May 10, 2013

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

Before the Atomic Safety and Licensing Board

In the Matter of	)	
	)	Docket No. 50-443-LR
NextEra Energy Seabrook, LLC	)	
	)	ASLBP No. 10-906-02-LR
(Seabrook Station, Unit 1)	)	

NEXTERA'S MOTION FOR SUMMARY DISPOSITION OF FRIENDS OF THE COAST/NEW ENGLAND COALITION CONTENTION 4D (SAMA ANALYSIS ATMOSPHERIC MODELING)

I. INTRODUCTION

Pursuant to 10 C.F.R. § 2.1205 and the Atomic Safety and Licensing Board's ("ASLB" or the "Board") Initial Scheduling Order (April 4, 2011), NextEra Energy Seabrook, LLC ("NextEra") moves for summary disposition of Friends of the Coast and the New England Coalition's ("Friends/NEC") Contention 4D. NextEra seeks summary disposition on the grounds that no genuine issue of material fact exists and NextEra is entitled to a decision as a matter of law. 10 C.F.R. § 2.710(d)(2). This Motion is supported by (1) a Statement of Material Facts as to which NextEra asserts that there is no genuine dispute (Attachment 1); (2) a Joint Declaration of Dr. Steven R. Hanna and Dr. Kevin R. O'Kula in Support of NextEra's Motion for Summary Disposition of Contention 4D (SAMA Analysis Atmospheric Modeling) ("Joint Decl.") (Attachment 2); (3) a report prepared by Hanna Consultants entitled "Analysis of Annual Wind Roses within about 50 Miles of the Seabrook Station, and Use of CALMET to Calculate the Annual Distribution of Trajectories from the Seabrook Station" ("Wind Rose Report") (Attachment 3); and (4) a report prepared by Dr. O'Kula entitled "Exposure Index Study Using MACCS2 and CALMET: A Sensitivity Study Supporting the Seabrook Station SAMA Analysis" ("EI Report") (Attachment 4).

II. PROCEDURAL BACKGROUND

NextEra applied to the Nuclear Regulatory Commission ("NRC", or the "Commission") for a renewed operating license ("LRA") for Seabrook Station ("Seabrook") in May 2010. Friends/NEC filed a Petition to Intervene and Request for a Hearing ("Petition") on October 20, 2010 raising four contentions, which included, *inter alia*, Contention 4, a multi-part challenge to NextEra's analysis of severe accident mitigation alternatives ("SAMA"). On February 15, 2011, the Board admitted portions of Contention 4, including Contention 4D which concerns SAMA analysis atmospheric modeling.[1]

Contention 4D alleges that NextEra

> use[d] an inappropriate air dispersion model, the straight line Gaussian Plume, and meteorological data inputs that did not accurately predict the geographic dispersion and deposition at Seabrook's coastal location.

Petition at 47. Friends/NEC assert that NextEra should have instead used a more advanced atmospheric dispersion model, such as AERMOD or CALPUFF. Petition at 51-52. They base their contention on the following claims:

> The Gaussian plume model is inappropriate because it assumes that a released radioactive plume travels in a steady straight line, and assumes meteorological conditions that are steady in time and uniform spatially across the study region. *Id.* at 48. It ignores the presence of sea breeze circulations, which dramatically alter air flow patterns. *Id.* at 49. It does not account for "hot spots" of radioactivity along the coast that will result when a plume heads out over water, remains tightly concentrated, and is blown back onto land. *Id.* at 50. MAACS2 should not be used at distances out to 50 miles. *Id.* at 48, 52-53, 58.
>
> The atmospheric model does not model the impact of terrain effects on atmospheric dispersion. Terrain effects can have a highly complex impact on wind field patterns and plume dispersion. *Id.* at 51.

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[1] *NextEra Energy Seabrook, LLC* (Seabrook Station, Unit 1), LBP-11-2, 73 N.R.C. 28, 69-73 (2011), *aff'd*, CLI-12-5, 75 N.R.C. 301, 327-29 (2012). The Commission later explained that the materiality of Friends/NEC's claims were a "close call" not obviously demonstrated, but that it had deferred to the Board's assessment. *FirstEnergy Nuclear Operating Co.* (Davis-Besse Nuclear Power Station, Unit 1), CLI-12-8, 75 N.R.C. 393, 417 & n.138 (2012).

> MACCS2 does not model dispersion close to the source (less than 100 meters away) thereby ignoring resuspension of contamination blowing offsite and affecting deposition in offsite communities and adding to costs. *Id.* at 52.
>
> Another significant defect is that the meteorological inputs (wind speed, wind direction, atmospheric stability, mixing heights) are based on data collected by Applicant at a single, on-site anemometer for a single year, 2005. *Id.* at 53.

As this Motion and the Joint Declaration demonstrate, the claims raised by Friends/NEC Contention 4D raise no genuine issue of material fact. The atmospheric dispersion model (ATMOS) embedded within the MAACS2 code employed in the Seabrook SAMA analysis is a reasonable model for determining the mean annual offsite consequences from postulated reactor accidents integrated over a large area for use in a cost-benefit analysis. Short-term fluctuations in wind direction and terrain effects have little effect on the summed concentration over the entire geographic domain. This conclusion is corroborated by both a study comparing the results of atmospheric dispersion models and by a specific analysis performed for Seabrook. Because there are no material facts in dispute, NextEra is entitled to a decision as a matter of law.

III. STATEMENT OF LAW

A. NRC Legal Standards for Summary Disposition

In ruling on motions for summary disposition in 10 C.F.R. Subpart L proceedings, the Board applies the standards in 10 C.F.R. Subpart G. 10 C.F.R. § 2.1205(c). The standards in Subpart G provide that summary disposition is appropriate where the record demonstrates that no genuine dispute exists regarding any material fact and the moving party is entitled to a decision as a matter of law. 10 C.F.R. § 2.710(d)(2).[2]

When a summary disposition motion is supported by affidavits in accordance with 10 C.F.R. § 2.710(b), the "party opposing the motion may not rest upon . . . mere allegations or

[2] *See also Carolina Power & Light Co.* (Shearon Harris Nuclear Power Plant), CLI-01-11, 53 N.R.C. 370, 384 (2001).

denials," but must, by affidavit or as otherwise provided in the rule, set forth "specific facts showing that there is a genuine issue of fact" warranting a hearing. 10 C.F.R. § 2.710(b); *Advanced Medical Systems, Inc.* (One Factory Row, Geneva, Ohio, 44041), CLI-93-22, 38 N.R.C. 98, 102 (1993). "Bare assertions or general denials are not sufficient. Although the opposing party does not have to show that it would prevail on the issues, it must at least demonstrate that there is a genuine factual issue to be tried." CLI-93-22, 38 N.R.C. at 102 (citations omitted). "[Opponents] have to present contrary evidence that is so significantly probative that it creates a material factual issue." *Id.* n.13 (*citing Public Service Co. of New Hampshire* (Seabrook Station, Units 1 and 2), CLI-92-8, 35 N.R.C. 145, 154 (1992)).

The Commission has encouraged Boards to use the summary disposition process where the proponent of a contention has failed to establish that a genuine issue exists, so that evidentiary hearing time is not unnecessarily devoted to such issues. *Statement of Policy on Conduct of Licensing Proceedings*, CLI-81-8, 13 N.R.C. 452, 457 (1981). The summary disposition procedures "provide in reality as well as in theory, an efficacious means of avoiding unnecessary and possibly time-consuming hearings on demonstrably insubstantial issues . . . ." *Houston Lighting & Power Co.* (Allens Creek Nuclear Generating Station, Unit 1), ALAB-590, 11 N.R.C. 542, 550 (1980).

In this proceeding, the claims in Contention 4D were copied from the *Pilgrim* license renewal proceeding. *Compare Entergy Nuclear Generation Co.* (Pilgrim Nuclear Power Station) ("*Pilgrim*"), LBP-11-18, 74 N.R.C. 29, 39-55 (2011), *aff'd*, CLI-12-1, 75 N.R.C. 39, 46-61 (2012). Indeed, at the *Seabrook* prehearing conference, Mary Lampert of Pilgrim Watch appeared to be the main spokesperson for Friends/NEC on this contention. *See* Tr. 144-50. All of the issues in the *Pilgrim* proceeding, however, were resolved in the applicant's favor after an

evidentiary hearing (*see* CLI-12-1, 75 N.R.C. at 46-61) – one in which the intervenor did not even bother to present any expert testimony or witness. *See CLI-12-1, 75 N.R.C.* at 51. Summary disposition is therefore a very appropriate tool to guard against a similar occurrence in this proceeding.

B. NEPA Standards As Applied to NRC SAMA Analysis

The National Environmental Policy Act ("NEPA") demands that federal agencies contemplating major actions prepare an environmental impact statement ("EIS") addressing "any adverse environmental effects which cannot be avoided should the proposal be implemented." 42 U.S.C. § 4332(C)(ii). Pursuant to this inquiry, an EIS must "discuss the extent to which adverse effects can be avoided" by mitigation. *Robertson v. Methow Valley Citizens Council*, 490 U.S. 332, 352 (1989). NEPA, however, does not require a "worst case" inquiry. *Pilgrim*, CLI-12-1, 75 N.R.C. at 57.

Accordingly, NRC's NEPA regulations require that license renewal applicants perform a plant-specific, quantitative assessment of measures that could significantly mitigate the frequency-weighted consequences of radiological impacts in a severe accident — a SAMA analysis.[3] The Commission has repeatedly stated that SAMA analyses are subject to NEPA's rule of reason.[4] Consequently, not every possible objection to a SAMA analysis gives rise to a genuine dispute regarding a material fact. For example, "whether there are 'plainly better' atmospheric dispersion models or whether the SAMA analysis can be refined further" are not material issues. *Pilgrim*, CLI-10-11, 71 N.R.C. 287, 315 (2010). Instead, to be litigable in an NRC hearing, a SAMA contention must identify a "*significant deficiency* in the SAMA analysis

[3] *See* Final Rule, Environmental Review for Renewal of Nuclear Power Plant Operating Licenses, 61 Fed. Reg. 28,467, 28,480-81 (June 5, 1996). *See also Mass. v. NRC*, 708 F.3d 63, 75-76 & n.19 (1st Cir. 2013) (endorsing the NRC's "site-specific and plant-specific" approach to performing SAMA analyses).

[4] *Pilgrim*, CLI-10-22, 72 N.R.C. 202, 208 (2010).

— i.e., a deficiency that could credibly render the SAMA analysis altogether unreasonable under NEPA standards." *Pilgrim*, CLI-12-1, 75 N.R.C. at 57 (emphasis in original).

The Commission has highlighted this requirement in the instant proceeding, noting that "the proper question is not whether there are plausible alternative choices for use in the analysis, but whether the analysis that was done is reasonable under NEPA." *Seabrook*, CLI-12-5, 75 N.R.C. at 323. The Commission elaborated that:

> A contention proposing alternative inputs or methodologies must present some factual or expert basis for why the proposed changes in the analysis are warranted (e.g., why the inputs or methodology used is unreasonable, and the proposed changes or methodology would be more appropriate). Otherwise, there is no genuine material dispute with the SAMA analysis that was done, only a proposal for an alternate NEPA analysis that may be no more accurate or meaningful.

Id. at 323-24.[5] Therefore, challenges to a SAMA analysis "must be tethered to the computer modeling and mathematical aspects of the analysis," *Davis Besse*, CLI-12-8, 75 N.R.C. at 415, and must demonstrate a significant defect skewing the cost benefit results. CLI-12-8, 75 N.R.C. at 414. Consequently, Friends/NEC cannot avoid summary disposition merely by alleging the existence of a better atmospheric dispersion model. Rather, they must provide evidence that NextEra's use of the ATMOS atmospheric dispersion model code was unreasonable.

IV. THERE IS NO GENUINE DISPUTE REGARDING ANY MATERIAL ISSUE

There is no question that ATMOS is a reasonable code for modeling atmospheric dispersion of a postulated radioactive release for use in a SAMA analysis. Its reasonableness for this purpose is established by two highly qualified experts, Drs. Hanna and O'Kula. Dr. Hanna, a Certified Consulting Meteorologist and Fellow of the American Meteorological Society

[5] *See also Davis Besse*, CLI-12-8, 75 N.R.C. at 406 ("because the SAMA analysis is largely quantitative, resting on inputs used in computer modeling, it will always be possible to propose that the analysis use one or more other inputs. But simply because a computer model also could have been run with alternate inputs does not suggest that the inputs used were unreasonable. We therefore have stressed that the 'proper question is not whether there are plausible alternative choices for use in the analysis, but whether the analysis that was done is reasonable under NEPA.'") (footnote omitted).

("AMS"), and a professor at the Harvard School of Public Health, has more than 45 years of experience in atmospheric turbulence and dispersion, in the analysis of meteorological air quality and data, and in the development, evaluation, and application of air quality models. Joint Decl. at ¶ 2. He has developed and evaluated numerous atmospheric transport and dispersion models for the Environmental Protection Agency ("EPA") and Department of Energy ("DOE"), as well as for other agencies. *Id.* at ¶ 3. Dr. O'Kula has more than three decades of experience with reactor probabilistic risk assessment ("PRA") and accident consequence analysis (including extensive experience with SAMA analyses in NRC license renewal proceedings), has taught MACCS2 training courses for DOE and its contractors, was the lead author of DOE guidance on use of MACCS2, and was a member of the Peer Review Committee for NRC's State-of-the-Art Reactor Consequences Analyses (SOARCA) Project. *Id.* at ¶¶ 9-12.

Both of these experts characterize the meteorological inputs used and the atmospheric transport and dispersion modeling employed in the Seabrook SAMA analysis as reasonable and adequate for determining the mean annual offsite consequences from postulated reactor accidents over a large area for use in a cost-benefit analysis. Joint Decl. at ¶ 18. Further, both Dr. Hanna and Dr. O'Kula find the challenges raised in Contention 4D to be misplaced because they appear intent on tracking individual plume trajectories for emergency management purposes or for determining single hourly maximum concentrations at a single location. *Id.* at ¶ 19. These are not the purposes of SAMA analysis, and they thus fail to challenge the adequacy of the MACCS2 code and its ATMOS atmospheric dispersion model, which are appropriate for calculating reasonable estimates of mean annual consequences from a postulated accident. *Id.*[6]

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[6] *See also Davis Besse*, CLI-12-8, 75 N.R.C. at 415 ("Unlike plume modeling for an actual severe accident, the SAMA analysis is not focused on predicting the precise trajectory of a real-time plume. As we noted in *Pilgrim*,

As these experts further explain, the ATMOS model is reasonable for a SAMA analysis because that analysis is focused on calculating integrated (summed) mean annual consequences over a broad region (50-mile radius). *Id.* at ¶ 46. Modeling individual plumes for determining worst-case scenarios at specific locations is distinctly different from the annual estimations and weighting by population and economic activity over a 50-mile domain required for a SAMA analysis. The short-term fluctuations in wind direction that may affect a single plume trajectory will cancel each other over a long period of time. *Id.* at ¶ 105. Also, any local high concentrations from terrain effects would be balanced by local low concentrations elsewhere, and would have little effect on the summed concentration over the entire geographic domain. *Id.*

This opinion is corroborated by several studies. First, a study by Molenkamp et al. (NUREG/CR-6853) compares ATMOS with more complex atmospheric transport and dispersion models, including a state-of-the-art, three-dimensional Lagrangian particle model, as well as two Lagrangian puff models (similar to CALPUFF, advocated by Friends/NEC). *Id.* at ¶¶ 111-13. The Molenkamp evaluation included comparison of simulated concentrations and dosages at a series of rings at various distances downwind, using one year of hourly-observed meteorological data from many weather sites in a large domain in the Midwest. *Id.* at ¶¶ 111, 114. The results show reasonably good agreement obtained with ATMOS/MACCS2 compared to the most advanced Lagrangian puff model; when averaged over a series of arcs out to 50 miles, the results for non-depositing exposure, depositing exposure, and deposition were in agreement within plus-or-minus 10%.[7] *Id.* at ¶ 114. When compared to the Lagrangian puff model most similar to

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the SAMA analysis is a probabilistic analysis involving 'statistical averaging over many hundreds of randomly selected hourly weather sequences' obtained from a year of hourly weather data.") (footnote omitted).

[7] Comparison of the average exposures and depositions for arcs and arc-sectors predicted by the ATMOS/MACCS2 model and the state-of-the-art Lagrangian particle model reveals that the two models' results are generally within a factor of two of one another. Joint Decl. at ¶ 116.

CALPUFF, ATMOS tended to predict larger consequences. *Id.* at ¶ 115. *Accord Pilgrim*, LBP-11-18, 74 N.R.C. at 46-47; CLI-12-1, 75 N.R.C. at 48-49.

Further, Dr. Hanna performed confirmatory wind trajectory analysis using CALMET-generated wind fields based on meteorological observations from 28 surface sites and 2 upper-air readings within or just outside the geographic domain within 50 miles of Seabrook. Joint Decl. at ¶¶ 117-25; Wind Rose Report at 28-36. CALMET, which develops three-dimensional time dependent meteorological fields for use by the EPA's CALPUFF Lagrangian puff dispersion model, is the most widely used and accepted technology in the U.S. for developing spatially variable wind fields that can be used to take into account changes in plume travel direction as a result of changes in the wind with time and with space across a geographic domain with a size similar to the Seabrook SAMA analysis domain. Joint Decl. at ¶¶ 117-18. CALMET also uses inputs of terrain elevations to parameterize slope flows and curvatures around mountain ranges and valley channeling. *Id.* at ¶ 119. Using CALMET, Dr. Hanna developed annual trajectory roses (for 8,760 hourly trajectories) that could be compared with the wind rose representing the 2005 meteorological data from Seabrook used in the SAMA analysis. *Id.* at ¶¶ 117, 120-21.

Comparing the annual trajectory roses produced by CALMET and the Seabrook annual wind rose shows that ATMOS and the three-dimensional CALMET trajectory model would produce similar directional distributions. *Id.* at ¶¶ 122-25. This also confirms that there is no significant impact from coastal breezes. *Id.* at ¶ 123.

An additional calculation was performed to quantitatively compare the results of the CALMET wind trajectory roses with the annual wind rose from the Seabrook SAMA analysis. *See* EI Report. An Exposure Index ("EI") was calculated, which is a function of the population distribution in the radial sectors around the plant weighted by the site-specific wind direction

frequencies. The EI may be thought of as a relative measure of the population potentially affected by a radiological release. *Id.* at ¶¶ 126-27. This analysis shows that use of a more complex atmospheric dispersion model would not materially change the results of the Seabrook SAMA analysis. *Id.* at ¶ 131. The EI analysis suggests that use of a more complex model like CALMET could potentially increase the calculated benefit of a SAMA by about 32%. In contrast, an increase by more than a factor of two would be needed in the best estimate of SAMA analysis benefits before another SAMA would be considered potentially cost beneficial. *Id.*

Further, Friends/NEC's complaints regarding the ATMOS model are largely inaccurate or misplaced. Their claim that the Seabrook SAMA analysis assumes meteorological conditions steady in time and spatially uniform (*e.g.*, Petition at 48) is not true.[8] The ATMOS module in the MACCS2 code is a Gaussian plume segment model which allows for modeling of multiple plume segments and takes into consideration hourly changes in meteorological input data (such as wind speed, stability, and precipitation) other than wind direction for each segment. Joint Decl. at ¶¶ 32-35, 48. In addition, ATMOS models each accident scenario as consisting of up to four plume segments. *Id.* at ¶ 35. For each plume segment, ATMOS assumes, for the first hour after release that the plume segment is governed by the meteorological data specified for that hour, and for subsequent hours, the meteorological data for the wind speed, stability, and precipitation affecting that plume segment are updated; only the wind direction remains unchanged. *Id.* at ¶¶ 35, 42, 48. When each subsequent plume segment is released, the process is repeated, with the direction of each plume segment determined by the wind direction at the initial hour, or other representative time during that plume segment's release. *Id.* The consequences for each accident scenario are calculated by combining the air concentration and

[8] Friends/NEC's claims that the ATMOS model should not be used to model atmospheric dispersion out to 50 miles (*see* Petition at 48, 52-53, 58) are likewise incorrect. *See* Joint Decl. at ¶ 47.

ground deposition resulting from each segment. *Id.* at ¶¶ 36, 42, 47. Accordingly, meteorological data are updated each hour that the plume travels across the SAMA analysis domain, out to 50 miles. *Id.* at ¶ 51. Further, MACCS2/ATMOS accounts for different meteorological patterns and wind directions by analyzing 8,760 weather trials for each accident scenario, thus encompassing the numerous meteorological conditions characteristic of the Seabrook environment. *Id.* at ¶¶ 41, 43-44, 49.

Contrary to Friends/NEC's claims (Petition at 49), the Seabrook SAMA analysis accounts for sea breezes, and more accurate atmospheric modeling of the sea breeze phenomenon would not significantly alter the overall impacts estimated by MACCS2. The Seabrook meteorological towers are located within about two miles of the coast and capture most of the local sea and land breezes. Joint Decl. at ¶ 55. In the context of a SAMA analysis, the sea breeze phenomenon generally has the beneficial effect of decreasing doses at specific locations because they act to dilute the plume and reduce the maximum plume centerline concentration. *Id.* at ¶ 54. Further, while a sea breeze generally penetrates inland only 10 to 20 miles, ATMOS conservatively treats any sea breeze observed at the Seabrook weather tower data as a prevailing wind that transports a plume segment 50 miles inland until it reaches the edge of the SAMA analysis domain, thus reaching more heavily populated inland areas and increasing consequences. *Id.* at ¶ 56. And considering the diurnal effects of land breezes (an offshore wind flow), the overall impacts of sea breezes will tend to be counter-balanced over the course of a year. *Id.* at ¶ 52. *Accord, Pilgrim*, LBP-11-18, 74 N.R.C. at 41-47; CLI-12-1, 75 N.R.C. at 54.

Further, the CALMET trajectory analysis described in the Wind Rose Report confirms that consideration of time and spatially variable wind fields, such as sea breezes, would have no significant impact on the SAMA analysis results. The trajectory analysis shows that the

Seabrook annual wind rose from the 13.1 m level (used in the SAMA analysis) is not significantly different from the CALMET trajectory annual wind roses, based on use of time-variable winds from 30 weather observing sites (28 surface sites and two upper air sites) within or just outside the Seabrook SAMA analysis domain. Joint Decl. at ¶¶ 123-24. In other words, short-term differences in observed winds such as sea breeze have little effect on the annual wind direction frequencies. *Id.*

Friends/NEC's claims with respect to "hot spots" have no factual basis. Basic fluid dynamics preclude a plume from remaining tightly concentrated over water. Joint Decl. at ¶¶ 63-64. Even under stable atmospheric conditions, plumes disperse significantly as they travel – concentrations decrease by at least a factor of ten for each factor of ten increase in distance – which means that any plume will have significantly dispersed by the time it travelled out to sea and then back onto land, as hypothesized by Friends/NEC. *Id.* at ¶ 65. And the CALMET trajectory analysis performed by Dr. Hanna shows that there is no consistent, frequently occurring pattern of wind blowing out to sea and reversing direction and heading for the coast that might conceivably affect the Seabrook SAMA analysis. *Id.* at ¶ 68. "Hot spots" as hypothesized by Friends/NEC simply are not technically credible and do not exist. *Id.* at ¶¶ 63-68. *Accord Pilgrim*, LBP-11-18, 74 N.R.C. at 52-55; *Pilgrim*, CLI-12-1, 75 N.R.C. at 52-53.

Contrary to Friends/NEC's claims (Petition at 51), the Seabrook SAMA analysis sufficiently considers varying wind fields caused by terrain variations in the SAMA analysis domain. Joint Decl. at ¶ 71. Although the ATMOS Gaussian plume segment model does not directly model individual terrain features, the terrain surrounding Seabrook throughout the 50-mile region of the SAMA analysis is relatively flat on average with a broad coastal plain and with a gradual increase in elevation to about 100 to 200 m on the northwestern edge of the

domain. *Id.* at ¶¶ 72-73. And, because terrain features have a dispersive effect on plumes at distances beyond the terrain obstacles, ignoring the dispersive effects of terrain impacts is conservative in the sense that it results in the overestimation of consequences. *Id.* at ¶ 74. In any event, a comparison of the annual wind roses from Seabrook with those from other sites on the SAMA analysis domain shows that they are similar. *Id.* at ¶ 75; Wind Rose Report at 17. Thus, terrain features did not significantly impact the annual wind roses at other locations so as to produce significant different annual wind patterns important for SAMA analysis purposes. Joint Decl. at ¶ 75. Finally, a comparison between wind roses produced by ATMOS (which ignores terrain effects) and CALMET (which considers terrain effects) shows no significant differences. *Id.* at ¶ 75; Wind Rose Report at 29-30. *Compare Pilgrim*, CLI-12-1, 75 N.R.C. at 51.

Friends/NEC's claim that the Seabrook SAMA analysis does not model contamination deposition onsite and resuspension of that deposition (Petition at 52) is not true. In the Seabrook SAMA analysis, ATMOS calculated deposition of radioactive materials within the first mile from the site with no distinction as to whether the deposition was onsite or offsite. Joint Decl. at ¶ 80. All plume contamination deposited within the first mile was subject to resuspension. The MACCS2 code accounts for resuspension by assuming that deposited radioactivity reenters the ambient wind stream due to mechanical agitation, such as by wind, vehicular traffic, etc. *Id.* Population dose and economic costs arising from resuspension were included by MACCS2 in the total dose population dose and economic cost consequences. In the CHRONC (long-term) phase, MACCS2 accounted for the effects of resuspension in both the population dose and economic cost consequences. *Id.*

Finally, contrary to Friends/NEC's claims (Petition at 53), using one year's worth of meteorological data from the single Seabrook site anemometer (necessitated because MACCS2

accepts only one year of data) is sufficient for SAMA analysis. One year's worth of data is sufficient because the 2005 meteorological data used to perform the Seabrook SAMA analysis is representative of other years. The 2005 Seabrook meteorological data were compared to the data for 2004, 2006, 2007, and 2008. The 2005 data for wind speed and wind direction were similar to, and thus representative of, the other years' wind speed and wind direction data. Joint Decl. at ¶¶ 83-88; Wind Rose Report at 15-17 & Appendix A. In fact, compared to the other years, the 2005 data provides the maximum dose and cost risk and are thus conservative. *Id.* at ¶ 83. Use of data from the single Seabrook site anemometer is also sufficient for multiple reasons. The Seabrook observed annual wind speed is representative of the other 27 surface sites on the SAMA analysis domain. Joint Decl. at ¶¶ 90, 98; Wind Rose Report at 25-27. The Seabrook annual wind rose, which depicts wind direction, is similar to other wind roses from sites on the SAMA analysis domain, indicating that short-term differences in observed winds such as sea breeze have little effect. Joint Decl. at ¶¶ 90, 92-96; Wind Rose Report at 17-24. In addition, the CALMET trajectory wind field model, which is based on the wind fields of 28 surface sites and two upper air readings within or just outside the Seabrook SAMA analysis domain, produces annual trajectory roses very similar to the annual wind rose from the Seabrook. Joint Decl. at ¶¶ 90, 123-24; Wind Rose Report at 29-36.[9]

In sum, the ATMOS Gaussian plume segment model embedded in the MACCS2 code provides a reasonable and adequate basis for determining whether SAMAs are cost-beneficial to implement. Joint Decl. at ¶¶ 132, 138. The use of alternative dispersion models for the SAMA

[9] *See also Davis Besse*, CLI-12-8, 75 N.R.C. at 415 ("Petitioners cite to various guidance documents that point out that there can be reasons warranting use of additional meteorological data collection sites, and further, that a straight-line Gaussian plume model may not be appropriate for all applications. But none of the cited documents is focused on data input or methodology needs for the NRC's license renewal SAMA analysis. Staff-endorsed guidance specific to performing SAMA analyses approves use of meteorological data obtained from the plant meteorological tower.") (footnote omitted).

analysis would have no material impact on the analysis and would result in no additional SAMAs becoming cost beneficial. *Id.* at ¶ 137. Replacing ATMOS with a more complex atmospheric dispersion model would require extensive work, testing, time and resources, but in the end would not make much of a difference because of the similarity of results produced. *Id.* at ¶¶ 107-10. NEPA does not require the NRC to engage in extensive revision of the MACCS2 code, particularly when there is considerable expert evidence that a different plume model would not change the overall results. *Pilgrim*, CLI-12-1, 75 N.R.C. at 60-61.

V. CONCLUSION

For the above-stated reasons, the Board should grant NextEra's motion for summary disposition of Friends/NEC Contention 4D.

VI. CERTIFICATION

In accordance with 10 C.F.R. §2.323(b), counsel for NextEra conferred with the representatives of the other parties in a sincere effort to resolve the matters at issue in the instant Motion prior to the filing of the Motion, but was unsuccessful in doing so.

Respectfully Submitted,

/Signed electronically by David R. Lewis /

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Dated: May 10, 2013

Counsel for NextEra Energy Seabrook, LLC

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CERTIFICATE OF SERVICE

I hereby certify that copies of the foregoing "NextEra's Motion for Summary Disposition of Friends of the Coast/New England Coalition Contention 4D (SAMA Analysis Atmospheric Modeling)" has been served through the E-Filing system on the participants in the above-captioned proceeding, this 10th day of May 2013.

/Signed electronically by David R. Lewis/
____
David R. Lewis

ATTACHMENT 1

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STATEMENT OF MATERIAL FACTS

NextEra Energy Seabrook, LLC ("NextEra") hereby submits, in support of its Motion for Summary Disposition of Friends of the Coast/New England Coalition Contention 4D (SAMA Analysis Atmospheric Modeling), this statement of material facts as to which NextEra contends that there is no genuine dispute.

A. ATMOS Meteorological Model

1. The ATMOS module embedded in the MACCS2 code employed in the Seabrook Station SAMA analysis is a Gaussian plume segment model that simulates a radioactive plume's transport, dispersion, and deposition. ATMOS allows each postulated accident scenario (release category) to be modeled as consisting of up to four plume segments, released over successive intervals. The direction each plume segment travels is determined by the wind direction at the time that plume segment is released (so the four plume segments may travel in different directions), and subsequent transport, dispersion, and deposition also takes into consideration hourly changes in other meteorological input data (such as wind speed, stability, and precipitation). Joint Decl. at ¶¶ 25-28, 33-36, 48, 51.

2. In the Seabrook SAMA analysis, 13 release categories identified from the Seabrook probabilistic risk analysis are considered, each of which is modeled as consisting of four

individual plume segments with different defined start times, durations, source term release fractions, and characteristics. Joint Decl. at ¶¶ 39-43 & Table 1.

3. Using one year of hourly meteorological data observed at Seabrook, ATMOS performed 8,760 simulations ("weather trials") for each release category, calculating the air and ground radioactivity concentrations that would result in grid elements over a 50-mile geographic domain if the postulated accident scenario were initiated in each of the 8,760 hours of the year. Other modules in MACCS2 calculated the population dose and offsite economic cost consequences for each simulation, resulting in a distribution of consequences from which mean values are determined. Joint Decl. at ¶¶ 27, 33, 41-44.

4. The meteorological modeling in the Seabrook Station SAMA analysis thus accounted for up to four changes in wind direction in each of the 8,760 simulations performed for each of the 13 release categories, because each release scenario is broken down into four plume segments, with the trajectory of each plume segment dependent upon the wind direction at the initial hour (or other representative time during that plume segment's release). Joint Decl. at ¶ 48.

5. MACCS2/ATMOS takes into account different meteorological patterns/wind directions by analyzing 8,760 weather trials for each accident scenario, thus encompassing the numerous meteorological conditions that are characteristic of the Seabrook Station environment. Joint Decl. at ¶ 49.

6. The ATMOS model is reasonable for a SAMA analysis because that analysis is focused on calculating integrated (summed) mean annual consequences over a broad region (50-mile radius). Joint Decl. at ¶ 46. Short-term fluctuations in wind direction and terrain

effects have little effect on the summed consequences over the entire geographic domain. *Id.* at ¶¶ 46, 49.

B. Comparison of ATMOS Module to More Complex Models

7. An extensive study (Molenkamp et al. (2004), NUREG/CR-6853) demonstrates that the MACCS2 ATMOS Gaussian plume segment model results are within the same range as more complex dispersion models that account for variable meteorological and terrain effects. Joint Decl. at ¶¶ 111-16. That study showed that, when averaged over all distances out to 50 miles, the results from the MACCS2 code were within 10% of the results obtained from a fully three dimensional model that accounted for terrain changes and spatial variability of the weather. Joint Decl. at ¶¶ 113-14.

8. The Molenkamp study also demonstrates that the ATMOS module is more conservative than some more advanced codes, as ATMOS tended to predict larger consequences than the Lagrangian puff model most similar to the CALPUFF model advocated by Friends/NEC. Joint Decl. at ¶¶ 115-16.

C. Confirmatory CALMET Analysis

9. A trajectory analysis performed using the CALMET code (which develops three-dimensional time dependent meteorological fields) and data from over 30 weather observing sites in or on the outskirts of the 50 mile geographic domain shows that the Seabrook Station annual wind rose (from the meteorological data used in the SAMA analysis) is not significantly different from the annual trajectory produced by CALMET. Joint Decl. at ¶¶ 122-24, Figure 4 & Table 2; Wind Rose Report at 28-36. Comparing the annual trajectory roses produced by CALMET and the Seabrook annual wind rose shows

that ATMOS and the three-dimensional CALMET trajectory model would produce similar directional distributions. Joint Decl. at ¶¶ 122-24.

10. Using the trajectory analysis, an "exposure index" calculation indicates that use of a more complex meteorological model could potentially produce an approximately 32% increase in total benefits, but this change is not large enough to make the next closest SAMA potentially cost beneficial. Joint Decl. at ¶¶ 130-31.

11. In the Seabrook SAMA analysis, for the next SAMA candidate to become potentially cost beneficial, the expected (best estimate) benefit value must increase by more than a factor of two. Joint Decl. at ¶ 131.

D. ATMOS and Sea Breezes

12. The Seabrook SAMA analysis accounts for sea breezes. The anemometers on the Seabrook Station meteorological towers are located within about two miles of the coast and capture most of the local sea breezes, whose effects generally extend to a distance of 10-20 miles from the coast. Joint Decl. at ¶ 55.

13. More accurate modeling of the sea breeze phenomenon would not significantly alter the overall impacts estimated by MACCS2/ATMOS. Sea breezes are generally beneficial for the purposes of a SAMA analysis because they reduce localized concentration by acting to dilute the plume and reduce the maximum plume centerline concentration. Joint Decl. at ¶ 54. Although a sea breeze generally extends inland only 10-20 miles, MACCS2/ATMOS conservatively treats sea breezes by modeling sea breeze-initiated plumes out to 50 miles, reaching the more heavily populated areas within the Seabrook

SAMA domain. Joint Decl. at ¶ 56. Further, the overall impacts of sea breezes will tend to be counter-balanced by the diurnal effects of land breezes. Joint Decl. at ¶ 52.

14. The CALMET trajectory analysis confirms that consideration of time and spatially variable wind fields, such as sea breezes, would have no significant impact on the SAMA analysis results. Joint Decl. at ¶ 122.

E. ATMOS and "Hot Spots"

15. "Hot spots," as defined by Friends/NEC, do not exist and have no impact on the Seabrook Station SAMA analysis. Joint Decl. at ¶¶ 63-68. Even under very stable atmospheric conditions, radioactive plumes disperse significantly as they travel, with concentrations decreasing by a factor of ten for each factor of ten increase in distance. Joint Decl. at ¶ 65.

16. The CALMET trajectory analysis confirms that, in the Seabrook Station SAMA domain, there is no consistent, frequently-occurring pattern of wind blowing out to sea and then reversing direction and heading for the coast. Joint Decl. at ¶ 68.

F. ATMOS and Terrain Variation

17. The Seabrook SAMA analysis sufficiently considers the varying wind fields caused by terrain variation. The terrain surrounding the Seabrook Station throughout the 50-mile region of the SAMA analysis is relatively flat on average with a broad coastal plain and with a gradual increase in elevation to about 100 to 200 m on the northwestern edge of the domain. Joint Decl. at ¶ 72; Wind Rose Report at 8, 12 (Figures 2 & 4). Further, because at distances beyond the terrain obstacles terrain features such as hills have a

dispersive effect on a plume, ATMOS's neglect of the dispersive effects of topographical obstacles is conservative in that it overestimates consequences. Joint Decl. at ¶ 74.

18. The similarity between the annual 2005 Seabrook Station wind rose and the wind roses from other sites on the SAMA domain demonstrates that terrain features in the SAMA domain do not produce significantly different annual wind patterns important for SAMA analysis purposes. Joint Decl. at ¶ 75.

19. Comparison of annual wind roses from an analysis with ATMOS ignoring terrain effects and a CALMET trajectory analysis that considers complexities caused by terrain and coast line shows no significant differences. Joint Decl. at ¶ 75.

G. ATMOS and Contamination Deposition Modeling

20. The Seabrook Station SAMA analysis calculated deposition of radioactive material within the first mile of Seabrook Station with no distinction as to whether deposition was onsite or offsite. Joint Decl. at ¶ 80.

21. All radioactive plume materials deposited within the first mile of Seabrook Station were subject to resuspension in the SAMA analysis in that the MACCS2 code assumed that deposited radioactivity reenters the ambient wind stream due to mechanical agitation from wind, vehicular traffic, or other phenomena. Joint Decl. at ¶ 80.

H. Adequacy of Meteorological Data Set

22. One year of meteorological data is sufficient to estimate the annual averaged impacts over the SAMA analysis domain if that data is representative of other years. Joint Decl. at ¶ 82. The 2005 meteorological data used in the MACCS2 consequence analysis are

representative and not significantly different from other years (2004-2008) that could have been selected as a basis for the SAMA analysis. Joint Decl. at ¶¶ 83-88; Wind Rose Report at 15-17. Further, compared to the other years, the 2005 data provides the maximum dose and cost risk and are thus conservative. *Id.* at ¶ 83.

23. Use of meteorological data from a single anemometer at Seabrook Station was sufficient for multiple reasons. The Seabrook Station annual wind speed is representative of the wind speeds from 27 other sites within and just beyond the Seabrook SAMA domain. Joint Decl. at ¶ 97; Wind Rose Report at 25-27. The Seabrook Station annual wind trajectory rose is similar to the wind trajectory roses of 27 other sites within and just beyond the Seabrook SAMA domain. Joint Decl. at ¶¶ 91-97; Wind Rose Report at 17-24; Appendix B. A CALMET trajectory analysis produces annual trajectory roses very similar to the annual wind rose from the Seabrook SAMA analysis. Joint Decl. at ¶ 90.

