE: July 29, 2010	PROJECT NO.: 2876

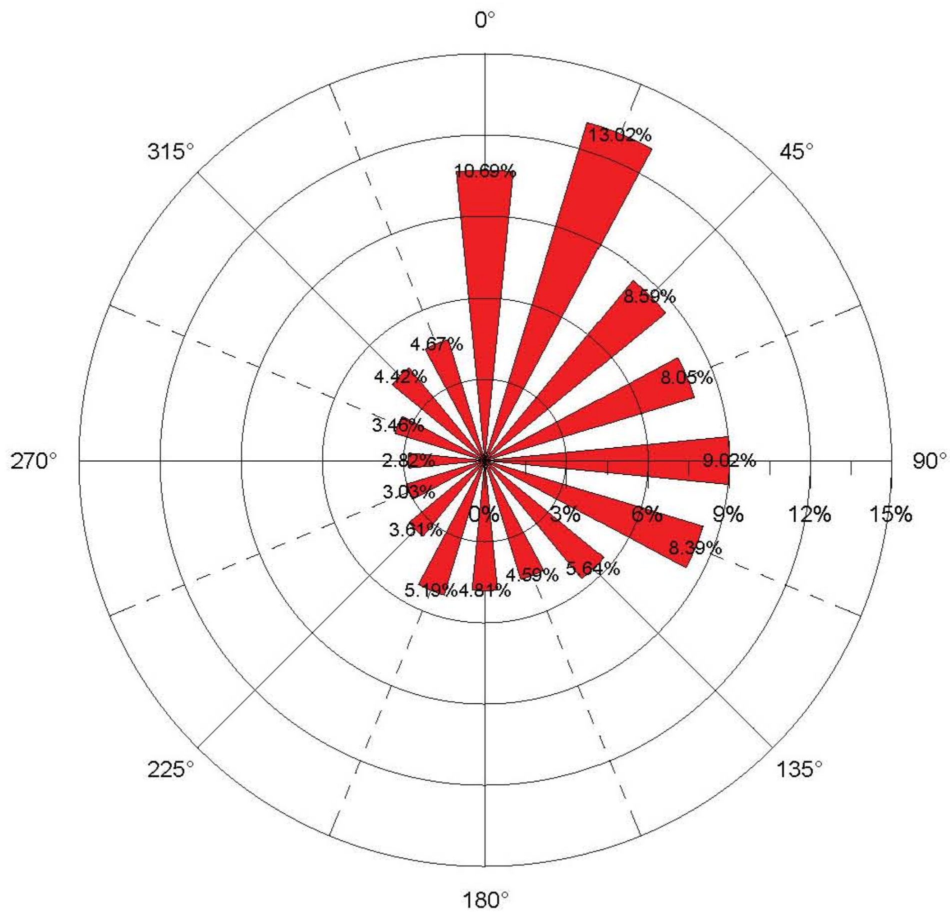
PROJECT TITLE:
Hanna Pilgrim Trajectory Frequency Distribution
Privileged and Confidential Attorney Work Product



COMMENTS:	MODELING OPTIONS:		COMPANY NAME:	
Figure 8 Trajectory Frequency Distribution 200 meter height 8 miles downwind	2001 CALMET Wind Fields		Epsilon Associates, Inc.	
			MODELER: Epsilon Associates, Inc.	Epsilon ASSOCIATES INC.
	OUTPUT TYPE: FREQ	RECEPTORS:		
	MAX:	UNITS: % of Time	DATE: July 29, 2010	PROJECT NO.: 2876

PROJECT TITLE:

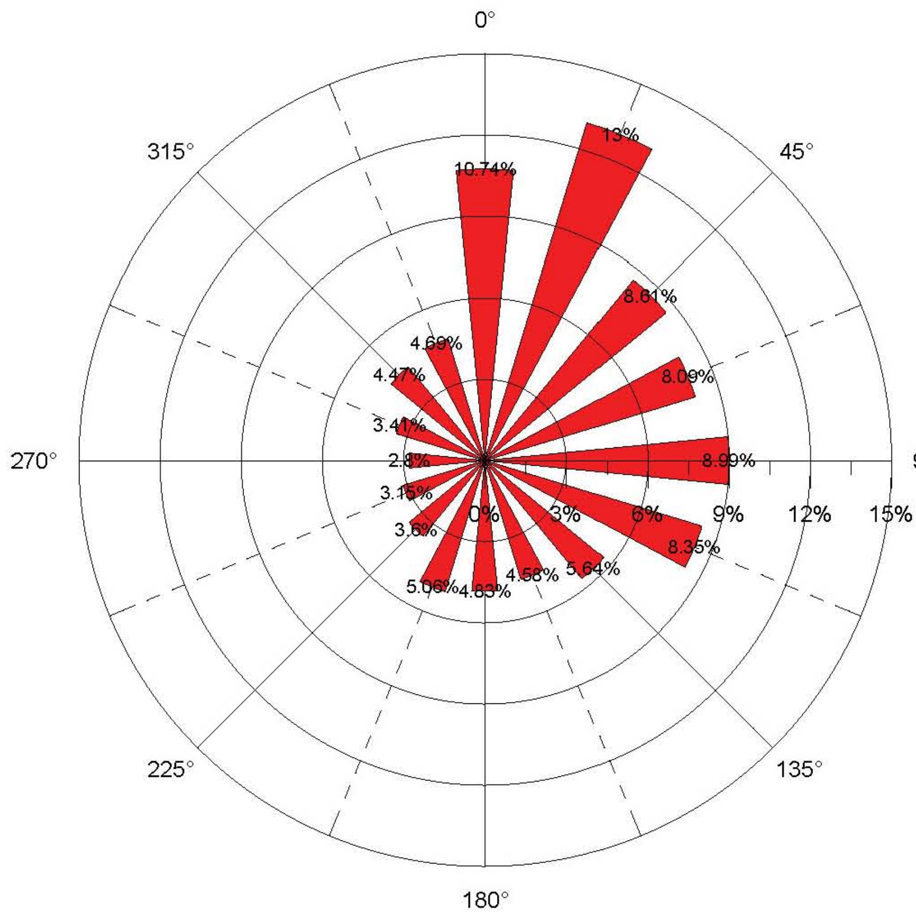
Hanna Pilgrim Trajectory Frequency Distribution
Privileged and Confidential Attorney Work Product



COMMENTS: Figure 9 Trajectory Frequency Distribution 200 meter height 9 miles downwind	MODELING OPTIONS: 2001 CALMET Wind Fields	COMPANY NAME: Epsilon Associates, Inc.	
		MODELER: Epsilon Associates, Inc.	
	OUTPUT TYPE: FREQ	RECEPTORS:	
	MAX:	UNITS: % of Time	DATE: July 29, 2010	PROJECT NO.: 2876

PROJECT TITLE:

Hanna Pilgrim Trajectory Frequency Distribution
Privileged and Confidential Attorney Work Product



COMMENTS:

Figure 10
Trajectory Frequency Distribution

200 meter height
10 miles downwind

MODELING OPTIONS:

2001 CALMET Wind Fields

COMPANY NAME:

Epsilon Associates, Inc.

MODELER:

Epsilon Associates, Inc.

OUTPUT TYPE:

FREQ

RECEPTORS:

MAX:

UNITS:

% of Time

DATE:

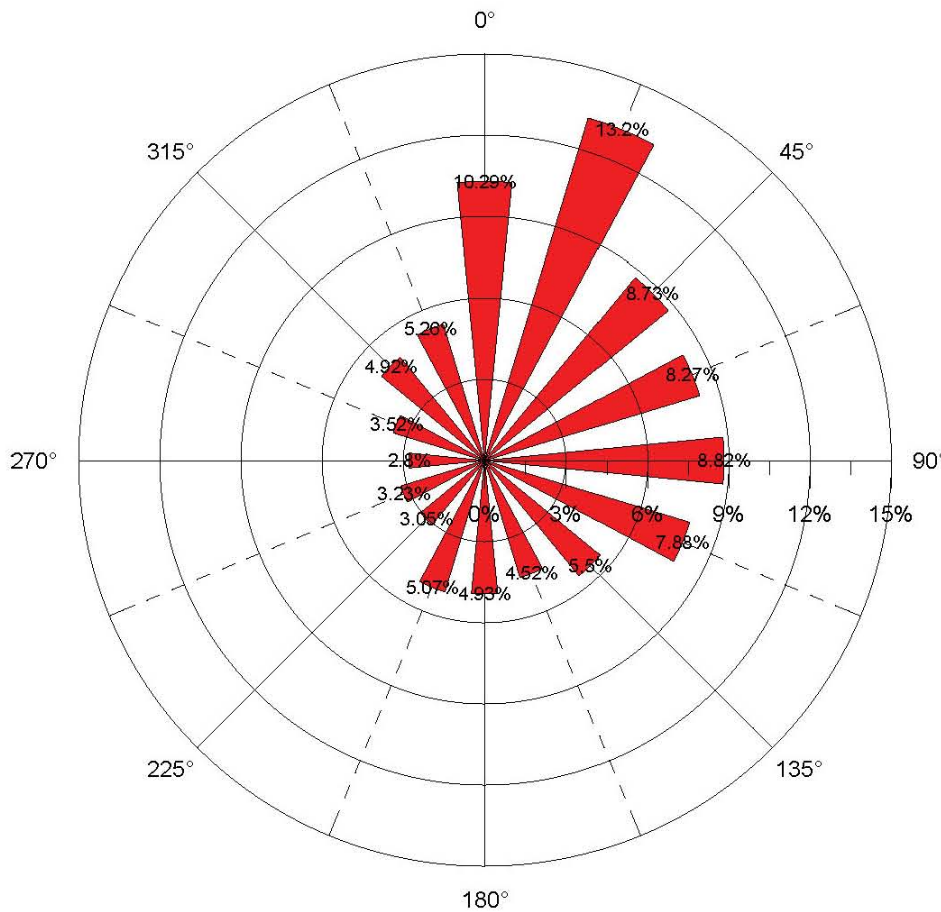
July 29, 2010

PROJECT NO.:

2876

PROJECT TITLE:

Hanna Pilgrim Trajectory Frequency Distribution
Privileged and Confidential Attorney Work Product



COMMENTS:

Figure 11
Trajectory Frequency Distribution

200 meter height
20 miles downwind

MODELING OPTIONS: 2001 CALMET Wind Fields

COMPANY NAME: Epsilon Associates, Inc.

MODELER: Epsilon Associates, Inc.

OUTPUT TYPE: FREQ

RECEPTORS:

MAX:

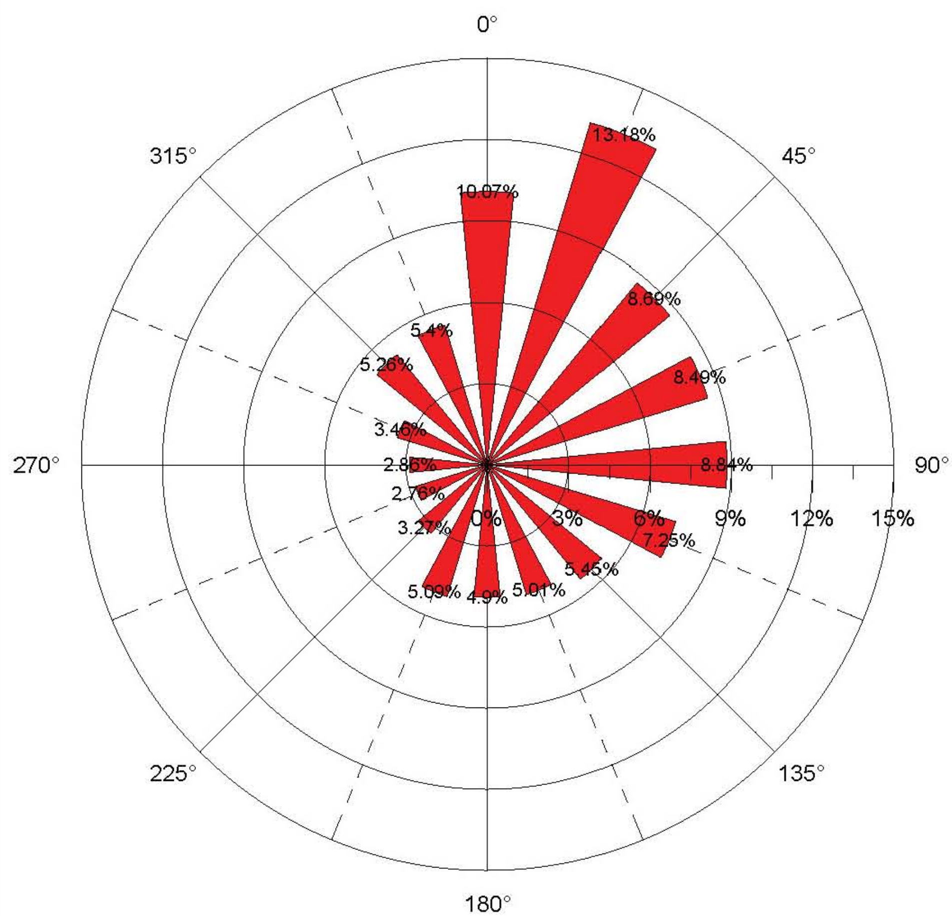
UNITS: % of Time

DATE: July 29, 2010

PROJECT NO.: 2876

PROJECT TITLE:

Hanna Pilgrim Trajectory Frequency Distribution
Privileged and Confidential Attorney Work Product



COMMENTS:

Figure 12
Trajectory Frequency Distribution

200 meter height
30 miles downwind

MODELING OPTIONS: 2001 CALMET Wind Fields

COMPANY NAME: Epsilon Associates, Inc.

MODELER: Epsilon Associates, Inc.

OUTPUT TYPE: FREQ

RECEPTORS:

MAX:

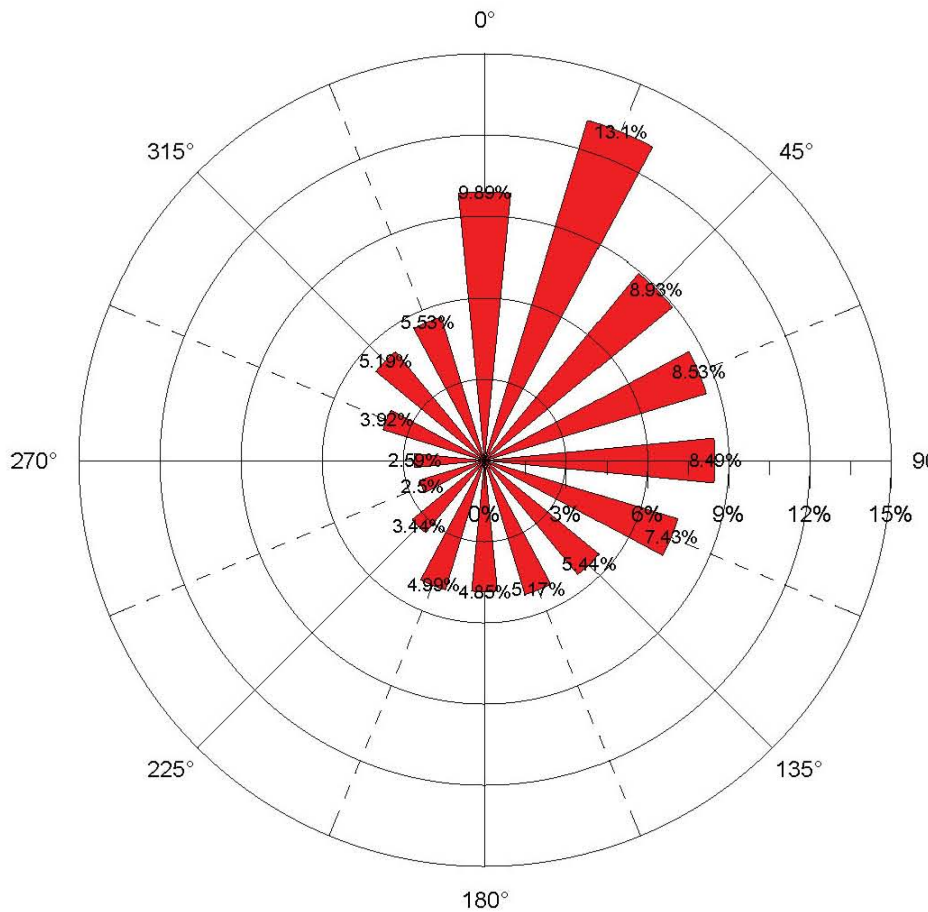
UNITS: % of Time

DATE: July 29, 2010

PROJECT NO.: 2876

PROJECT TITLE:

Hanna Pilgrim Trajectory Frequency Distribution
Privileged and Confidential Attorney Work Product



COMMENTS:

Figure 13
Trajectory Frequency Distribution

200 meter height
40 miles downwind

MODELING OPTIONS:

2001 CALMET Wind Fields

COMPANY NAME:

Epsilon Associates, Inc.