Respectfully Submitted,

/Signed (electronically) by David R. Lewis /

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Counsel for NextEra Energy Seabrook, LLC

Dated: May 10, 2013

ATTACHMENT 2

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

Before the Atomic Safety and Licensing Board

In the Matter of	)	
	)	Docket No. 50-443-LR
NextEra Energy Seabrook, LLC	)	
	)	
(Seabrook Station, Unit 1)	)	
	)	May 10, 2013

JOINT DECLARATION OF STEVEN R. HANNA AND KEVIN R. O'KULA IN SUPPORT OF NEXTERA'S MOTION FOR SUMMARY DISPOSITION OF CONTENTION 4D (SAMA ANALYSIS ATMOSPHERIC MODELING)

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TABLE OF CONTENTS

Section **Page**

Table of Contents

TABLE OF CONTENTS

Figures	Page

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UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

Before the Atomic Safety and Licensing Board

In the Matter of	)	
	)	Docket No. 50-443-LR
NextEra Energy Seabrook, LLC	)	
	)	ASLBP No. 10-906-02-LR
(Seabrook Station, Unit 1)	)	

JOINT DECLARATION OF STEVEN R. HANNA AND KEVIN R. O'KULA IN SUPPORT OF NEXTERA'S MOTION FOR SUMMARY DISPOSITION OF CONTENTION 4D (SAMA ANALYSIS ATMOSPHERIC MODELING)

Steven R. Hanna and Kevin R. O'Kula state as follows under penalties of perjury:

I. PROFESSIONAL QUALIFICATIONS

A. Dr. Steven R. Hanna ("SRH")

1. (SRH) My name is Steven R. Hanna. My professional qualifications are provided in Attachment A. In brief, I received my B.S., M.S., and Ph.D. degrees in Meteorology from Penn State University in 1964, 1966, and 1967, respectively. I am a Fellow of the American Meteorological Society ("AMS"), the 1994 recipient of the AMS Award for Outstanding Contribution to the Advance of Applied Meteorology, and the 2010 recipient of the AMS Helmut E. Landsberg Award for "Significant novel and insightful contributions in applied meteorology and urban studies, including field work, data interpretation, model development, and model evaluation". I am an AMS Certified Consulting Meteorologist with over 45 years of experience; and from 1988-1997, I was Chief Editor of the Journal of Applied Meteorology

2. (SRH) I am a specialist in atmospheric turbulence and dispersion, in the analysis of meteorological and air quality data, and in the development, evaluation, and application of air quality models. I have over 155 publications in peer-reviewed journals, including three in the

past year. Since 1968, I have been teaching graduate level classes on atmospheric boundary layers and dispersion, recently at George Mason University (1997-2002) and now at Harvard School of Public Health (since 2002) and at the Harvard-Cyprus International Institute (since 2007).

3. (SRH) I developed and evaluated numerous atmospheric transport and dispersion models for the Environmental Protection Agency ("EPA") as well as for the Department of Defense ("DOD"), Department of the Interior ("DOI"), and Department of Energy ("DOE"). In all these cases, I evaluated the models with extensive field observations and was program manager for several of the field experiment campaigns. Many scientific aspects of my Hybrid Plume Dispersion Model ("HPDM") for calculating dispersion of plumes from tall stacks were used as the bases for the EPA AERMOD model. I co-developed the CALMET/CALPUFF Lagrangian puff model, which is one of the models recommended by the EPA for mesoscale distances (i.e., distance scales from about 20 km to 500 km). I lecture on dispersion modeling, and carry out AERMOD training in my graduate level course at Harvard School of Public Health.

4. (SRH) From 1967-1981, I was employed by the NOAA Atmospheric Turbulence and Dispersion Laboratory ("ATDL") in Oak Ridge, TN. My primary role was carrying out DOE and NRC-funded research in support of their meteorological analysis and dispersion modeling concerns. My 1982 Handbook on Atmospheric Diffusion (co-authored by Gary Briggs and Ray Hosker) summarized my research findings and translated them into recommendations for applied dispersion models. During this period, my colleagues and I at ATDL assisted the DOE and NRC in the development and implementation of models for application to specific

scenarios (such as ATMOS). My recommended formulas are still widely used in applied dispersion models around the world.

5. (SRH) While with environmental consulting companies (ERT, from 1981-1985, and Sigma from 1985-1997), I developed several dispersion codes. My Rough Terrain Dispersion Model and Hybrid Plume Dispersion Model ("HPDM") subsequently formed the basis for many algorithms in the EPA's AERMOD model. I developed the Offshore and Coastal Dispersion ("OCD") model for the DOI for use in assessing overwater dispersion of emissions from offshore oil platforms and from coastal facilities. Under support of the California Air Resources Board ("CARB") and later under support of EPA and the National Park Service (NPS), I was part of the Sigma team that developed CALMET/CALPUFF.

6. (SRH) Since 1997, I have been president and chief scientist of Hanna Consultants. During this time, I have developed and evaluated an enhanced Heavy Gas System ("HGSYSTEM") model for dense gas releases and the "simple urban dispersion model" for releases at street level in downtown areas. I led the DHS-sponsored Madison Square Garden 2005 tracer experiments and evaluated my urban dispersion model with those data. I also developed a Monte Carlo code to assess the uncertainties of dispersion models and applied it to Community Multiscale Air Quality ("CMAQ") model's predecessors and to AERMOD. In addition to supporting NextEra on SAMA analysis-related issues regarding the Seabrook Station license renewal application, I provided testimony on atmospheric dispersion modeling in SAMA analysis for the Pilgrim Nuclear Generating Station license renewal proceeding.

7. (SRH) Thus, I have extensive experience in the development and evaluation of atmospheric dispersion models for a wide range of applications, including development and evaluation of AERMOD, and CALMET/CALPUFF.

B. Dr. Kevin R. O'Kula ("KRO")

8. (KRO) My name is Kevin R. O'Kula. I am an Advisory Engineer with URS Professional Solutions ("URS") LLC, in Aiken, South Carolina. I am a consultant to NextEra Energy Seabrook, LLC ("NextEra") on source term, dispersion/consequence and severe accident mitigation alternatives ("SAMA") analysis issues.

9. (KRO) My professional qualifications are provided in Attachment B. In brief, I have over 30 years of experience as a technical professional and manager in the areas of safety analysis methods and guidance development, computer code validation and verification, probabilistic risk assessment ("PRA"), deterministic and probabilistic accident and consequence analysis applications for reactor and non-reactor nuclear facilities, source term evaluation, risk management, software quality assurance ("SQA"), and shielding analysis. I obtained my B.S. in Applied and Engineering Physics from Cornell University in 1975, and my M.S. and Ph.D. in Nuclear Engineering from the University of Wisconsin in 1977 and 1984, respectively.

10. (KRO) In addition, I have over 20 years of experience using and applying the MELCOR Accident Consequence Code System 2 ("MACCS2") computer code and its predecessor, MACCS. I co-chaired a U.S. Department of Energy ("DOE") Accident Phenomenology and Consequence evaluation program in the 1990s that evaluated applicable computer models for radiological dispersion and consequence analysis. More recently, I was a technical peer reviewer of the Sandia National Laboratories ("Sandia") and NRC State-of-the-Art Reactor Consequence Analyses ("SOARCA") Project that reviewed updated and more realistic evaluations of severe accident progression in U.S. nuclear power plants. By virtue of my training and experience, I also am familiar with the Modular Accident Analysis Program

("MAAP"), MELCOR[1] and similar codes and the manner in which they are typically used to support severe accident analyses, PRAs, and SAMA analyses.

11. (KRO) I have taught MACCS2 training courses for DOE and its contractors at Lawrence Livermore National Laboratory, Los Alamos National Laboratory, Idaho National Laboratory, Oak Ridge, the Waste Isolation Pilot Plant, and the DOE Safety Basis Academy. In addition, I was the lead author of a DOE guidance document on the use of MACCS and MACCS2 for DOE safety analysis applications, and managed overall completion of equivalent reports for DOE on MELCOR (similar in function to MAAP) and GENII (similar in function to MACCS2). As part of the SOARCA Project Peer Review Committee, I provided critical review and comment to Sandia and the NRC on the use of integrated modeling of accident progression and offsite consequences from postulated severe accidents using both improved computational analysis tools and more accurate inputs and assumptions reflecting current-day plant operations, and accident management/response planning

12. (KRO) In addition to supporting NextEra on SAMA analysis-related issues regarding the Seabrook Station license renewal application, I have supported other license renewal applications. These include both completed and ongoing support of SAMA activities for the license renewal applications of Pilgrim Nuclear Generating Station, Prairie Island Nuclear Power Plant, Indian Point Energy Center, and Davis-Besse Nuclear Power Station.

II. ISSUES RAISED IN CONTENTION 4D (SAMA ANALYSIS ATMOSPHERIC MODELING)

13. (SRH, KRO) We are providing this Declaration in support of the "Applicant's Motion for Summary Disposition of Friends/NEC's Contention 4D (SAMA Analysis

[1] MELCOR (Methods for Estimation of Leakages and Consequences of Releases) is a severe accident computer model developed by Sandia National Laboratories for the NRC.

Atmospheric Modeling)" in the above-captioned proceeding. We understand that, in May 2010, NextEra submitted a license renewal application ("LRA") to the U.S. Nuclear Regulatory Commission ("NRC") seeking to renew its operating license for the Seabrook Station Unit No. 1 ("Seabrook" or "Seabrook Station") for another 20 years.[2] The SAMA analysis was originally described in Section 4.20 and Attachment F of the Environmental Report ("ER") (Appendix E to the LRA).[3]

14. (SRH, KRO) We have thoroughly reviewed the various inputs and assumptions used in NextEra's SAMA analysis, as submitted in May 2010 and revised in March 2012,[4] to calculate offsite consequences associated with a postulated severe accident at the Seabrook Station, including relevant supporting technical documentation for the SAMA analysis prepared by a NextEra contractor. We also have reviewed the SAMA analysis revisions and clarifications that NextEra provided in response to NRC Staff requests for additional information ("RAIs") in January, April and June 2011, and September 2012.[5] We have also reviewed the relevant portions of the Second Draft Report for Comment of NUREG-1437, Generic Environmental

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[2] *See* Letter from Paul O. Freeman, Site Vice President, NextEra Energy Seabrook, LLC to Document Control Desk, U.S. N.R.C. "Seabrook Station, Application for Renewed Operating License," May 25, 2010 (ADAMS Accession No. ML101590099).

[3] *See* ER § 4.20 (Severe Accident Mitigation Alternatives) & Attach. F (Severe Accident Mitigation Alternatives Analysis).

[4] *See* Letter SBK-L-12053 from Paul O. Freeman, Site Vice President, NextEra Energy Seabrook, LLC to Document Control Desk, U.S. N.R.C. "Seabrook Station, Supplement 2 to Severe Accident Mitigation Alternatives Analysis" March 19, 2012 (ADAMS Accession No. ML12080A137).

[5] *See* Letter SBK-L-11001from Paul O. Freeman, Site Vice President, NextEra Energy Seabrook, LLC to Document Control Desk, U.S. N.R.C., "Seabrook Station, Response to Request for Additional Information," January 13, 2011 (ADAMS Accession No. ML110140810); Letter SBK-L-11067 from Paul O. Freeman, Site Vice President, NextEra Energy Seabrook, LLC to Document Control Desk, U.S. N.R.C. "Seabrook Station, Response to Request for Additional Information", April 18, 2011 (ADAMS Accession No ML11111A035); Letter SBK-L-11125 from Paul O. Freeman, Site Vice President, NextEra Energy Seabrook, LLC to Document Control Desk, U.S. N.R.C. "Seabrook Station, Supplement to Response to Request for Additional Information - April 18, 2011," June 10, 2011 (ADAMS Accession No ML11166A255); Letter SBK-L-12185 from Kevin T. Walsh to Document Control Desk, U.S. N.R.C., "Seabrook Station Supplement 3 to Severe Accident Mitigation Alternatives Analysis, Response to RAI Request dated July 16, 2012," September 13, 2012 (ADAMS Accession No. ML12262A513).

Impact Statement for License Renewal of Nuclear Plants, Supplement 46 Regarding Seabrook Station (Apr. 2013) concerning SAMA analysis, specifically Section 5.3 and Appendix F. We thus have personal knowledge of the modeling methods, inputs, and assumptions used in the Seabrook Station SAMA analysis, as described in the Seabrook Station ER and other related documentation.

15. (SRH, KRO) In preparing this Joint Declaration, we also reviewed relevant pleadings of the parties, including the October 20, 2010 "Friends of the Coast and New England Coalition Petition for Leave to Intervene, Request for Hearing, and Admission of Contentions" ("Petition"), and Orders issued by the Atomic Safety and Licensing Board ("Board") and the Commission, applicable NRC regulations and guidance documents, and relevant technical reports and studies.

16. (SRH, KRO) We understand that, as admitted by the Board and the Commission, Friends of the Coast and New England Coalition ("Friends/NEC" or "Intervenors") Contention 4D claims that the Seabrook license renewal environmental report underestimates the cost of a severe accident at Seabrook, allegedly because the air dispersion model used in the computer code to perform the Seabrook SAMA analysis is inappropriate for Seabrook. *See*, *e.g.*, Petition at 47. ATMOS is the module in the MACCS2 code that performs the atmospheric transport and dispersion modeling necessary to predict the atmospheric radionuclide concentrations that are subsequently evaluated in other modules of the MACCC2 code to estimate the consequences of a postulated release of a radioactive plume due to a severe accident. Intervenors base their contention on two sets of claims, which for purposes of response we have labeled as follows.

Basis 1 — The Seabrook SAMA analysis used an inappropriate dispersion model, the straight line Gaussian plume, and meteorological data inputs that did not accurately predict the geographic dispersion and deposition of radionuclides at Seabrook's coastal location. Petition at 37, 47.

Sub-basis 1(a) The Gaussian plume model is inappropriate because it assumes that a released radioactive plume travels in a steady straight line, and assumes meteorological conditions that are steady in time and uniform spatially across the study region. Petition at 48. It ignores the presence of sea breeze circulations, which dramatically alter air flow patterns. *Id.* It does not account for "hot spots" of radioactivity along the coast that will result when a plume heads out over water, remains tightly concentrated, and is blown back onto land. *Id.* at 50. MAACS2 should not be used at distances out to 50 miles. Petition at 48, 52-53, 58.

Sub-basis 1(b) The atmospheric model does not model the impact of terrain effects on atmospheric dispersion. Terrain effects can have a highly complex impact on wind field patterns and plume dispersion. Petition at 51.

Sub-basis 1(c) MACCS2 does not model dispersion close to the source (less than 100 meters away) thereby ignoring resuspension of contamination blowing offsite and affecting deposition in offsite communities and adding to costs. Petition at 52.

Sub-basis 1(d) Another significant defect is that the meteorological inputs (wind speed, wind direction, atmospheric stability, mixing heights) are based on data collected by Applicant at a single, on-site anemometer for a single year, 2005. Petition at 53.

Basis 2 NextEra should have instead used a more advanced atmospheric dispersion model, such as AERMOD or CALPUFF, which are recommended by the EPA. Petition 51-52.

These issues are the same as the claims that were raised by an intervenor and to which we responded as expert witnesses in the Pilgrim license renewal proceeding.[6]

17. (SRH) In connection with the preparation of this testimony, I have carefully reviewed the data and assumptions that were used in the meteorological and atmospheric transport and dispersion modeling used in the Seabrook Station SAMA analysis, as well as the

[6] See Testimony of Dr. Kevin R. O'Kula and Dr. Steven R. Hanna on Meteorological Matters Pertaining to Pilgrim Watch Contention 3 (January 3, 2011).

modeling methodology in MACCS2 (with which I was already familiar). I have documented my review of the meteorological observations in a report entitled "Analysis of Annual Wind Roses within about 50 Miles of the Seabrook Station, and Use of CALMET to Calculate the Annual Distribution of Trajectories from the Seabrook Station" (March 2013) ("Wind Rose Report"), provided as Exhibit 1.

III. SUMMARY OF CONCLUSIONS

18. (SRH, KRO) The meteorological inputs used and the atmospheric transport and dispersion modeling that NextEra performed in the MACCS2 code are reasonable and adequate for the purpose for which they are being used; that is, to determine the average (mean) annual offsite consequences over a large area for use in a cost-benefit analysis.

19. (SRH, KRO) Friends/NEC's objections appear to be based in large measure on their assumption that individual plume trajectories and the resulting single hourly maximum concentrations at single locations are important, as in an application for a major-source construction permit under the Clean Air Act, or for emergency management purposes of tracking a single plume. However, the SAMA analysis is based on the annual consequences of a set of postulated severe accident scenarios, integrated over a 50-mile radius spatial domain around the Seabrook Station. For this purpose, and as discussed in detail below, MACCS2 and its embedded transport and dispersion ATMOS module are appropriate for calculating reasonable estimates of the mean annual consequences.

IV. BACKGROUND ON SAMA ANALYSIS AND MACCS2 CODE

A. NRC SAMA Analysis

20. (KRO) Severe nuclear accidents are those in which substantial damage is done to the reactor core whether or not there are serious offsite consequences.[7] In the context of a nuclear power plant PRA, a severe accident is described as a beyond design-basis accident involving multiple failures of equipment or functions. Although a severe accident in general will have a lower likelihood than a design-basis accident, it may have greater consequences.[8] The NRC's GEIS provides an evaluation of severe accident impacts that applies to all U.S. nuclear power plants. *See id*. at 5-1 to 5-20. Based on the GEIS evaluation of severe accidents, 10 C.F.R. Part 51 concludes that "[t]he probability weighted consequences of atmospheric releases, fallout onto open bodies of water, releases to ground water, and societal and economic impacts from severe accidents are small for all plants."[9] Thus, by definition, a SAMA analysis considers postulated events whose probability of occurrence is so low that they are excluded from the spectrum of design-basis accidents postulated by NRC regulations.

21. (KRO) A SAMA analysis is a site-specific, frequency-weighted assessment of the benefits and costs of mitigation alternatives that might be used to reduce the risks (frequencies, consequences, or both) of potential nuclear power plant severe accidents. A SAMA analysis is not intended to model a single radiological release event under specific meteorological conditions at a single moment in time. Instead, it models a set of postulated plant-specific, severe accident releases that could, based on probabilistic analysis, occur at any

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[7] *Policy Statement on Severe Reactor Accidents Regarding Future Design and Existing Plants*, 50 Fed. Reg. 32,138 (Aug. 8, 1985).

[8] NUREG-1437, "Generic Environmental Impact Statement for License Renewal of Nuclear Plants," Vol. 1, at 5-1 (May 1996) ("GEIS").

[9] 10 C.F.R. Part 51, Subpart A, App. B, Table B-1 (Postulated Accidents; Severe accidents).

time under varying weather conditions during a one-year period. The objective is to estimate mean annual impacts for the entire 50-mile radius region surrounding a nuclear power plant.

22. (KRO) NRC-endorsed industry guidance on SAMA analyses states: "The purpose of the analysis is to identify SAMA candidates that have the potential to reduce severe accident risk and to determine if implementation of each SAMA candidate is cost-beneficial."[10] A SAMA analysis thus identifies potential changes to a nuclear power plant, or its operations, that could reduce the already-low risk (frequency and/or consequences) of a severe accident for which the benefit of implementing the change may outweigh the cost of implementation. Changes to the plant that could reduce the risk of a severe accident include "hardware changes, procedure changes, or enhancements to programs, including training and surveillance programs." NEI 05-01 at 23. These potential changes are referred to as SAMAs or SAMA candidates.

23. (KRO) The methodology for the overall SAMA analysis approach is based on NRC guidance.[11] Broadly speaking, a SAMA analysis involves four major sequential steps:

- Characterize the overall plant-specific severe accident risk using PRAs and other risk studies to identify the leading contributors to core damage frequency ("CDF") and offsite risk based on a plant-specific risk study;
- Identify potential plant improvements (i.e., SAMA candidates) that could reduce the risk of a severe accident;
- Quantify the risk-reduction potential and the implementation cost for each SAMA candidate; and
- Determine whether implementation of the SAMA candidates may be cost-effective.[12]

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[10] NEI 05-01, Rev. A, "Severe Accident Mitigation Alternatives (SAMA) Analysis Guidance Document" at 1 (Nov. 2005) ("NEI 05-01") (ML060530203). The NRC Staff has endorsed NEI-05-01. Final License Renewal Interim Staff Guidance LR-ISG-2006-03: Staff Guidance for Preparing Severe Accident Mitigation Alternatives Analyses (Aug. 2007).

[11] *See* NUREG/BR-0184, "Regulatory Analysis Technical Evaluation Handbook, Final Report" (January 1997) (ML050190193) and NUREG/BR-0058, "Regulatory Analysis Guidelines of the U.S. Nuclear Regulatory Commission, Revision 4" (August 2004) (ML042820192).

The SAMA evaluation of a plant is based on the numerical evaluation of severe accident risk impacts in four categories: (1) offsite exposure cost, (2) offsite economic cost, (3) onsite exposure cost, and (4) onsite economic cost. NEI 05-01 at 16.

24. (KRO) The basis for a SAMA analysis conducted for a U.S. nuclear power plant is a sequential, three-level PRA, *i.e.*, a comprehensive assessment of postulated accident sequences resulting in damage to the core and containment, radiological release, and their associated frequencies. A PRA assesses the risk from an operating nuclear power plant by answering three basic questions: (1) What can go wrong?; (2) How likely is it?; and (3) What are the consequences? As discussed in NEI 05-01 and summarized below, the PSA[13] for a commercial nuclear power plant is divided into three levels, Level 1, Level 2, and Level 3. Plant -specific Level 1 and 2 PSA models and a site-specific Level 3 PSA model are required to perform a SAMA analysis. Various computer codes—including the MACCS2 code at issue in Contention 4D—are used in support of a SAMA analysis. These include codes used to develop a Level 1 PRA (analysis of initiating events and ensuing accident sequences leading to core damage) and a Level 2 PRA (analysis of accident progression leading to containment failure and bypass, and release of radionuclides to the environment). The output of the Level 1 PRA is used in the Level 2 PRA. The output of the Level 2 PRA, in turn, is used in the Level 3 PRA (analysis of offsite consequences). As shown in the NEI 05-01 industry guidance, the Level 3 PRA portion of SAMA analyses typically uses the MACCS2 code to calculate the offsite dose and offsite economic impacts within the 50-mile radius SAMA region resulting from postulated

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[12] NUREG-1850, "Frequently Asked Questions on License Renewal of Nuclear Power Reactors, Final Report," (March 2006) ("NUREG-1850") (ML061110022) at 4-32 – 4-34.

[13] Probabilistic Safety Assessment ("PSA") is often used interchangeably with PRA. In this declaration we use both without distinction.

releases of radioactive materials to the atmosphere.[14] NEI 05-01 at 13. MACCS2 performs these calculations based on plant- and site-specific, regional, industry, and standardized regulatory inputs. The PRA sequential analysis and set of products from each level is shown below in Figure 1. Thus, a PRA using plant-specific information is a key component of a SAMA analysis.

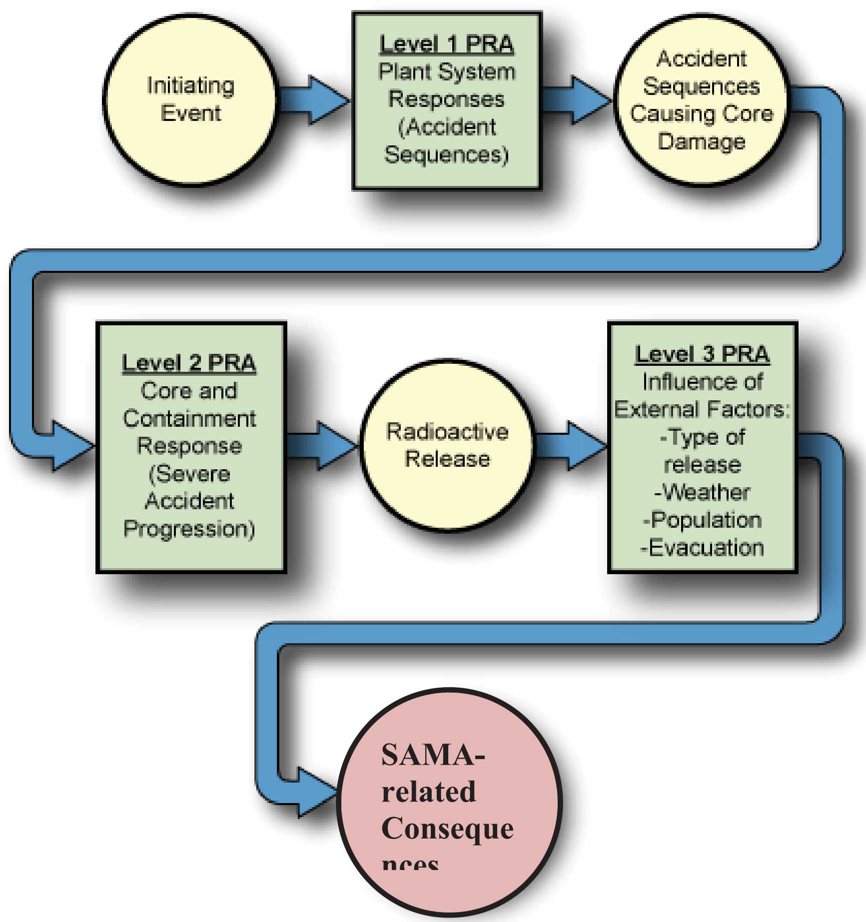

Figure 1. Three-Level Probabilistic Risk Assessment for Reactor Operation (adapted from U.S. Nuclear Regulatory Commission, *Probabilistic Risk Assessment (PRA)*. http://www.nrc.gov/about-nrc/regulatory/risk-informed/pra.html)

[14]To my knowledge, all license renewal applications in the U.S. have used MACCS2 for this purpose.

B. MACCS2 Code and the ATMOS Atmospheric Transport and Dispersion Model

25. (KRO) The Seabrook Station SAMA analysis was based on the Seabrook Station-specific Level 3 PRA information, consistent with guidance from NEI 05-01. The PRA was used to develop a set of 13 accident scenarios and the source term characteristics associated with each of the postulated accident scenarios. NextEra used the MACCS2 code, version 1.13.1, in its original SAMA analysis documented in the Appendix E to the Seabrook Station LRA ER (Attachment F, Severe Accident Mitigation Alternatives, May 25, 2010). MACCS2 was used to calculate the consequences caused by each of the 13 accident scenarios. As is the standard practice for cost-benefit analysis, and based on the area that might be impacted by a severe accident, the area of interest covered a 50-mile radius area surrounding the Seabrook Station. Subsequently, NextEra used the same version 1.13.1 of MACCS for the analysis in response to the NRC's request for additional information (SBK-L-11001[15]), and the results of the current SAMA analysis (SBK-L-12053[16]) are based on its application.

26. (KRO) The NRC sponsored the development of the MACCS code as a successor to the CRAC2 code to evaluate impacts of severe accidents at nuclear power plants on the surrounding public. Its development was a collaborative effort by numerous industry professionals. Prior to its use for regulatory purposes, MACCS was first used in the NUREG-1150[17] PSA study and was independently verified by Idaho National Engineering and Environmental Laboratory.[18] After verification, the NRC released MACCS, Version 1.5.1 1 for

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[15]SBK-L-11001, January 13, 2011, *supra* note 5.

[16]SBK-L-12053, March 19, 2012, *supra* note 4.

[17]NUREG-1150, Severe Accident Risks: An Assessment for Five U.S. Nuclear Power Plants.

[18]NUREG/CR-5376, C. A. Dobbe et al., Quality Assurance and Verification of the MACCS Code, Version 1.5, Idaho National Engineering Laboratory.

unrestricted use. MACCS was used for PSAs at commercial reactors (both U.S. and international), as well as non-reactor nuclear facilities. Originally released in 1997, MACCS2 was jointly developed by the NRC and DOE as an improved version of the MACCS code to assess potential accidents at a broad range of reactor and nonreactor nuclear facilities. Version 1.13.1 was released in January 2004. The MACCS2 code simulates the atmospheric release of radioactivity, the direction, speed of travel, and dispersion (spread and dilution) of the plume based on meteorological inputs; and ultimately, it calculates radiological health effects and economic impacts. It considers, among other things, phenomena related to atmospheric transport and deposition under time variant meteorology, short and long-term mitigative actions, potential exposure pathways, deterministic and stochastic health effects, and economic costs. The MACCS2 code is periodically updated and subject to peer review as part of the continual improvement process in its software life cycle. The NRC and Sandia National Laboratories have invested in maintenance and extension of the MACCS2 code to support severe accident consequence assessment and PSA/SAMA analyses.

27. (KRO) The MACCS2 code executes three modules in sequence to calculate severe accident consequence values necessary for a SAMA analysis. The first is ATMOS, which calculates the air and ground radioactivity concentrations, plume size, and timing information for all plume segments as a function of downwind distance. The results of the ATMOS calculations are stored for subsequent use by EARLY and CHRONC. The second module is EARLY, which uses radioactivity concentrations calculated by ATMOS and other inputs (e.g. population) to calculate consequences due to radiation exposure in the emergency phase (the first seven days) from the time of release. The last module is CHRONC, which uses radioactivity concentrations calculated by ATMOS and other inputs (e.g. population and economic data) to calculate the

long-term doses due to exposure after the emergency phase and the economic impacts from each accident sequence. The meteorological concerns raised in Contention 4D and discussed in this testimony solely relate to the ATMOS module and its meteorological inputs. The three-module sequence of MACCS2 calculations is shown in Figure 2.

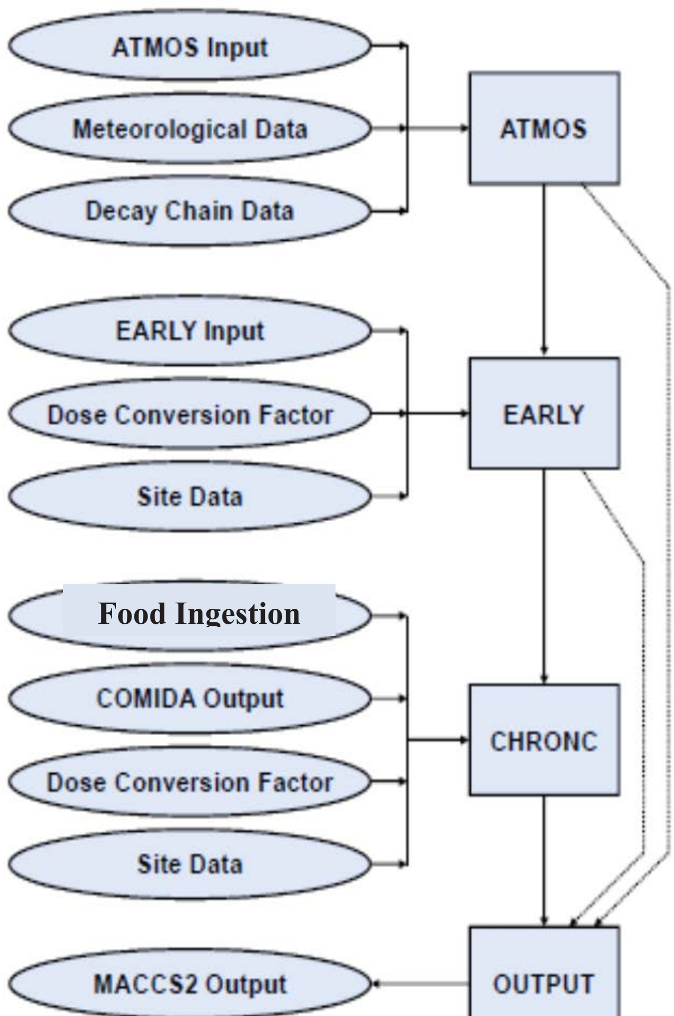

Figure 2. MACCS2 Code Schematic (Based on MACCS2 Code Workshop, N. Bixler, Overview of MACCS2 Code Models, March 2011, PSA 2011 Topical Meeting). This is a generic input and output data flow sheet and is representative of most MACCS2 analyses.

28. (KRO) The key consequence values of interest computed by MACCS2 are: (1) total offsite population dose (person-sievert[19]); and the (2) total offsite economic cost calculated in dollars. In order to obtain corresponding risk values for population dose and offsite economic costs, the offsite population dose and offsite economic cost consequence values are multiplied (outside of the MACCS2 code) by the calculated severe accident frequency results obtained from the plant-specific PSA and related information. This results in the specific offsite risk metrics for determining potentially cost-beneficial SAMAs, i.e., (1) population dose risk ("PDR") in units of person-rem/year; and (2) the offsite economic cost risk ("OECR") in units of dollars/year. There are multiple steps in the calculation sequence and several modules in the MACCS2 structure for performing the calculations to derive the total offsite population dose and PDR and the total offsite economic cost and the OECR. These steps are as follows:

First, The user enters into MACCS2 the different accident sequences (referred to as postulated accident scenarios) which encompass the full range of severe accident scenarios evaluated for the SAMA analysis, each uniquely describing the amount of radioactive release, the timing, elevation, and the energy released. The postulated accident scenarios are obtained from site-specific PSA and related information.

Second, The region surrounding the facility (in which the accident releases are modeled and for which consequences are calculated) is divided into a polar coordinate grid with the plant at its center, similar to Figure 3 below, which depicts the 16 standard meteorological wind direction sectors that are used in most MACCS2/ATMOS applications.

Third, One year's worth of hourly weather observations are analyzed including atmospheric stability, wind speed, and precipitation conditions that occur from January 1 through December 31. Each hour of weather data, for a total of 8,760 hourly weather observations, is used as an initiation point of a weather sequence to simulate the atmospheric conditions during which a radioactive release may potentially occur.

Fourth, For each postulated accident scenario and its associated atmospheric release, ATMOS models the transport and dispersion using the Gaussian plume segment model based on the meteorological conditions for the initial hour of the release and for hours immediately

[19] The sievert is a unit of dose, (biological effect due to radiation). However, the units are usually converted to units of dose that are more familiar, i.e., "rem" where one (1) sievert = 100 rem, and population dose is usually discussed in terms of person-rem.

subsequent to the release (other than for wind direction, which remains constant for the period of time the plume segment remains within the 50-mile radius SAMA domain). ATMOS calculates the air and ground radioactivity concentrations within each grid spatial element of the polar grid over which that plume passes.

For the Seabrook site, the polar grid is comprised of a series of ten radial rings centered at the Seabrook Station with boundaries at radii of 1, 2, 3, 4, 5, 10, 20, 30, 40, and 50 miles. As seen in Figure 3, each of the radial rings marked by these boundaries is transected by 16 wind direction sectors emanating from the plant, each of 22.5-degree width.[20] Each sector represents a standard compass wind direction (e.g., NW, SSE, etc.). As a result, each ring of the radial spatial grid is divided into 16 radial sectors of 22.5-degree width, for a total of 10 rings x 16 sectors, or 160 spatial or "grid" elements.

[20]Note that for clarity purposes, the radii at 1, 2, 3, 4, and 5 miles are not shown.

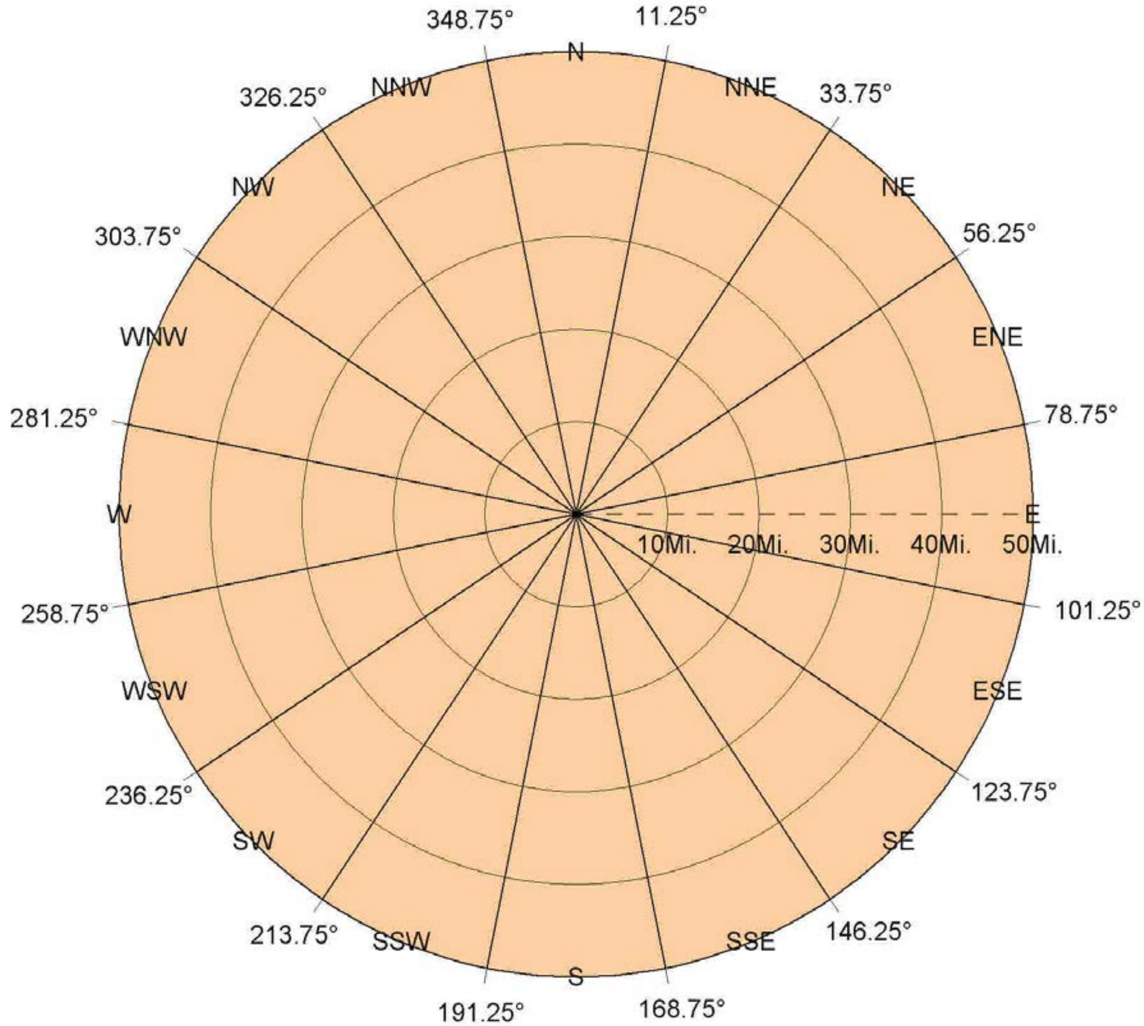

Figure 3. Polar grid used in the MACCS2 SAMA Analysis, The angular grid is aligned with the standard meteorological wind direction sectors.

<u>Fifth</u>, Using the output information from ATMOS, and the population, land use, and economic data, and interdiction model applicable to each grid spatial element (defined by a 22.5 degree sector and by two radial distances), MACCS2 calculates the offsite population dose and offsite economic cost during the short-term phase (lasting seven days from the time of the release) and the subsequent long-term phase (approximately 30 years) for each simulated radioactive release. MACCS2 does this by calculating the population dose and economic cost for each of the individual grid spatial elements affected by the simulated radiological release and then summing the results over all of the grid spatial elements.

Sixth, Performing steps four and five for the series of simulated radioactive releases for each of the postulated accident scenarios leads to a distribution of population dose results and a distribution of offsite economic cost results for each postulated accident scenario. Each result is weighted by its probability of occurrence. For the Seabrook Station SAMA analysis, steps four and five produce an offsite population dose distribution of 8,760 results for each postulated accident scenario. Similarly, steps four and five produce an offsite economic cost distribution of 8,760 results for each postulated accident scenario. The arithmetic mean or expected result of the population dose and the offsite economic cost for each postulated accident scenario is determined and reported in the MACCS2 calculation.[21]

Seventh, for each postulated accident scenario, the arithmetic mean of the population dose distribution as computed by MACCS2 is multiplied by the mean annual frequency of occurrence of the accident scenario to provide the population dose risk ("PDR") for each accident scenario. The individual PDRs for the 13 different accident scenarios are summed to determine the overall PDR for the SAMA analysis. Similarly, for each postulated accident scenario, the arithmetic mean of the offsite economic cost distribution as computed by MACCS2 is multiplied by the mean annual frequency of occurrence of the accident scenario to provide the offsite economic cost risk ("OECR") for each accident scenario. The individual OECRs for the 13 different accident scenarios are summed to determine the overall OECR for the SAMA analysis. Thus, the calculations of the plant-specific PDR and OECR are performed outside of MACCS2.

29. (KRO) To determine whether a SAMA is potentially cost beneficial, the expected value or benefit of implementing a SAMA (i.e., the expected value of the risk (PDR and OECR as well as the risk of onsite costs and occupational exposure[22]) averted by the SAMA) is compared to the cost of implementing the SAMA. This cost and benefit information is prepared following the guidance for severe accident impact calculations based on the NRC-accepted methods found in NUREG/BR-0184.

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[21] The mean as used here is the arithmetic average of the distribution of consequences obtained from the MACCS2 analysis for each accident scenario, i.e., it is the summation of the consequences associated with the 8,760 results weighted by the probability of each result. For a SAMA analysis accident scenario, MACCS2 calculates the population dose mean from the distribution of population doses, and then repeats the process to calculate the economic cost mean from the distribution of economic costs.

[22] The onsite economic costs (e.g. onsite cleanup costs, onsite property damage, replacement power costs) and occupational exposure values are calculated separately from the offsite consequences and do not depend on the MACCS2 modeling. This portion of the analysis is not challenged by the Contention and is therefore not discussed further in this declaration.

V. BACKGROUND ON ATMOSPHERIC TRANSPORT AND DISPERSION MODELING

A. Atmospheric Transport and Dispersion Models

30. (SRH) Atmospheric transport modeling is the mathematical simulation of the movement, caused by the mean wind field (wind speed and direction, averaged over 15 minutes to one hour), of the center of a pollutant cloud or plume, consisting of a gaseous emission, or particulate matter, or both. Atmospheric dispersion modeling is the simulation of how air pollutants disperse or spread (relative to the center of the plume or cloud) in the atmosphere due to turbulent wind motions, which vary from second to second. The modeling also includes processes such as deposition and chemical reactions, which are determined from the pollutant concentration distributions. Atmospheric transport and dispersion modeling is performed with computer programs that solve fundamental mathematical equations and algorithms.

31. (SRH) The inputs for an atmospheric transport and dispersion model are the characteristic of the release being modeled, such as release amount, duration of the release, time at which the release begins, plume sensible heat flux (proportional to the rate at which air is released from the source and the difference in temperature between the plume and the ambient air), and elevation, as well as meteorological variables, such as wind speed and direction, stability class (a measure of atmospheric turbulence), and rainfall rate and amount. These inputs affect the transport and dispersion of a plume. The outputs of the transport and dispersion model are concentrations or dosages (concentrations summed over time), and/or deposition to the ground surface of the pollutant for some averaging or sampling time over the geographic domain of interest.

32. (SRH) Because atmospheric transport and dispersion models are used for a multitude of purposes by many different agencies and groups in the U.S., there are numerous

plume transport and dispersion models. The models can be grouped into the following general categories:

Straight-line Gaussian plume models: These models (such as AERMOD) are based on the Gaussian or normal crosswind distribution of concentration, described below, and simulate plume transport and dispersion based on meteorological and plume inputs during the one hour (or other basic time period) of the release. These inputs are not changed during the simulation.

Gaussian plume segment or element models: These models simulate a pollutant release as a series of one or more elements or segments, which are based on changing meteorological conditions from hour to hour (or other basic time period). For example, plume transport and dispersion may be simulated using the Gaussian plume formula based on meteorological inputs during the hour at the time of the release. On an hourly basis thereafter (or whatever time period is chosen), new, updated meteorological data for that current hour are used to simulate plume transport and dispersion. The plume is seen as a series of segments or elements moving across the geographical domain. The ATMOS module in MACCS2 is an example of a dispersion model in this category, varying meteorological parameters other than wind direction.

Lagrangian puff models: These models simulate the plume as discrete puffs with approximate spherical shapes and simulate the transport and dispersion of the individual puffs with changing wind speed and direction over a multi-hour period based on wind fields established by a separate wind field model. Lagrangian puff models calculate the movement of each puff in steps of time that march forward from one time, t_1, to the next time, t_2, with time increment, $\Delta t = t_2 - t_1$. It is assumed that the mean wind speed and direction and the stability and all other ambient conditions remain constant during this time increment Δt. The atmospheric dispersion of the puffs during Δt is typically calculated using a Gaussian formula. The final estimated concentration and deposition at each time and location are calculated by summing the contributions from each puff that has an arbitrary non-zero impact.

Lagrangian particle models: These models use the same type of wind fields that are used by Lagrangian puff models but follow individual "particles." A particle is usually assumed to be a small parcel of inert neutrally buoyant air. Thousands of particles are followed by the model, where the particle's motion is randomly chosen based on knowledge of the variance of turbulent speeds and their time scale. Concentration is calculated by counting the numbers of particles within a given small grid box over a given averaging time.

Three-dimensional time dependent numerical models: These models solve the basic equations of motion, state, energy, and other relevant processes using a 3-D grid and marching the solution forward in time steps. The EPA's CMAQ model is an example, and is used for simulating regional patterns of pollutants like ozone and aerosols. . Another example is Computational Fluid Dynamics ("CFD") models, which are used for

calculating flow and dispersion around buildings and other local scenarios. CMAQ uses a horizontal grid size of about 10 km, while CFD models use a grid size of about 1 m.

B. The ATMOS Module in the MACCS2 Code

33. (SRH, KRO) A key aspect of the ATMOS module is that it uses a Gaussian plume segment model to simulate the radioactive plume's transport, dispersion, and deposition from the source location to a distance 50 miles away. For each simulated radioactive plume release, ATMOS performs all of the calculations pertaining to atmospheric transport, dispersion, and deposition of the plume, as well as the radioactive decay that occurs in the plume. The resulting outputs of the ATMOS calculations are stored for subsequent use by EARLY and CHRONC. In addition to the air and ground concentrations, ATMOS stores information on wind direction, arrival and departure times, and plume dimensions.

34. (SRH) As described above, a Gaussian plume dispersion model assumes that the atmospheric content or concentration being modeled has a Gaussian shape or distribution in a crosswind (lateral and vertical) direction for continuous releases (and also in the direction of the wind for instantaneous releases, or puffs). The Gaussian (or normal) distribution is appropriate for most environmental variables. In the specific case of atmospheric dispersion modeling of a postulated radioactive release, a Gaussian distribution means that, as the plume is carried downwind from its emission source, the crosswind distributions of concentrations ("C") of radioactivity within the plume can be approximated by assuming that the highest concentrations occur on the horizontal and vertical midlines of the plume, with the distribution about these midlines characterized by Gaussian- or bell-shaped concentration profiles.

35. (SRH, KRO) The Gaussian plume segment model in ATMOS allows each accident scenario (release category) to be modeled as consisting of up to four plume segments, released over successive intervals. For each plume segment, ATMOS assumes that the plume

segment is governed by the meteorological data specified for the initial hour (or other representative time during that plume segment's release). For subsequent hours, the meteorological data for the wind speed, stability, and precipitation affecting that plume segment are updated; only the wind direction remains unchanged. When each subsequent segment is released, this process is repeated. Therefore, unlike a standard straight-line Gaussian plume model, the Gaussian plume segment model in ATMOS changes several key variables on an hourly basis, and allows each accident scenario to be modeled in up to four segments which may travel in different directions.

36. (SRH, KRO) As stated above, for each single segment simulation the wind direction remains unchanged for the weather sequence. Thus, for example, as long as the plume segment remains on the 50-mile radius SAMA analysis domain, it will travel and disperse in the direction specified, and ATMOS will calculate air concentration and ground deposition for each of the affected spatial grid elements in the affected regions of the polar coordinate grid. If an accident scenario is modeled as consisting of several plume segments, this process will be repeated for each segment to determine the combined air concentration and ground deposition resulting from each accident scenario. These air concentration and ground deposition estimates are used to calculate population dose and economic consequences based on the population and economic input data for each of the affected grid elements.

37. (SRH, KRO) ATMOS also requires source term information, describing the amount of radioactivity released for each radionuclide. This includes the amount of radioactivity released over a given time, and its characteristics (radioactive decay chain data, particle sizes for

aerosols and deposition characteristics, etc.).[23] Also required are the associated plume physical parameters, such as height of release, release duration and sensible heat content (proportional to the difference between the plume and ambient air temperatures), and initial plume dimensions (height and width).

38. (SRH, KRO) Because ATMOS takes into account the land-use surface characteristics over the region of transport, ATMOS requires the user to specify the surface roughness length, z_o, which, in MACCS2/ATMOS, is a single value assumed to be characteristic of the fifty-mile-radius region of interest surrounding the site. The surface roughness length is used for calculating the vertical wind profile, and is also an indication of the relative amount of mechanical mixing caused by wind shear generated by surface elements, such as vegetation and structures. The MACCS2 code developers provide surface roughness length guidance for several land-use classes.

39. (KRO) For Seabrook, the atmospheric source term for each accident scenario, defined as a release category and used as input information to ATMOS, was determined in part by the MAAP computer code (version 4.0.7), using input data information based on the plant's Level 2 PRA analysis. The MAAP code, developed for the nuclear industry by the Electric Power Research Institute (EPRI), accounts explicitly for source term release and depletion mechanisms in the containment based on the current best estimate understanding of severe accident phenomena. The result is a set of parameters characterizing the timing and radionuclide

[23] In MACCS2, particle characteristics are not input in terms of particle size, density, or other physical parameters, but indirectly through use of a deposition velocity. The deposition velocity can be prescribed using tables available in the MACCS2 or other applicable documentation and is based on observations during field experiments over the past 60 years. The deposition velocity is defined as the flux of radioactivity to surfaces (structures, ground, and vegetation), divided by the atmospheric concentration near the surface.

release specified in terms of release fractions (broken into four plume segments for input to ATMOS in the Seabrook Station application) for each of the release categories.

40. (KRO) For the Seabrook Station, thirteen release categories are defined, with each release category describing a specific plant-specific accident progression and timing of release based on the Level 1 and 2 PRA. The thirteen release categories are: LE1 - Large/Early Containment Bypass – Steam Generator Tube Rupture; LE2 - Large/Early Containment Bypass – Interfacing Systems Loss-of-Coolant Accident (ISLOCA); LE3 Large/Early Containment Penetration Failure to Isolate; LE4 – Large Containment Basemat Failure with Delayed Evacuation; SE1 – Small/Early Containment Bypass – SG Tube Rupture with Scrubbed Release; SE2 - Small/Early Containment Bypass – ISLOCA with Scrubbed Release; SE3 – Small/Early Containment Penetration Failure to Isolate; LL3 – Large/Late Containment Venting; LL4 - Large/Late Containment Overpressure Failure; LL5 – Large/Late Containment Basemat Failure; SELL- Small/early Containment Penetration Failure to Isolate and Large/Late Containment Basemat Failure; INTACT1/INTACT2 – Nominal/Excessive Containment Leakage cases. For each of these release categories, four plume segments are defined as shown in Table 1. Release fractions for each plume segment in each release category are specified elsewhere.[24]

Table 1. Characteristics of the Seabrook Station Release Categories for the SAMA Analysis

Release Type	Release Category	Time After Scram when General Emergency is Reached, (s)	Plume segments	Release time from shutdown, (s)	Plume duration, (s)
Large, Early	LE 1	9,328	1	9,328	3,982
			2	13,309	86,400
			3	99,709	73,091
			4	172,800	86,400
	LE 2	40,162	1	40,162	7,898

[24] These release fractions are provided SAMA Supplement 2, SBK-L-12053, in the Tables on pages 20-26, but not repeated here.

Release Type	Release Category	Time After Scram when General Emergency is Reached, (s)	Plume segments	Release time from shutdown, (s)	Plume duration, (s)
			2	48,060	38,340
			3	86,400	86,400
			4	172,800	86,400
	LE 3	2,984	1	4,262	6,113
			2	10,375	76,025
			3	86,400	86,400
			4	172,800	86,400
	LE 4	1,984	1	3,125	71,633
			2	74,758	11,642
			3	86,400	86,400
			4	172,800	86,400
Small, Early	SE 1	75,413	1	75,416	41,393
			2	116,809	742
			3	117,551	55,249
			4	172,800	86,400
	SE 2	42,865	1	42,869	23,638
			2	66,506	19,894
			3	86,400	86,400
			4	172,800	86,400
	SE 3	3,445	1	5,108	7,024
			2	12,132	74,268
			3	86,400	86,400
			4	172,800	86,400
Large, Late	LL 3	2,988	1	4,280	5,875
			2	10,156	76,244
			3	86,400	86,400
			4	172,800	86,400
	LL 4	2,988	1	4,280	5,875
			2	10,156	86,400
			3	96,556	76,244
			4	172,800	86,400
	LL 5	63,529	1	71,219	10,249
			2	81,468	10,037
			3	91,505	86,400
			4	177,905	81,295
Large Late	SELL	63,378	1	71,035	10,829
			2	81,864	4,536
			3	86,400	86,400
			4	172,800	86,400
Intact (Containment Leakage)	INTACT1	6,527	1	8,957	11,858
			2	20,815	65,585
			3	86,400	86,400
			4	172,800	86,400

Release Type	Release Category	Time After Scram when General Emergency is Reached, (s)	Plume segments	Release time from shutdown, (s)	Plume duration, (s)
	INTACT2	6,523	1	8,953	12,035
			2	20,988	65,412
			3	86,400	86,400
			4	172,800	86,400

* (Based on SBK-L-12053, SAMA Supplement 2 (March 2012), beginning on pages 18, 20-26.)

41. (KRO) MACCS2 version 1.13.1 allows several modes of input for weather information for PRA purposes. The first is a statistical sampling of categories of weather data to determine the consequences of each release category (referred to as weather bin sampling). This method was adopted when the data storage capacity and the speed of computer processing was more limited. However, recognizing that computers are now much more powerful, a second mode is also available, and is the weather input method selected in MACCS2 for the Seabrook Station SAMA analysis. This mode consists of reading in every hour of the meteorological basis year (2005). For every hour of the year, MACCS2 calculates the offsite consequences that would be projected for each release category if the accident scenario were initiated during that hour.

42. (KRO) As an illustration, consider a four-plume segment simulation composed of a first plume segment of one (1) hour duration, the second plume segment of four (4) hours duration, the third plume segment of eight (8) hours, and a fourth plume segment of eight (8) hours duration. In the first weather trial, the first plume segment starts at the beginning of the weather data series, at the beginning of the first hour, and moves in the direction of the wind at that hour but otherwise follows the hourly progression of weather until it exits the fifty-mile radius grid. With a full calendar year of data, this means we start with January 1, 2005, beginning at midnight (12:00 AM). Plume segment 2 is released at the beginning of the second hour of weather data (1:00 am), moves in the direction of the wind for that hour as read in from

Seabrook Station meteorological data, and otherwise follows the sequence of hourly data until it exits the fifty-mile radius grid. Plume segment 3 starts with the sixth hour of weather data (5:00 AM), moves in the direction of the wind at this sixth hour, and otherwise follows the sequence of hourly data until it exits the fifty-mile radius grid. Finally, plume segment 4 starts with the fourteenth hour of weather data (1:00 PM), moves in the direction of the wind in the fourteen hour, and otherwise follows the sequence of hourly data until it exits the fifty-mile radius grid. The consequences are calculated from the superposition of the four plume segments.

43. (KRO) With the completion of the first weather trial, the release sequence is computed again using the next weather sequence beginning with its starting hour of weather. In this case, that would be day 1 (January 1, 2005 at hour 2 (1:00 AM)) for the first plume segment, then following the same time sequencing as described earlier but with a one-hour shift. In total, 8,760 weather trials are performed (365 days x 24 hours per day = 8,760 hours) with each simulation consisting of four plume segments with different start times, durations, radioactivity amounts by radionuclide group, and other related information.

44. (KRO) As a result, in the Seabrook Station analysis, there are 8,760 results for each release category's population dose, each with a probability of occurrence of 1/8,760 = 1.14E-4. The mean offsite population dose based on the characteristics of each release category is the average of these 8,760 results. The same approach is applied to offsite economic costs, i.e., there are also 8,760 results for offsite economic costs, each with an equal probability of occurrence, from which the mean offsite economic cost is determined.

45. (KRO) Once the mean annual population dose and mean annual offsite economic cost for a specific release category are calculated, the next release category (source term) is

analyzed and the calculation process is repeated using the same year of Seabrook Station meteorological data (2005). All thirteen release categories are analyzed in this manner.

VI. EVALUATION OF FRIENDS/NEC'S CONTENTION AND BASES

A. Response to Basis 1: the ATMOS Gaussian Plume Segment Model is Appropriate for SAMA Analysis

46. (SRH, KRO) The ATMOS Gaussian plume segment model is reasonable for a SAMA analysis because that analysis is focused on calculating integrated (summed) annual consequences over a broad region (50-mile radius). Worst-case impacts at a specific location and for a specific hour are not of major concern here. We disagree with Friends/NEC's claim that the ATMOS Gaussian plume model is not appropriate. Friends/NEC's claims are placing more importance on tracking the direction of individual plumes and estimating maximum short-term impacts at a single location. While that exercise may be useful for emergency response purposes or for an EPA-type estimate of short-term worst-case impacts at specific locations, it is not useful for SAMA analyses, which provide a reasonable estimate of the annual offsite consequences for SAMA cost benefit determinations.

1. Response to Sub-basis 1(a): ATMOS Accounts for Changing Meteorological Conditions Over the 50-Mile SAMA Domain

47. (SRH, KRO) Petitioners make multiple assertions alleging that the ATMOS module is incapable of modeling meteorological conditions in the Seabrook SAMA domain. These erroneous assertions include statements that ATMOS inappropriately assumes that meteorological conditions are steady in time and uniform spatially across the study region, ignores the presence of sea breeze circulations, does not account for potential "hot spots" of radioactivity, and is inappropriate to predict dispersion of a pollutant out to 50 miles, the edge of the SAMA domain. See Petition at 48-53, 58. As discussed in detail in subsequent paragraphs,

these claims are incorrect or otherwise immaterial to the Seabrook SAMA cost benefit determinations.

a. The ATMOS Gaussian Plume Segment Model Accounts for Changing Meteorological Conditions

48. (SRH, KRO) As a Gaussian plume segment model, the ATMOS model allows for hourly changes in the meteorological input data (wind speed, stability, and precipitation) other than wind direction for as long as the plume segment remains on the SAMA domain. And because each release scenario is broken down into four plume segments, with the trajectory of each plume segment depending on the wind direction at the hour it is released (or other representative time during that plume segment's release), the combined results of the four plume segment releases are also affected by changes in wind direction over the entire release period. Friends/NEC's claim that the Seabrook SAMA analysis inappropriately assumes meteorological conditions steady in time and spatially uniform, *e.g.*, Petition at 48, simply is not true.

49. (SRH, KRO) Further, in the Seabrook SAMA analysis, ATMOS automatically takes into account different meteorological patterns/wind directions by performing multiple runs (all 8,760 hours in 2005) for each accident scenario for the numerous meteorological conditions that are naturally characteristic of the Seabrook Station environment. Consequently, the details of a particular plume segment's trajectory do not have a material impact on the annual calculations summed over the 50-mile radius domain. The unique behavior in a single wind trajectory for a specific plume will tend to be compensated by the trajectories of other plumes. Therefore, ATMOS produces a reasonable estimate of the annual SAMA-specific consequences.

50. (SRH) In addition, the annual wind rose and the CALMET annual trajectory rose comparisons that I performed and are discussed in the Wind Rose Report and below (*see* ¶¶ 116-124, *infra*) show the similarity of annual wind direction roses at 28 weather sites within the 50

mile SAMA analysis domain. As discussed in those paragraphs below, no significant change in the SAMA analysis would result from using a different atmospheric dispersion model that considers time and spatially variable regional weather data.

51. (SRH) Friends/NEC also claim that the Gaussian plume model is inappropriate to predict dispersion of a pollutant out to 50 miles, the edge of the SAMA domain. *See* Petition at 48, 58 (asserting that the EPA does not approve of use of a straight-line Gaussian plume model to predict dispersion beyond 50 kilometers/32 miles), 52-53 (asserting that the MACCS2 code should be applied with caution at distances greater than ten to fifteen miles). I do not agree. As previously explained, MACCS2/ATMOS does not use a standard straight-line Gaussian plume model such as AERMOD (EPA's near-field model that is referred to in their 50 km statement above). Rather, MACCS2/ATMOS uses a Gaussian plume segment model, which allows wind speed, stability, and precipitation to change from one hour to the next along the plume trajectory. Note that the NRC does not restrict the use of MACCS2 to 50 km.

b. The Seabrook On-Site Meteorological Data Appropriately Captures and Treats Sea-Breeze Effect

i. The Sea Breeze Effect

52. (SRH) The "sea breeze" commonly refers to *cool* breezes blowing off the ocean on sunny summer days. However, in the meteorological lexicon, not all breezes blowing off the ocean are sea breezes. For example, there could be a general (synoptic) flow off the ocean, as on a day with east winds over the entire New England area. The sea breeze is defined on the basis of its cause, which is differential heating of the land and ocean surfaces on a summer day with light general (synoptic) winds. The warm land surface generates relatively low pressure in the air near the surface during daylight hours, which forces a flow from the ocean towards the land.

Most studies of sea breezes in the New England area find that sea breezes of this type occur on about 30 or 40 days in the summer.

53. (SRH) Further, many people do not realize that, on days with sea breezes, the same differential heating processes cause a "land breeze" (from the land to the ocean) at night. This is because the land is then cooler than the ocean, and the resulting pressure gradient drives an offshore wind flow. Over the whole year and over the whole SAMA geographic domain, though, the coastal breeze phenomenon would have little net effect.

54. (SRH) Coastal land and sea breezes are a type of mesoscale or medium range phenomena that can lead to relatively slow (over a few hours) variations in wind speeds and directions as much as 90° to 180°. Therefore, they would be likely to increase lateral spread of the plume over that time period and reduce concentrations and dosages at specific locations near the centerline of the plume. Accordingly, for an averaging period of a few hours or more, because of the broad (as much as 180°) variations in wind direction during a coastal breeze episode, sea and land breezes act to dilute the plume and reduce the maximum plume centerline concentration. Thus, for applications such as the SAMA analysis, the sea breeze phenomenon generally has the beneficial effect of decreasing doses at specific locations where the maximum concentration would occur and for specific time periods rather than increasing them.

ii. The Seabrook meteorological data for 2005 reflects sea breezes

55. (SRH) Friends/NEC's claim that NextEra's model "ignores" sea breezes (Petition at 49) is incorrect. Because the Seabrook Station is located two miles (3.3 km) from the coast, the anemometers on the meteorological tower are usually going to capture the sea breeze, whose effects generally extend to a distance of 10 to 20 miles from the coast. Thus, most of these on-

shore coastal breezes are captured by the Seabrook Station on-site meteorological tower during 2005 and are therefore reflected in the MACCS2 analysis.

56. (SRH, KRO) The ATMOS modeling will also be conservative because it treats the sea breeze observed at the Seabrook weather tower data as a prevailing wind that transports a plume segment 50 miles inland until it reaches the edge of the SAMA domain. That is, the ATMOS-simulated plume segment does not follow the sea breeze to its 10 to 20 mile inland extent and then turn and flow in another direction. Once a plume segment is released during a specific hour with a specific wind direction, ATMOS assumes that it proceeds in that direction for the entire 50-mile SAMA domain range, possibly reaching the more heavily populated inland areas and thus conservatively increasing the offsite population dose consequences.

57. (SRH) Moreover, in my Wind Rose Report, I compared the Seabrook Station annual wind rose with those from nine other sites (of the 27 available sites within and just outside the SAMA domain) that were near the coast. These included Isle of Shoals NH (off the coast and 12 miles to the ENE), Pease airport NH (13 miles to the NNE), Beverly airport MA (22 miles to the S), Wells Reserve ME (34 miles to the NNE), Sanford airport ME (35 miles to the NNE), Boston Logan airport MA (38 miles to the SSW), Blue Hill Observatory MA (49 miles to the SSW), Portland airport ME (59 miles to the NNE), and Plymouth airport MA (68 miles to the S). In my Wind Rose Report, Figure 9 plots the wind direction fractions, by sector, for the data from these nine coastal sites and for Seabrook Station. It is found that the Seabrook Station data approximately track the other data, showing maxima towards the eastern quadrant and minima towards the western quadrant.

58. (SRH) Therefore I conclude that the Seabrook Station meteorological observations capture the main characteristics of the sea breeze (and other coastal wind circulations) on the New England coast.

iii. NextEra Considered The Effects Caused by the Thermal Internal Boundary Layer

59. (SRH) Friends/NEC claim that a "[s]ea breeze pulls the plume down towards the land surface increasing dose to the population" (Petition at 49) is not consistent with my knowledge of atmospheric physics. Sea breezes form during the summer on sunny days when the land surface is warmer than the sea surface. As the cooler and more stable overwater air associated with the sea breeze encounters the warmer land surface at the coastline, its lower layers are gradually warmed from the bottom as it moves inland. A deepening well-mixed layer occurs near the surface. The boundary between the well-mixed layer near the surface and the more stable air above is called the thermal internal boundary layer ("TIBL"). The TIBL height, z_{TIBL}, grows with distance from the coastline, x, according to the approximate relation $z_{TIBL} = 0.1x$, for $x < 10$ km. Note that a TIBL can occur with or without a sea breeze. All that is necessary for a TIBL formation is an onshore wind at a time when the boundary layer over the water is stable and there is heating of the land surface due to the sun shining. This can occur during a sea breeze, but it can also occur when there is a general synoptic flow from the water.

60. (SRH) When a sea breeze occurs and its flow direction is opposite to the general synoptic flow direction, at the inland extent of the sea breeze (as much as 10 to 20 miles from the coast), the wind fields may change magnitude and direction as distance increases. A "sea breeze" front may be present with persistent upward vertical motions, which frequently are marked by a line of clouds. In some locations, such as Florida, there are such large vertical motions that thunderstorms may form along the sea breeze front on some days in the summer.

61. (SRH) If, for example, there is a tall stack (50 to 100 m or more) at the coastline during a scenario (daytime during the summer with sun and onshore winds) when a TIBL might form, the plume may initially find itself in the stable air above the TIBL. However, as the plume is transported inland, with its centerline at a fixed height above ground, the plume may intercept the rising TIBL when the plume height equals z_{TIBL}. For example, if a plume released at the coastline rises to a height of 300 m, it will intercept the TIBL at an inland height of about 3 km. Because the air below the TIBL is well-mixed, the rate of dispersion of the plume will increase as it passes through the TIBL. The rate of dispersion would be similar to that found in the unstable boundary layer farther inland (i.e., 20 or 30 km from the coast). Again, this is generally a dispersive effect. This phenomenon (plume passing through a TIBL) is treated by many operational dispersion models and there have been several field experiments focusing on coastal fossil-fired power plant plumes.

62. (SRH) The effect of the TIBL on a Seabrook Station plume is expected to be minimal. This is because Seabrook Station is about 2 miles (3 km) from the coast, where the TIBL would initiate. Using the approximation $z_{TIBL} = 0.1$ x, most of the time when a TIBL might form (daytime sunny periods with onshore flows in the summer), its height at Seabrook Station would be about 300 m, which is far above the plume centerline height associated with any of the SAMA analysis scenarios. Thus, the Seabrook Station plume is likely to always be in the well-mixed air below the TIBL, and would disperse as a normal sunny-day well-mixed plume.

c. Petitioners' claims with respect to "hot spots" are both technically incorrect and immaterial

63. (SRH) Friends/NEC argues that a plume blown over water, rather than being rapidly dispersed, "will remain tightly concentrated due to the lack of turbulence, and will

remain concentrated until winds blow it onto land," leading to "hot spots of radioactivity in places along the coast." Petition at 50. This claim, based on a report by Beyea (ML061640065), is both technically incorrect and immaterial. The claim that the plume will remain tightly concentrated over water is based on a fundamental misunderstanding of the equations of fluid motion and of atmospheric dispersion. As explained below, plumes from stack releases in the atmospheric boundary layer always disperse significantly and never remain "tightly concentrated."

64. (SRH) Beyea's report provides little technical support for Friends/NEC's hot spot claim. Beyea only briefly raises at pages 11-12 of his paper the potential specter of "hot spots" (Beyea's own words), with no supporting scientific justification. Beyea is not a meteorologist and he provides no scientific rationale to support his conjecture. The basic fluid dynamics theories do not allow a concentration of material such as that surmised by Beyea, and it is well-known that the atmosphere is very diffusive (due to turbulence), even during very stable conditions.

65. (SRH) "Hot spots," as claimed by Friends/NEC, simply do not exist. Therefore, one cannot estimate their occurrence or spatial and time-dependent pattern. Friends/NEC's speculative claim of hot spots requires the confluence of impossible circumstances. First, the postulated release must remain "tightly concentrated" as it travels out to sea. Even under very stable conditions plumes disperse significantly as they travel (e.g., concentrations decrease by at least a factor of ten (10) for each factor of ten (10) increase in distance). Next, the postulated release must travel out to sea and back, being carried by a variable wind field which, they claim, does not cause the "tightly concentrated" release to disperse. Again, even under very stable conditions plumes disperse significantly as they travel.

66. (SRH) The rate of dispersion over the water, such as over the Gulf of Maine, is sometimes greater and sometimes less than over land. The differences are mostly due to stability effects, which are partly determined by the air-water temperature difference. Because we are simulating a full year of meteorological conditions, we have roughly as many time periods when the air is warmer than the water (mostly in the late spring and early summer) and therefore the atmosphere is stable (less dispersive), as time periods when the air is cooler than the water (mostly in the late fall and early winter) and therefore the atmosphere is unstable (more dispersive).

67. (SRH) Additionally, for other conditions the same, at a given height over water the wind speed is greater than over land, which would enhance dilution and tend to decrease concentrations. Note that my Wind Rose Report concludes that, for the weather observing sites on the Seabrook Station SAMA domain, the average annual wind speed at the three overwater buoys and the Isle of Shoals is about twice the average annual wind speed at the on-land weather sites. While the surface roughness length is less over water than over land which would tend to slightly decrease vertical dispersion, the two effects would tend to counter each other. Over the full year, the annual summed concentrations and dosages over the Gulf of Maine are expected to be not significantly different from those over land because the seasonal and daily stability differences and roughness differences tend to cancel each other out

68. (SRH) The CALMET analysis and trajectory calculations discussed in my Wind Rose Report and also below at ¶¶ 116-124 show that there is no consistent, frequently-occurring pattern of wind blowing out to sea and then reversing direction and heading for the coast that might conceivably affect the time and space integrated results of the SAMA analysis. The comparison of the CALMET trajectory roses and the Seabrook Station annual wind roses shows

only slight differences. As will be shown below, a change of transport and dispersion models to a trajectory model such as CALMET would have an immaterial impact on the SAMA analysis. In short, "hot spots," as hypothesized by Friends/NEC, do not exist and therefore do not impact deposition and ultimately have no impact on Seabrook Station's SAMA analysis.

69. (SRH) Friends/NEC also cites two Zagar and Angevine papers from 2004 and 2006, which primarily concern ozone episodes over a broad (500 – 1000 km) region in the northeastern U.S. in summer. *See* Petition at 50. NOAA (their employer) sponsored an extensive field experiment over the New England region in the summer of 2002, aiming to study a few multiday episode periods of relatively high ozone concentrations. A major goal was to improve understanding of why regional ozone episodes were observed in Eastern coastal Maine and New Brunswick, far from the east-coast pollutant source regions. Zagar and Angevine confirm that stable meteorological conditions can sometimes occur in the boundary layer over the ocean during hot summer days with offshore winds. The broad (500 km wide) air masses of ozone can be transported from the coastal areas across the Gulf of Maine to Eastern Maine and New Brunswick. Because both papers concern analysis of field observations that are intentionally focused on worst case summertime scenarios for regional ozone concentrations over the ocean, they are not relevant for SAMA analysis, which applies to an entirely different pollutant *from a point source,* and which is based on annual summed consequences, weighted by population in specific geographic sectors over the 50-mile radius domain. Ozone is a secondary pollutant formed mainly by reactions among released pollutants such as nitrogen oxides and volatile organic compounds, where the emissions and the area of high ozone concentrations cover an area with size ranging from hundreds of km to 1000 km.

70. (SRH) Furthermore, it is already well-known that stable conditions sometimes exist over the ocean during the summer (due to warm air passing over colder water). However, these impacts of a few days of stable conditions over the ocean during the summer on the overall SAMA analysis, which covers the entire year, would be offset by unstable conditions over the ocean during some periods during the winter (due to cold air passing over warmer water) that result in increased dispersion and lower concentrations. Furthermore, equally stable meteorological conditions can exist over land during the summer during many nights, which is directly accounted for by the Gaussian plume segment model in the SAMA analysis. Therefore the analyses of a few days with relatively high regional ozone concentration during a summer field experiment described in the 2004 and 2006 Zagar and Angevine papers are not relevant for a SAMA analysis.

2. Response to Sub-basis 1(b): ATMOS Sufficiently Considers Varying Wind Fields Caused by Terrain Variations

71. (SRH) Intervenors state that "The atmospheric model included in the code does not model the impact of terrain effects on atmospheric dispersion." Petition at 51. However, based on my analysis, I conclude that the SAMA MACCS2 analysis, using ATMOS and its Gaussian plume segment model, sufficiently considers varying wind fields caused by terrain variations on the domain.

72. (SRH) As I discussed in my Wind Rose Report, the terrain surrounding the Seabrook Station throughout the 50-mile region of the SAMA analysis is relatively flat on average with a broad coastal plain and with a gradual increase in elevation to about 100 to 200 m on the northwestern edge of the domain. About half of the circular domain is occupied by the Atlantic Ocean. In general, there is limited rugged terrain or narrow valley features within 50

miles of Seabrook Station. Wind Rose Report Figures 2 and 4 show the terrain elevations and the land use map, respectively, used for the CALMET trajectory modeling.

73. (SRH, KRO) The ATMOS Gaussian plume segment model does not directly model individual terrain features, such as the possible effects of plumes impacting on the side of a large hill. Close to the stack, say at distances less than 5 km, when plumes may have a small size and may impact the side of the hill, there may be a short term (a few hours) concentration impact in that small area. This impact may be of interest for an EPA-based worst-case analysis with AERMOD, but not for a SAMA analysis that focuses on mean annual consequences (population doses and economic costs) over the 50-mile radius area. However, the Seabrook Station has no significant hills within a distance of 5 km that might cause such short term localized plume impacts.

74. (SRH) At larger distances over the entire 50-mile radius SAMA area, terrain features such as hills can have a significant dispersive effect on a plume once the plume passes over and around the features. For example, when topographical features, such as a group of hills, intervene between a source and a receptor point, the plume becomes more spread out and less concentrated than it would have been otherwise. Thus, on the scales of the SAMA domain, ignoring the dispersive effects of topographical obstacles is conservative in the sense that it results in the overestimation of the consequences.

75. (SRH) The CALMET trajectory evaluation in my Wind Rose Report, using meteorological observations from 27 additional surface weather sites and two radiosonde (upper air) sites on the SAMA domain, also shows that, for purposes of calculating annual impacts, the use of the ATMOS Gaussian plume segment model with the onsite Seabrook Station meteorological data is appropriate for the Seabrook Station SAMA analysis and is not

invalidated by terrain effects. I compared the annual 2005 wind rose at the Seabrook Station with the wind roses from other sites on the SAMA domain and found they were similar. Thus, terrain features did not significantly impact the annual wind roses at other locations so as produce significant different annual wind patterns important for SAMA analysis purposes. The CALMET trajectory analysis further confirmed the minimal impact of terrain on annual wind field patterns important for SAMA analyses. CALMET produces wind fields that specifically take into account observations at sites influenced by local topography, including the coastline, the inland hills, and other features. Based on the produced wind fields – which took into account complexities caused by the terrain and coastline – I determined that the difference in annual wind roses between an analysis with ATMOS ignoring terrain and an analysis with CALMET considering terrain does not appear to be significant.

76. (SRH) Thus, any impact of topography and other terrain features on wind field patterns is localized and has minimal, inconsequential impact on the results of the SAMA analyses.

77. (SRH) Friends/NEC assert that multiple reports and studies prepared by government agencies support their claim that "a straight line Gaussian plume model cannot account for the effects of complex terrain." Petition at 53-61. This assertion is without merit for the many reasons already stated herein. In almost all cases, the studies cited by Friends/NEC are not specific to performing SAMA analyses. Some of the studies address a wide range of assessments for which meteorological information is needed. For example, Regulatory Guide 1.23 (Revs. 0 (1972) and 1 (2007), which are cited at Petition at 53 and 55, respectively) provides guidance for an onsite meteorological measurements program to collect data needed to perform various assessments, including site suitability, radiation protection programs, and

emergency response, as well as the evaluation of environmental risk from a range of accidents. See Regulatory Guide 1.23 Rev. 1 at 4-5. Regulatory Guide 1.23 explicitly acknowledges that the "specific types of meteorological information needed differ for each of the assessments." Id. at 5.

78. (SRH) In other cases, the studies are specific to tracking an individual plume for emergency planning purposes or monitoring air quality, which are irrelevant for conducting meteorological studies supporting a SAMA analysis. For example, Friends/NEC cite to NUREG-0737, Supp. No. 1, Clarification of TMI Action Plan Requirements, Requirements for Emergency Response Capability (Jan. 1983). Petition at 54. As its title indicates, the study pertains to emergency planning. For another example, Friends/NEC cite to a 2009 NRC presentation to the National Radiological Emergency Planning conference. Petition at 56. The first portion of the presentation (ML091050226) expressly states that the purpose of the presentation is to provide a "fuller understanding of the capabilities, limitations and uncertainties of dose assessment" (Slide 4), which is "conducted during emergency response to assess the radiological impact of accidental releases of radionuclides in order to provide appropriate protective actions for the workers and the public" (Slide 6).

79. (SRH) Friends/NEC cite two studies that in fact support the Seabrook SAMA analysis. As will be discussed later, *infra* ¶¶ 110-115, the 2004 study performed by Molenkamp, et al.[25] (Petition at 54) showed that ATMOS/MACCS2 was able to predict radionuclide concentrations within the same range as more complex atmospheric dispersion models that

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[25] NUREG/CR-6853, Comparison of Average Transport and Dispersion Among a Gaussian, a Two-Dimensional, and a Three-Dimensional Model (Oct. 2004)

account for changes in terrain. The MACCS2 guidance document[26] cited by Friends/NEC (Petition at 58-59) acknowledges the "inherent conservatism" in the MACCS2 code by ignoring the dispersive effects of topographical obstacles and thus overestimating consequences.