MODELER:

Epsilon Associates, Inc.

Epsilon ASSOCIATES INC.

OUTPUT TYPE: FREQ

RECEPTORS:

MAX:

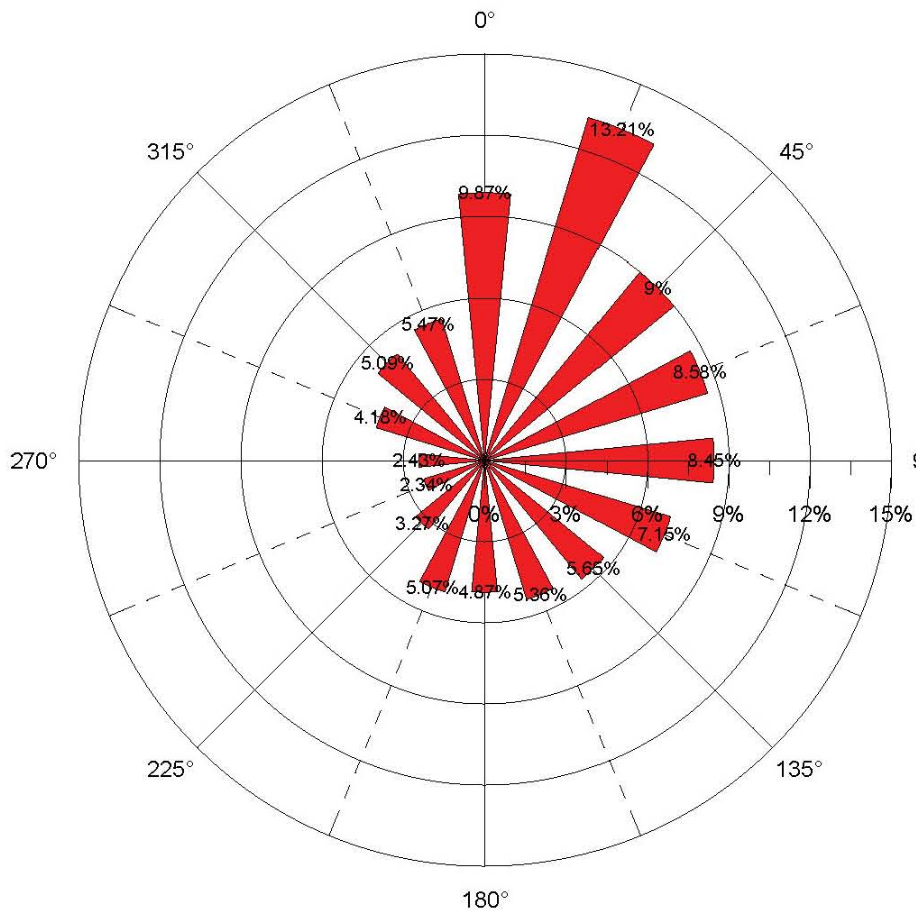
UNITS: % of Time

DATE: July 29, 2010

PROJECT NO.: 2876

PROJECT TITLE:

Hanna Pilgrim Trajectory Frequency Distribution
Privileged and Confidential Attorney Work Product



COMMENTS: Figure 14 Trajectory Frequency Distribution 200 meter height 50 miles downwind	MODELING OPTIONS: 2001 CALMET Wind Fields		COMPANY NAME: Epsilon Associates, Inc.	
			MODELER: Epsilon Associates, Inc.	Epsilon ASSOCIATES INC.
	OUTPUT TYPE: FREQ	RECEPTORS:		
	MAX:	UNITS: % of Time	DATE: July 29, 2010	PROJECT NO.: 2876

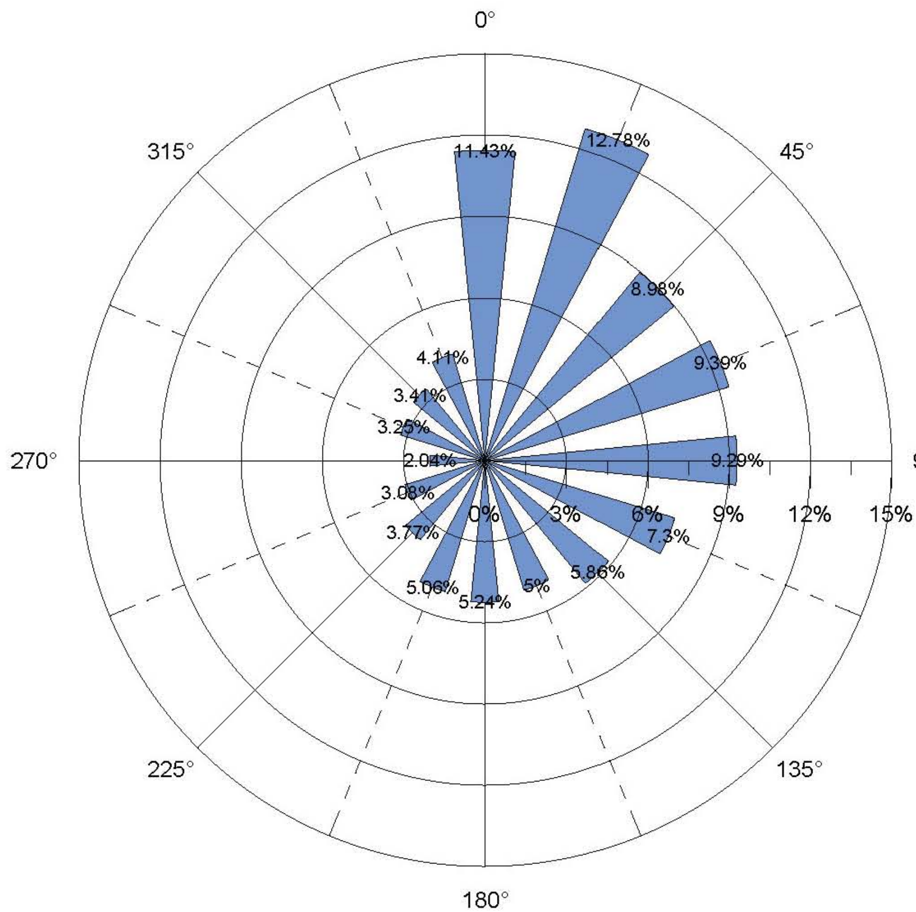
Appendix E
CALMET Trajectory Roses for 500 m Elevation

This appendix contains 14 plots containing trajectory roses for 2001, for trajectories initiated at the Pilgrim Station at an elevation of 500 m above the surface. The hourly wind fields that are used have been calculated by CALMET based on observations within a 124 by 124 mile domain.

Each plot is for a different downwind distance: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 20, 30, 40, and 50 miles.

PROJECT TITLE:

Hanna Pilgrim Trajectory Frequency Distribution
Privileged and Confidential Attorney Work Product



COMMENTS:

Figure 1
Trajectory Frequency
Distribution

500 meter height
1 mile downwind

MODELING OPTIONS:

2001 CALMET Wind Fields

COMPANY NAME:

Epsilon Associates, Inc.

MODELER:

Epsilon Associates, Inc.