3. Response to Sub-basis 1(c): MACCS2 Accounts for Resuspension of Radioactive Contamination Blowing Offsite

80. (KRO) Friends/NEC also allege that MACCS2 ignores onsite dispersion of contamination from a severe accident and thus ignores any resuspension of that contamination blowing offsite onto offsite communities. Petition at 52. NextEra's use of MACCS2 does not ignore onsite dispersion and does not ignore resuspension of contamination that may be blown offsite. For the Seabrook Station SAMA analysis, the first polar grid ring for purposes of calculating air and ground deposition concentrations was 1.0 mile. The MACCS2 Seabrook Station SAMA analysis calculated deposition of radioactive materials within this 1-mile ring with no distinction of whether the deposition was onsite or offsite. Furthermore, all plume materials deposited within this 1.0-mile ring were subject to resuspension in the Seabrook Station SAMA analysis as provided for by the MACCS2 code. During the seven-day emergency phase, MACCS2 accounts for resuspension by assuming that deposited radioactivity reenters the ambient wind stream due to mechanical agitation by wind, vehicular traffic, etc. Population dose and economic costs arising from resuspension are included by MACCS2 in the total population dose and economic cost consequences. In the CHRONC (long-term) phase, MACCS2 accounts for the effects of resuspension in both the population dose and economic cost consequences.

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[26] DOE-EH-4.2.1.4-MACCS2-Code Guidance, MACCS2 Computer Code Application Guidance for Documented Safety Analysis, Final Report (June 2004) at p. 3-8.

Thus, the Seabrook Station SAMA analysis fully considers resuspension of all radioactive materials deposited within the first polar coordinate ring.[27]

4. Response to Sub-basis 1(d): Use of a Single Year's Meteorological Data from a Single Onsite Source is Appropriate

81. (SRH) Friends/NEC claim that the use of a single year's meteorological data from a single onsite anemometer is insufficient to capture sea breeze or variability. Petition at 53. These challenges are without merit, as discussed below.

a. Use of single year's data

82. (SRH) One year of meteorological data was used in the SAMA analysis because MACCS2 can only accept as an input one year of data. One year of meteorological data is sufficient to estimate the annual integrated (summed) averaged impacts over the SAMA analysis domain if those data are representative. An analysis that I performed shows that that the year 2005 wind data used are representative of other years. The SAMA results are expressed as averages over the year and over the 50-mile radius domain, weighted by the population distribution. Other meteorological models that use more than one year typically serve a different purpose. For example, the EPA generally requests use of five years of data (although will allow one year in the case of special on-site meteorological observations) because EPA regulations focus on short term (few hours) maximum concentrations at specific locations. These are extreme worst-case events and it is desirable to use as long a period of data as possible to capture

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[27] The MACCS2 code was used in the Seabrook Station MACCS2 analysis as part of the overall SAMA analysis to calculate offsite consequences in terms of the offsite population dose and the offsite economic cost. The Seabrook Station SAMA analysis uses the methodology established by the NRC in NUREG/BR-0184 and NUREG/BR-0058, Rev. 4 to calculate onsite exposure and economic costs, and so did not use the MACCS2 code for these purposes.

the extreme events. But the SAMA analysis is not focused on extreme events or on specific locations and instead is focused on annual averages over the 50 mile domain.

83. (KRO) In addition, based on a sensitivity assessment of the five years of data (2004-2008) available for the MACCS2 calculations supporting the SAMA analysis[28], the meteorological data associated with year 2005 provides the maximum dose risk and cost risk and was chosen as the baseline data set for the updated SAMA analysis. Thus, it is sufficient to use one year of data, and the use of 2005 is well suited for this purpose.

84. (SRH) Further, my analysis of the meteorological data, presented in my Report, concludes that the average annual wind speed and the annual wind rose from the Seabrook Station 13.1 m (43 ft.) level on the meteorological tower for the year 2005 (used for the SAMA analysis), are representative of (i.e., not significantly different from) other years in the five year range from 2004-2008.

85. (SRH) In my Report, I compared the 2005 Seabrook Station annual wind roses with wind roses from the same site for 2004, 2006, 2007, and 2008. These five annual wind roses were compared qualitatively (by side-by-side visual analysis) and quantitatively (by tabulating wind direction frequencies per 22.5° sector). The five annual wind rose plots from each of the two levels at Seabrook Station (shown in Appendix A of the Wind Rose Report) "look visually similar" from year to year. That is, the relative occurrence of high and low values at a particular direction from year to year is similar across all five years. At the 13.1 m (43 ft.) and 63.7 m (209 ft.) levels, the dominant directions for all years are the directions toward the

[28] Letter SBK-L-12053 from Paul O. Freeman, Site Vice President, NextEra Energy Seabrook, LLC to Document Control Desk, U.S. N.R.C. "Seabrook Station, Supplement 2 to Severe Accident Mitigation Alternatives Analysis" March 19, 2012 (ADAMS Accession No. ML12080A137) at 33.

east, in the 90 degree sector from about 56° to about 146°. As seen later, for most other sites in the domain the dominant directions over this area are also towards the east.

86. (SRH) The wind roses for the five years at the 13.1 m (43 ft.) level at Seabrook Station are compared quantitatively in Table 2 in my Wind Rose Report. The numbers that are entered in the table are fractions, and sum to 1.00 over the 16 wind direction sectors for each year. The average and the range of the five numbers (one for each year) for each of the 16 wind rose direction sectors are also listed in the table. I found that the number of times that a given year has the maximum or minimum fraction over the five years in a given sector varies somewhat from year to year for the 16 sectors, and that there is no year that stands out as a major outlier. For everything equal, each year would have 16/5 = 3.2 maxima and 3.2 minima. Thus the numbers for the year 2005 (5 maxima and 2 minima) are within the range of statistical expectation.

87. (SRH) The annual average wind speeds for 2004 – 2008 at the 13.1 m (47 ft) level of the Seabrook Station meteorological tower are 3.21, 3.21, 3.28, 3.29, and 3.10 m/s, respectively. The 3.21 m/s value for 2005 is "near the middle" of the five numbers and is therefore representative.

88. (SRH) Based on the results summarized above, I concluded that the annual wind rose and annual average wind speed from 2005 at Seabrook Station are representative of other years.

b. Use of single anemometer location

89. (SRH) The Seabrook Station SAMA analysis used meteorological observations from the on-site meteorological tower. The tower, its instruments, and its data recording systems

conform to NRC guidance. This is a standard method and the NRC allows use of single meteorological observing sites in SAMA analyses at other sites, including several coastal sites.

90. (SRH) My Wind Rose Report primarily deals with the question of whether the use of other meteorological sites in the SAMA domain would significantly modify the SAMA analysis results. My analysis deals with annual averaged wind speeds and annual wind roses and annual CALMET trajectory distributions, since the SAMA analysis involves an integration or sum over all hours of the year and over the entire domain. In my report, I looked at data from 27 additional meteorological monitoring sites, within and just outside the 50-mile SAMA analysis radius. I show that the Seabrook Station observed annual wind speed is representative of the other 27 sites on the domain, and that the Seabrook Station annual wind rose is similar to others on the domain. I also show that use of all 28 wind sites (plus two "upper air" readings) to derive trajectories using the CALMET wind field model, produces annual trajectory roses very similar to the annual wind rose from the Seabrook Station. Thus I conclude that use of the single Seabrook Station anemometer location provides adequate estimates of wind speeds and wind direction distributions across the SAMA domain.

i. Wind Direction

91. (SRH) The annual wind roses from 27 other sites within and just outside of the 50-mile SAMA analysis radius around Seabrook Station were compared to the 2005 annual Seabrook Station 13.1 m (43 ft.) level wind rose used in the SAMA analysis. Wind Rose Report Table 1 lists the surface sites and Wind Rose Report Figure 3 shows their locations. A combination of visual and quantitative comparisons is used in this analysis, too. Wind Rose Report Appendix B contains the complete set of annual wind roses from the 27 other sites and from the Seabrook Station.

92. (SRH) Wind Rose Report Figure 7 shows one example of an annual wind rose comparison from Appendix B. The Seabrook Station 13.1 m annual wind rose is compared with that from the Pease Airport, which is the closest airport to the Seabrook Station site. The two wind roses are found to "look" similar, with dominant wind directions towards the east. There are slight differences in some sectors and this is typical of the differences found at the other 27 sites.

93. (SRH) None of the sites on the Seabrook Station SAMA analysis domain are located in deep river valleys or adjacent to mountains which could strongly influence the wind direction distributions. Some of the inland sites (e.g., Manchester, NH) have annual wind roses that are slightly influenced by local broad river valley orientations. However, in general the visual impression from the complete set of annual wind roses is that the Seabrook Station annual wind rose is similar to the others in the domain.

94. (SRH) A quantitative comparison of the Seabrook Station 13.1 m (43 ft.) annual wind rose and the annual wind roses from the 27 other sites is given in Table 3 of the Wind Rose Report. The sites are highlighted in the Table if their fractions are more than a factor of two larger or smaller than the overall average for that wind direction sector. Just as found in the qualitative comparisons of the annual wind roses, the quantitative comparisons show that most sites have dominant flows from the western quadrant, with the maximum blowing towards the NE to SE.

95. (SRH) In the Wind Rose Report Table 3, about 20% of the stations and wind direction sectors have fractions that are a factor of two or more larger or smaller than the average for that sector. Thus for any station, the average number of fractions larger or smaller than a factor of two from the average is 0.20 * 16 = 3.2. The number of fractions larger or smaller than

a factor of two from the average for all 28 stations in the Table ranges from 0 (E. Milton MA and Wells Beach ME) to 10 (Nashua NH). For the Seabrook Station, this number is 4 (2 sectors smaller and 2 larger than a factor of two). Thus the Seabrook Station meteorological observations are near the middle (i.e., representative) for this criterion, too.

96. (SRH) In the Wind Rose Report, I plot the fractions for all sites as a function of wind direction sector. The Seabrook Station 13.1 m (43 ft.) wind direction fractions generally are "near the middle" of the data in the figure for the other stations at each wind direction sector. Occasionally the Seabrook Station fractions are near the maximum or minimum of the sector group (e.g., the maximum at 270° and second from the minimum at 0°). However, this variability happens with most sites.

97. (SRH) In my Report, I conclude from this analysis of annual wind roses that the Seabrook Station 13.1 m (43 ft) annual wind rose is representative of other sites in the SAMA domain.

ii. Wind speed

98. (SRH) The annual wind roses for the 43 ft (13.1 m) level of the Seabrook Station site and for the other 27 sites in the SAMA domain described above indicate different colors on the direction petals for different wind speed ranges. In Table 5 of my Report, I compare the average annual wind speeds (calculated so that calms are accounted for) of the 28 sites. It is seen that the Seabrook Station annual average wind speed, at 3.02 m/s, is near the middle of the group. The average of the annual wind speeds for the 24 overland sites is 3.20 m/s and the range is from 1.16 m/s at Jaffrey, NH, to 5.30 m/s at Providence, RI. Thus the Seabrook Station annual average wind speed is only about 6% less than the multi-site average for the 24 overland sites, and can be considered to be representative of the SAMA analysis domain.

B. Response to Basis 2: Use of Alternate Atmospheric Dispersion Models Is Not Warranted

99. (SRH) Friends/NEC's claim that NextEra should have used alternate atmospheric dispersion models (*e.g.*, Petition at 52, 57-58) is but another example of its focus on individual plume tracking for short-term impacts on specific locations. The codes referenced by Friends/NEC, (e.g., AERMOD and CALPUFF), were developed by EPA to better predict individual plume behavior in order to meet specific regulatory requirements of the Clean Air Act, which are usually the maximum concentration at any location within the larger geographic domain being modeled. These codes are not appropriate for analyzing the long-term integrated consequences used for SAMA analyses.

1. EPA's AERMOD and CALPUFF Models

100. (SRH) AERMOD is similar to ATMOS in that both are atmospheric transport and dispersion models. In 2005, the AERMOD model replaced the Industrial Source Complex (ISC) Short Term model as EPA's approved model for estimating impacts of industrial sources. AERMOD and ISC are standard straight-line Gaussian plume models. AERMOD must be run for each hour of a multiyear period (5 years is recommended) as required under the Clean Air Act. Shorter time periods (e.g., 1 year) can be used if there are high-quality local (on-site) meteorological observations available. Although AERMOD is a straight-line Gaussian plume model, it incorporates updated treatments of several components, such as boundary layer profiles of wind speed, turbulence and temperature; atmospheric stability; convective dispersion; building downwash; and terrain impact. These enhancements enable direct calculation of the Gaussian plume dispersion parameters, σ_y, and σ_z, based on meteorological inputs instead of using the Pasquill discrete stability classes and discrete mixing height values. But otherwise, the Gaussian Plume dispersion formula is used. AERMOD also includes features for modeling

plume impact on nearby high terrain (facing the source) and for modeling plume downwash due to local building influences, referred to above.

101. (SRH) While AERMOD has these features, it still assumes, like any straight line Gaussian Plume model, that plume concentrations at downwind distances out to about 30 to 50 miles can be simulated using the meteorological conditions observed during a given hour. Although some of the methodologies in AERMOD are more modern when compared to ATMOS, it produces nearly the same predictions as the EPA's earlier Gaussian plume models.

102. (SRH) One important distinction mentioned several times already is that although both use the same Gaussian crosswind shape or distribution model, ATMOS uses a Gaussian plume segment model while AERMOD uses a standard straight-line Gaussian plume model. As discussed previously, the segment model used in ATMOS allows meteorological parameters such as stability, wind speed, and precipitation to vary from hour-to-hour along each plume segment trajectory until it reaches the edge of the SAMA domain at a radius of 50 miles. The straight-line model used in AERMOD is not capable of modifying the meteorological parameters for a release at a certain hour to account for changes observed in subsequent hours.

103. (SRH) The EPA's CALPUFF dispersion model is classified as a Lagrangian puff model. The center of the pollutant cloud or puff or plume is following the wind as it changes direction and speed over a multi-hour period. CALPUFF uses the CALMET meteorological processor, which uses observations from several sites and develops 3-D time-dependent meteorological fields across the geographic domain for use by CALPUFF. When wind fields or stability classes are variable in time and space, the plume trajectory calculated using the CALMET outputs may be curved and the CALPUFF cloud may have variable dispersion rates, neither of which is considered in the standard straight line Gaussian plume model, AERMOD.

Considering these variations is important for EPA requirements where maximum concentration averaged over an hour or a few hours at any location in a broad area must be calculated for each hour during a multiyear period, as required under the Clean Air Act.

104. (SRH) CALPUFF is designed so that its concentration predictions reduce to those of a standard Gaussian plume model, such as AERMOD, in the limit of constant meteorological conditions in time and space across the geographic domain. Because all of these models (including ATMOS) have been calibrated with the same set of field observations, their accuracy is about the same.

105. (SRH) Although long term annual averaged concentrations are included in the list of averaging times of interest to the EPA (at specific locations), EPA Clean Air Act applications also require consideration of maximum short-term (e.g. one-hour, eight-hour and/or 24-hour, depending on the pollutant) averaged concentrations at a specific location. Modeling individual plumes for determining such worst-case scenarios at specific locations is distinctly different from the annual estimations and weighting by population and economic activity over a 50-mile radius required for a SAMA analysis. The short-term fluctuations in wind direction that may affect a single plume trajectory will cancel each other over a long period of time. Also, any local high concentrations, say on a hillside near the stack, would be balanced by local low concentrations caused by terrain effects at other locations, and would have little effect on the summed concentration over the entire geographic domain.

106. (SRH) Although AERMOD and CALPUFF can be used to develop annual averages over a broad area similar to MACCS2, they were specifically developed to perform the type of worst case analyses previously described. AERMOD and CALPUFF require the user to specify the receptor locations where concentrations will be calculated, and specific important

locations can be identified for evaluation, such as a school (i.e., a "sensitive population"). Additionally, both AERMOD and CALPUFF have a "postprocessor" that automatically searches through calculated hourly concentrations at all receptor locations across the domain and which selects the maximum concentrations (following NAAQS averaging times and other criteria) at the specific locations, plus identifying the maximum anywhere in the domain. As an example, EPA restricts emissions of carbon monoxide such that maximum concentrations at any downwind position do not exceed 9 parts per-million (ppm) based on an 8-hour rolling average time. The 8-hour standard is met when the 3-year average of the 4th-highest daily maximum 8-hour average does not exceed 0.075 ppm at any one monitor. Comparatively, SAMA analysis uses MACCS2 and ATMOS to predict mean long-term (annual) consequences summed for a broad geographic area (e.g., a circle with a radius of 50 miles, or 7,854 square miles) used for cost-benefit analysis.

2. Impracticability of Replacing ATMOS with AERMOD or CALPUFF

107. (KRO) To the best of my knowledge, the MACCS2 code (and its predecessors), including the ATMOS module and its embedded Gaussian plume segment model, is the only software that has been applied to meet the consequence analysis portion of the regulatory requirements for a SAMA analysis. MACCS2-based results have been accepted by the NRC for PRA/SAMA applications, and have been used since the inception of SAMA cost/benefit determinations, including for numerous coastal locations such as the Seabrook Station.

108. (SRH, KRO) Currently it is not feasible to "plug" AERMOD or CALPUFF into MACCS2 as a replacement for ATMOS and still obtain SAMA consequences metrics without significant changes and much time and effort. Replacing the ATMOS module with AERMOD or CALPUFF or another meteorological model and dispersion model would be a very

complicated process, particularly since neither AERMOD nor CALPUFF is designed to model all required dose pathways from a reactor accident (e.g., food ingestion doses), decontamination processes and long-term economic consequences. While not impossible, software verification and validation, and other software quality assurance processes following such a change, as discussed below, would be time consuming as well as resource and cost-intensive.

109. (KRO, SRH) The modules used in MACCS2 are closely integrated and designed to work sequentially. Although ATMOS, AERMOD and CALPUFF are all atmospheric transport and dispersion models, there are logistical, software, and technical interface issues that preclude interchangeability. MACCS2 is not designed to accept outputs from either AERMOD or CALPUFF, and those models are not designed to accept source emissions information from MACCS2. Replacing ATMOS with either AERMOD or CALPUFF would require development of an entirely new set of software for SAMA analysis. To integrate AERMOD or CALPUFF into MACCS2 would constitute a significant undertaking, on behalf of not only NextEra, but the NRC and the industry as well. First, the software models are written in different languages and are not compatible. Second, new data and mathematical routines that share information would have to be written, and data input/output interface and supporting information transfer issues among modules would have to be resolved. Third, software quality assurance testing, obtaining comparison to earlier results, documentation of user guidance, model descriptions, and other requirements would need to be completed. Fourth, training among licensees and regulators would need to take place. Fifth, a regulatory framework, with the necessary reviews and approvals, would need to be created and implemented, including new NRC standard review plans for the staff and industry guidance.

110. (SRH, KRO) Thus, replacing the ATMOS module with AERMOD or CALPUFF would constitute an entire new modeling programming system that would require extensive work and testing to assure that the modified software would work as intended. It took EPA about eight years to develop AERMOD and another eight years to evaluate and accept AERMOD as a regulatory basis for complying with EPA requirements. With the rollout of any new regulatory code, there is a need to extensively check the solution against previous versions and scenarios. And because all three models (ATMOS, AERMOD, and CALPUFF) are likely to produce similar results in the context of SAMA-specific outputs, having been calibrated against the same set of field data, such an effort is likely to, in the end, not make much of a difference.

3. ATMOS Predicts Radionuclide Concentrations Within the Same Range as Lagrangian Models

111. (SRH, KRO) An extensive study by Molenkamp et al. (2004) showed that ATMOS/MACCS2 was able to predict concentrations within the same range as more complex NRC and DOE Lagrangian models. The Molenkamp et al. (2004) study (NUREG/CR-6853) compared four NRC and/or DOE-developed atmospheric transport and dispersion models (ATMOS/MACCS2, ADAPT/LODI, RASCAL, and RATCHET) using one year of hourly-observed meteorological data from many weather sites in a large domain in the Midwest, referred to as the Southern Great Plains (SGP) site, centered on Oklahoma and Kansas.

112. (SRH) It is my professional opinion that the Molenkamp et al. (2004) study and its conclusions are applicable here because the topography types of the Molenkamp et al. (2004) study site are sufficiently similar to that of the bulk of the coastal Seabrook Station SAMA domain in which the population is located. The general slope of the SGP is upwards from the southeast to the northwest, but there are many small-to-moderate river valleys, hills and other irregularities in the terrain.

113. (SRH, KRO) ATMOS/MACCS2 is the model used in the Seabrook Station SAMA analysis. ADAPT/LODI is a state-of-the-art, Lagrangian particle model, that links two codes – the ADAPT code used to estimate the wind field in three dimensions (3-D) based on weather observations throughout the region and the LODI code used to estimate the gaseous and particulate material transport and dispersion. The ADAPT/LODI model can account for terrain changes and time and space variability of weather. RASCAL and RATCHET are Lagrangian puff models (similar to CALPUFF), which account for two-dimensional (x and y) variations in meteorological inputs, and have slightly different representations of dispersion and of deposition. RASCAL 3.0 is used in NRC's Incident Response Center for response to radiological emergencies. RATCHET is similar to RASCAL but has more sophisticated dispersion and deposition modeling capabilities.

114. (SRH, KRO) The Molenkamp et al. (2004) evaluation included comparison of simulated concentrations and dosages at a series of rings at various distances downwind, out to 100 miles. For comparison with the Seabrook Station SAMA analysis, the results for distances of 50 miles or less are of particular interest. The results show reasonably good agreement obtained with ATMOS/MACCS2 compared to the ADAPT/LODI model. The average of the three arc-average ratios (for the 10-, 20-, and 50-mile arcs) for ATMOS/MACCS2 for non-depositing exposure, depositing exposure, and deposition is 1.08, 1.09, and 0.98, respectively. In other words, when averaged over all distances out to 50 miles, the agreement in arc average results between MACCS2 and LODI was better than plus or minus 10%.

115. (SRH, KRO) The model most similar to CALPUFF, RATCHET, gave results that are slightly lower than LODI, by about 28%, on average. Similarly, RATCHET tended to under-

predict relative to MACCS2. Thus, in the Molenkamp study, ATMOS/MACCS2 tended to predict larger consequences, relative to RATCHET.

116. (SRH, KRO) While other results were reported in the Molenkamp et al. study, the comparisons described above provide particular insight into the relative performance of the ATMOS/MACCS2 code relative to more sophisticated models for obtaining mean annual results over a grid size comparable to that used in SAMA analysis. All of the arc averages and the great majority of the arc-sector average exposures and depositions are within a factor of two when comparing ATMOS/MACCS2 to the state-of-the-art model, LODI.

4. Confirmatory CALMET Trajectory Analysis

117. (SRH) In order to confirm the representativeness of the Seabrook meteorological data, I performed a wind trajectory analysis using CALMET-generated wind fields to evaluate and confirm that, even if the time and spatially variable observed winds over the domain are directly accounted for, the annual trajectory rose is very similar to the 2005 Seabrook Station 13.1 m (43 ft) annual wind rose used in the SAMA analysis. I used the EPA CALMET diagnostic mass-consistent wind model to produce a three-dimensional spatially variable wind field over the domain for each hour of 2005. CALMET uses inputs of hourly observations from the 28 surface weather observing sites within and just outside the SAMA domain, plus twice-daily (at 7 am and 7 pm EST) radiosonde balloon sounding observations from two "upper air" sites. Using this spatially-variable wind field, I then calculated trajectories for hypothetical plumes released each hour from the Seabrook Station, and noted at what point they passed the radial arcs at one mile increments from 1 to 10 miles, and at 20, 30, 40 and 50 miles. Trajectories were calculated for three elevations: 100 m, 200 m, and 500 m. I then developed

annual trajectory roses (for 8760 hourly trajectories) for these three elevations and for 14 radial arcs to compare with the observed Seabrook Station 2005 annual wind rose.

118. (SRH) CALMET is the most widely used and accepted technology in the U.S. for developing spatially variable wind fields that can be used to take into account changes in plume travel direction as a result of changes in the wind with time and with space across a geographic domain with a size similar to the SAMA analysis domain. CALMET develops three-dimensional time dependent meteorological fields for use by the EPA's CALPUFF Lagrangian puff dispersion model. CALMET is an independent "stand-alone" code. I did not subsequently run CALPUFF because the main contention is the accuracy of the plume trajectories used in the SAMA analysis and whether they are affected substantially by the observed variable wind fields, which can be evaluated directly by CALMET.

119. (SRH) As mentioned in paragraph 115, CALMET uses inputs of hourly-observed winds at several (28 in our case) surface sites on the domain, as well as at two upper air sites (where radiosonde balloons are released twice each day). The model uses an interpolation and extrapolation method based on weighting each observation by the inverse square of the distance from the observation site to the point of interest and then imposing mass conservation. CALMET also uses inputs of terrain elevations and land use, plus cloudiness and rain. The terrain elevations are used to parameterize slope flows and curvatures around mountain ranges and valley channeling. Using these inputs, CALMET is able to calculate, for the year 2005 in our case, hourly spatially variable wind fields used to produce the trajectory roses necessary for this analysis. A detailed explanation of the CALMET wind trajectory analysis is included in my Report.

120. (SRH) The trajectory heights of 100, 200, and 500 m were chosen so as to cover the range of possible plume heights in the MACCS2/ATMOS calculation (Note that a plume well mixed from 0 to 1000 m will have an average height of 500 m). It is expected that, for the Seabrook Station SAMA analysis where the typical mixing height is about 1000 m (3,280 ft.), on most days during the year, the plumes will become well mixed through the vertical layer from the surface to the mixing height of 1000 m (3,280 ft.) by a downwind distance of about 10 miles, and will remain well mixed vertically at larger distances. There will be a few very stable hours when the plume may not mix across the entire 1000 m depth, but these will not contribute significantly. Thus, for the full year of 8760 hours of CALMET calculations, the trajectories at 500 m (1,640 ft.), at the mass-mean height of the 1000 m deep plume are the most useful for comparative analysis. As stated above, we also carried out the trajectory calculations for plume elevations of 100 and 200 m, to investigate the sensitivity of the results to changes in the assumed elevations.

121. (SRH) Given the hourly CALMET-generated wind fields for the entire year, I developed computer software that "released" a hypothetical small, inert, neutrally-buoyant parcel from the Seabrook Station at the beginning of each hour, and followed its trajectory until it passed the 50 mile circle, noting where (i.e., the angular position in degrees) each trajectory passed the radial arcs at one mile increments from 1 to 10 miles, and at 20, 30, 40 and 50 miles (corresponding to the same radial arcs used to define the grid elements in the MACCS2 code) for plume elevations of 100, 200, and 500 m. I counted the angular position where each trajectory passed these arcs. Thus at each radius, over a year there would be 8,760 instances where trajectories passed the circle. The statistical distribution around the circle was determined and used to generate annual trajectory roses, for comparison with the annual Seabrook Station wind

rose used in the SAMA analysis. The software to calculate the trajectories and determine their statistical distribution from the CALMET wind outputs was developed independently by my team.

122. (SRH) As an example, Figure 4 below (Wind Rose Report Figure 11) compares, on the same page, the Seabrook Station 2005 annual wind rose (bottom panel) and the 2005 annual trajectory rose at the 500 m height at a downwind distance of 50 miles (top panel). The trajectory rose shows how often the hourly trajectory will be at particular wind direction sectors (22.5º degrees wide) as it crosses the 50-mile arc. Visually comparing the 50 mile/500 m trajectory rose to the 2005 Seabrook Station annual wind rose shows clear similarity.

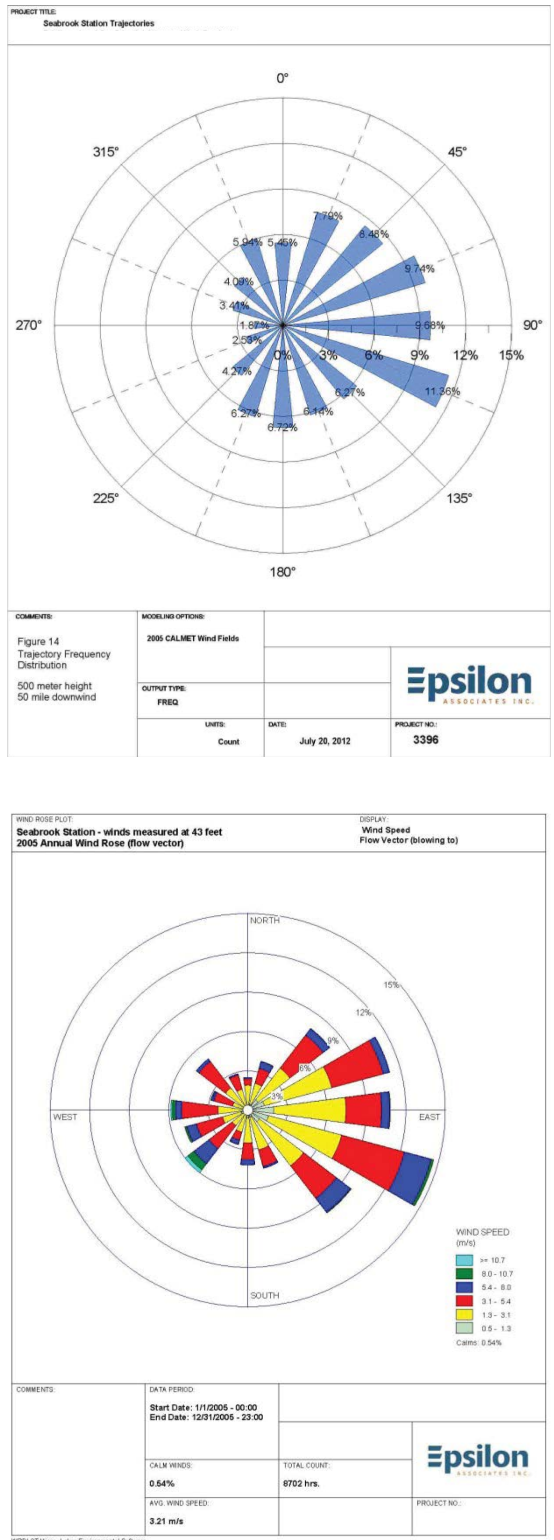

Figure 4. CALMET-generated trajectory rose at 500 m height and 50 miles distance (top panel). Seabrook Station 13.1 m (43 ft) annual wind rose for 2005 (bottom panel).

123. (SRH) It follows that, for all hours of 2005, the Gaussian plume segment model with constant wind direction for a plume released at a given hour used in ATMOS and the three-dimensional CALMET trajectory model would produce similar directional distributions. The ATMOS model annual distribution of concentrations with wind angle would approximately follow the Seabrook Station annual wind rose, which is used as inputs. The CALMET trajectories at the 500 m elevation at the 50-mile radius have traversed the entire area and have been affected by any sea breeze and terrain impacts to the extent they exist and are accounted for by the wind observations from the 28 sites over the Seabrook Station SAMA domain. The CALMET analysis confirms that there is no significant impact due to coastal breezes, including sea breezes, as observed by the 28 surface wind stations and used as inputs to CALMET, on the results of the analysis as discussed above. Thus, it is again clear that short-term differences in observed winds have little effect on the annual wind direction frequencies.

124. (SRH) Table 2 below (Table 5 in the Wind Rose Report) contains a quantitative verification of the visual comparison presented in the two panels of Figure 4 above. The Table first lists the 16 wind direction sectors. The third and fourth columns list the fraction of occurrence for each wind direction sector for the 13.1 m (43 ft.) level of the Seabrook Station meteorological tower (used in the SAMA analysis) and for the CALMET trajectory analysis (500 m elevation trajectories, at a distance of 50 miles from the Seabrook Station), respectively. The final column lists the difference between the CALMET trajectory and the Seabrook Station fractions for each 22.5° direction sector. The root mean square (RMS) difference (i.e., the standard deviation) of the 16 difference numbers is 0.0269. No sector difference is larger than 0.0399. Note that the differences are not strong functions of the magnitude of the wind fraction in a sector. Since the average fraction per sector is 0.0625 (i.e., 1/16), the RMS difference

divided by the average fraction per sector is 0.43, supporting the conclusion that there is minimal difference between the 2005 annual wind roses from the Seabrook Station 13.1 m (43 ft.) observations and from the CALMET trajectories (500 m level and 50-mile distance).

Table 2. Comparison of annual 2005 wind direction rose fractions from the CALMET trajectory analysis (500 m elevation trajectories, at 50 miles from the Seabrook Station), with annual 2005 wind direction rose fractions from the 43 ft. (13.1 m) level of the Seabrook Station meteorological tower (used in the SAMA analysis). These are for the same annual wind roses shown in Figure 4.

Wind Direction Blowing Towards 22.5 ° sector	Compass Direction	SS 13.1 m 2005 fraction	CALMET Trajectory 500 m at 50 mi fraction	SS - CALMET difference
348.75 - 11.25	**N**	0.0251	0.0545	-0.0294
11.25 - 33.75	**NNE**	0.0387	0.0779	-0.0392
33.75 - 56.25	**NE**	0.0787	0.0848	-0.0061
56.25 - 78.75	**ENE**	0.1120	0.0974	0.0146
78.75 - 101.25	**E**	0.1086	0.0968	0.0118
101.25 - 123.75	**ESE**	0.1465	0.1136	0.0329
123.75 - 146.25	**SE**	0.0991	0.0627	0.0364
146.25 - 168.75	**SSE**	0.0461	0.0614	-0.0153
168.75 - 191.25	**S**	0.0421	0.0672	-0.0251
191.25 - 213.75	**SSW**	0.0274	0.0626	-0.0352
213.75 - 236.25	**SW**	0.0602	0.0427	0.0175
236.25 - 258.75	**WSW**	0.0497	0.0253	0.0244
258.75 - 281.25	**W**	0.0586	0.0187	0.0399
281.25 - 303.75	**WNW**	0.0291	0.0341	-0.0050
303.75 - 326.25	**NW**	0.0493	0.0409	0.0084
326.25 - 348.75	**NNW**	0.0288	0.0594	-0.0306
	stdev =	0.0363	0.0268	0.0269

125. (SRH) I conclude that any short-term differences in observed winds across the SAMA domain have little effect on the annual distributions of trajectory directions. The visual and quantitative comparisons of annual trajectory roses for the three levels and the 14 distance arcs[29] versus the annual wind rose from the Seabrook Station suggest that the annual Seabrook Station wind rose used in the SAMA analysis is similar to the annual calculated trajectory roses.

[29] The 14 distance arcs are 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 20, 30, 40, and 50 miles.

For example, for the dominant winds towards the east in this geographic area, most of the trajectories pass over the water. The fractions of wind directions towards the more populated areas to the south to southwest (the Boston metropolitan area), to the northeast (the Portland area) and to the west (the Nashua-Manchester area) are relatively small for both the trajectory roses and the Seabrook Station wind rose.

5. Exposure Index Analysis

126. (KRO) An additional calculation was performed to quantitatively compare the results of the CALMET annual wind trajectory roses with the annual wind rose for the Seabrook Station in the MACCS2 analysis. A composite site-specific index called the Exposure Index (EI) was calculated, which is a function of the population distribution surrounding the plant of interest weighted by the site-specific wind direction frequency. The results of the EI analysis are documented in a report entitled, "Exposure Index Study Using MACCS2 and CALMET: A Sensitivity Study Supporting the Seabrook Station SAMA Analysis," ("EI Report"), which is provided at Exhibit 2.

127. (KRO) PSA and SAMA experience shows that the PDR and OECR are primarily affected by the population distribution and the long-term (annual) wind frequency distributions. Secondary factors, such as terrain, precipitation, and stability class have some effect on these risks, but their impact is usually less important. The EI may be thought of as a relative measure of the population potentially affected by a radiological release. The EI is influenced by the way that the population is distributed and the likelihood of the wind to be in a given direction. Quantitatively, the EI is proportional to the mean annual wind direction frequencies weighted by population in those sectors. Because the PDR and OECR are strongly dependent on wind-directed radiological exposures to high population densities, the EI can provide an indication of

relative change between the models for estimating the impact of using different wind direction frequencies. In other words, if population and regional characteristics are held constant for the same 50-mile radius region, the relative change in EI, from the MACCS2 based SAMA wind rose in one case to the CALMET based trajectory rose in the other, will indicate the relative change in PDR and OECR that would result from using the CALMET based trajectory rose instead of the Seabrook Station SAMA wind rose.

128. (KRO) To perform the EI comparison, three different annual wind direction frequency distributions were used: the Seabrook Station SAMA analysis annual wind rose as processed by the MACCS2 code; (2) the CALMET annual trajectory rose at the 500-m elevation; and (3) the CALMET annual trajectory rose at the 100-m elevation. The CALMET trajectory rose input was obtained from Dr. Hanna's Wind Rose Report. The EI was calculated by weighting the wind direction percentages for each of 80 polar coordinate elements around the Seabrook Station site (i.e., the sixteen radial sectors in each of five distance regions: 0-10 miles; 10-20 miles; 20-30 miles; 30-40 miles; and 40-50 miles) by the population in that grid element. This approach is similar to the approach used by the NRC Staff in the Generic Environmental Impact Statement on License Renewal, NUREG-1437 at section 5.3.3.2.1.

129. (KRO) The analysis was first performed by calculating the EI over the entire 50-mile polar grid using the Seabrook population distribution from the SAMA analysis and the MACCS2 annual wind rose output based on the Seabrook wind observations at the single, 13.1 m height. The CALMET annual trajectory roses were then applied in another calculation of the EI for the trajectory heights of 500-m and 100-m. In each case, the same population distribution is used and the only difference is whether the CALMET annual trajectory rose or the Seabrook Station MACCS2 annual wind rose is used. The calculations for the EI for the MACCS2 annual

wind rose and the CALMET 500 m and 100 m trajectories annual roses are provided in the EI Report.

130. (KRO) As explained in the EI Report, the total CALMET-based EI for the 50-mile SAMA domain using the 500-m trajectory annual wind direction rose data is about 34% higher than the Seabrook MACCS2-based EI. The total CALMET based EI for the 50-mile SAMA domain using the 100-m trajectory annual wind direction rose data is about 35% higher than the Seabrook MACCS2-based EI. While either CALMET set of results is about the same difference compared to that obtained with the single, Seabrook Station-based set results, the 500-m elevation results provided by CALMET are judged to be a better comparison over those calculated for the CALMET 100-m elevation. This is because, as explained by Dr. Hanna above, most atmospheric plumes released from the Seabrook Station will mix vertically as they move downwind and generally will extend to the full mixing layer height in the final twenty miles or so of travel downwind, where most of the population is found in the 50-mile domain around the Seabrook Station site.

131. (KRO) The end result of the EI comparison can be compared to the difference in benefit and the cost to implement of the current list of SAMA candidates. Approximately 91% of the total averted costs result from offsite consequences, and the remaining averted costs result from onsite consequences.[30] Thus, a 35% increase in offsite consequences results in an approximately 32% increase in total averted costs. If the EI-results with an approximate estimate of a 35% increase in offsite consequences were directly transferable to the PDR and OECR quantitative results reported in the SAMA analysis, this would not change nearly enough to identify another SAMA as potentially cost effective if we were to use a CALMET-based

[30] *See* SBK-L-12185 (ADAMS Accession No. ML12262A513) at p.13.

methodology. Increasing each SAMA's total benefit value (with seismic multiplier) by approximately 32% to account for the CALMET-based EI methodology would not result in the identification of any potentially cost beneficial SAMAs. This is because there needs to be more than a factor of two increase in the best estimate SAMA benefit before another SAMA would be considered potentially cost beneficial. SAMA #77 is the closest to becoming potentially cost beneficial.[31] Its best estimate (with seismic risk multiplier) total benefit of $6.41 million would need to increase by more than a factor of two in order to meet or exceed the expected SAMA cost of more than $15 million.