OUTPUT TYPE: FREQ

RECEPTORS:

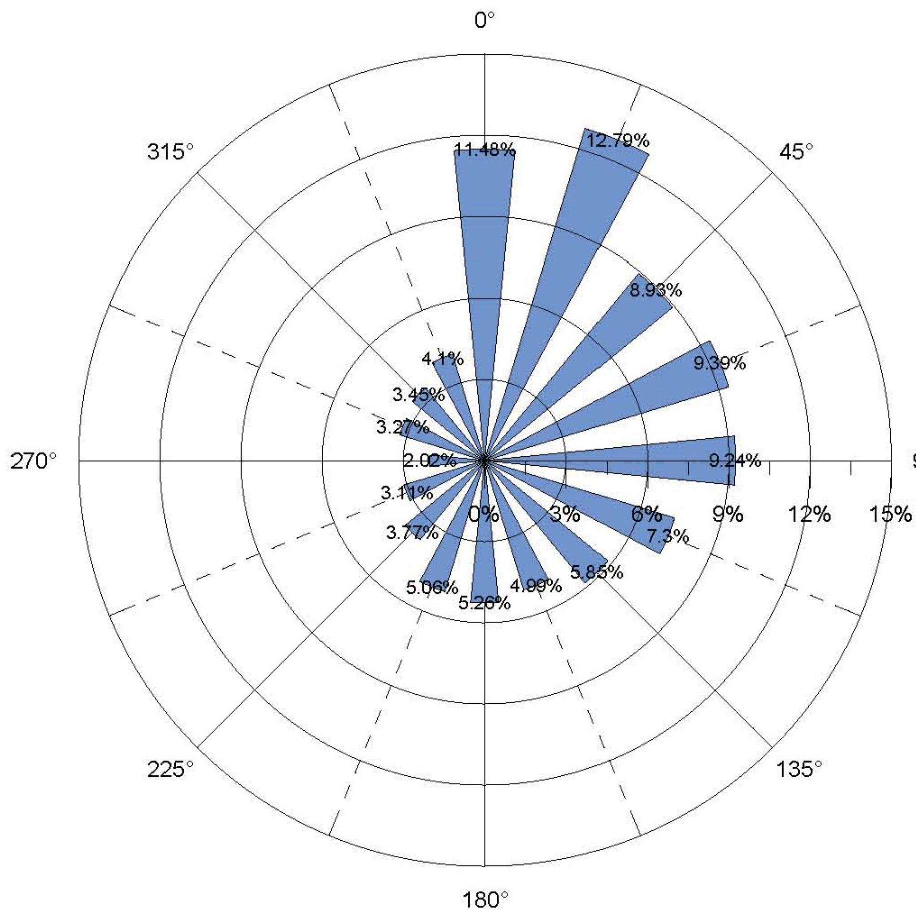
MAX:

UNITS: % of Time

DATE: July 29, 2010

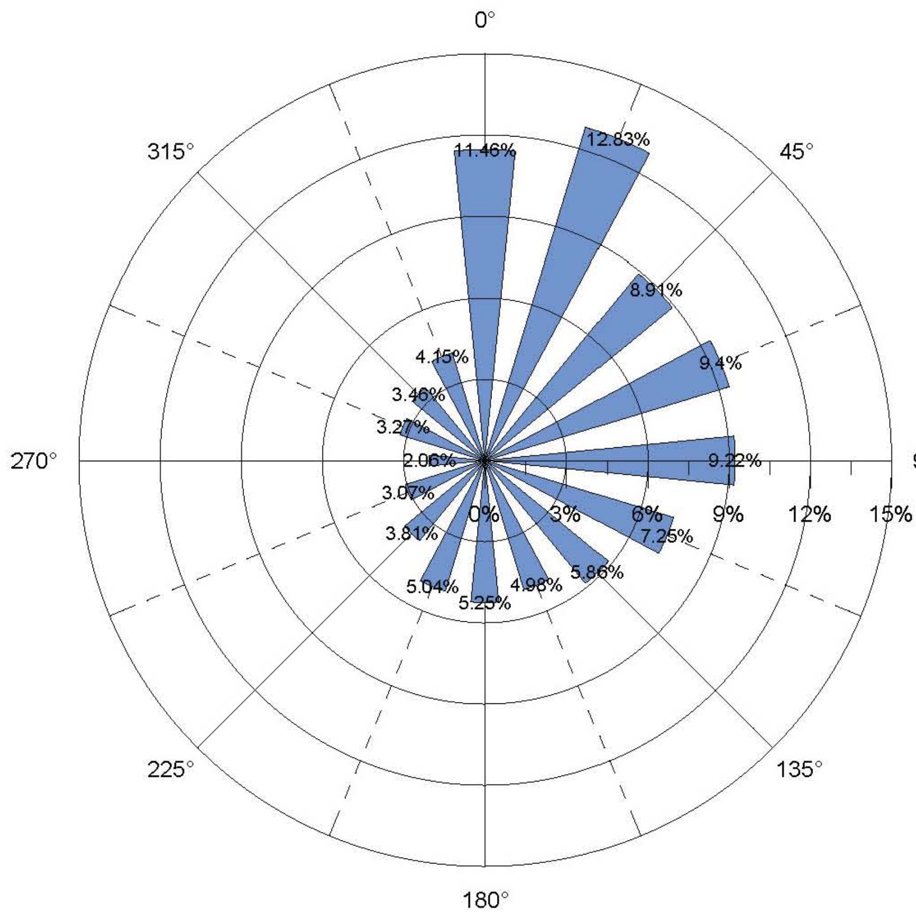
PROJECT NO.: 2876

PROJECT TITLE:
Hanna Pilgrim Trajectory Frequency Distribution
Privileged and Confidential Attorney Work Product



COMMENTS: Figure 2 Trajectory Frequency Distribution 500 meter height 2 miles downwind	MODELING OPTIONS: 2001 CALMET Wind Fields		COMPANY NAME: Epsilon Associates, Inc.	
			MODELER: Epsilon Associates, Inc.	Epsilon ASSOCIATES INC.
	OUTPUT TYPE: FREQ	RECEPTORS:		
	MAX:	UNITS: % of Time	DATE: July 29, 2010	PROJECT NO.: 2876

PROJECT TITLE:
Hanna Pilgrim Trajectory Frequency Distribution
Privileged and Confidential Attorney Work Product



COMMENTS:	MODELING OPTIONS:		COMPANY NAME:	
Figure 3 Trajectory Frequency Distribution 500 meter height 3 miles downwind	2001 CALMET Wind Fields		Epsilon Associates, Inc.	
			MODELER: Epsilon Associates, Inc.	Epsilon ASSOCIATES INC.
	OUTPUT TYPE: FREQ	RECEPTORS:		
	MAX:	UNITS: % of Time	DATE: July 29, 2010	PROJECT NO.: 2876

PROJECT TITLE:

Hanna Pilgrim Trajectory Frequency Distribution
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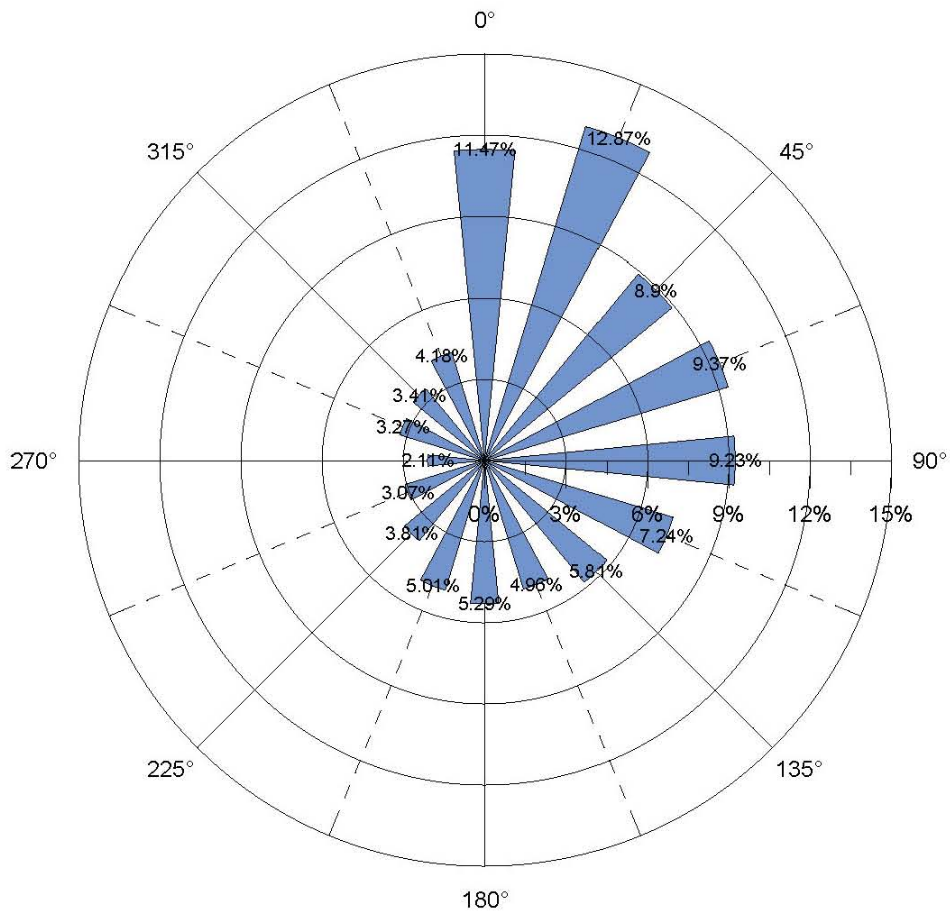