VII. CONCLUSIONS

132. (SRH, KRO) In summary, we conclude that the meteorological inputs used and the atmospheric transport and dispersion modeling that NextEra performed for support of its Seabrook Station MACCS2 analyses were reasonable and adequate to determine the mean annual offsite risks over a 50-mile radius region in a SAMA-specific cost-benefit analysis.

133. (SRH, KRO) The ATMOS module in MACCS2 is a Gaussian plume segment model which allows modeling of multiple plume segments and takes into consideration hourly changes in meteorological input data (such as wind speed, stability, and precipitation) other than wind direction for each segment. MACCS2/ATMOS takes into account different meteorological patterns/wind directions by analyzing 8,670 weather trials for each accident scenario, thus encompassing the numerous meteorological conditions that are characteristic of the Seabrook Station environment.

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[31] *See* Letter SBK-L-12053 from Paul O. Freeman, Site Vice President, NextEra Energy Seabrook, LLC to Document Control Desk, U.S. N.R.C. "Seabrook Station, Supplement 2 to Severe Accident Mitigation Alternatives Analysis" March 19, 2012 (ADAMS Accession No. ML12080A137). Adjustments were made to SAMA Candidates #91, #94, #99, #102, and #107 in SBK-L-12185 (September 13, 2012).

134. (SRH, KRO) Further, our evaluation has determined that more precise atmospheric modeling of the sea breeze phenomenon would not significantly alter the overall impacts estimated by MACCS2. The Seabrook Station meteorological towers are located within about two miles of the coast and capture most of the local sea and land breezes. The Seabrook SAMA analysis conservatively treated the effects of sea breeze. Comparisons of the Seabrook Station annual wind rose with annual wind roses at 27 other sites within and just outside the SAMA analysis domain show that there are no substantive differences. Moreover, considering other diurnal effects of land breezes, the overall impacts of sea breezes will tend to be counter-balanced over the course of a year. The CALMET trajectory analysis described in a supporting study confirms that consideration of time and spatially variable wind fields, such as sea breezes, would have no significant impact on the SAMA analysis results. The trajectory analysis shows that the Seabrook Station annual wind rose from the 13.1 m level (used in the SAMA analysis) is not significantly different from the CALMET annual trajectory roses, based on use of time-variable winds from 30 weather observing sites (28 surface sites and two upper air sites) within and just outside the SAMA analysis domain.

135. (SRH) "Hot spots," as defined by Friends/NEC, do not exist and have no impact on the Seabrook Station SAMA analysis. Even under the most stable conditions, plumes will always disperse at a large rate, with at least a factor of ten decrease in concentration with each factor of ten increase in distance travelled. Furthermore, analysis with the EPA CALMET model shows that there is no consistent pattern of wind blowing out to sea and then reversing direction and heading for the coast that could affect the SAMA analysis outcomes.

136. (SRH) The 2005 meteorological data used in the MACCS2 consequence analysis are representative and not significantly different from other years (2004-2008) that could have

been selected as a basis for the SAMA analysis. Thus, the basis year 2005 is technically justified as the baseline dataset for the Seabrook Station SAMA analysis, and accounts for the effects of relevant phenomena, such as periods of sea breeze.

137. (SRH, KRO) The Gaussian plume segment model, as employed in the MACCS2 code for the Seabrook Station SAMA analysis, provides a reasonable and adequate basis for determining whether SAMAs are cost-beneficial to implement. Because of the time- and spatially-averaged type of consequences required for a SAMA analysis, the use of alternative dispersion models for the SAMA analysis would have no material impact on the analysis and would result in no additional SAMAs becoming cost beneficial. A multi-laboratory comparison between MACCS2 and more complex DOE and NRC atmospheric transport and dispersion models to calculate average air concentration and land concentration consequences for a Midwest site, and analogous to those estimated for the Seabrook Station SAMA analysis purposes, show reasonable agreement. Specifically, the calculated annual mean consequence results for MACCS2 and more complex models agreed within a margin of plus or minus 10% (± 10%). The CALMET trajectory analysis shows that the Seabrook Station annual wind rose from the 13.1 m level (used in the SAMA analysis) is not significantly different from the CALMET trajectory annual wind roses, based on use of spatially and time-variable winds from 30 weather observing sites within and just outside the SAMA domain. And the EI analysis suggests that use of a more complex model like CALMET could potentially produce about a 32% increase in total benefits, but this change is not large enough to make the next closest SAMA, #77, potentially cost beneficial.

138. (SRH, KRO) Therefore, for purposes of identifying whether any SAMAs are cost beneficial, the MACCS2 ATMOS Gaussian plume segment methodology is adequate and

accounts for variations in the region of transport over the 50-mile SAMA analysis domain for the Seabrook Station analysis. In summary, we conclude that the Seabrook Station SAMA analysis meteorological "inputs," including the meteorological data and the Gaussian plume segment model embedded in MACCS2, are sufficiently representative and reasonably applied in the SAMA consequence analysis of offsite population dose and economic costs. Use of an alternative, more complex model is not practical or reasonable for a plant license renewal applicant. We have thoroughly evaluated the claims in Contention 4D against information in the recently-amended Seabrook Station ER and its supporting technical documentation, the applicable accepted standards for performing PRAs and SAMA analyses, and the studies and reports discussed above. Based on our evaluation, we conclude the Friends/NEC's claims in Contention 4D are technically unfounded and have no basis.

139. In accordance with 28 U.S.C. § 1746, we declare under penalty of perjury that the foregoing is true and correct.

Executed in accord with 10 C.F.R. § 2.304(d)
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May 10, 2013

ATTACHMENT A

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Ph.D., M.S., B.S.,	Meteorology, Penn State University (1967, 1966, 1964)

April 1997-Present:	President, Hanna Consultants, Kennebunkport, ME
April 2002-Present:	Adjunct Associate Prof., Harvard School of Public Health, Boston, MA
July 1997- July 2003	Research Professor, George Mason University, Fairfax, VA
April 1997-Dec. 2000:	Research Associate, Harvard School of Public Health, Boston, MA
1992-April 1997:	Principal Meteorologist, Earth Tech, Inc., Concord, MA
1985-1992:	Founder and Vice President, Sigma Research Corp., Westford, MA
1981-1985:	Principal Meteorologist, Environmental Research & Technology, Inc. (ERT), Concord, MA
1967-1981:	Research Meteorologist and Acting Director (1979-1981) USDOC/NOAA, Environmental Research Laboratories, Atmospheric Turbulence and Diffusion Laboratory, Oak Ridge, TN

AWARDS

Dr. Hanna is the 1994 recipient of the American Meteorological Society's Award for Outstanding Contribution to the Advance of Applied Meteorology, and is a 1996 Centennial Fellow of the College of Earth and Mineral Sciences of Penn State University. On June 2, 2003, he testified at a Congressional hearing on the subject of “Following Toxic Clouds: Science and Assumptions in Plume Modeling”. In January, 2005, he was named a Fellow of the American Meteorological Society. In January 2010, he received the AMS Helmut E. Landsberg award for “Significant novel and insightful contributions in applied meteorology and urban studies, including field work, data interpretation, model development, and model evaluation”.

PROFESSIONAL SUMMARY

Dr. Hanna is a specialist in atmospheric turbulence and dispersion, in the analysis of meteorological and air quality data, and in the development, evaluation, and application of air quality models. He is an AMS Certified Consulting Meteorologist with over 40 years of experience. He has led several research and development projects involving, for example, the analysis of uncertainties of dispersion models, the statistical evaluations of hazardous gas dispersion models and regional ozone models, the development of models for the dispersion of emissions from tall power plant stacks, from offshore oil platforms, and from accidental and intentional releases of hazardous chemicals, and the analysis of data from large urban and regional field experiments. From 1988-1997, Dr. Hanna was Chief Editor of the *Journal of Applied Meteorology*, and has published over 150 articles in refereed journals, six chapters in books, and five books in which he is the primary author.

RELATED PROFESSIONAL EXPERIENCE

Model Evaluation, Model Uncertainty, and Concentration Fluctuations

Under support of the American Petroleum Institute, a statistical method for evaluating air quality models was developed and applied to many types of source scenarios, models, and field data sets. This method is now accepted as a standard in international research on dispersion model evaluation (e.g., see www.harmo.org/kit). The U.S. Air Force, the U.S. Army, and the American Petroleum Institute supported the further development of a framework for evaluating and for estimating the uncertainty in environmental models. During the past few years, the Department of Defense, the Department of Energy, the Environmental Protection Agency, and the Department of Homeland Security have sponsored additional studies of model evaluation methods, with emphasis on scenarios where chemical or biological agents might be released.

From 1993 through 2006, the Electric Power Research Institute supported the development of uncertainty analysis methods for photochemical grid models. The Nuclear Regulatory Commission has had Dr. Hanna review their uncertainty analysis methods for linked emissions-dispersion-exposure-risk consequence models. The American Petroleum Institute has had Dr. Hanna lead a long-term study in which the uncertainties of dispersion models for toxic gases in urban areas were investigated. In November 2006, Dr. Hanna presented an invited talk on air quality model uncertainty at an EPA workshop on uncertainties in estimation of future changes in air quality due to changes in climate.

From 2004 through 2007, Dr. Hanna was a lead scientist in a Defense Threat Reduction Agency (DTRA) study involving improvements of methods to account for mesoscale and regional-scale uncertainties in transport and dispersion estimates.

From 2006 through 2010, Dr. Hanna led model evaluation efforts for the HPAC-Urban model and for Rockle-type urban models (supported by DTRA), for the JEM model (supported by DOD), and for the LATRA3D model (supported by the USAF).

Regional Air Quality Data Analysis and Model Evaluation

Dr. Hanna was the chief scientist for analysis of field data from several regional and urban-scale ozone experiments, including the South Central Coastal Cooperative Aerometric Monitoring Program (SCCCAMP), the Lake Michigan Ozone Study (LMOS), and the Gulf of Mexico Air Quality Study (GMAQS). He was the manager and chief scientist for the multi-agency Cross-Regional Model Evaluation project, in which four regional air quality models were evaluated with field data from the LMOS, Northeast, and SARMAP domains. From 1999 through 2005, Dr. Hanna was the chief scientist on two DOI/MMS-sponsored studies involving boundary layers and air quality in the Gulf of Mexico.

Dr. Hanna led a ten-year effort in which the effects of uncertainties in input parameters on the uncertainties in predictions of regional air quality models were assessed using Monte Carlo methods. In 2005, Dr. Hanna completed a study of the uncertainties in the BEIS3 model, which is used to estimate biogenic emissions for input to photochemical grid models. He led a Monte Carlo uncertainty study of model predictions of benzene and 1,3-butadiene in the Houston area.

Modeling of Turbulence and Diffusion

Dr. Hanna has developed applied diffusion models for several industrial and governmental clients, including a diffusion model for complex terrain (RTDM) for the Westvaco Corporation, a model for overwater diffusion (OCD) for the Minerals Management Service, a cooling tower plume model (ATCOOL) for the Department of Energy (DOE), a model for diffusion from tall stacks (HPDM) for EPRI, a hazardous gas model for chemical reactions and thermodynamics associated with UF_6 releases, and a baseline urban dispersion model.

In the past five years, Dr. Hanna's baseline urban dispersion model was further enhanced for use in estimating impacts of possible terrorist attacks with chemical and biological agents. It was evaluated with field data from Los Angeles, Salt Lake City, Oklahoma City, and New York City. He led the evaluation of DTRA's HPAC-Urban model with field data from Oklahoma City and New York City. He was the chief scientist of the Madison Square Garden-2005 (MSG05) tracer experiment in New York City.

Hazardous Gas Model Development and Analyses

The American Institute of Chemical Engineers (AIChE) Center for Chemical Process Safety (CCPS) sponsored the writing of the Guidelines for use of Vapor Cloud Dispersion Models in 1987, and the preparation of greatly-enhanced second edition in 1996. The AIChE/CCPS also sponsored preparation of the 2002 book entitled Wind Flow and Vapor Cloud Dispersion at Industrial and Urban Sites.

A USAF/API study was completed in which 15 hazardous gas models were evaluated with data from 8 field studies.

An industry-government consortium supported the five-year PERF 93-16 Dispersion Modeling Project, including field and laboratory experiments, in which dense gas models were

improved so that they account for high surface roughnesses, short-duration releases, and stable ambient conditions. Dr. Hanna was responsible for the planning and coordination of the technical components of the project and carried out the analysis of the Kit Fox field data and the evaluation of the HGSYSTEM 3+ model.

From 2005 through the present, Dr. Hanna has led DARPA, DHS, DTRA, and Chlorine Chemistry Council studies of emissions and dispersion of chlorine released from railcars. In the DTRA study, source emission model improvements were made for Toxic Industrial Chemicals (TICs). He is currently analyzing the observations from the DHS Jack Rabbit chlorine and anhydrous ammonia field experiments, and is a member of the Scientific Advisory Board, responsible for planning future field experiments.

Hazardous Gas Modeling for DTRA, DOE-CBNP, and DHS

From 1997-2002, Dr. Hanna was the director and chief scientist of the Coordinated Hazardous Atmospheric Release Modeling (CHARM) project at George Mason University. The research, supported by the Defense Threat Reduction Agency (DTRA), was concerned with development and evaluation of mesoscale meteorological models and atmospheric dispersion models for releases of chemical and biological agents. Also, from 2000 through the present, DHS is supporting studies focused on improvements in guidance given to emergency responders concerning transport and dispersion in urban areas.

Reviews of Diffusion Research

Dr. Hanna has been requested to prepare written reviews of various aspects of diffusion research by many national and international agencies, industries, and universities. He is a member of peer-review panels for NRC, DOE, EPA, CDC, DHS, CARB, and DOD programs. In March, 1997, he chaired the Peer Review Panel for the Atmospheric Modeling Division of the EPA National Exposure Research Laboratory. In June, 2000, he was a member of the Peer Review Panel for the EPA research program on ozone and air toxics. In November, 1997, he chaired the Peer Review Panel for the U.S. modeling program for the Khamisiyah, Iraq, chemical releases. In 1998 he chaired the Peer Review Panel for the EPA's new AERMOD model. In 2000, he was member of the Peer Review Panel for the Army Research Office's Atmospheric Boundary Layer Program. In 2003, he was a reviewer of the DOE VTMX research program. In 2005, he was a reviewer of the DTRA Chemical/Biological Defense Science Program. In 2009, he gave a keynote address at the Workshop on Evaluations of IMAAC models (for DHS).

Teaching Experiences at Universities

Dr. Hanna has been an adjunct professor and/or research professor at several universities during his career (Vanderbilt University from 1969 through 1973, University of Tennessee from 1974 through 1981, Harvard School of Public Health from 1983 through the present, and George Mason University from 1997 through 2002). Approximately once each year throughout this period, he has taught graduate-level courses in atmospheric turbulence and dispersion. The Vanderbilt and UT lectures were used as the basis for the textbook by Hanna, Briggs, and Hosker (1982), which has been widely adopted as a basic text at other universities. In addition, three or four times a year from 1987-1997, Dr. Hanna taught a two-day short course entitled "Vapor Cloud Dispersion" as part of AIChE/CCPS conferences. Since 2002, he has taught 8 to 16

lectures a year in Air Quality Meteorology graduate-level courses at HSPH in Boston and in their International Institute in Cyprus.

From 1997 through 2003, Dr. Hanna organized and ran the annual GMU July Workshop on Atmospheric Transport and Dispersion Modeling.

Business Experience

In 1985, Dr Hanna was a cofounder of Sigma Research Corporation, which carried out basic and applied research on meteorology and air quality issues for a variety of clients. The company grew successfully and was purchased by Earth Tech in 1992. Since 1997, Dr. Hanna has continued his consulting under Hanna Consultants, and currently spends about three-fourths of his time on that effort. The other one-fourth of his time is spent at Harvard School of Public Health. Hanna Consultants projects are sponsored by government agencies, chemical industries, environmental consulting companies, industrial associations, and universities.

Expert Witness

Dr. Hanna has provided testimony in depositions in several litigation cases and has testified in two trials and at two hearings. In most of these cases, he was required to apply and interpret atmospheric transport and dispersion models. He has modeled releases of methyl mercaptan, ammonia and chlorine from rail cars, oleum from valve ruptures, ammonia from a tank rupture, sulfuric acid from a stack, hydrogen sulfide from a missile spill, water vapor and particulates from paper mills and cooling towers, small particles and ozone from power plants over the eastern U.S., wind flows in Manhattan street canyons, and wind patterns and dispersion of potential releases from nuclear power plants.

On June 2, 2003, Dr. Hanna was one of seven scientists invited to testify at a hearing before the U.S. Congress' Subcommittee on National Security, Emerging Threats, and International Relations, on the subject of "Following Toxic Clouds: Science and Assumptions in Plume Modeling".

PROFESSIONAL ORGANIZATIONS

Sigma Xi, AAAS, AWMA
AMS: Chief Editor, J. Appl. Meteorol., 1988-1997
Chairman, Atmos. Turb. and Diff. Committee, 1977-1978
Member, AMS/EPA Cooperative Work Group, 1979-1981
Member, AMS Board on Urban Meteorology, 2002-2009
Co-Chairman of Urban Environment Conference in 2004 (Vancouver) and 2006 (Atlanta)
Chairman, 1974 Atmos. Turb. and Diff. Conference, Santa Barbara
Recipient of 1994 AMS Award for Outstanding Contribution to the Advance of Applied Meteorology
AMS Certified Consulting Meteorologist (Number 361)
Fellow, 2005
Co-Chairman of 2006 Forum on Managing our Physical and Natural Resources: Successes and Challenges, Annual Meeting, Atlanta
Chairman of F.A. Gifford Memorial Session at AMS Annual Meeting, 2008

Recipient of 2010 AMS Helmut E. Landsberg Award for "Significant novel and insightful contributions in applied meteorology and urban studies, including field work, data interpretation, model development, and model evaluation"

INVITED AUTHOR OF BOOKS

1. Hanna, S.R., 1982: *Review of Atmospheric Diffusion Models for Regulatory Applications*. World Meteorological Organization Technical Note No. 177, WMO No. 581, Geneva, Switzerland.

2. Hanna, S.R., G.A. Briggs and R.P. Hosker, 1982: *Handbook on Atmospheric Diffusion*. DOE/TIC-11223, Department of Energy, 102 pp.

3. Hanna, S.R. and P.J. Drivas, 1987: *Guidelines for the Use of Vapor Cloud Dispersion Models.* Published by CCPS/AIChE, 345 East 47th St., New York, NY 10017, 178 pp.

4. Hanna, S.R., and D.G. Strimaitis, 1988: *Workbook of Test Cases for Vapor Cloud Source Emission and Dispersion Models*. Published by CCPS/AIChE, 345 East 47th St., New York, NY 10017, 103 pp.

5. Hanna, S.R., P.J. Drivas, and J.C. Chang, 1996: *Guidelines for Use of Vapor Cloud Dispersion_ Models (Second Edition)*. Published by AIChE/CCPS, 345 East 47th St., New York, NY 10017, 285 pages + diskette.

6. Hanna, S.R. and R.E. Britter, 2002: *Wind Flow and Vapor Cloud Dispersion at Industrial and Urban Sites.* ISBN No: 0-8169-0863-X, CCPS/AIChE. 3 Park Ave., New York, NY 10016-5901, 140 pages + CD-ROM.

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ATTACHMENT B

KEVIN R. O'KULA

Advisory Engineer

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KEY AREAS:

- **Probabilistic Risk Analysis and Assessment**
- **Regulatory Standard & Guidance Development**
- **Computer Model Verification and Validation**
- **Accident and Consequence Analysis for Design Basis Accident Support**
- **Level 3 PRA Standard Development**
- **MACCS2 Code Applications**
- **New Reactor Design Accident Analysis and PRA Suppo**
- **Severe Accident and Quantitative Risk Analysis**
- **Tritium Dispersion and Consequence Analysis**

PROFESSIONAL SUMMARY:

Dr. O'Kula has over 30 years of experience as a manager and technical professional in the areas of commercial and production reactor probabilistic risk assessment (PRA) and severe accident analysis, accident and consequence analysis, source term evaluation, safety software quality assurance (SQA), safety analysis standard and guidance development, computer code evaluation and verification, risk management, hydrogen safety, reactor materials dosimetry, shielding, and tritium safety applications. He is currently the lead for the PRA technical area in the Risk Assessment and Analysis Group. Dr. O'Kula is a member of the American Nuclear Society (ANS) Standard working group ANS 58.25 on Level 3 Probabilistic Safety Assessment, and recently concluded activities as a member of the Peer Review Committee for the Nuclear Regulatory Commission's (NRC's) State-of-the-Art Reactor Consequence Analysis (SOARCA) Program. Kevin was part of the Department of Energy (DOE) team writing DOE G 414.1-4, *Safety Software Guide*. He coordinated technical support for the DOE Office of Environment, Safety, and Health (EH) in addressing Defense Nuclear Facilities Safety Board (DNFSB) Recommendation 2002-1 on Software Quality Assurance (SQA), and is a technical consultant to DOE/Health, Safety and Security (HS-31) in completing a DOE Accident Analysis Handbook.

He is supporting, or has supported, Atomic Safety Licensing Board (ASLB) relicensing issue resolution for several commercial plants including Seabrook Station, Davis-Besse, Indian Point, Prairie Island, and Pilgrim Nuclear Power Station, on MACCS2 and severe accident mitigation alternatives (SAMA) analysis. He was also part of the accident analysis and PRA/severe accident teams supporting the Design Certification Document for the U.S. Advanced Pressure Water Reactor (US-APWR) a joint effort with URS Power Division and Mitsubishi Heavy Industries (MHI). This project also included severe accident mitigation design alternatives (SAMDA) analysis. He has provided similar support for an alternative reactor technology, the Pebble Bed Modular Reactor (PBMR) prior to the project's cessation.

Dr. O'Kula was a member of the Partner, Assess, Innovate, and Sustain (PAIS) Safety Case team for the Sellafield Sites in the United Kingdom in the early 2009 period. The PAIS team identified and began implementation of improvement opportunities in nuclear safety and related areas for Sellafield. Recommendations were documented in comprehensive reports to the Site's Nuclear Management Partners consortium in March 2009.

Kevin is currently coordinating the Failure Mode, Effects, and Criticality Analysis (FMECA) for URS PS support to BNI to the Tank Waste Immobilization and Treatment Plant (WTP) design at Hanford. He also coordinated URS SMS support to the Quantitative Risk Analysis (QRA) for evaluation of hydrogen events to risk-inform the WTP design, including fault tree analysis and reliability data, and human factors areas. He is also a contributor to the DOE response on the use of risk assessment methodologies as part of the DNFSB Recommendation 2009-1 implementation action for Risk Assessment. He led work in reviewing EIS food pathway consequence analysis performed on assumed accident conditions from the Mixed Oxide Fuel Fabrication Facility (MFFF), sited at the Savannah River Site. This project compared and evaluated the impacts calculated from three computer models, including MACCS2, GENII, and UFOTRI.

He is past chair of the American Nuclear Society (ANS) Nuclear Installations Safety Division (NISD), and the Energy Facility Contractors Group (EFCOG) Accident Analysis Subgroup, and has recently completed a term as the ANS NISD Program Committee Chair. He is a member of the Nuclear Hydrogen Production Technical Group under the ANS's Environmental Sciences Division, and is chair for the EFOCG Hydrogen Safety Interest Group. He was the Technical Program Chair for two ANS embedded topical meetings on Operating Nuclear Facility Safety (Washington, D.C., 2004) and the Safety and Technology of Nuclear Hydrogen Production, Control and Management (Boston, MA, 2007). He is the Assistant Technical Program Committee Chair for the Probabilistic Safety Assessment (PSA) Meeting in Columbia, SC, scheduled for September 22-26, 2013.

Dr. O'Kula was PRA group manager for K Reactor at the time of restart in the early 1990s. He led a successful effort demonstrating Savannah River Site (SRS) K-Reactor siting compliance to 10 CFR 100, and tritium facility compliance with SEN-35-91.

He was the project leader for independent Verification and Validation (V&V) of urban dispersion software for the Defense Threat Reduction Agency (DTRA) and is the current V&V project manager for the evaluation of several chemical/biological software tools for the U.S. Army Test and Evaluation Command (ATEC) and Chemical-Biological Program (Dugway Proving Ground (Utah) and Edgewood Chemical/Biological Center in Maryland.

EDUCATION:

Ph.D., Nuclear Engineering, University of Wisconsin, 1984
M.S., Nuclear Engineering, University of Wisconsin, 1977
B.S., Applied and Engineering Physics, Cornell University, 1975

TRAINING:

Conduct of Operations (CONOPS), 1994
Harvard School of Public Health, Atmospheric Science and Radioactivity Releases, 1995
Consequence Assessment, (Savannah River Site, 1995)
U.S. DOE Risk Assessment Workshop (Augusta, GA, 1996)
MELCOR Accident Computer Code System (MACCS) 2 Computer Code, 1997, 2005, 2011
MCNPX Training Class (ANS Meeting, 1999)

CLEARANCE:

Inactive DOE "L"

PROFESSIONAL EXPERIENCE:

URS Safety Management Solutions LLC **2000 to Present**
Advisory Engineer and Senior Fellow Advisor

Dr. O'Kula is a lead technical consultant to the Department of Energy's response plan to Defense Nuclear Facilities Safety Board (DNFSB) Recommendation 2010-1, Safety Analysis Requirements for Defining Adequate Protection for the Public and the Workers, in the area of completion of a DOE Accident Analysis Handbook. This project will complete an accident analyst's desktop guide for performing consistent, standardized analysis to support Documented Safety Analysis for DOE facilities.

Kevin recently concluded activities as a member of the NRC-Sandia National Laboratories State-of-the-Art Reactor Consequence Analysis (SOARCA) Project Peer Review Committee. The SOARCA team provided recommendations on applying MACCS2 for modeling accident phenomena and subsequent off-site consequences from postulated severe reactor accidents. This activity supported the efforts of Sandia National Laboratories (SNL) and the Nuclear Regulatory Commission (NRC) to provide more realistic assessment of severe accidents.

Dr. O'Kula is also part of the Level 3 PRA Standard working group charged with developing an ANSI/ANS standard for Level 3 PRA analysis. He participated in a team that conducted an SQA gap analysis on the bioassay code [Integrated Modules for Bioassay Analysis (IMBA)] based on DOE G 414.1-4 requirements. He identified safety analysis codes that were designated as DOE "toolbox" codes, and oversaw production of the first documents (QA criteria and application plan, code guidance reports, and gap analysis) for six accident analysis codes designated for the DOE Safety Software Toolbox. He provided support to DOE/EH-31 (now DOE/HSS) for addressing SQA issues for safety analysis software. He was a contributor to DOE G 414.1-4, *Safety Software Guide* on SQA practices, procedures, and programs.

Kevin continues to support MACCS2 and related Severe Accident Mitigation Alternatives (SAMA) analysis issue resolution as a subject matter expert for a number of commercial nuclear plant license renewal applications. Included are the Pilgrim Nuclear Power Station, Indian Point Energy Center (Units 2 and 3), Davis-Besse Nuclear Plant, and Seabrook Nuclear Power Plants.

He was part of tritium environmental release analysis team that supported evaluation of tritium control and management areas for the Braidwood plant. He supported an initial SAMDA document for the Mitsubishi Heavy Industries (MHI) US-APWR (1610 MW_e evolutionary PWR), as well as complete a control room habitability study for postulated toxic chemical gas releases.

Kevin was part of a Washington Group team that developed a Design Control Document (DCD) for the MHI US-APWR using input information from MHI. He was Chapter lead on Chapter 15 (Transient and Accident Analysis), and later transitioned to severe accident evaluation and documentation support to Chapter 19 (PRA and Severe Accidents). He was the Chapter 19 lead for PRA and Severe Accident for COLA development for the Pebble Bed Modular Reactor (PBMR).

Dr. O'Kula developed the outline, coordinated contributors, and assembled the first draft of the DOE *Accident Analysis Guidebook*, a reference guide for hazard, accident, and risk analysis of nuclear and chemical facilities operated in the DOE Complex. He is also the primary author and coordinator for the *Accident Analysis Application Guide* for the Oak Ridge contractor. Dr. O'Kula also developed a one-day course and exam for the guide, which he later presented to the Oak Ridge, Paducah, and Portsmouth staff.

Dr. O'Kula also led an independent V&V review for the DTRA of the U.K.-developed Urban Dispersion Model (UDM) software for predicting chemical and biological plume dispersion in city environments, and is leading projects to verify and validate chemical/biological simulation suite software applications for the Dugway Proving Ground (Utah), and the Edgewood Chemical Biological Center (ECBC) in Maryland.

Managing Member, Consequence Analysis **1997-2000**

Dr. O'Kula was responsible for the consequence analysis associated with accident analysis sections of Documented Safety Analysis (DSA) reports and other safety basis documents for SRS, Oak Ridge, and other DOE nuclear facilities. He also developed the methodology and identified appropriate computer models for this purpose. Additionally, Dr. O'Kula developed training to enhance consistency and standardize analyses in the consequence analysis area. He was project manager for environmental assessment support to SRS on a transportation safety analysis using the RADTRAN code.

Dr. O'Kula coordinated development of a DOE Accident Analysis Guidebook involving over 10 sites and organizations. He also led the effort to produce Computer Model Recommendations for source term (fire, spill, and explosion), in-facility transport, and dispersion/consequence (radiological and chemical) areas.

Westinghouse Savannah River Company **1989 to 1997**
Group Manager

Dr. O'Kula managed consequence analyses associated with accident analysis sections of DSA reports and other safety basis documents. He also developed the associated methodologies and identified appropriate computer models. He was a member of the management team supporting Criticality Safety Evaluation preparation assisting Safe Sites of Colorado and the dispositioning of final criticality safety issues for the decommissioning and decontamination of nuclear facilities at the Rocky Flats Environmental Technology Site.

In a teaming arrangement with Science Applications International Corporation, Kevin initiated discussions that led to development of an emergency management enhancement tool to risk inform likely source terms. Applied this approach to a Savannah River nuclear facility (K Reactor), and was part of the team to provide this methodology for use on the British Advanced Gas-Cooled Reactors (AGRs) (for the United Kingdom's Nuclear Installation Inspectorate). Model was knowledge-based, and required development of an Accident Progression Event Tree (APET) for the facility in question.

Dr. O'Kula managed the completion of the SRS K Reactor PRA program. He was the lead for development of the K Reactor Source Term Predictor Model and assisted with the core technology lay-up program to preserve competencies in reactor safety. He coordinated a 25-person group responsible for K Reactor probabilistic and deterministic dose analyses, and led the examination of reduced power cases at project termination. He developed risk and dose management applications to cost-effectively prioritize facility modifications.

Kevin interfaced with DOE Independent and Senior Review teams to finalize study acceptance, and transitioned the risk assessment team to risk management functions for nuclear and waste processing facilities. In addition, he successfully prepared a 10 CFR 100 Siting white paper to resolve issues raised by the DNFSB, and teamed with DOE/HQ legal support to document resolutions. He led the development of a position paper demonstrating SRS Replacement Tritium Facility compliance with DOE Safety Policy (SEN-35-91).

Staff Engineer

Dr. O'Kula led an analytical team quantifying the tritium source term during a Loss of River Water design basis accident. He evaluated airborne tritium levels with multi-cell CONTAIN model, interfaced with a multidisciplinary team to resolve Operational Readiness Review concerns, developed an SRS-specific methodology for applying MACCS as a tool for Level 3 PRA Applications, and applied CONTAIN code for K Reactor source term analysis.

E.I. du Pont de Nemours & Company **1982 to 1989**
Principal Engineer, Research Engineer

Dr. O'Kula performed risk analysis duties for the Savannah River Laboratory (SRL) Risk Analysis Group, after earlier conducting research activities for the Reactor Materials and Reactor Physics Groups. He performed initial planning for offsite irradiation of test specimens to evaluate remaining reactor lifetime for Savannah River reactor components.

Westinghouse Electric Corporation **1975**
Summer Student, Reactor Licensing
Monroeville, PA

American Electric Power Corporation **1973 to 1974**
Co-op Student, Reactor Physics and Reactor Licensing
New York, NY

Long Island Lighting Company **1972**
Summer Intern
Riverhead, NY

PARTIAL LIST OF PUBLICATIONS (2000-2012):

K. R. O'Kula, M. G. Wentink, and C.R. Lux , *Early Lessons Learned from Risk Applications of DOE Nonreactor Nuclear Facilities***,** 2012 EFCOG Safety Analysis Workshop, May 5-10, 2012 (Santa Fe, NM).

M. G. Wentink, K. R. O'Kula (Primary and Presenting Author), H. A. Ford, C.R. Lux, and H. C. Benhardt, *Operational Frequency Analysis Model Supporting the QRA for Risk-Informing the Design of a Waste Processing Facility***,** American Nuclear Society Winter Meeting, October 30 - November 3, 2011 (Washington, D.C.).

K. R. O'Kula, D. C. Thoman, J. Lowrie, and A. Keller, *Perspectives on DOE Consequence Inputs for Accident Analysis Applications*, American Nuclear Society 2008 Winter Meeting and Nuclear Technology Expo, November 9-13, 2008 (Reno, NV).

K. R. O'Kula, F. J. Mogolesko, K-J Hong, and P. A. Gaukler, *Severe Accident Mitigation Alternative Analysis Insights Using the MACCS2 Code*, American Nuclear Society 2008 Probabilistic Safety Assessment (PSA) Topical Meeting, September 7-11, 2008 (Knoxville, TN).

K. R. O'Kula and D. C. Thoman, *Modeling Atmospheric Releases of Tritium from Nuclear Installations*, American Nuclear Society Embedded Topical Meeting on the Safety and Technology of Nuclear Hydrogen Production, Control and Management, June 24-28, 2007 (Boston, MA).

K. R. O'Kula and D. C. Thoman, *Analytical Evaluation of Surface Roughness Length at a Large DOE Site (U)*, American Nuclear Society Winter Meeting, November 12-16, 2006 (Albuquerque, NM).

K. R. O'Kula and D. Sparkman, *Safety Software Guide Perspectives for the Design of New Nuclear Facilities (U),* Winter Meeting of the American Nuclear Society, November 13 – 17, 2005 (Washington, D.C.).

K. R. O'Kula and R. Lagdon, *Progress in Addressing DNFSB Recommendation 2002-1 Issues: Improving Accident Analysis Software Applications*, Fifteenth Annual Energy Facility Contractors Group Safety

Analysis Workshop, April 30 – May 5, 2005, Los Alamos, NM (2005).

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PUBLICATIONS (1988-1999):

Dr. O'Kula authored or co-authored more than 20 publications between 1988 and 1999. Details are available upon request.

PROFESSIONAL SOCIETIES AND STANDARDS COMMITTEES

- American Nuclear Society
- Health Physics Society
- ANS Level 3 PRA Standard Committee 58.25

ATTACHMENT 3

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

March 2013

Report Number 150-01

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Prepared for

Seabrook Station

Table of Contents

1. Introduction

1.1 Overview of Purpose of Study

The main purpose of the study is to evaluate whether the use of the 2005 Seabrook Station (SS) meteorological tower wind observations as inputs to the ATMOS module of MACCS2 in the Seabrook Station SAMA analysis are a satisfactory representation of the annual 2005 wind field conditions over the SAMA analysis geographic domain (a 50 mile radius around Seabrook 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 and wind speeds for 2005 from other weather observing sites in the domain are analyzed and compared to the Seabrook Station annual wind rose and wind speed. This part of the study also assesses the similarity of the 2005 wind direction observations used in the SAMA analysis to the wind direction observations for other years at Seabrook Station.

Second, the EPA's CALMET wind field model (IWAQM 1998, Scire et al. 2005a and b) is used to develop a three-dimensional (i.e., two horizontal directions and the vertical direction) wind field over the SAMA analysis domain for each hour of 2005 in order to perform a trajectory analysis for the 50-mile region surrounding Seabrook Station. The CALMET wind field model is applied to all hours of 2005 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 Seabrook Station during each hour of 2005 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 Seabrook 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.

1.2 Methodology and Data Acquired

To investigate whether the Seabrook Station annual wind direction distributions (wind rose) and annual wind speeds are representations of the 50-mile radius geographic area being modeled in the SAMA analysis, 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 at special on-land locations (such as the Blue Hill Observatory on top of a large hill in East Milton, MA, and the Wells Reserve site at a NOAA Estuary Research facility in Wells, ME), and others are offshore buoys and lighthouses.

We reviewed the NCDC on-line lists of available official sites, and contacted the NCDC representatives to discuss our choices and settle on a final list. We obtained data from all official sites within or just outside of the 50 mile radius circle. In a few cases, there was only a fraction of a year of data available. For the annual wind rose and wind speed analysis, we did not use NCDC sites where there was less than 50% data capture.

We obtained the Seabrook Station hourly meteorological data from 2004 through 2008. The primary meteorological inputs to the Seabrook Station SAMA analysis calculations were the 2005 wind data from the 43 ft (13.1 m) level and the temperature difference between the 209 ft (63.7 m) and 43 ft (13.1 m) levels of the meteorological tower, plus the precipitation observations from a rain gauge near the base of the meteorological tower. The meteorological tower is located about 100 m from the marsh and about 2 km from the ocean. The Seabrook 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 analysis 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.

Table 1 contains a listing of the 31 sites (besides Seabrook Station) for which weather data were obtained from NCDC and other sources. The first column gives the site USAF ID, where available, and the second column gives the airport call letters (referred to as WBAN) of the International Civil Aviation Organization (ICAO). The direction and distance of each site from SS is given, as well as the site base elevation (msl), the anemometer height above local ground, and the north latitude and west longitude.

The first block of 24 sites (SS plus 23 NCDC sites) contains overland sites with only near-surface observations (most at a height of 10 m).

The second block in Table 1 consists of two upper air sites (Gray, Maine and Chatham, Massachusetts), whose data are used in the CALMET wind field and trajectory analysis. These are the closest sites where upper air (radiosonde) observations are available. 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 pressure levels such as 850 millibars (mb) (about 1300 m above sea level) and 500 mb (about 5400 m above sea level) as well as at levels where inversion bases and other significant phenomena occur.