COMMENTS:	MODELING OPTIONS:		COMPANY NAME:	
Figure 4 Trajectory Frequency Distribution 500 meter height 4 miles downwind	2001 CALMET Wind Fields		Epsilon Associates, Inc.	
			MODELER: Epsilon Associates, Inc.	Epsilon ASSOCIATES INC.
	OUTPUT TYPE: FREQ	RECEPTORS:		
	MAX:	UNITS: % of Time	DATE: July 29, 2010	PROJECT NO.: 2876

PROJECT TITLE:

Hanna Pilgrim Trajectory Frequency Distribution
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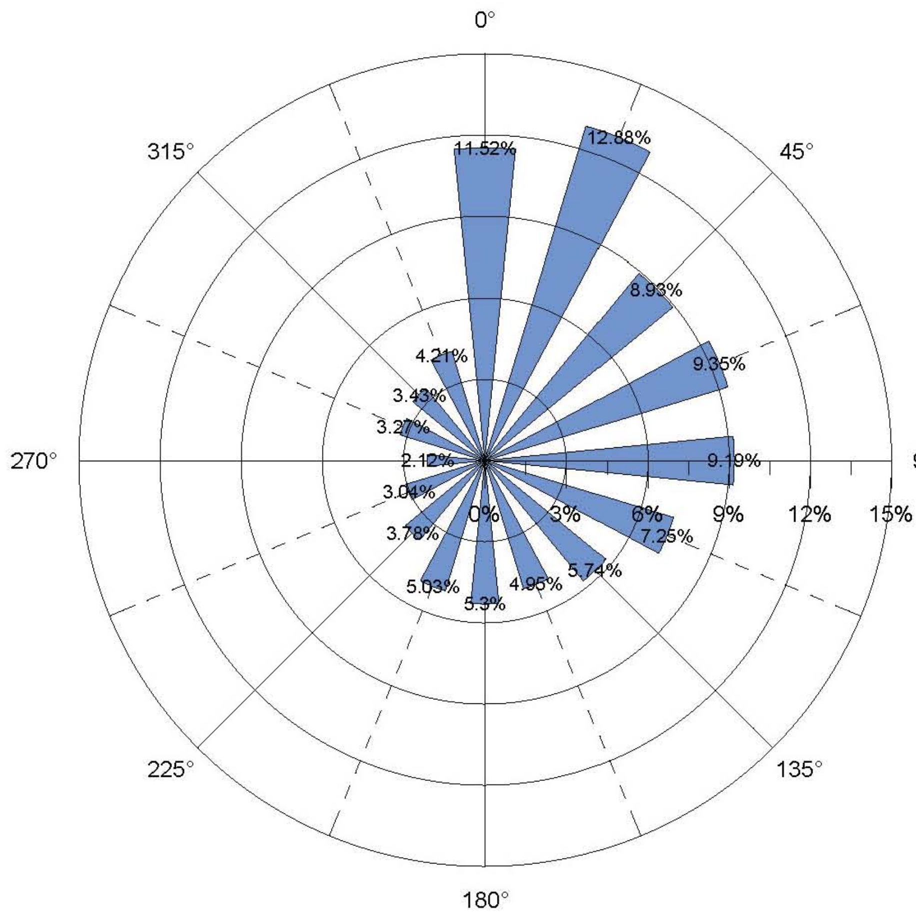

COMMENTS: Figure 5 Trajectory Frequency Distribution 500 meter height 5 miles downwind	**MODELING OPTIONS:** 2001 CALMET Wind Fields		**COMPANY NAME:** Epsilon Associates, Inc.
			MODELER: Epsilon Associates, Inc.
	OUTPUT TYPE: FREQ	**RECEPTORS:**	
	MAX:	**UNITS:** % of Time	**DATE:** July 29, 2010
			PROJECT NO.: 2876

PROJECT TITLE:

Hanna Pilgrim Trajectory Frequency Distribution
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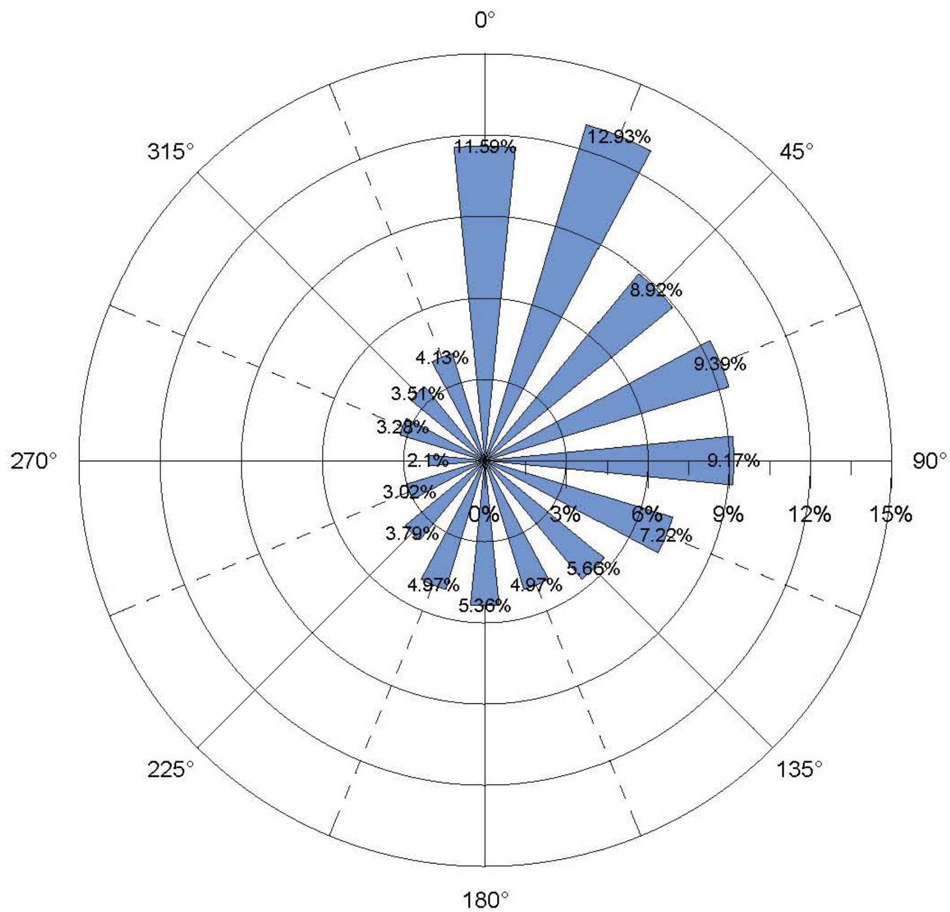

COMMENTS:	MODELING OPTIONS:		COMPANY NAME:	
Figure 6 Trajectory Frequency Distribution 500 meter height 6 miles downwind	2001 CALMET Wind Fields		Epsilon Associates, Inc.	
			MODELER: Epsilon Associates, Inc.	Epsilon ASSOCIATES INC.
	OUTPUT TYPE: FREQ	RECEPTORS:		
	MAX:	UNITS: % of Time	DATE: July 29, 2010	PROJECT NO.: 2876

PROJECT TITLE:

Hanna Pilgrim Trajectory Frequency Distribution
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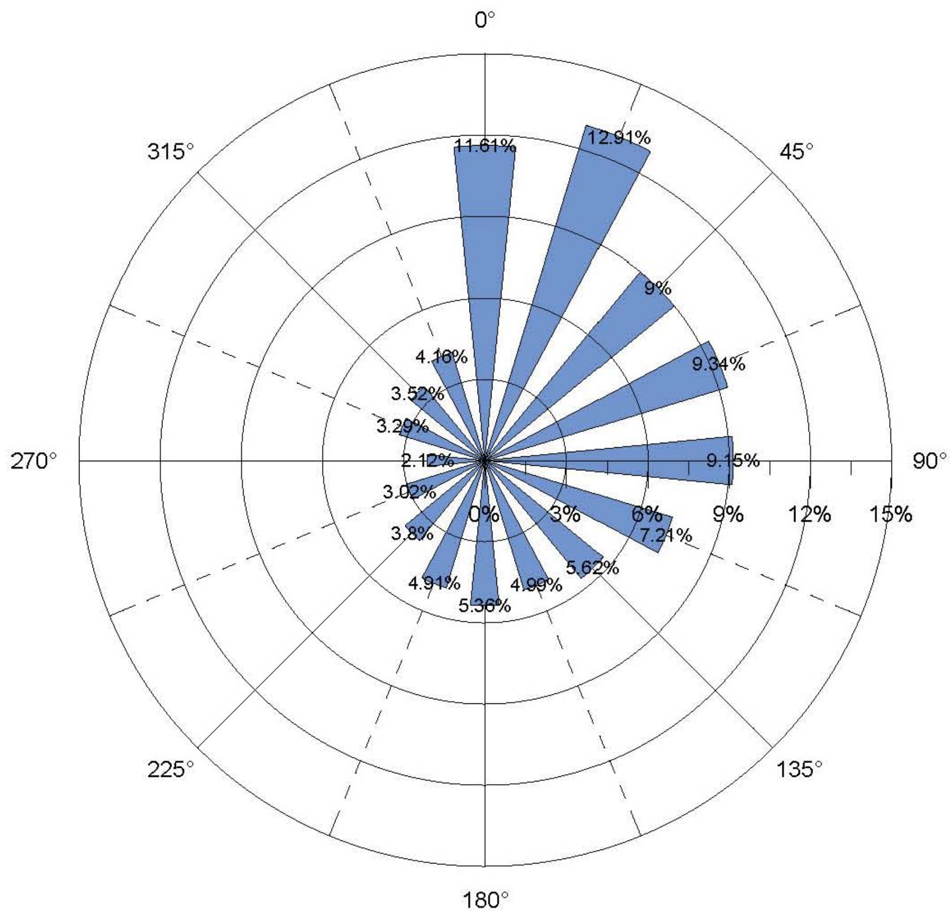

COMMENTS:	MODELING OPTIONS:		COMPANY NAME:	
Figure 7 Trajectory Frequency Distribution 500 meter height 7 miles downwind	2001 CALMET Wind Fields		Epsilon Associates, Inc.	
			MODELER: Epsilon Associates, Inc.	Epsilon ASSOCIATES INC.
	OUTPUT TYPE: FREQ	RECEPTORS:		
	MAX:	UNITS: % of Time	DATE: July 29, 2010	PROJECT NO.: 2876

PROJECT TITLE:

Hanna Pilgrim Trajectory Frequency Distribution
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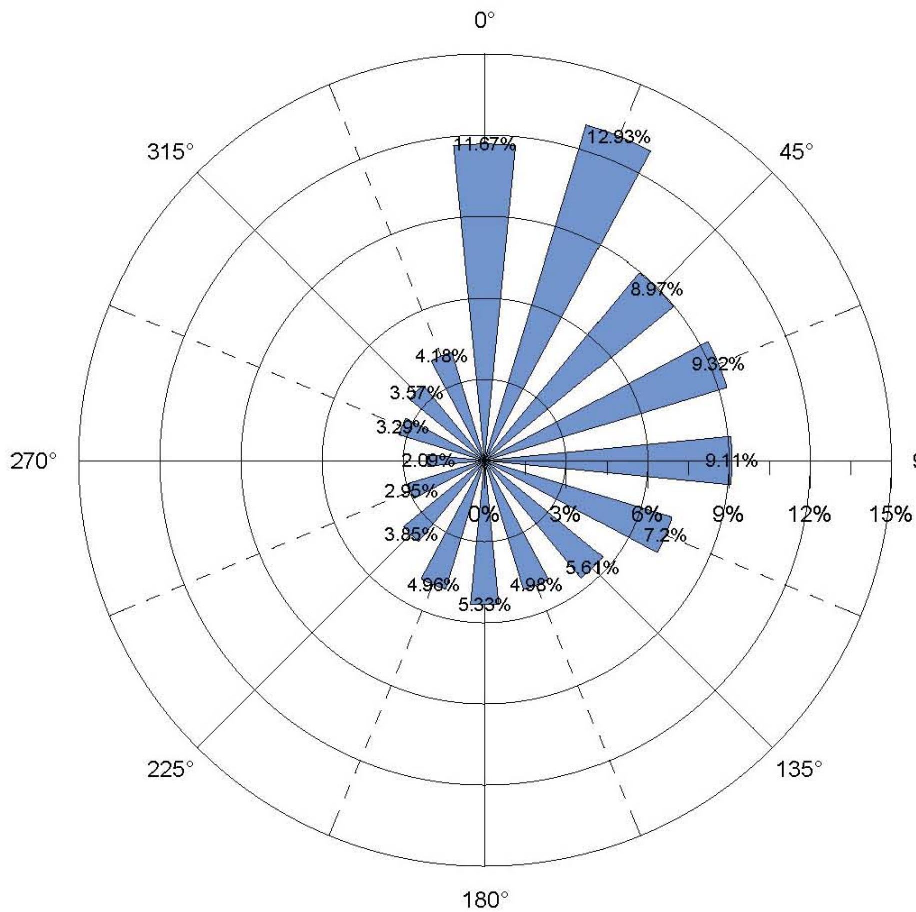

COMMENTS:	MODELING OPTIONS:		COMPANY NAME:	
Figure 8 Trajectory Frequency Distribution 500 meter height 8 miles downwind	2001 CALMET Wind Fields		Epsilon Associates, Inc.	
			MODELER: Epsilon Associates, Inc.	Epsilon Associates Inc.
	OUTPUT TYPE: FREQ	RECEPTORS:		
	MAX:	UNITS: % of Time	DATE: July 29, 2010	PROJECT NO.: 2876

PROJECT TITLE:

Hanna Pilgrim Trajectory Frequency Distribution
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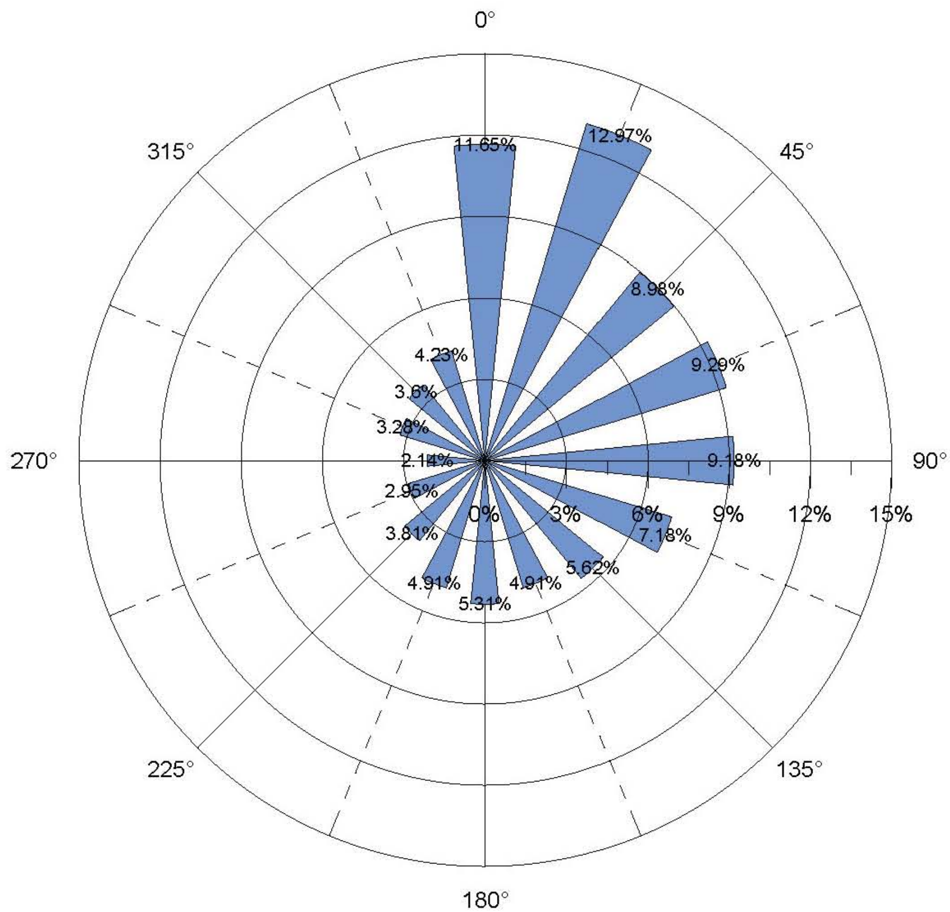

COMMENTS:	MODELING OPTIONS:		COMPANY NAME:	
Figure 9 Trajectory Frequency Distribution 500 meter height 9 miles downwind	2001 CALMET Wind Fields		Epsilon Associates, Inc.	
			MODELER: Epsilon Associates, Inc.	Epsilon ASSOCIATES INC.
	OUTPUT TYPE: FREQ	RECEPTORS:		
	MAX:	UNITS: % of Time	DATE: July 29, 2010	PROJECT NO.: 2876

PROJECT TITLE:

Hanna Pilgrim Trajectory Frequency Distribution
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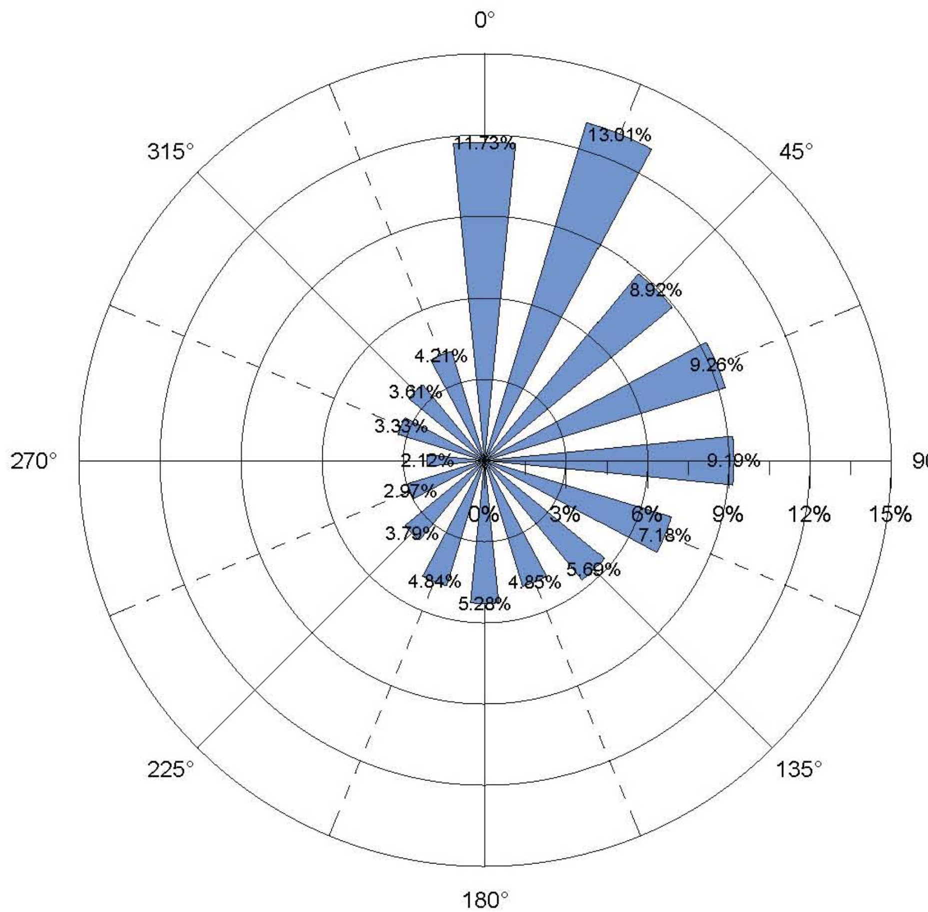

COMMENTS: Figure 10 Trajectory Frequency Distribution 500 meter height 10 miles downwind	**MODELING OPTIONS:** 2001 CALMET Wind Fields		**COMPANY NAME:** Epsilon Associates, Inc.
			MODELER: Epsilon Associates, Inc.
	OUTPUT TYPE: FREQ	**RECEPTORS:**	
	MAX:	**UNITS:** % of Time	**DATE:** July 29, 2010
			PROJECT NO.: 2876

PROJECT TITLE:

Hanna Pilgrim Trajectory Frequency Distribution
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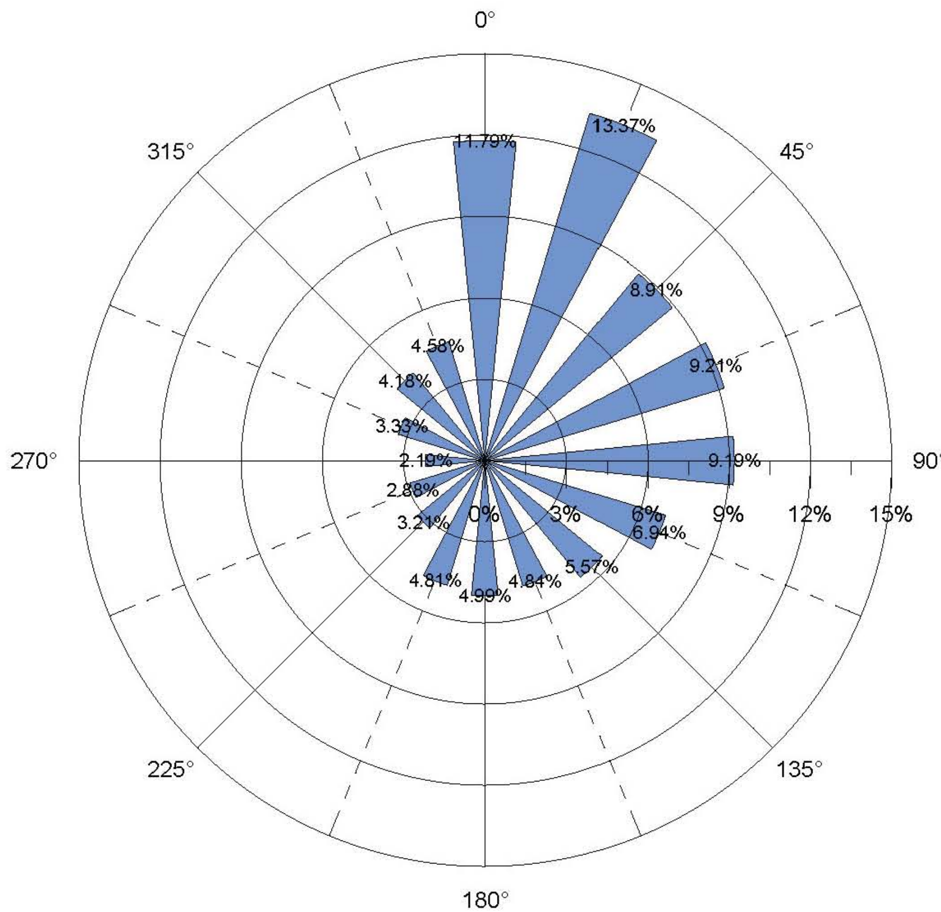

COMMENTS:	MODELING OPTIONS:		COMPANY NAME:	
Figure 11 Trajectory Frequency Distribution 500 meter height 20 miles downwind	2001 CALMET Wind Fields		Epsilon Associates, Inc.	
			MODELER: Epsilon Associates, Inc.	Epsilon Associates Inc.
	OUTPUT TYPE: FREQ	RECEPTORS:		
	MAX:	UNITS: % of Time	DATE: July 29, 2010	PROJECT NO.: 2876

PROJECT TITLE:

Hanna Pilgrim Trajectory Frequency Distribution
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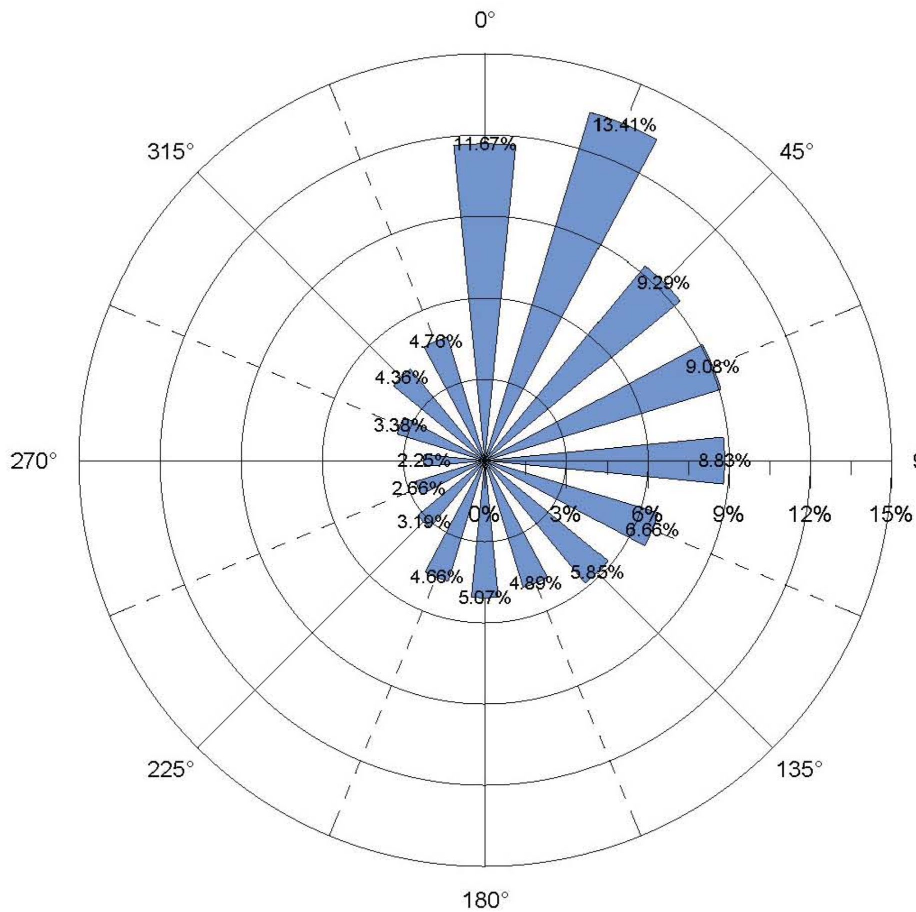