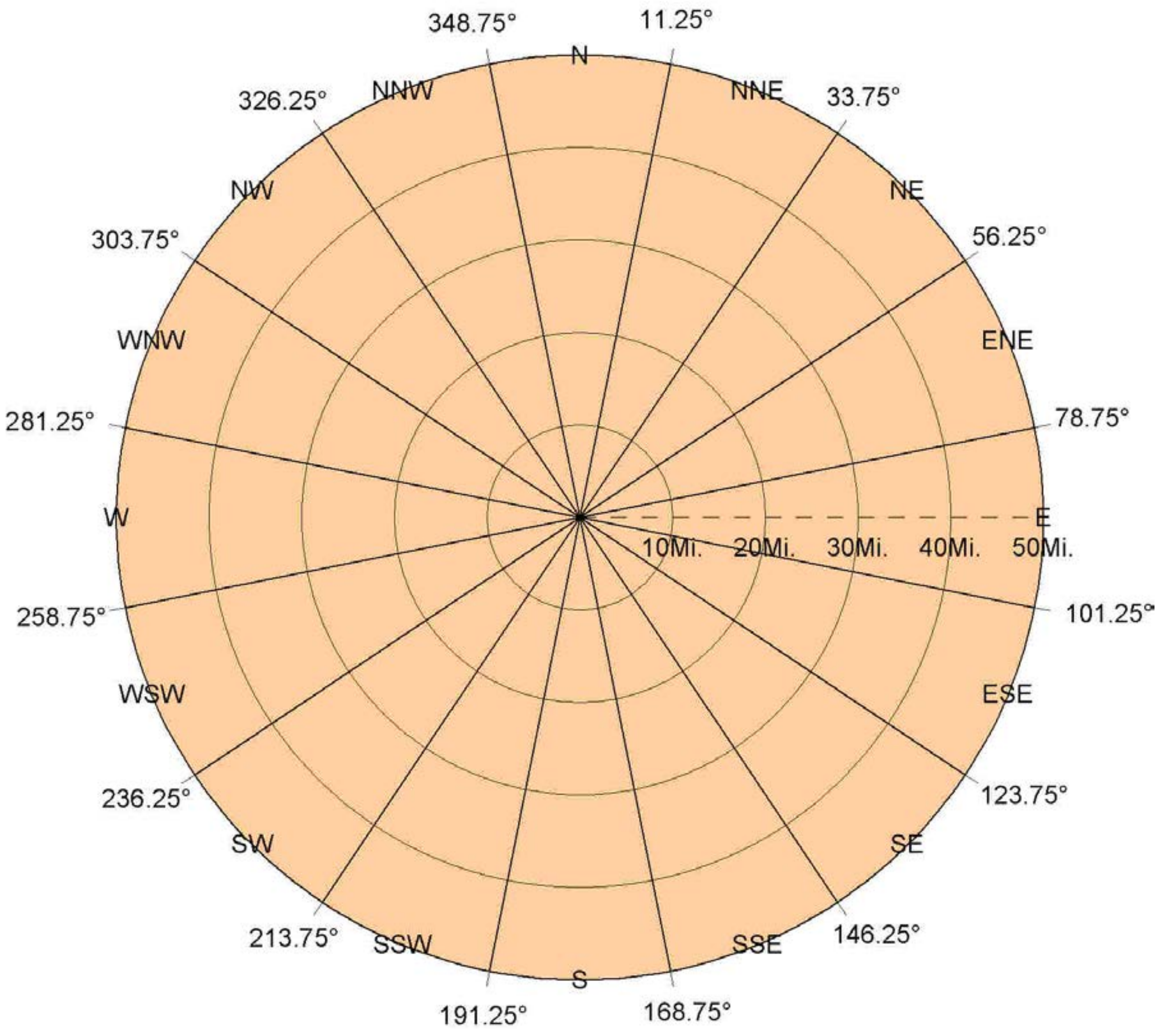


Figure 1. Angles assumed for standard meteorological wind direction sectors.

Table 1. Meteorological station site summary. The symbols R and C indicate whether the sites were used in the wind rose and/or CALMET trajectory analyses, respectively.

Station ID		R = Wind rose; C = CALMET		Dir.		Base		
USAF	WBAN	Station Name (ICAO code)	ST	From (SS)	Dist. (mi.)	Elev. (m)	Anem ht (m)	Lat N, Long W
N/A	N/A	RC Seabrook Station (SS)	NH	-	-	3.0	13.1, 63.7	42.898, 70.851
725059	14702	RC Bedford Hanscom Field (KBED)	MA	SW	37.1	40.5	10	42.470, 71.289
725088	54733	RC Beverly Municipal (KBVY)	MA	S	22.3	32.9	10	42.584, 70.916
725090	14739	RC Boston/Logan Internat (KBOS)	MA	SSW	37.9	9.1	10	42.367, 71.017
726050	14745	RC Concord Municipal (KCON)	NH	WNW	38.6	105.5	7.9	43.203, 71.502
744907	14753	RC E. Milton Blue Hill (KMQE)	MA	SSW	49.2	193.5	15.2	42.217, 71.117
725107	04780	RC Fitchburg Municipal (KFIT)	MA	WSW	51.7	106.1	10	42.554, 71.759
726163	54770	RC Jaffrey Municipal (KAFN)	NH	W	58.7	317.0	10	42.805, 72.003
726165	99999	RC Keene Dillant Hopkins (KEEN)	NH	W	71.7	149.0	10	42.898, 72.271
744904	94723	RC Lawrence Municipal (KLWM)	MA	SW	18.5	45.4	10	42.717, 71.123
743945	14710	RC Manchester (KMHT)	NH	W	29.5	70.7	10	42.933, 71.436
743946	54754	RC Nashua Boire (KASH)	NH	WSW	34.7	61.0	10	42.782, 71.515
725098	54704	RC Norwood Memorial (KOWD)	MA	SSW	52.4	15.2	10	42.191, 71.173
726055	04743	RC Pease International (KPSM)	NH	N	12.6	30.5	10	43.078, 70.823
725064	54769	RC Plymouth Municipal (KPYM)	MA	S	68.3	45.4	10	41.917, 70.733
726060	14764	RC Portland Internat Jetport (KPWM)	ME	NNE	58.7	19.2	10	43.646, 70.309
725070	14765	RC Providence/Green State (KPVD)	RI	SSW	87.0	18.9	6.1	41.717, 71.433
997278	99999	RC Providence NOS (FOXR1)	RI	SSW	81.0	10.0	4.2	41.807, 71.402
725073	64708	RC Provincetown AWOS (KPVC)	MA	SSE	66.2	2.4	10	42.067, 70.217
726056	54791	RC Rochester Skyhaven (KDAW)	NH	N	25.4	103.6	10	43.284, 70.929
726064	99999	R Sanford Municipal (KSFM)	ME	NNE	35.1	74.0	10	43.394, 70.708
997707	99999	R Wells Beach (WELM1)	ME	NNE	32.3	6.0	10	43.320, 70.563
998015	99999	R Wells Reserve (WEXM1)	ME	NNE	34.0	19.0	10.4	43.338, 70.550
725095	94746	RC Worcester Regional (KORH)	MA	SW	68.4	310.0	10	42.267, 71.876
744940	14684	C Chatham (KCHH)	MA	SSE	97.0	16.0	-	41.667, 69.950
722790	54762	C Portland/Gray (KGYX)	ME	NNE	74.9	125.9	-	43.900, 70.267
992420	44013	RC Buoy 16 NM East Of Boston, MA (DB242)	MA	S	35.7	0	5	42.346, 70.651
996340	44018	C Buoy 17NM East-Northeast of Provincetown, MA (DB634)	MA	SE	82.3	0	5	42.126, 69.630
992760	44005	RC Buoy Gulf Of Maine 78 NM East Of Portsmouth, NH (DB276)	NH	ENE	87.4	0	5	43.204, 69.128
994270	99999	RC Lighthouse Isle of Shoals, NH (IOSN3)	NH	ENE	12.5	13.1	19.2	42.967, 70.623
726036	99999	C Lighthouse Matinicus Rock, ME (MISM1)	ME	ENE	117.6	16.2	22.9	43.783, 68.855
992780	44007	RC Buoy Portland 12 NM Southeast Of Portland, ME (DB278)	ME	NE	56.3	0	5	43.531, 70.144

The third block in Table 1 consists of six overwater sites (four buoys and two offshore lighthouses). These observations are also near the surface.

To account for time and space variations in wind fields caused by physical phenomena, we devised a method to evaluate whether the annual wind rose used for the SAMA analysis – the wind rose for 2005 from the 43 ft (13.1 m) level of the Seabrook Station met tower – was consistent with or was conservative or non-conservative with respect to the effective annual wind rose that would reflect variable flow vectors in the 50-mile radius domain. Our methodology was to use the EPA's CALMET diagnostic wind model (Scire et al., 2005a, 2005b) to determine spatially variable wind fields for each hour of the SAMA analysis year (2005). The input winds used by CALMET were from official weather observing sites throughout a 200 km by 200 km (124 mile by 124 mile) square that is centered on Seabrook 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 that may occur across such a large domain and during such a long period of time.

Given the hourly CALMET-generated wind fields for the entire year of 2005, we developed software to start a hypothetical trajectory from the Seabrook Station location 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 8760 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 are distances that were used in the SAMA analysis.

Thus, at each radius, over a year there would be 8760 instances where trajectories passed each of the circles. Each angle for a given trajectory crossing was then assigned to one of the sixteen 22.5° 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 Seabrook Station 43 ft (13.1 m) 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 Appendices.

The trajectory roses are compared with the Seabrook Station 2005 wind rose from a height of 43 ft (13.1 m) (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. 2005a, 2005b). 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) mass-consistent 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 software carries out 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 cross each of the 22.5° ½ direction sectors.

The CALPUFF transport and dispersion model and its diagnostic meteorological model, CALMET, is a so-called Lagrangian puff model, since it 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. This formed the basis for the NRC's RASCAL model. 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 three-dimensional array of wind vectors for each hour. In the plots shown later, a wind vector 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 Seabrook 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 Version

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 about 100 km (about 62 miles) from Seabrook 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. Generally CALPUFF is used to simulate short-term (one hour to one day) worst case conditions at a specific location, since the EPA regulations generally require adherence to strict quantifiable numerical air quality standards.

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. However, there is much overlap in the actual applications of these EPA models.

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 Seabrook Station 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 Seabrook Station to the edge of the modeling domain. The buffer zone allows for winds to be predicted beyond the SAMA analysis 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 (the standard size used in CALMET for this type of geographic domain) was used. Figure 2 shows the modeling domain in relation to the Seabrook Station location, the 50 mile radius, and the terrain. It is seen that the 4 km resolution is able to capture most of the terrain features. 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 2005 m. The 10 m height is the level at which most observing stations measure the winds. The trajectory analysis is of interest at 100 m, 200 m and 500 m. The 500 m level is approximately half the value of the approximate mixing height, 1000 m, in the Seabrook Station 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. In addition to the Seabrook Station meteorological tower, twenty three surface stations and six 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).

Table 1 above listed the surface weather stations for which wind data were obtained. The letter "C" in the third column indicates the meteorological stations used in the 2005 CALMET analysis (Seabrook Station plus 23 NCDC sites plus six offshore sites, plus the two upper air stations). Figure 3 shows the modeling domain and the locations of the meteorological observing stations used in the CALMET modeling.

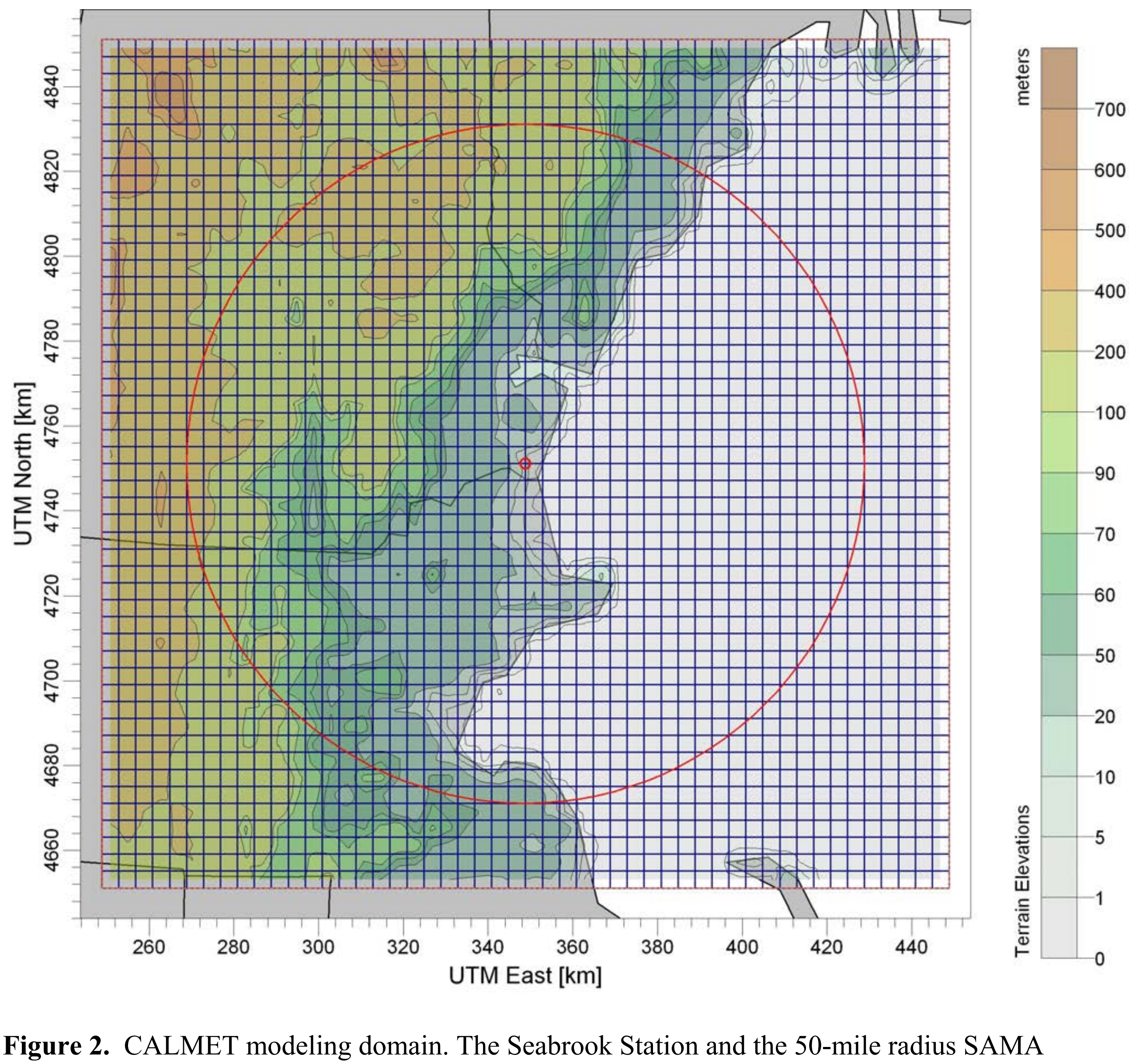


Figure 2. CALMET modeling domain. The Seabrook Station and the 50-mile radius SAMA analysis domain circle around the Seabrook Station are shown. Terrain elevations are shown as used in CALMET with 4 km grid resolution.

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 general weather conditions. The SMERGE program was updated to properly read and exclude the parameters that are unnecessary for the CALMET analysis.

To prepare the twice daily radiosonde observation data from NCDC for input to CALMET, the CALMET pre-processor, READ62, was used. Additionally, software available in the CALPUFFView GUI from Lakes Environmental was used as a first option to correct any missing data. This software substitutes missing soundings from one upper air data file (typically a nearby location) into another upper air data file. The data files were then manually edited to address any unacceptable soundings in the files, such as duplicate and obviously incomplete or incorrect soundings. The expert meteorologist's discretion was used in this process

2.3.2 Preparation of Geophysical Data Bases for CALMET

<u>Terrain Data</u>

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 from 1 degree DEM files, which cover 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. Even using these data files, there remained a few areas (mainly over the ocean) with no DEM data coverage. To determine terrain heights in these areas through the CALMET terrain preprocessor, 30-arc-second (~900 m spacing) digital global terrain data (GTOPO30) were used.

The CALMET modeling domain around Seabrook Station encompasses a range of terrain elevations, from expanses of open ocean, to relatively flat coastal plain locations, to the hills with elevations of a few hundred meters in central Maine and New Hampshire. The spacing of the terrain data in the 7.5 minute DEM file is approximately every 30 m (98.4 ft). The spacing of the 1-degree DEM file is approximately 90 m (295 ft), and the spacing of the 30-arc-second data is 900 m (2953 ft). The CALMET pre-processor, TERREL, was used to process the terrain data for input to CALMET. 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 were shown previously in Figure 2.

The coastal plain can be seen in Figure 2, which illustrates the gradual upslope, reaching an elevation of 100 m at an inland distance of about 20 to 30 miles and 200 m at an inland distance of about 30 to 50 miles. The trajectories from the Seabrook Station to the major population centers in the Boston area and the Portsmouth NH and Portland ME areas are along the coastal plain.

<u>Land Use Data</u>

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). Global Land Cover Characterization (GLCC) was used to supplement the CTG data where CTG data were missing. The GLCC data set is a 1-km resolution land cover database also available from USGS. 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 categories used by CALMET. Figure 4 shows the dominant land use categories for each CALMET grid cell in the modeling domain.

Before incorporating the many surface wind observations, CALMET starts with an initial three-dimensional wind field based on the Gray, Maine, NWS upper air observations, taken by a rising radiosonde balloon. The upper air observations are adjusted to reflect the effects of the CALMET fine-scale (4 km) 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. Any 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 location and R_{scale} is a scaling distance (noted as R_1 and R_2 in CALMET), which is based on physical reasoning and experience. R_{scale} is on the order of 10 km (6.2 mi) to 100 km (62 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.

The weighting factor, $\exp(-(R/R_{scale})^2)$, is applied to the observations and to the Step 1 field winds within the radius of influence. The scaling distance, R_{scale} (either R_1 or R_2), is a measure of the spatial representativeness of the surface (R_1) or upper air (R_2) observation sites. For a single surface observing station, R_1 represents the distance from that station at which the observation and the Step 1 wind field are weighted equally. A value of R_1 = 50 km (31 mi) was assumed for the surface layer. Therefore, at distances less than 50 km (31 mi), the surface observation is given more weight, and beyond 50 km (31 mi), the Step 1 wind field dominates. A value of R_2 = 100 km (62 mi) was assumed for the upper air (layers aloft). These values are used in most CALMET applications and are partially based on 20 years of experience by many users.

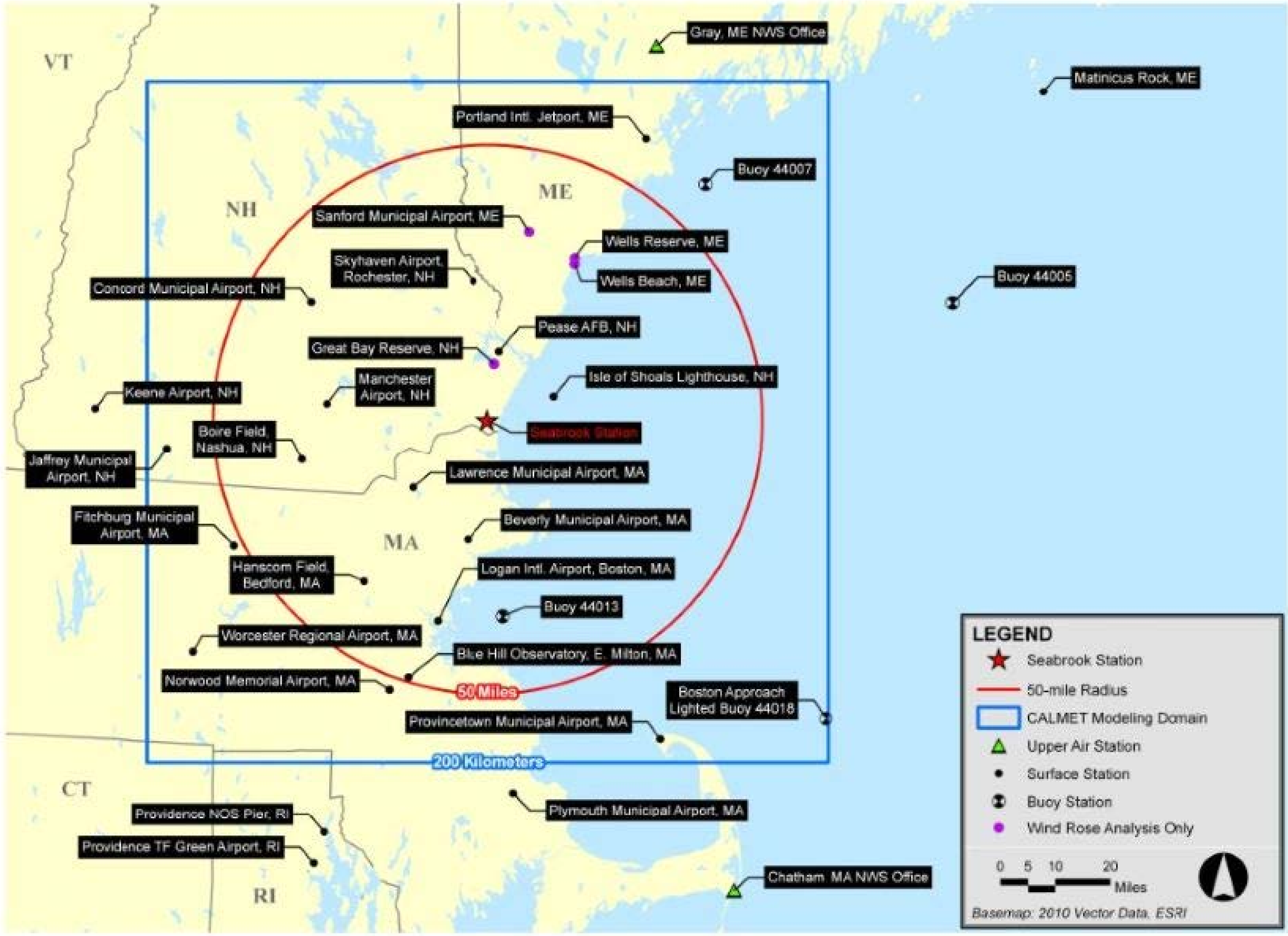


Figure 3. Locations of meteorological stations used in wind rose analysis and CALMET modeling and listed in Table 1. Land surface, buoy and upper air station locations are shown. The 50-mile radius circle around Seabrook Station is shown in red and the 200 km by 200 km CALMET modeling domain is shown in blue.

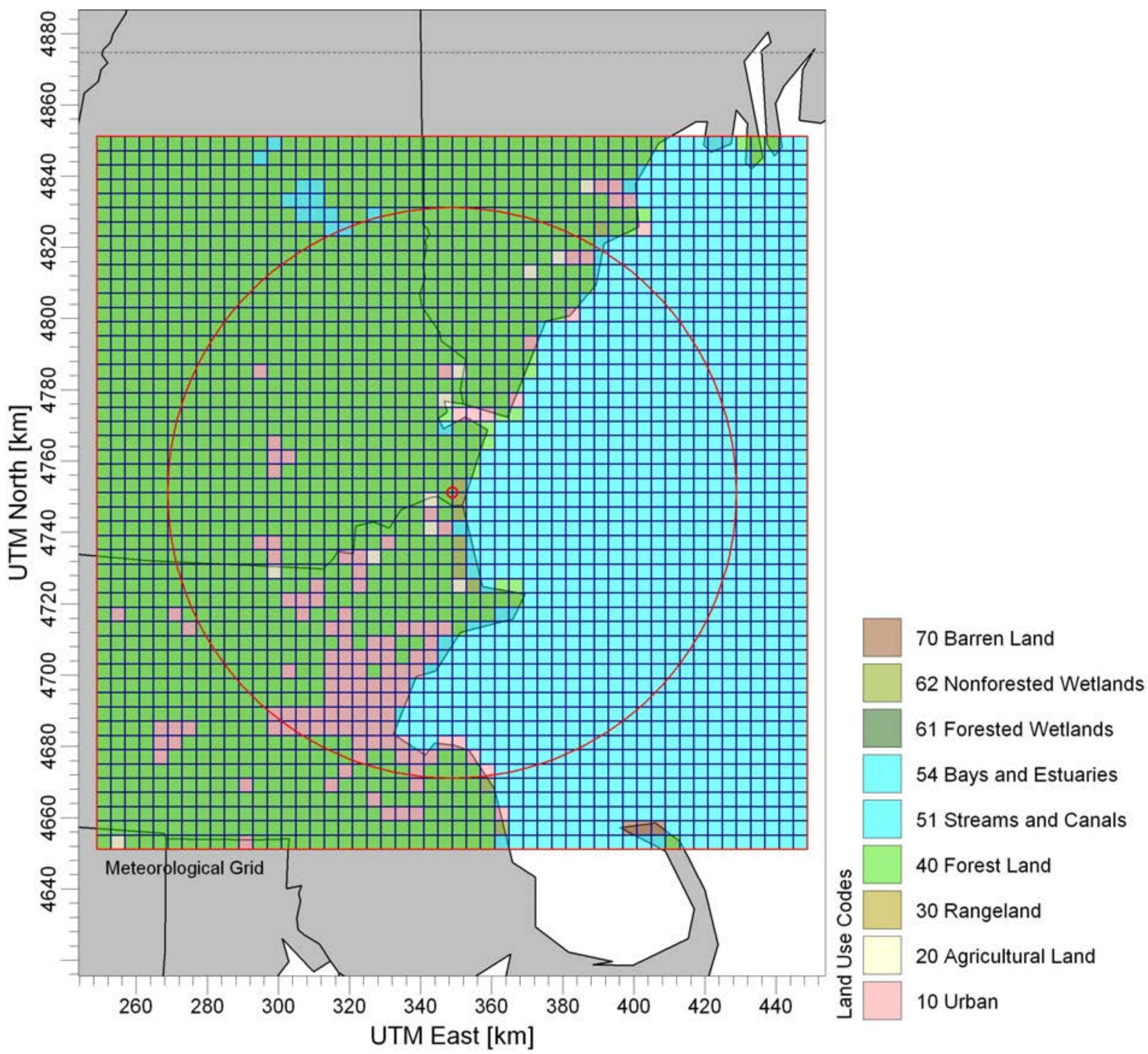


Figure 4. Land use categories (at 4 km resolution) in the CALMET modeling domain. The Seabrook Station and the 50-mile radius circle around Seabrook Station are shown.

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.

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).

2.3.4 An Example of CALMET Meteorological Modeling Results

Initially we attempted to run CALMET as a single computer run for all 8760 hours of NCDC-provided meteorological data for 2005. When running the subsequent software to compute trajectories, we found that the computational process was exceedingly slow 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 2005). This adjustment resulted in much smaller CALMET output files and 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 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 Seabrook 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, 2005 and ran through hour 23 of January 1, 2006.

As an example of the type of hourly wind information that is produced by CALMET, Figure 5 is a plot of the surface wind field vectors generated at a height of 100 m by the model for 2200 (10:00 pm) on January 31, 2005. The figure illustrates that, at this time, the dominant flows are from northwest to southeast over the domain, with some variations in speed and direction from one part of the domain to another.

2.4 Development of Trajectory Analysis Software

The wind fields output by the CALMET software were used to calculate hypothetical trajectories on the SAMA analysis domain. The trajectory is the path of a small non-buoyant inert parcel of air "released" from Seabrook Station at the beginning of each hour, and moved by the spatially-variable 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 Seabrook Station meteorological tower and is followed until it passes the 50 mile (81 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.

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

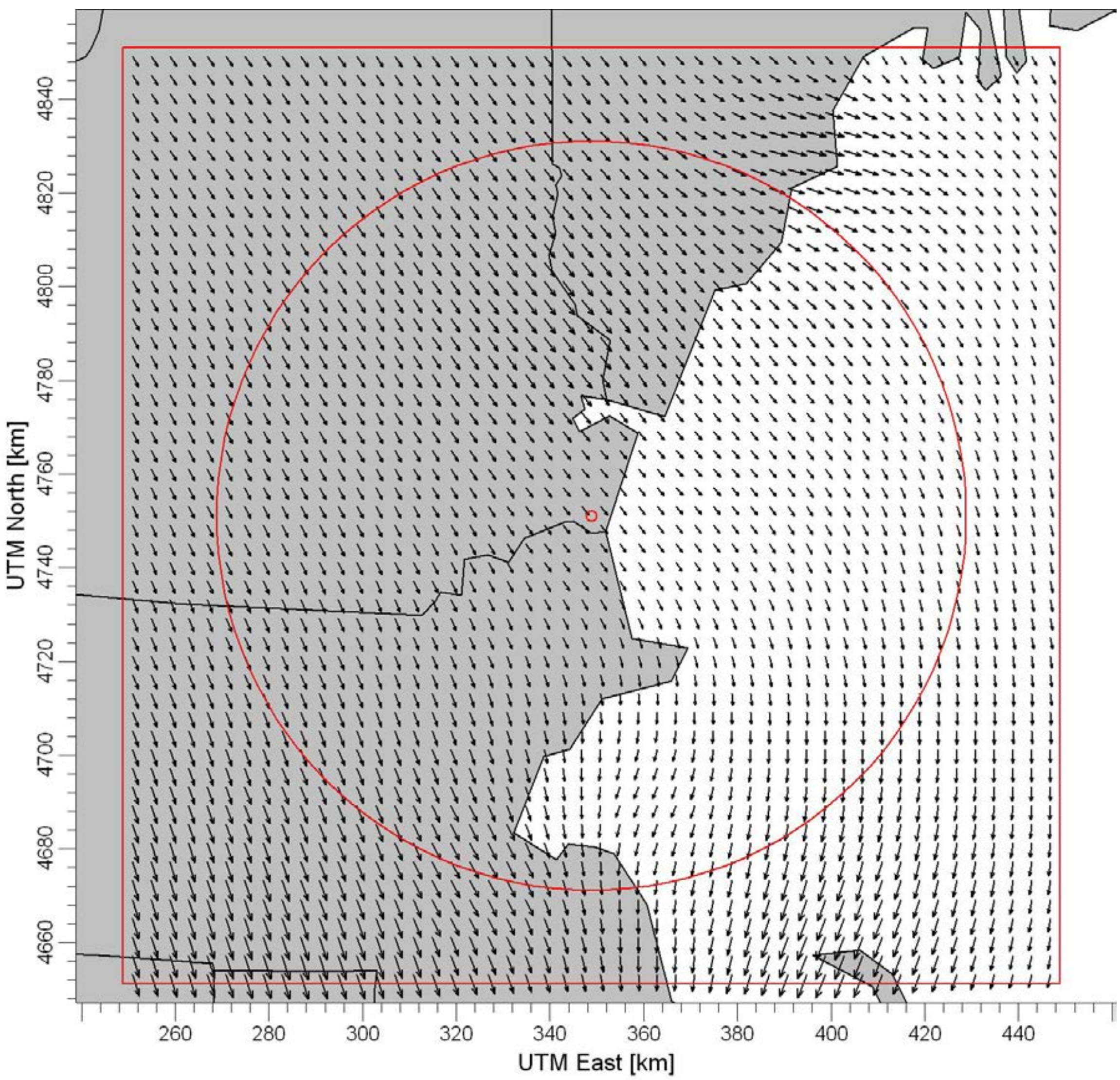


Figure 5. CALMET wind vectors at 100 m at 2200 on January 31, 2005. The direction of the wind is shown by the direction the vector or "arrow" is moving, and the speed of the wind is indicated by the length of the arrow. Seabrook Station and the 50-mile radius circle around it are shown in red.

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 Seabrook Station 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 22.5º each. The full year of 8760 trajectory angle locations on each distance arc is then analyzed to calculate the fractional occurrence of trajectory crossings in each 22.5° direction sector at each distance. This allows the "trajectory roses" to be plotted and compared easily with the 2005 Seabrook Station site 13.1 m wind rose plot.

3. Results of Wind Data Comparisons

For the Seabrook Station SAMA analysis, the hourly observations of wind and temperature difference from 2005 at the Seabrook Station meteorological tower were used as inputs. Winds were used from the 43 ft (13.1 m) level. Temperature differences between the 43 ft (13.1 m) and 209 ft (63.7 m) levels were used. Precipitation observations from the rain gauge next to the Seabrook Station meteorological tower were also used as inputs to the SAMA analysis.

3.1 Representativeness of 2005 Seabrook Station Annual Wind Rose Compared with Other Years (2004, 2006, 2007, 2008) at Seabrook Station

The study first considered whether the 2005 wind rose from the 43 ft (13.1 m) level of the Seabrook Station meteorological tower (used in the SAMA analysis) is representative of other years. To investigate this, we used the hourly wind observations from the Seabrook Station meteorological tower for 2004 through 2008.

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).

Appendix A contains the annual wind roses for the five years for the 43 ft (13.1 m) and 209 ft (63.7 m) levels of the Seabrook Station meteorological tower. As a representative example, the annual wind rose for 2005 from the 43 ft (13.1 m) level is shown in Figure 6. These wind data were used in the SAMA analysis. It is seen that the dominant wind directions are towards the east (i.e., offshore).

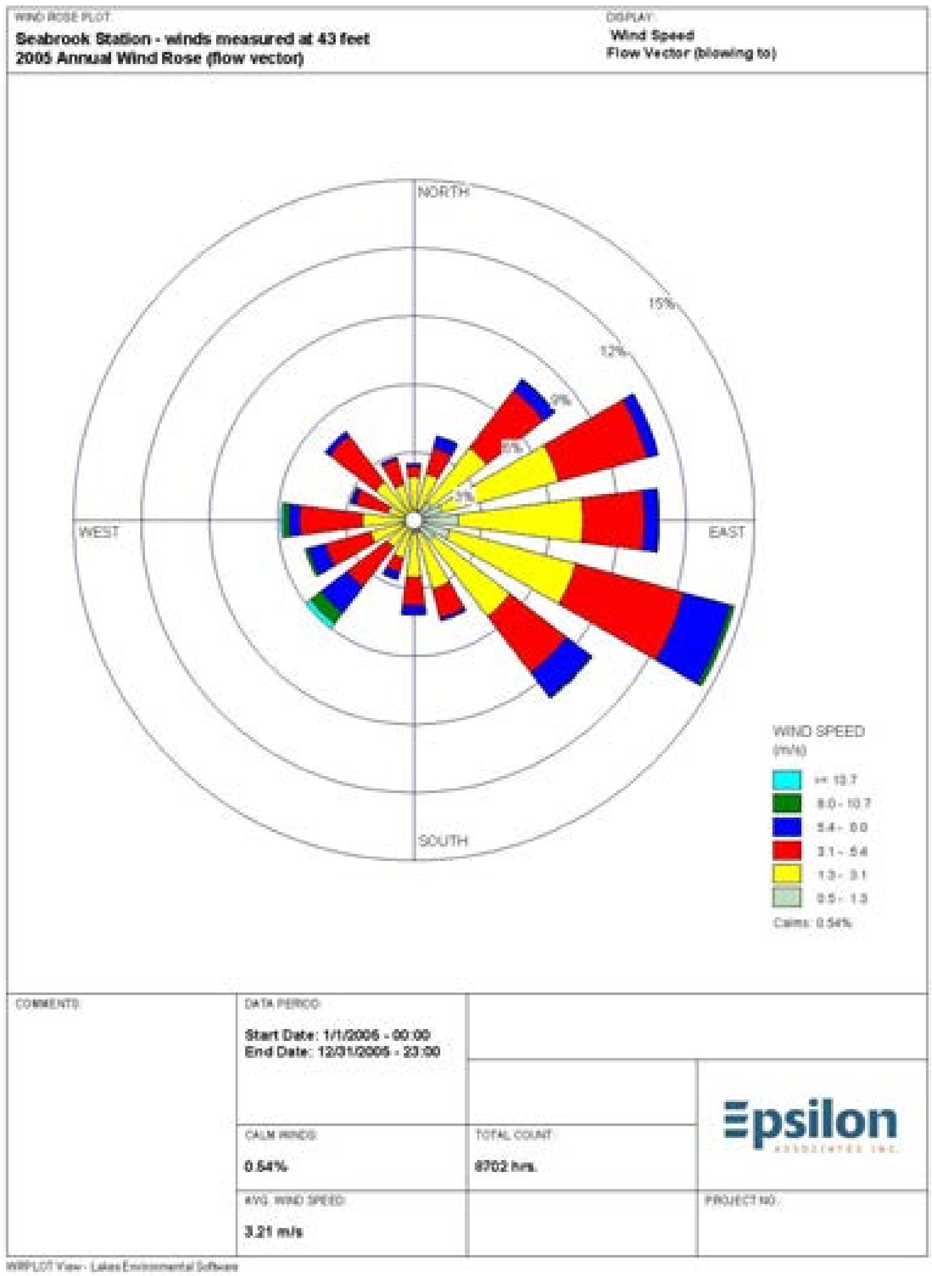


Figure 6. Annual wind rose for 2005 for the Seabrook Station 43 ft (13.1 m) level. These are the wind data used in the SAMA analysis.

When the eye looks at the five annual wind rose plots from each of the two levels at Seabrook Station, shown in Appendix A, they "look visually similar" from year to year. That is, the relative occurrence of high and low values at a particular direction from year to year is similar across all five years. At the 43 ft (13.1 m) and 209 ft (63.7 m) levels, the dominant directions for all years are the directions toward the east, in the 90 degree sector from about 56° to about 146°. As seen later, for most other sites in the domain the dominant directions over this area are also towards the east.

In Table 2, the wind roses for the five years at the 43 ft (13.1 m) level at Seabrook Station are compared quantitatively. The numbers that are entered in the table are fractions, and sum to 1.00 over the 16 wind direction sectors for each year. In addition, the right hand side of Table 2 lists the average and the range of the five numbers (one for each year) for each of the 16 wind rose direction sectors. The colors red and green are used in Table 2 to indicate which year had the largest and smallest percentages, respectively, for each direction sector. The numbers of maxima and minima 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. For everything equal, each year would have 3.2 maxima and 3.2 minima. The numbers for the year 2005 (5 maxima and 2 minima) are within the range of statistical expectation.

Based on the results summarized above, it is concluded that the annual wind rose from 2005 at Seabrook Station is representative of other years.

3.2 2005 Seabrook Station Annual Wind Rose Compared with Other Sites in the Area

The annual wind roses from 27 other sites within and just outside of the 50-mile radius around Seabrook Station were compared to determine how the 2005 annual Seabrook Station 43 ft (13.1 m) level wind rose used in the SAMA analysis compared to the annual wind roses at other sites on the SAMA analysis geographic domain. Table 1 (presented earlier) listed the surface sites (in addition to the Seabrook Station site) obtained from NCDC and elsewhere, and an "R" next to a site name indicates that it is a surface sites used in the annual wind rose comparisons. Figure 3 showed their locations. 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 analysis 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 27 other sites and from the Seabrook Station 43 ft (13.1 m) and 209 ft (63.7 m) levels.

Table 2 - Comparison of the fractions of occurrence for the 16 direction sectors (towards) in the annual wind rose from the 13.1 m (43 ft) level of the Seabrook Station meteorological tower for the year 2005 (used in the SAMA analysis) with percentages from that location for 2004 through 2008. The next to last column gives the average over the five years, and the last column gives the range. A red color indicates that the number is the highest and a green color indicates that it is the smallest over the five years. At the bottom of the table, the numbers of times highest (red) and times lowest (green) for each year are listed.

(Blowing to) Wind Direction	Compass Direction	2004	2005	2006	2007	2008	5 yr Avg	5 yr Range
348.75 - 11.25	**N**	**0.031**	0.025	0.026	**0.023**	0.030	**0.027**	**0.008**
11.25 - 33.75	**NNE**	**0.053**	0.039	0.049	**0.038**	0.042	**0.044**	**0.015**
33.75 - 56.25	**NE**	0.091	**0.079**	**0.096**	0.080	0.080	**0.085**	**0.005**
56.25 - 78.75	**ENE**	**0.080**	0.112	0.114	**0.122**	0.113	**0.108**	**0.042**
78.75 - 101.25	**E**	**0.104**	0.109	0.125	**0.134**	0.131	**0.121**	**0.030**
101.25 - 123.75	**ESE**	**0.1605**	0.147	0.154	0.1599	**0.132**	**0.151**	**0.028**
123.75 - 146.25	**SE**	0.111	**0.099**	0.104	**0.126**	0.120	**0.112**	**0.027**
146.25 - 168.75	**SSE**	0.041	**0.046**	0.038	0.042	**0.037**	**0.041**	**0.009**
168.75 - 191.25	**S**	0.035	**0.042**	**0.027**	0.034	0.033	**0.034**	**0.015**
191.25 - 213.75	**SSW**	**0.028**	0.027	**0.020**	0.022	0.021	**0.023**	**0.008**
213.75 - 236.25	**SW**	0.052	**0.060**	0.059	**0.036**	0.037	**0.049**	**0.024**
236.25 - 258.75	**WSW**	**0.041**	**0.050**	0.043	0.046	0.048	**0.045**	**0.009**
258.75 - 281.25	**W**	**0.061**	0.059	**0.051**	0.053	0.059	**0.056**	**0.010**
281.25 - 303.75	**WNW**	0.037	0.029	**0.025**	0.032	**0.039**	**0.032**	**0.014**
303.75 - 326.25	**NW**	0.040	**0.049**	0.038	**0.028**	0.034	**0.038**	**0.021**
326.25 - 348.75	**NNW**	0.039	0.029	0.030	**0.023**	**0.043**	**0.033**	**0.020**
Number with Max		**5**	**5**	**1**	**3**	**2**	**avg range =**	**0.018**
Number with Min		**3**	**2**	**4**	**5**	**2**		

Note that all of the wind rose plots in this report include a listing of the average wind speed and the percentage of calms, as well as an indication of the percentage of winds in the 16 sectors. A calm is defined using the known minimum threshold of the wind vane or anemometer used for the observation at each site. The Seabrook Station has fewer calms because it uses a fast response anemometer. 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 average wind speed listed on each wind rose plot is calculated only for non-calm, non-missing hours. In Table 4 (described in Section 3.3), the average annual wind speed is recalculated to account for calms. This is necessary to compare annual winds speeds from one site to another. Note that the total hours of good weather data in a year is determined by whether any weather variable is available (e.g., pressure, temperature, dew point temperature, wind speed and wind direction). However out of that total there are a certain number of “missing hours”, meaning that wind speed and wind direction are not available, and there are also a certain number of “calm hours”, meaning that the wind was below the threshold for the sensors.

Figure 7 shows one example of a wind rose comparison from Appendix B. In this example, the Seabrook Station 13.1 m wind rose is compared with that from the Pease Airport, which is the closest airport to the Seabrook Station site. The two wind roses “look” similar, with dominant wind directions towards the east. There are slight differences in some sectors and this is typical of the differences found at other sites in Appendix B. Each plot in the appendix has a similar format to that seen in Figure 7, showing the annual 2005 wind rose for the Seabrook Station meteorological tower 43 ft (13.1 m) level and the wind rose from another site on the same page. Two wind roses are presented on a single page to make visual comparisons easier.

None of the sites are located in deep river valleys or adjacent to mountains, which could strongly influence the wind direction distributions. Some of the inland sites (e.g., Manchester, NH) have annual wind roses that are slightly influenced by local river valley orientations. However, in general the visual impression from the complete set of annual wind roses is that the Seabrook Station annual wind rose is similar to the others in the domain.

A quantitative comparison of the Seabrook Station 43 ft (13.1 m) wind rose and the wind roses from the 27 other sites in Appendix B is given in Table 3. Because the sites had varying fractions of calms and missing data, it was necessary to normalize the direction sector distributions so that the 16 fractions would sum to 1.000 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. The red and green highlighting indicate the sites with fractions that are more than a factor of two larger and more than a factor of two smaller, respectively, than the overall average for that wind direction sector.

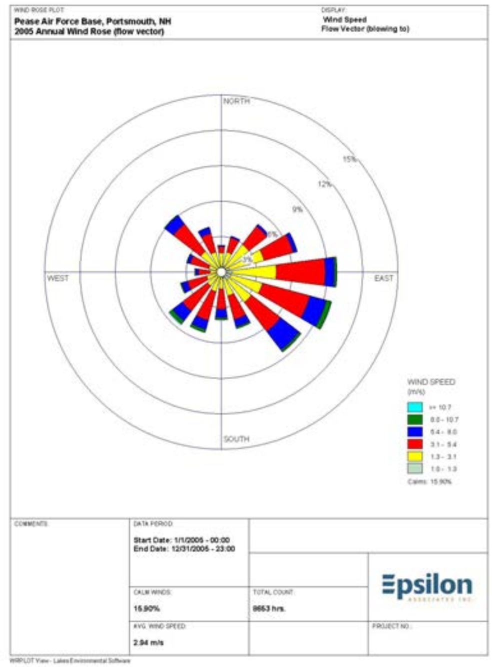
Just as found in the qualitative comparisons of the wind roses, the quantitative comparisons in Table 3 show most sites have dominant flows from the western quadrant, with the maximum blowing towards the NE to SE.

There are 47 stations and wind direction sectors in Table 3 with a fraction that is a factor of two or more less that the average for that sector, and 45 stations and sectors with a fraction that is a factor of two or more larger than the average for that sector. Since there are 28 * 16 = 448 total station-sector pairs, this means that there are about 20 % ((45+47)/448) of the pairs that are a factor of two or more larger or smaller than the average for that sector. Thus for any station, the average number of fractions larger and smaller than a factor of two from the average is 0.20 * 16 = 3.2. The number for all 28 stations ranges from 0 (E. Milton and Wells Beach) to 10 (Nashua). For the Seabrook Station, this number is 4 (2 sectors smaller and 2 larger than a factor of two). Thus the Seabrook Station is near the middle (i.e., representative) for this criterion, too.

Figures 8 and 9 contain plots of the data in Table 3. The vertical axis is the frequency of wind directions in a given sector, and the horizontal axis is the wind direction. Points are plotted at the middle of each 22.5 ° sector. Figure 8 contains data for all 28 stations. The Seabrook Station 13.1 m wind directions (blue triangles connected by a blue line) clearly track near the middle of the data for the other stations at each wind direction sector. Occasionally the Seabrook Station curve is near the maximum or minimum of the group (e.g., the maximum at 270° and second from the minimum at 0°). However, this variability happens with most sites.

Figure 9 plots the data from the coastal sites and the sites nearest Seabrook Station. East Milton Blue Hill, MA, is included because it is on an exposed hilltop. There are nine of these sites. As before it is seen that the Seabrook Station data approximately track the other data, showing maxima towards the Eastern quadrant and minima towards the western quadrant.

It is concluded from this analysis of annual wind roses that the Seabrook Station 13.1 m (43 ft) annual wind rose is representative of other sites in the SAMA domain.



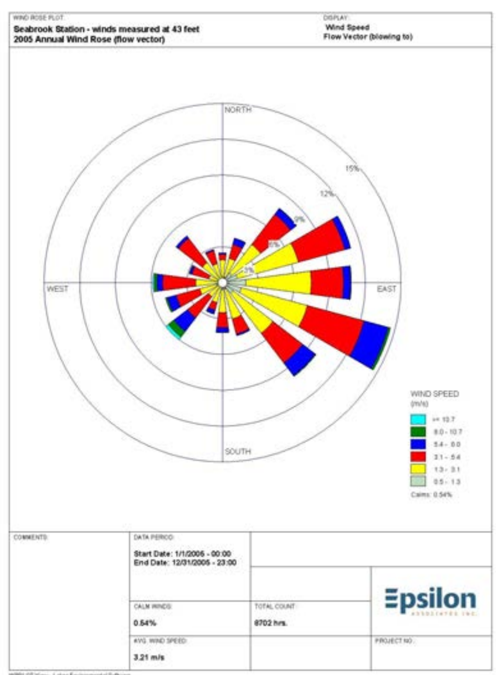


Figure 7. Annual wind roses for Seabrook Station 43 ft (13.1 m) level (bottom) and for Pease NH (top). The percentage of winds blowing towards the indicated direction are shown.

Table 3. Annual wind direction fractions, expressed as direction the wind is blowing towards, for 22.5° wind direction sectors for the 43 ft (13.1 m) level of the Seabrook Station meteorological tower, and for 27 other sites within and just outside of the 50-mile radius SAMA analysis geographic domain around Seabrook Station. Light green indicates sites and WD sectors with frequencies a factor of 2 or more larger than the average, and light red indicates sites and WD sectors with frequencies a factor of 2 or more less than the average. The max, min, and average over all sites are listed in the last three columns.

Wind Direction Sector (blowing to, °)	Center of WD Sector (°)	SS 13.1m 2005 NH	Bedford 2005 MA	Beverly 2005 MA	Boston Logan 2005 MA	Buoy Boston 44013 2005 MA	Buoy Portland 44007 2005 ME	Buoy Portsmouth 44005 2005 NH	Concord 2005 NH	E Milton Blue Hill 2005 MA	Fitchburg 2005 MA	Isle of Shoals Lighthouse 2005 NH	Jaffrey 2005 NH	Keene 2005 NH	Lawrence 2005 MA	Man-chester 2005 NH	Nashua 2005 NH
348.75 - 11.25	**0 (N)**	0.0251	0.0357	0.0438	0.0391	0.0524	0.1057	0.0631	0.0792	0.0970	0.0527	0.0787	0.1744	0.1493	0.0180	0.0889	0.0748
11.25 - 33.75	**22.5 (NNE)**	0.0387	0.0631	0.0430	0.0739	0.0619	0.1148	0.0766	0.0421	0.0848	0.0512	0.0578	0.2252	0.1144	0.0923	0.0901	0.0306
33.75 - 56.25	**45 (NE)**	0.0787	0.1129	0.0705	0.1039	0.0635	0.0823	0.0675	0.0365	0.0827	0.0478	0.0745	0.0866	0.0592	0.1345	0.0414	0.0306
56.25 - 78.75	**67.5 (ENE)**	0.1120	0.1070	0.0826	0.0638	0.0734	0.0651	0.0652	0.0391	0.0811	0.0716	0.0729	0.0493	0.0436	0.0917	0.0461	0.0371
78.75 - 101.25	**90 (E)**	0.1086	0.0936	0.0894	0.0931	0.0753	0.0676	0.0956	0.0445	0.1062	0.1505	0.0897	0.0864	0.0416	0.0858	0.0472	0.0919
101.25 - 123.75	**112.5 (ESE)**	0.1466	0.0927	0.0848	0.0989	0.0790	0.0551	0.0762	0.0844	0.0979	0.1679	0.1064	0.0793	0.0536	0.0710	0.0592	0.1413
123.75 - 146.25	**135 (SE)**	0.0991	0.0917	0.1085	0.0831	0.0842	0.0595	0.0878	0.1669	0.0704	0.1230	0.0742	0.0663	0.0676	0.0822	0.1009	0.2049
146.25 - 168.75	**157.5 (SSE)**	0.0461	0.0722	0.0743	0.0639	0.0650	0.0664	0.0726	0.1183	0.0491	0.0519	0.0429	0.0537	0.1244	0.0574	0.1377	0.1360
168.75 - 191.25	**180 (S)**	0.0421	0.0591	0.0663	0.0580	0.0721	0.0801	0.0650	0.0775	0.0450	0.0220	0.0432	0.0452	0.1433	0.0497	0.0962	0.0842
191.25 - 213.75	**202.5 (SSW)**	0.0274	0.0531	0.0657	0.0553	0.0708	0.0634	0.0686	0.0497	0.0538	0.0174	0.0783	0.0351	0.0806	0.0617	0.0677	0.0312
213.75 - 236.25	**225 (SW)**	0.0602	0.0603	0.0636	0.0501	0.0493	0.0616	0.0753	0.0508	0.0544	0.0251	0.0758	0.0140	0.0461	0.0807	0.0493	0.0224
236.25 - 258.75	**247.5 (WSW)**	0.0497	0.0423	0.0299	0.0387	0.0307	0.0568	0.0454	0.0452	0.0291	0.0384	0.0387	0.0051	0.0116	0.0614	0.0379	0.0082
258.75 - 281.25	**270 (W)**	0.0586	0.0353	0.0174	0.0525	0.0353	0.0275	0.0412	0.0376	0.0227	0.0331	0.0278	0.0012	0.0078	0.0431	0.0286	0.0112
281.25 - 303.75	**292.5 (WNW)**	0.0291	0.0326	0.0310	0.0518	0.0497	0.0182	0.0257	0.0271	0.0238	0.0266	0.0236	0.0024	0.0051	0.0261	0.0242	0.0100
303.75 - 326.25	**315 (NW)**	0.0493	0.0250	0.0829	0.0458	0.0784	0.0197	0.0279	0.0419	0.0381	0.0486	0.0394	0.0135	0.0049	0.0300	0.0391	0.0324
326.25 - 348.75	**337.5 (NNW)**	0.0288	0.0235	0.0463	0.0280	0.0590	0.0560	0.0462	0.0593	0.0640	0.0723	0.0760	0.0622	0.0470	0.0145	0.0454	0.0530

Wind Direction Sector (blowing to, °)	Center of WD Sector (°)	Norwood 2005 MA	Pease 2005 NH	Plymouth 2005 MA	Portland 2005 ME	Provi-dence Green 2005 RI	Provi-dence NOS 2005 RI	Province-town 2005 MA	Rochester Skyhaven 2005 NH	Sanford 2006 ME	Wells Beach 2011 ME	Wells Reserve 2011 ME	Worcester 2005 MA	max	min	avg
348.75 - 11.25	**0 (N)**	0.0598	0.0270	0.0513	0.0850	0.0764	0.0974	0.0861	0.0602	0.0448	0.0969	0.0882	0.0333	**0.1744**	**0.0180**	**0.0709**
11.25 - 33.75	**22.5 (NNE)**	0.1006	0.0375	0.1421	0.0769	0.0748	0.0549	0.1305	0.0349	0.0803	0.0704	0.0594	0.0520	**0.2252**	**0.0306**	**0.0777**
33.75 - 56.25	**45 (NE)**	0.0825	0.0606	0.1003	0.0694	0.0783	0.0526	0.0845	0.0051	0.0979	0.0549	0.0790	0.0872	**0.1345**	**0.0051**	**0.0723**
56.25 - 78.75	**67.5 (ENE)**	0.0738	0.0793	0.0700	0.0647	0.0616	0.0334	0.0481	0.0108	0.1158	0.0579	0.0734	0.1341	**0.1341**	**0.0108**	**0.0687**
78.75 - 101.25	**90 (E)**	0.0830	0.1168	0.0850	0.0803	0.0916	0.0433	0.0685	0.0223	0.1346	0.0651	0.1040	0.1486	**0.1505**	**0.0223**	**0.0861**
101.25 - 123.75	**112.5 (ESE)**	0.0860	0.1153	0.0824	0.0795	0.0985	0.0522	0.0748	0.0535	0.1143	0.0900	0.0772	0.1285	**0.1679**	**0.0522**	**0.0910**
123.75 - 146.25	**135 (SE)**	0.0867	0.1015	0.0628	0.0889	0.0903	0.0960	0.0923	0.1144	0.0454	0.0927	0.0929	0.0731	**0.2049**	**0.0454**	**0.0931**
146.25 - 168.75	**157.5 (SSE)**	0.0845	0.0590	0.0465	0.0799	0.0597	0.1036	0.0626	0.2385	0.0343	0.0876	0.0836	0.0463	**0.2385**	**0.0343**	**0.0792**
168.75 - 191.25	**180 (S)**	0.0561	0.0482	0.0619	0.0901	0.0775	0.0944	0.0590	0.1103	0.0815	0.0973	0.0704	0.0401	**0.1433**	**0.0220**	**0.0691**
191.25 - 213.75	**202.5 (SSW)**	0.0484	0.0631	0.0869	0.0646	0.0809	0.1096	0.0654	0.0996	0.0664	0.0820	0.0513	0.0602	**0.1096**	**0.0174**	**0.0628**
213.75 - 236.25	**225 (SW)**	0.0610	0.0667	0.0829	0.0486	0.0677	0.0781	0.0660	0.0833	0.0625	0.0437	0.0283	0.0828	**0.0833**	**0.0140**	**0.0575**
236.25 - 258.75	**247.5 (WSW)**	0.0747	0.0427	0.0408	0.0400	0.0287	0.0275	0.0287	0.0440	0.0336	0.0242	0.0187	0.0429	**0.0747**	**0.0051**	**0.0363**
258.75 - 281.25	**270 (W)**	0.0357	0.0267	0.0261	0.0449	0.0144	0.0091	0.0257	0.0312	0.0189	0.0275	0.0346	0.0170	**0.0586**	**0.0012**	**0.0283**
281.25 - 303.75	**292.5 (WNW)**	0.0200	0.0362	0.0216	0.0251	0.0095	0.0124	0.0263	0.0205	0.0203	0.0341	0.0364	0.0176	**0.0518**	**0.0024**	**0.0245**
303.75 - 326.25	**315 (NW)**	0.0192	0.0726	0.0174	0.0212	0.0144	0.0269	0.0302	0.0294	0.0218	0.0255	0.0363	0.0190	**0.0829**	**0.0049**	**0.0340**
326.25 - 348.75	**337.5 (NNW)**	0.0279	0.0468	0.0222	0.0408	0.0757	0.1086	0.0515	0.0420	0.0277	0.0502	0.0661	0.0173	**0.1086**	**0.0145**	**0.0485**

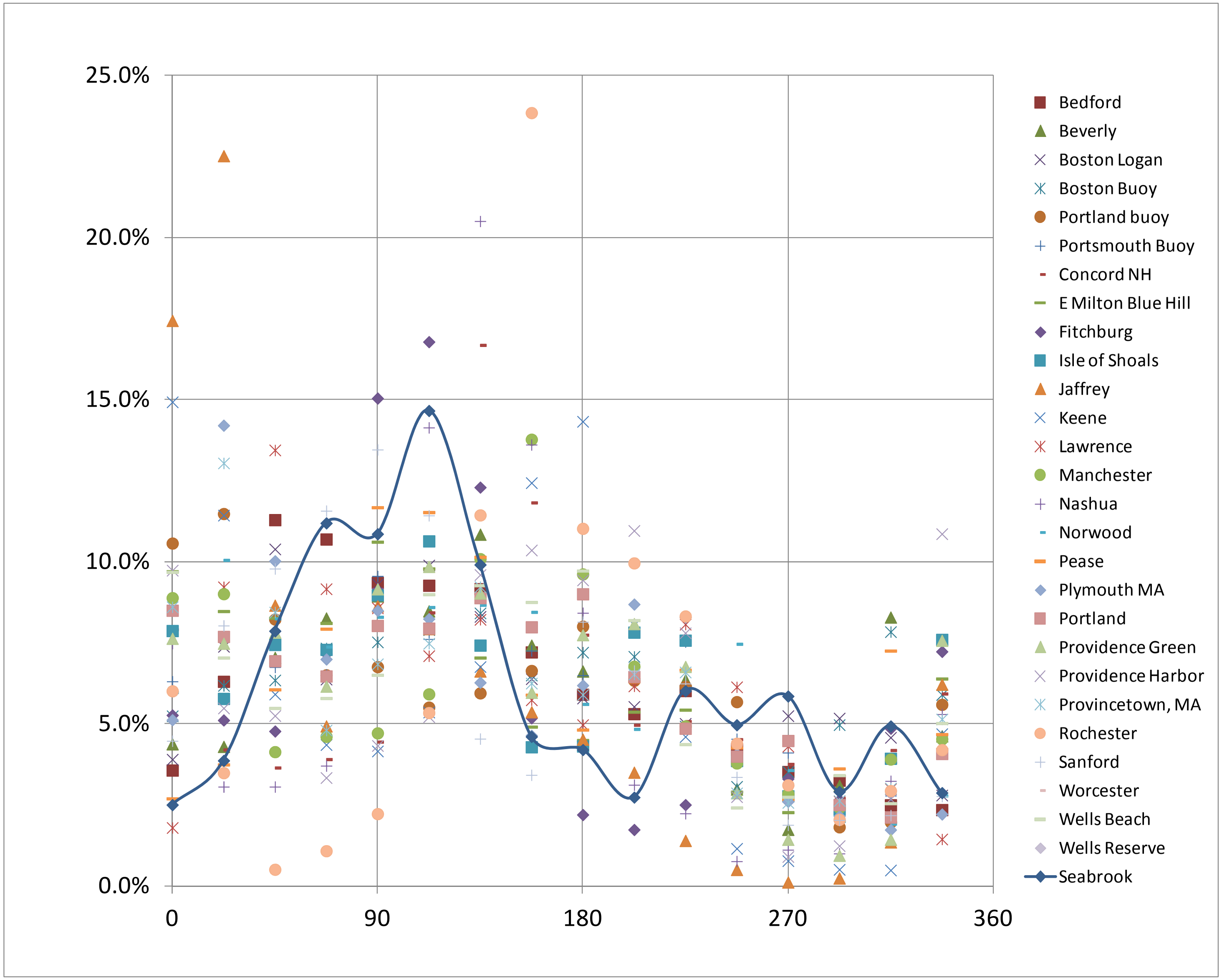


Figure 8. Plot of wind direction frequencies for 28 stations in Table 3. Solid line is Seabrook Station 13.1 m level.

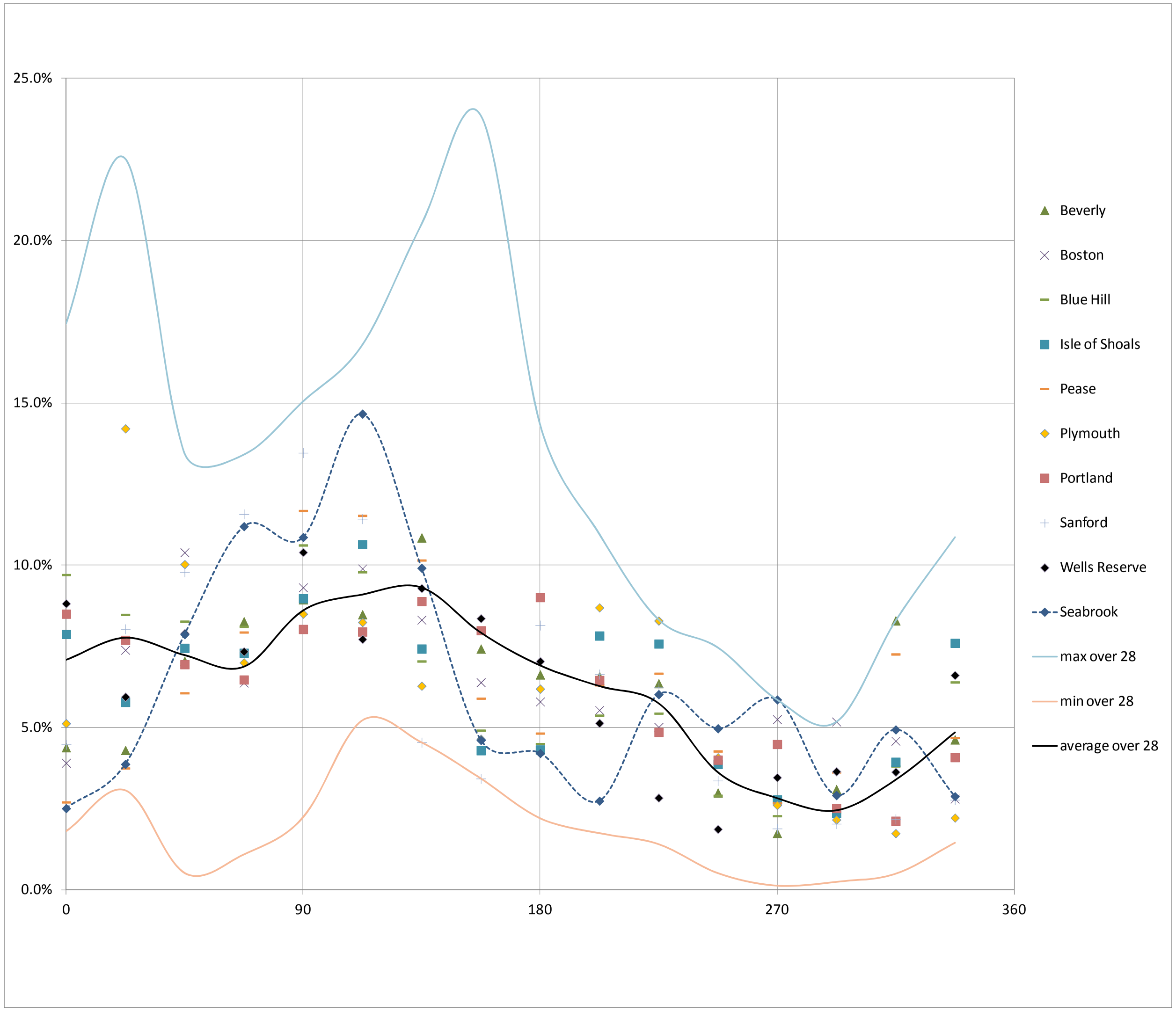


Figure 9. Plot of wind direction frequencies for coastal stations in Table 3. The dashed blue line is Seabrook Station 13.1 m and the solid lines are the min (salmon), max (light blue), and average (black) of the 28 stations.

3.3. 2005 Seabrook Station Annual Average Wind Speed Compared with Other Sites in the Area

Atmospheric transport and dispersion models such as the ATMOS module in MACCS2 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 turbulent 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 4 contains the 2005 average annual wind speeds at the Seabrook Station 43 ft (13.1 m) level (used in the MACCS2/ATMOS runs), at the Seabrook Station 209 ft (63.7 m) level, and at the 27 non-Seabrook Station sites used in the wind rose comparison and indicated in Table 1. Figure 3, presented earlier, showed the site locations.

The annual average wind speed in the next to last column of Table 4 includes the effects of missing hours and calm hours:

> (Wind speed including calms and missing hours) = (wind speed excluding calms and missing hours) * (1.00 – fraction calm – fraction missing)/(1.00 - fraction missing) + (0.75 m/s wind speed for calm hours)*fraction calm/(1.00 – fraction missing)

Note that an effective wind speed of 0.75 m/s is assigned to all calm hours. The National Weather Service states that all wind speeds less than 3 kts (about 1.5 m/s) are reported as calms. We therefore assume that there is a uniform distribution of wind speeds between 0.0 and 1.5 m/s for all reported "calm" hours, with an average of 0.75 m/s.

Any wind observations at levels, z_2, different from 10 m are extrapolated down or up to 10 m using the log law for wind speeds, assuming a surface roughness length, z_o, of 0.1 m for overland sites (typical of rural areas) and 0.01 m for overwater sites:

$$u\ (10\ m) = u(z_2)(\ln(10/z_o))/(\ln(z_2/z_o))$$

This extrapolation must be done for the two Seabrook Station tower levels (where z_2 = 13.1 m and 63.7 m), for Concord where z_2 = 7.9 m, for Providence Green where z_2 = 6.1 m, for the three buoys (44005, 44007, and 44013) where z_2 = 5 m, for East Milton Blue Hill where z_2 = 15.2 m, for Isle of Shoals where z_2 = 19.2 m, for Providence NOS where z_2 = 4.2 m, and for Wells Reserve where z_2 = 10.4 m

One way of determining if there is a significant difference between a data point and a set of other data points is to rank all of the data points from bottom to top and see where the data point of interest falls in the distribution. It is found that the 3.02 m/s average annual wind speed at the Seabrook Station SAMA 13.1 m level (extrapolated to 10 m) is ranked 15^{th} (from the minimum) in the set of 24 data points (excluding the 209 ft (63.7 m) measurement height at Seabrook Station and the four overwater stations), meaning that it is well within the 95 % range. The mean and median of these 25 data points are 3.20 m/s and 2.58 m/s, respectively. Thus the Seabrook Station 13.1 m wind speed (extrapolated to 10 m) is about 6 % less than the mean and about 17 % larger than the median of the 24 points.

The four overwater sites (three offshore buoys and the Isle of Shoals lighthouse) have an extrapolated 10 m mean wind speed of 6.8 m/s, which is about a factor of 2.25 larger than the Seabrook 10 m wind speed. In general, overwater wind speeds are larger at a given height in the surface boundary layer than overland wind speeds, due to the smaller surface roughness length over water and the extensive open upwind fetches.

It is concluded that the annual averaged wind speed measured at the Seabrook Station 13.1 m level, used in the SAMA analysis, is representative of the annual averaged wind speed measured at the other sites on the SAMA domain.

Table 4. Average annual wind speed listed for the two levels of the Seabrook Station tower and for 27 other weather sites in the SAMA analysis domain and used in the wind rose comparisons. More details of these sites are in Table 1. Sites with measurements at heights other than 10 m 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 for land and 0.01 m for water locations.

	Any met data	Missing	Calm	Missing	Calms	Avg wind speed, no calms nor missing hrs	Avg wind speed, including calms and missing hrs	Avg wind speed
Station Name	total hrs	hrs	hrs	fraction	fraction	(m/s)	(m/s)	z = 10 m
Seabrook Station 13.1 m	8760	58	47	0.0066	0.0054	3.21	3.20	3.02
Seabrook Station 63.7 m	8760	405	8	0.0462	0.0009	5.19	5.19	3.70
Bedford, MA	8760	146	1894	0.0167	0.2162	3.08	2.57	2.57
Beverly, MA	8761	179	1189	0.0204	0.1357	3.5	3.12	3.12
Boston Logan, MA	8761	1	340	0.0001	0.0388	4.93	4.77	4.77
Buoy Boston 44013 5 m	8609	7	98	0.0008	0.0114	5.87	5.81	6.45
Buoy Portland 44007 5 m	6012	4	78	0.0007	0.0130	5.59	5.53	6.14
Buoy Portsmouth 44005 5 m	8551	3782	31	0.4423	0.0036	7.53	7.49	8.31
Concord, NH 7.9 m	8761	24	3343	0.0027	0.3816	2.31	1.71	1.80
E. Milton Blue Hill MA 15.2 m	8726	39	464	0.0045	0.0532	5.48	5.23	4.81
Fitchburg, MA	8764	226	2676	0.0258	0.3053	2.55	1.99	1.99
Lighthouse Isle of Shoals 19.2 m	8586	1	127	0.0001	0.0148	7.26	7.16	6.30
Jaffrey, NH	8761	107	4520	0.0122	0.5159	1.6	1.16	1.16
Keene, NH	8761	656	3611	0.0749	0.4122	1.84	1.35	1.35
Lawrence, MA	8761	101	1885	0.0115	0.2152	2.91	2.44	2.44
Manchester, NH	8761	86	2106	0.0098	0.2404	2.79	2.29	2.29
Nashua, NH	5316	2418	1201	0.4549	0.2259	2.28	1.65	1.65
Norwood, MA	8761	220	2554	0.0251	0.2915	2.68	2.10	2.10
Pease, NH	8760	107	1373	0.0122	0.1567	2.94	2.59	2.59
Plymouth, MA	8761	254	1835	0.0290	0.2095	3.36	2.80	2.80
Portland, ME	8761	7	1307	0.0008	0.1492	3.42	3.02	3.02
Providence Green, RI 6.1 m	8761	1	824	0.0001	0.0941	3.98	3.68	4.03
Providence NOS, RI 4.2 m	6320	48	316	0.0076	0.0500	4.5	4.31	5.30
Provincetown, MA	8762	1736	265	0.1981	0.0302	5.2	5.03	5.03
Rochester, NH	8761	189	3503	0.0216	0.3998	2.12	1.56	1.56
Sanford, ME	8741	67	2575	0.0077	0.2946	2.62	2.06	2.06
Wells Beach, ME	8166	86	554	0.0105	0.0678	3.38	3.20	3.20
Wells Reserve, ME 10.4 m	8551	1	895	0.0001	0.1047	2.29	2.13	2.12
Worcester, MA	8761	9	614	0.0010	0.0701	4.37	4.12	4.12

4. Results of CALMET Trajectory Analysis, including Trajectory Roses

4.1 CALMET 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). For every hour of the year, CALMET produces mass-consistent three-dimensional wind fields over the 200 km square geographic domain, including the circular SAMA analysis domain with 50 mile (81 km) radius, shown in Figure 2. The separate computer program, COMPTRAJ, was run on each monthly wind field file produced by CALMET (as discussed in Section 2, runs using monthly files rather than the full annual file were used in order to reduce the run time of the COMPTRAJ software). However, trajectories released from the Seabrook Station during the last few hours of a given month may still be on the CALMET 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 another separate computer program, TRAJFREQ, was run to count the frequency of occurrence of trajectory crossings for each 22.5° direction sector at each of the downwind distances used in the SAMA analysis.

For each hour of initiation of a trajectory at the Seabrook Station, the trajectory path determined from the CALMET wind field is unlikely to follow a straight line. This is because the three-dimensional wind fields have some spatial variability during any given hour, and also because there is variability from hour-to-hour in the wind fields. In general, the spatial variability in winds during a given hour is dependent on the synoptic-scale wind speed over the domain (i.e., the variability is larger during light winds and smaller during strong winds). These short term variabilities would be of more importance if interest were only in a specific single hour of release. But because the SAMA analysis by definition covers a full year, as well as spatially integrating across the SAMA analysis domain, it is expected that, on average, trajectory curvatures towards the left for one hour would be balanced by trajectory curvatures towards the right on another hour. This assumption of a tendency towards balancing of trajectory curvatures would be valid as long as variabilities are random and not systematic, when the entire year and domain are considered. To make a difference, systematic variations would have to be persistent over the most of the year. The analysis below compares the annual trajectory wind roses (based on variable wind fields) with the annual wind rose from the Seabrook Station 13.1 m level (used in the SAMA analysis).

The Golden Software, GRAPHER, has been 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 CALMET Trajectory Analysis Results

Full sets (for the 14 distance arcs) of the CALMET trajectory annual frequency roses at 100 m are presented in Appendix C, at 200 m in Appendix D and at 500 m in Appendix E. A few specific results are described below that support some general conclusions.

Figure 10 (top panel) shows the annual CALMET trajectory frequency rose at the 100 m height at a downwind distance of 1 mi (1.6 km). This shows how often the hourly trajectory position will be located within particular wind direction sectors (22.5° wide, as illustrated in Figure 1) as the trajectory crosses the 1 mile (1.6 km) arc. Each trajectory was computed based on spatially and time-varying winds simulated by CALMET using wind and temperature observations from the 28 surface wind measuring stations and the vertical profiles from the two upper air stations. The bottom panel of Figure 10 shows the wind rose plot for 2005 for the 43 ft (13.1 m) level wind measurements from the Seabrook Station meteorological tower. The annual CALMET trajectory frequency rose and the SS wind rose in the top and bottom panels are visually similar, due to the fact that the SS site has an annual wind direction rose that is similar to other stations in the SAMA domain (see Section 3). Both wind roses in Figure 10 indicate that the dominant wind directions in this area are towards the NE to SE, reflecting the general synoptic flow. At this low elevation (100 m) above ground and relatively small downwind distance (1 mile), this CALMET trajectory rose would be in better agreement with the Seabrook Station 43 ft (13.1 m) wind rose than are the CALMET trajectory roses for any other trajectory heights or distances calculated (and shown in Appendices C, D, and E). This is because CALMET applies a fairly high weighting to the local (closest) station (i.e., SS) 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.

The 100 m elevation trajectory was chosen for comparison in Figure 10 because, at a downwind distance of 1 mile (1.6 km), a 100 m height is likely to be about at the midpoint of a dispersing plume released near the surface. On average, the top of the upward-dispersing plume grows as about 0.1 x, where x is distance downwind. So at x = 1.6 km, the plume top will be at about 160 m and the midpoint of the plume at about 80 m.

Figure 11 compares the annual wind roses for the other extreme (compared to Figure 10) – the highest CALMET trajectory level (500 m) and the largest distance (50 miles). This comparison is more relevant for the SAMA analysis, since most of the population in the SAMA analysis domain is located at downwind distances of 30 to 50 miles. At downwind distances greater than approximately 6 miles (10 km), the plume is likely to be well-mixed vertically from the surface to the typical mixing height of 1000 m. Thus the midpoint of the plume will, on average, be at a level of about 500 m. The top panel of Figure 11 shows the annual trajectory frequency rose for the 500 m (1640 ft) level at that distance. As in Figure 10, the wind rose from the 13.1 m level of the Seabrook Station meteorological tower is plotted in the bottom. Here the differences are slightly larger than in Figure 10, since at 500 m height and 50 mile distance, the CALMET derived wind fields are more influenced by the upper air observations (from Gray ME and Chatham MA) and by the observations from the other 27 surface sites. Nevertheless, the two annual wind roses are visually very similar.

Table 5 allows quantification of the visual impressions from Figure 11. The table lists the fractions of Seabrook Station 43 ft (13.1 m) wind directions and CALMET trajectory directions (for the 500 m elevation and the 50 mile distance) for each of the 16 wind direction sectors in Figure 11. The last column in the table lists the difference for each 22.5° sector. Note that the differences do not appear to be strong functions of the magnitude of the wind fraction in a sector (a later figure will show this more clearly). The mean absolute difference of the 16 numbers is 0.0232 and the standard deviation is 0.0269. Since the average fraction per sector is 0.0625 (i.e., 1/16), the mean absolute difference divided by the average fraction per sector is 0.371, supporting the conclusion that the SS and the CALMET annual wind roses are similar.

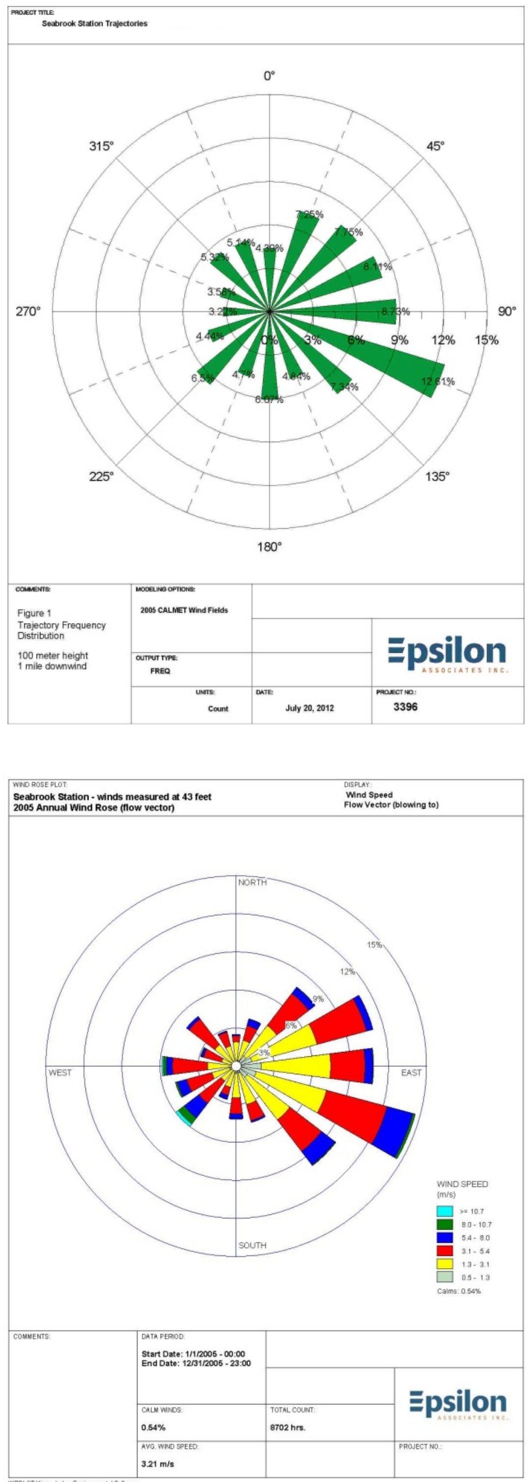


Figure 10. CALMET-generated trajectory rose at 100 m (328 ft) height and 1 mile (1.6 km) distance (top panel). Seabrook Station 43 ft (13.1 m) annual wind rose (bottom panel).