COMMENTS:	MODELING OPTIONS:		COMPANY NAME:	
Figure 12 Trajectory Frequency Distribution 500 meter height 30 miles downwind	2001 CALMET Wind Fields		Epsilon Associates, Inc.	
			MODELER: Epsilon Associates, Inc.	Epsilon Associates Inc.
	OUTPUT TYPE: FREQ	RECEPTORS:		
	MAX:	UNITS: % of Time	DATE: July 29, 2010	PROJECT NO.: 2876

PROJECT TITLE:

Hanna Pilgrim Trajectory Frequency Distribution
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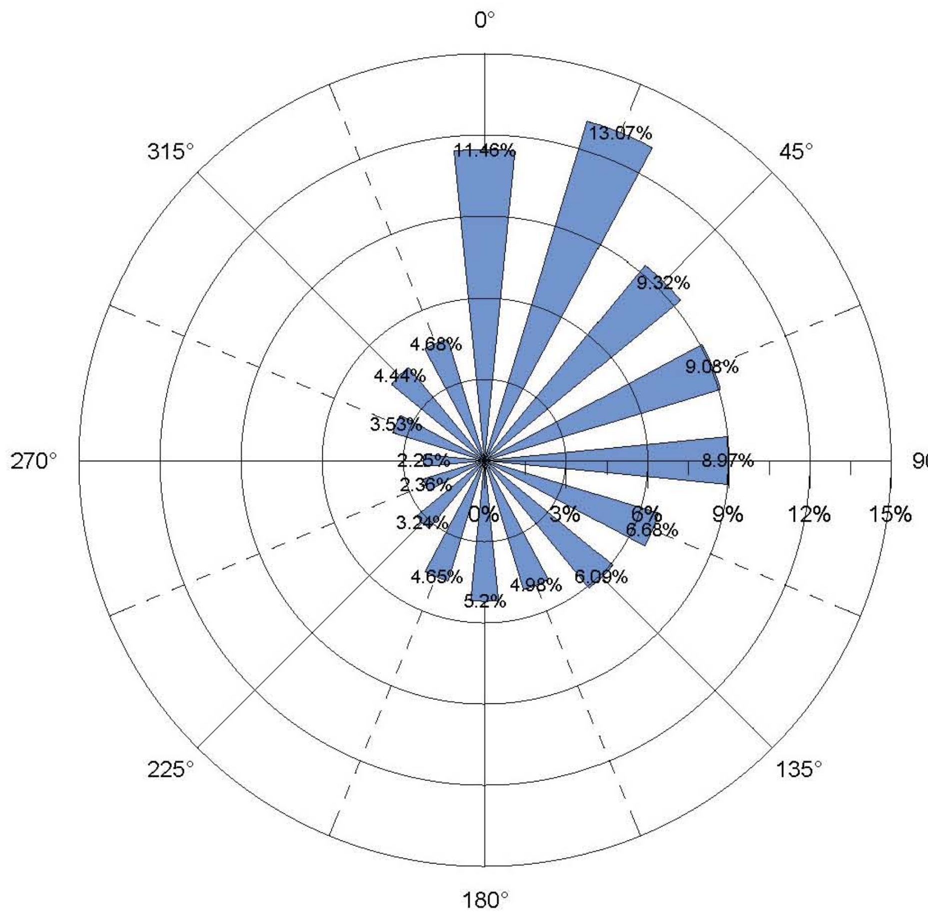

COMMENTS:	MODELING OPTIONS:		COMPANY NAME:	
Figure 13 Trajectory Frequency Distribution 500 meter height 40 miles downwind	2001 CALMET Wind Fields		Epsilon Associates, Inc.	
			MODELER: Epsilon Associates, Inc.	Epsilon ASSOCIATES INC.
	OUTPUT TYPE: FREQ	RECEPTORS:		
	MAX:	UNITS: % of Time	DATE: July 29, 2010	PROJECT NO.: 2876

PROJECT TITLE:
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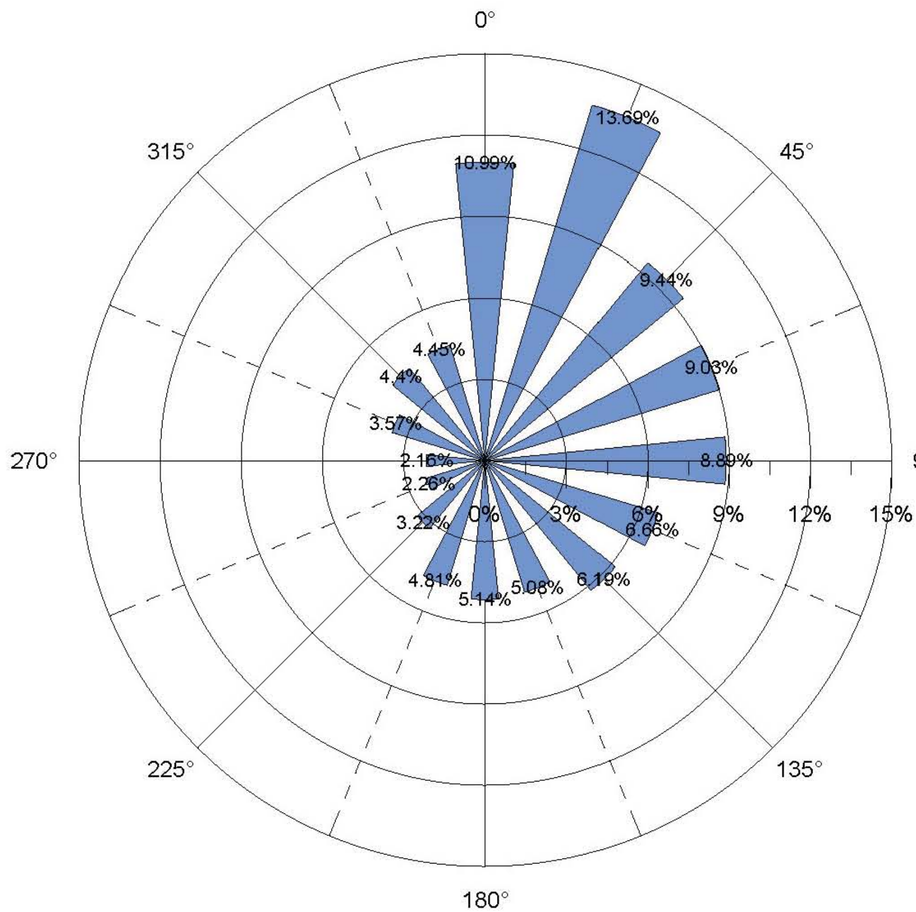

COMMENTS:	MODELING OPTIONS:		COMPANY NAME:	
Figure 14 Trajectory Frequency Distribution 500 meter height 50 miles downwind	2001 CALMET Wind Fields		Epsilon Associates, Inc.	
			MODELER: Epsilon Associates, Inc.	Epsilon ASSOCIATES INC.
	OUTPUT TYPE: FREQ	RECEPTORS:		
	MAX:	UNITS: % of Time	DATE: July 29, 2010	PROJECT NO.: 2876