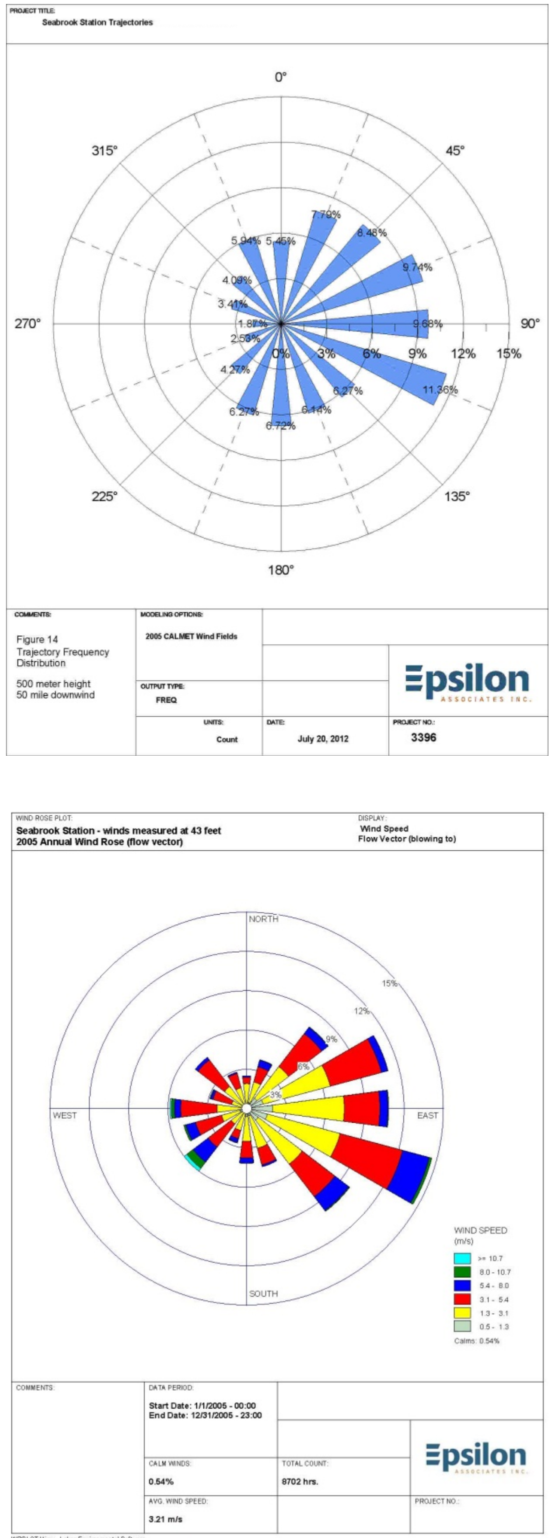


Figure 11. CALMET-generated trajectory rose at 500 m (1640 ft) height and 50 miles (80.5 km) distance (top panel). Seabrook Station 43 ft (13.1 m) annual wind rose (bottom panel).

Table 5. Comparison of annual 2005 wind direction fractions from the CALMET trajectory analysis (500 m elevation trajectories, at a distance of 50 miles from Seabrook Station), with wind direction fractions from the 43 ft (13.1 m) level of the Seabrook Station meteorological tower (used in the SAMA analysis). The bottom row lists the standard deviation of the 16 numbers in that column.

Wind Direction Blowing Towards 22.5 ° sector	Compass Direction	SS 13.1 m 2005 fraction	CALMET Trajectory 500 m at 50 mi fraction	SS - CALMET difference
348.75 - 11.25	**N**	0.0251	0.0545	-0.0294
11.25 - 33.75	**NNE**	0.0387	0.0779	-0.0392
33.75 - 56.25	**NE**	0.0787	0.0848	-0.0061
56.25 - 78.75	**ENE**	0.1120	0.0974	0.0146
78.75 - 101.25	**E**	0.1086	0.0968	0.0118
101.25 - 123.75	**ESE**	0.1465	0.1136	0.0329
123.75 - 146.25	**SE**	0.0991	0.0627	0.0364
146.25 - 168.75	**SSE**	0.0461	0.0614	-0.0153
168.75 - 191.25	**S**	0.0421	0.0672	-0.0251
191.25 - 213.75	**SSW**	0.0274	0.0626	-0.0352
213.75 - 236.25	**SW**	0.0602	0.0427	0.0175
236.25 - 258.75	**WSW**	0.0497	0.0253	0.0244
258.75 - 281.25	**W**	0.0586	0.0187	0.0399
281.25 - 303.75	**WNW**	0.0291	0.0341	-0.0050
303.75 - 326.25	**NW**	0.0493	0.0409	0.0084
326.25 - 348.75	**NNW**	0.0288	0.0594	-0.0306
	stdev =	0.0363	0.0268	0.0269

Figures 12 and 13 provide scatter plots of the data in Table 5 that allow some useful conclusions to be drawn. Figure 12 is a scatter plot of the 16 SS 13.1 m fractions versus the corresponding CALMET trajectory fractions (columns 3 and 4 in the table). There is a correlation of 0.69, primarily because the SS 13.1 m level and CALMET annual wind roses agree that the three dominant wind direction sectors are towards the ENE, E, and ESE. Also interesting is the fact that the four largest SS fractions are slightly larger than the corresponding CALMET fractions, and vice versa for the four smallest SS fractions. This latter result could have been foreseen from the standard deviations listed at the bottom of columns 3 and 4 in Table 5: 0.0363 for SS and 0.0268 for CALMET. That is, the SS fractions show more variability across the 16 wind direction sectors. But this too is expected from basic statistical principles (e.g., the central limit theorem) since SS is a single site while the CALMET winds are essentially a weighted average over all 28 sites.

Figure 13 investigates the relationship (if any) between the magnitude of the SS-CALMET difference fractions (i.e., the magnitude of the numbers in column 5 in Table 5) and the average value of the SS and CALMET fractions (the average of the numbers in columns 3 and 4). It is obvious from "looking at" the scatter plot in Figure 13 that there is no relation. That is, the magnitudes of the differences are not significantly dependent on the magnitudes of the fractions themselves. This result suggests that the differences are due to a natural (random) variability and not to any systematic phenomenon.

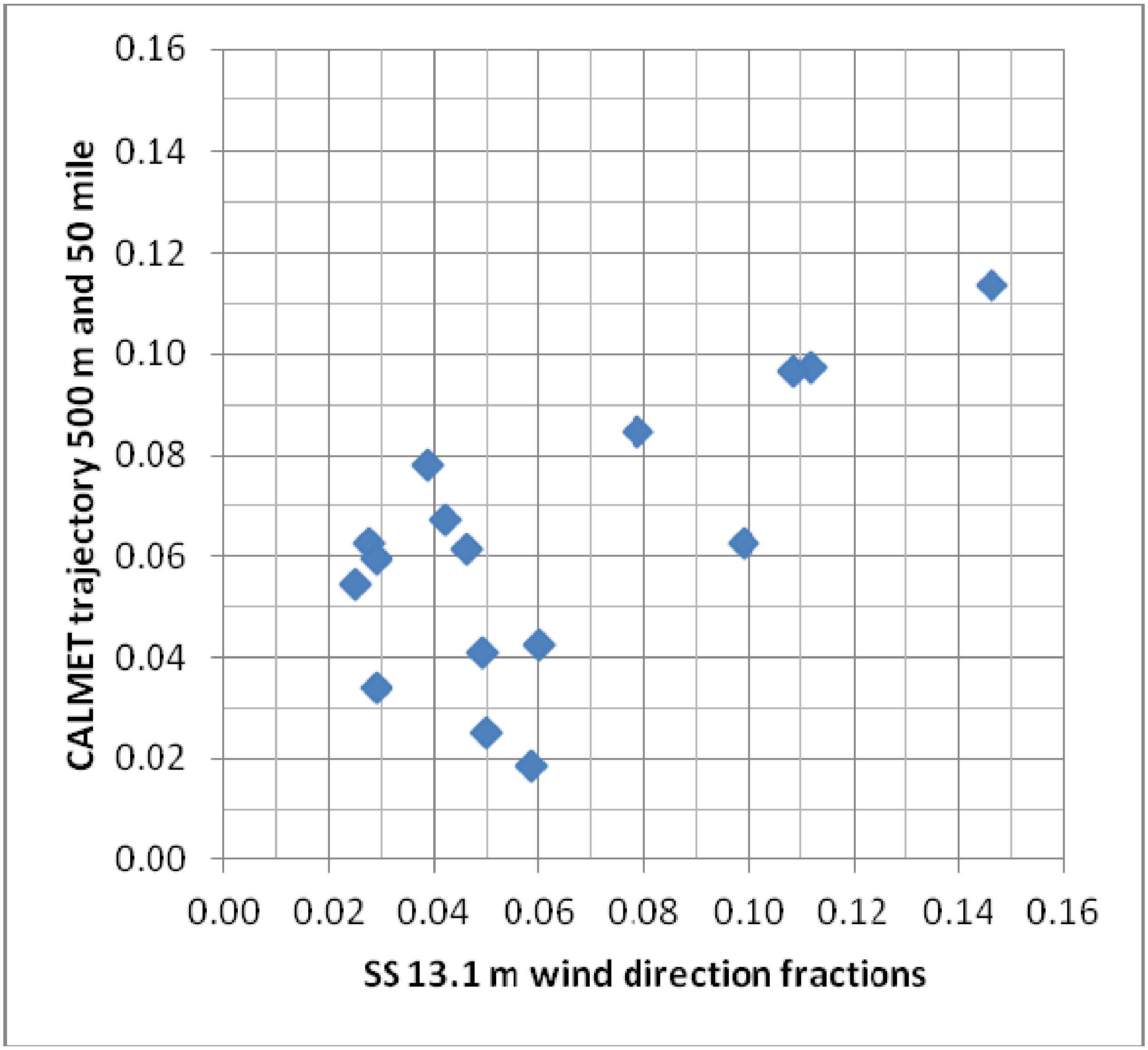


Figure 12. Plot of 22.5° sector fractions of annual wind rose data for the SS 13.1 m level (x axis) versus the CALMET trajectory 500 m level at 50 miles (y axis), using the data in Table 5.

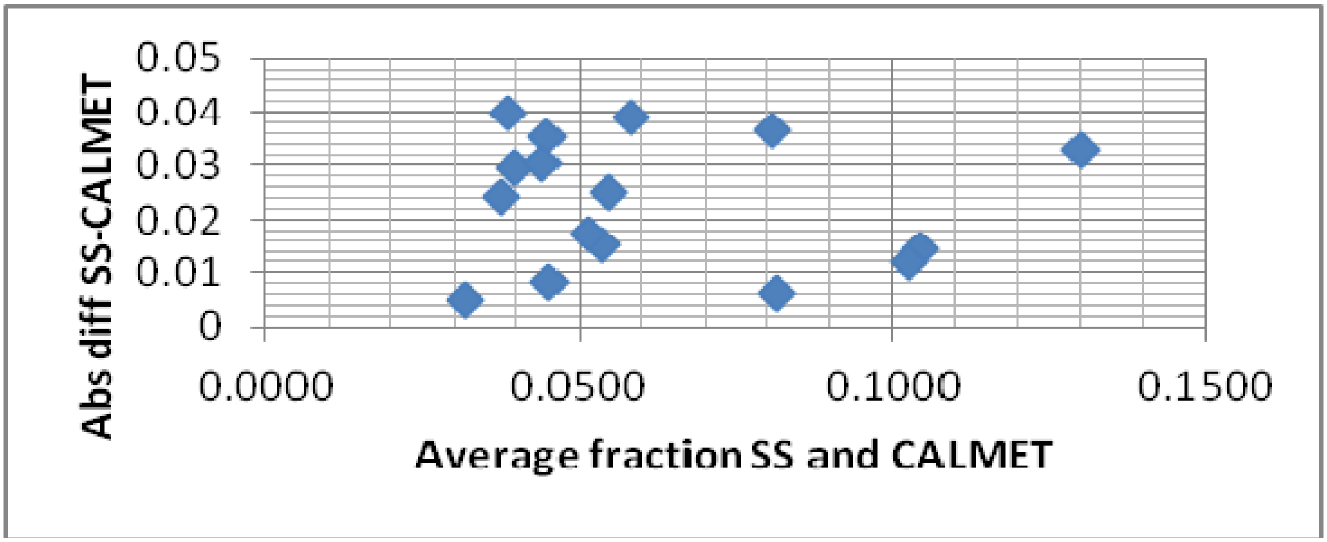


Figure 13. Plot of 22.5° sector fractions of annual wind rose data for the magnitude of the difference in the SS (13.1 m level) and the CALMET (500 m level at 50 miles) (y axis) versus the average of the fractions of the SS 13.1 m level and CALMET trajectory 500 m level at 50 miles (x axis), using the data in Table 5.

5. Conclusions

We used several approaches to compare the Seabrook Station 13.1 m (43 ft) level wind speed and direction observations from 2005 (used in the SAMA analysis) with the wind observations from other weather sites in the SAMA analysis domain (a geographic area within a 50-mi (80.5 km) radius of Seabrook Station).

Our analyses show that the annual Seabrook Station wind rose from 2005 is representative of annual Seabrook Station wind roses from other years in the period from 2004 through 2008.

The annual wind direction rose from the Seabrook Station 13.1 m (43 ft) level was compared to the annual wind roses from 27 other sites within and near the SAMA analysis domain. The Seabrook annual wind rose is found to be typical of others in the SAMA domain, with dominant wind flows towards the eastern sector. The quantitative comparison of annual wind frequencies by 22.5° sector and by site leads to the conclusion that the annual wind frequency distributions at the Seabrook site are within the range of those at the other sites and therefore are representative of the general flow patterns over the SAMA analysis domain.

The average annual wind speeds at the Seabrook Station site were compared with annual average wind speeds from other weather sites in the SAMA domain. These same sites were used in the wind rose comparisons. Most observations were at or near a height of 10 m, although a few were at slightly larger or smaller heights. Focusing on the near-10 m level observations (available from Seabrook Station plus 27 other sites), our analyses show that the Seabrook Station annual wind speed is only slightly larger than the all-site average wind speed and is well within the range of the wind speeds observed at all sites. Thus the Seabrook Station 13.1 m (43 ft) level average annual wind speed is representative of that observed at other weather sites in the SAMA analysis domain.

The EPA's widely-used CALMET mass-consistent, diagnostic meteorological model was used to produce spatial varying and time varying (hourly) wind fields over the a 200 km by 200 km domain encompassing the 81 km (50-mile) radius geographic domain. The wind fields were calculated using observed 2005 meteorological variables from about 30 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 Seabrook Station site at elevations of 100, 200, and 500 m. The angle at which each trajectory path crossed the circles with radii 1, 2, 3, 4, 5, 10, 20, 30, 40, and 50 miles was determined and used to produce annual "trajectory roses" with fractions for each 22.5° sector (just like the wind roses). The radial distances listed above correspond to distances used in the SAMA analysis. Visual comparisons and quantitative comparisons lead to the conclusion that the annual CALMET trajectory roses agree fairly well with the annual wind rose from the 13.1 m level on the SS meteorological tower. The SS 13.1 m level annual wind rose has a maximum towards the eastern sector and so does the annual CALMET trajectory rose.

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Appendix A
Annual Wind Roses at Seabrook Station

This appendix contains plots of annual wind roses for five years of hourly wind observations at Seabrook Station. These wind roses are from the 13.1 m (43 ft) and 63.7 m (209 ft) levels of the Seabrook Station meteorological tower for 2004 through 2008. The 2005 data from the 13.1 m level 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.

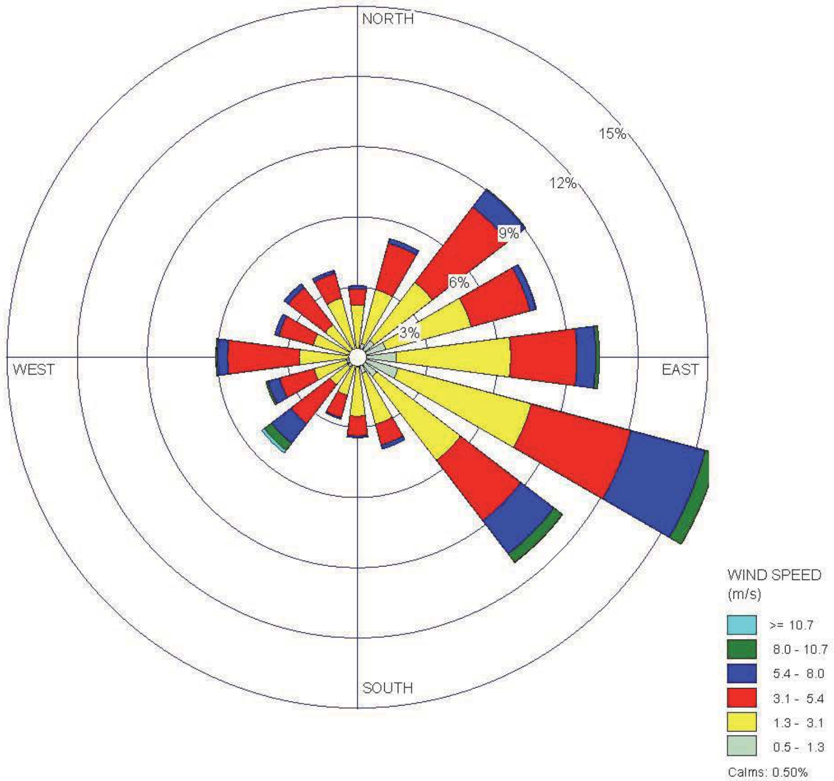
The wind roses are presented in the following order:

13.1 m (43 ft) (2004, 2005, 2006, 2007, 2008)
63.7 m (209 ft) (2004, 2005, 2006, 2007, 2008)

WIND ROSE PLOT:

Seabrook Station - winds measured at 43 feet
2004 Annual Wind Rose (flow vector)

DISPLAY:
Wind Speed
Flow Vector (blowing to)



COMMENTS:

DATA PERIOD:
Start Date: 1/1/2004 - 00:00
End Date: 12/31/2004 - 23:00

CALM WINDS:
0.50%

TOTAL COUNT:
8619 hrs.

AVG. WIND SPEED:
3.21 m/s

Epsilon ASSOCIATES INC.

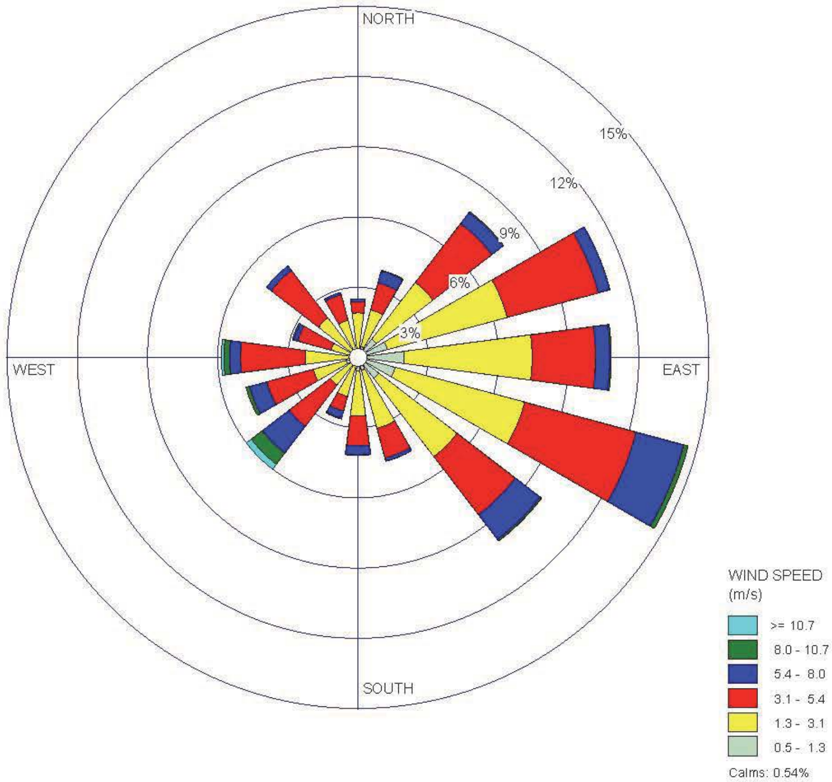
PROJECT NO.:

WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:

Seabrook Station - winds measured at 43 feet
2005 Annual Wind Rose (flow vector)

DISPLAY:
Wind Speed
Flow Vector (blowing to)



COMMENTS:

DATA PERIOD:

Start Date: 1/1/2005 - 00:00
End Date: 12/31/2005 - 23:00

CALM WINDS:

0.54%

TOTAL COUNT:

8702 hrs.

AVG. WIND SPEED:

3.21 m/s

Epsilon ASSOCIATES INC.

PROJECT NO.:

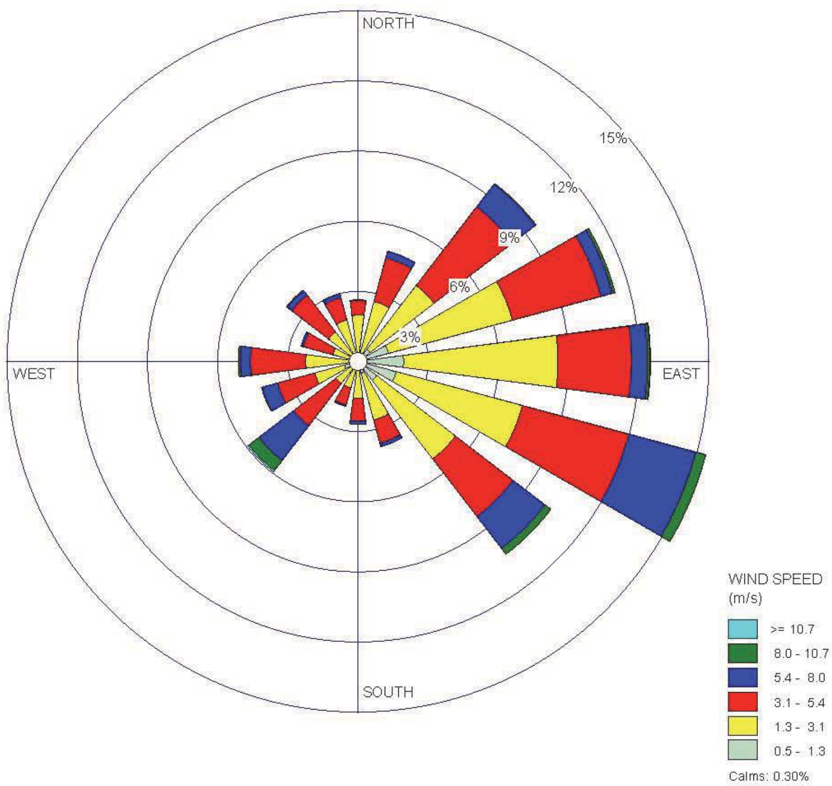
WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:

Seabrook Station - winds measured at 43 feet
2006 Annual Wind Rose (flow vector)

DISPLAY:

Wind Speed
Flow Vector (blowing to)



COMMENTS:

DATA PERIOD:

Start Date: 1/1/2006 - 00:00
End Date: 12/31/2006 - 23:00

CALM WINDS:

0.30%

TOTAL COUNT:

8432 hrs.

AVG. WIND SPEED:

3.28 m/s

Epsilon ASSOCIATES INC.

PROJECT NO.:

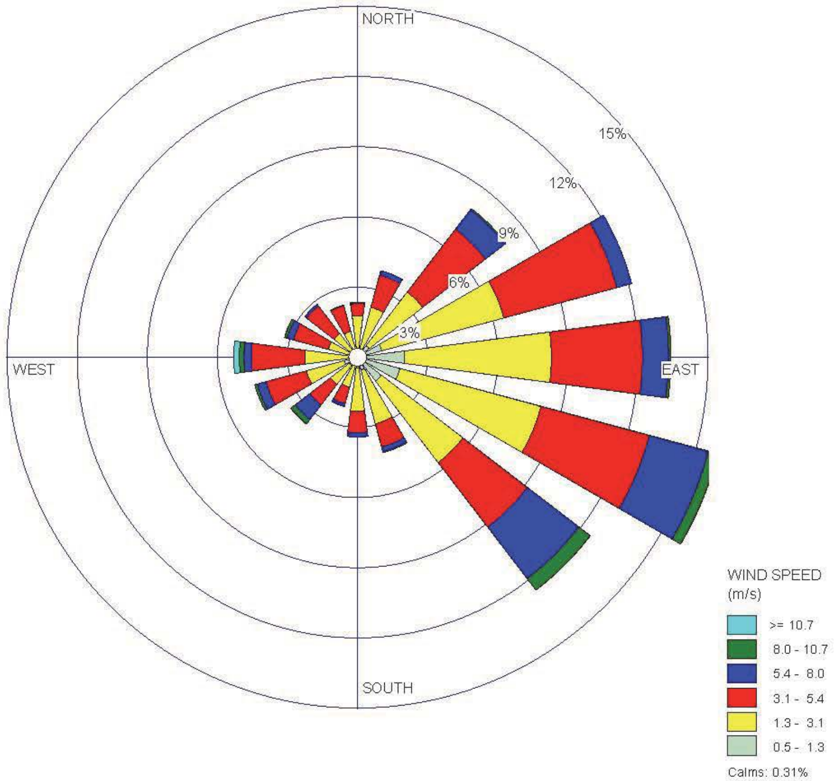
WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:

Seabrook Station - winds measured at 43 feet
2007 Annual Wind Rose (flow vector)

DISPLAY:

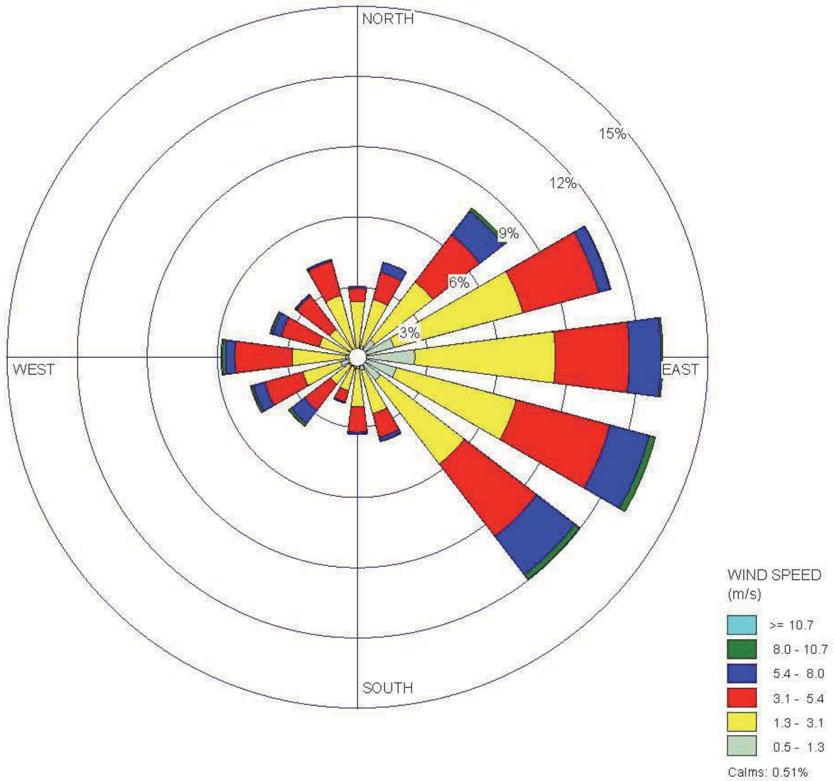
Wind Speed
Flow Vector (blowing to)



COMMENTS:	DATA PERIOD:			
	Start Date: 1/1/2007 - 00:00 **End Date: 12/31/2007 - 23:00**			
	CALM WINDS: **0.31%**	TOTAL COUNT: **8391 hrs.**	Epsilon ASSOCIATES INC.	
	AVG. WIND SPEED: **3.29 m/s**		PROJECT NO.:	

WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:	DISPLAY:
Seabrook Station - winds measured at 43 feet **2008 Annual Wind Rose (flow vector)**	**Wind Speed** **Flow Vector (blowing to)**



COMMENTS:	DATA PERIOD:		
	Start Date: 1/1/2008 - 00:00 **End Date: 12/31/2008 - 23:00**		Epsilon ASSOCIATES INC.
	CALM WINDS: **0.51%**	TOTAL COUNT: **8660 hrs.**	
	AVG. WIND SPEED: **3.10 m/s**		PROJECT NO.:

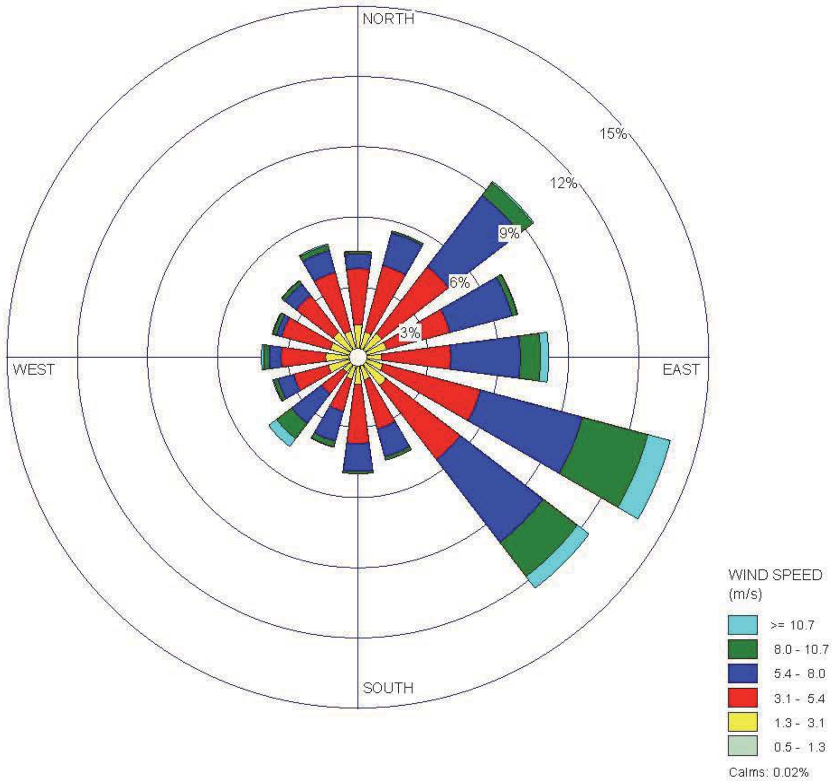
WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:

Seabrook Station - winds measured at 209 feet
2004 Annual Wind Rose (flow vector)

DISPLAY:

Wind Speed
Flow Vector (blowing to)



COMMENTS:

DATA PERIOD:

Start Date: 1/1/2004 - 00:00
End Date: 12/31/2004 - 23:00

CALM WINDS:

0.02%

TOTAL COUNT:

8684 hrs.

AVG. WIND SPEED:

5.12 m/s

PROJECT NO.:

Epsilon ASSOCIATES INC.

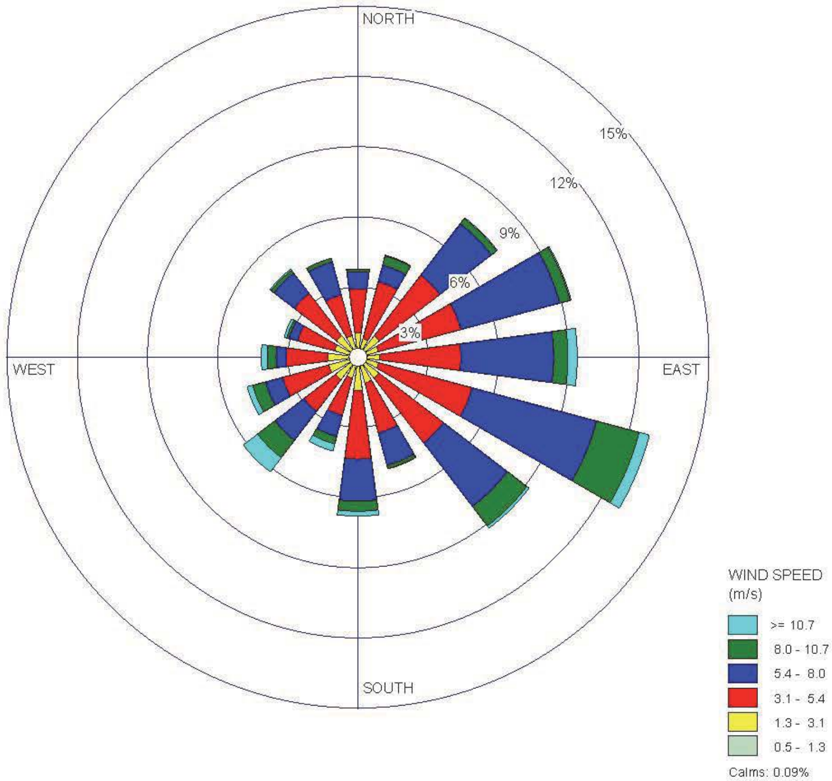
WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:

Seabrook Station - winds measured at 209 feet
2005 Annual Wind Rose (flow vector)

DISPLAY:

Wind Speed
Flow Vector (blowing to)



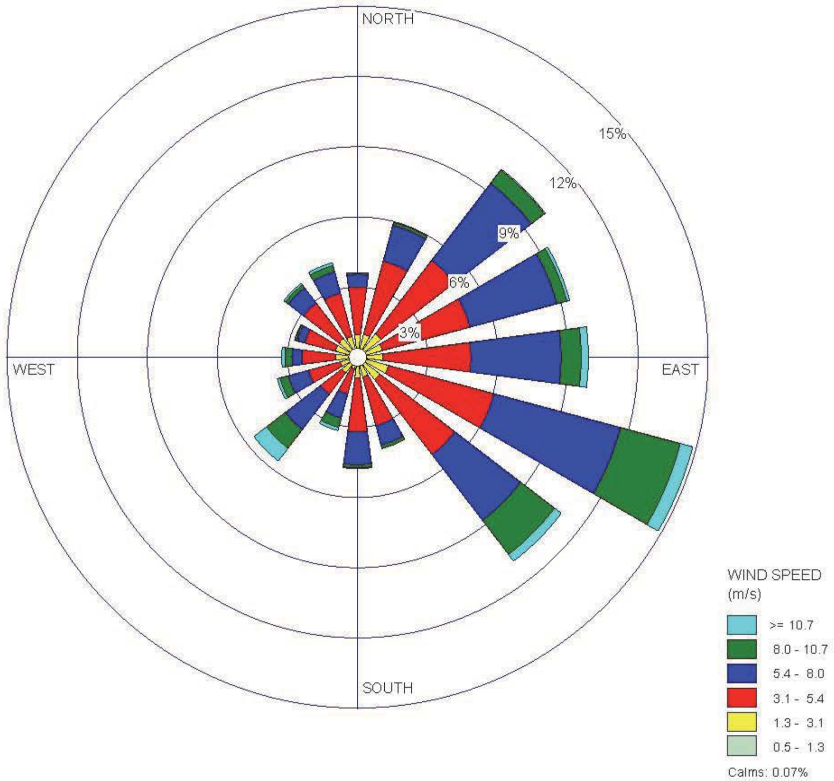
COMMENTS:	DATA PERIOD:		
	Start Date: 1/1/2005 - 00:00 **End Date: 12/31/2005 - 23:00**		
	CALM WINDS: **0.09%**	TOTAL COUNT: **8355 hrs.**	Epsilon ASSOCIATES INC.
	AVG. WIND SPEED: **5.19 m/s**		PROJECT NO.:

WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:

Seabrook Station - winds measured at 209 feet
2006 Annual Wind Rose (flow vector)

DISPLAY:
Wind Speed
Flow Vector (blowing to)



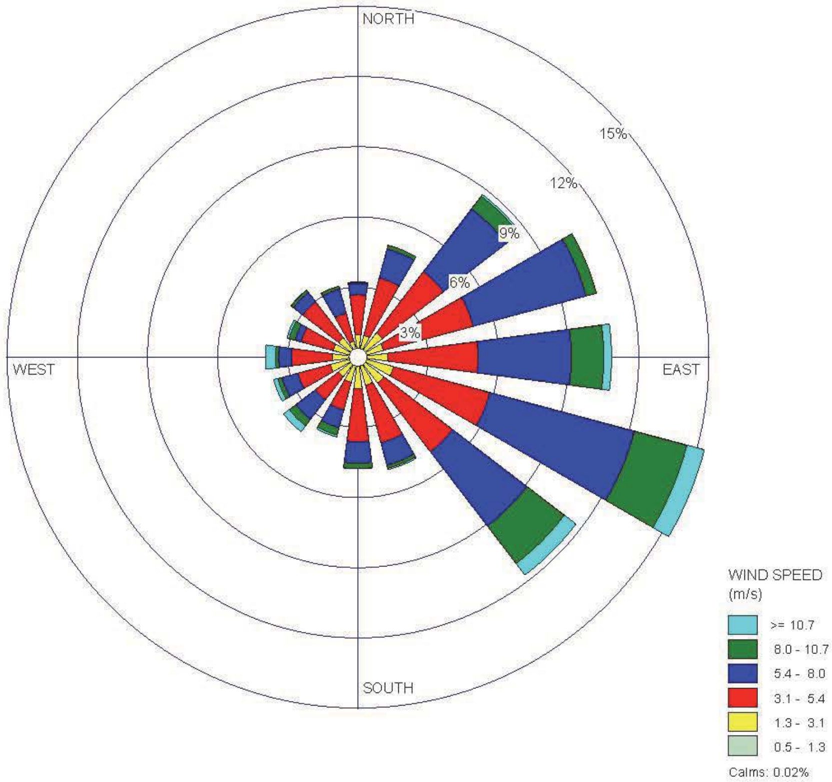
COMMENTS:	DATA PERIOD:		
	Start Date: 1/1/2006 - 00:00 End Date: 12/31/2006 - 23:00		Epsilon ASSOCIATES INC.
	CALM WINDS: **0.07%**	TOTAL COUNT: **8483 hrs.**	
	AVG. WIND SPEED: **5.30 m/s**		PROJECT NO.:

WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:

Seabrook Station - winds measured at 209 feet
2007 Annual Wind Rose (flow vector)

DISPLAY:
Wind Speed
Flow Vector (blowing to)



COMMENTS:

DATA PERIOD:

Start Date: 1/1/2007 - 00:00
End Date: 12/31/2007 - 23:00

CALM WINDS:

0.02%

TOTAL COUNT:

8358 hrs.

AVG. WIND SPEED:

5.23 m/s

Epsilon ASSOCIATES INC.

PROJECT NO.:

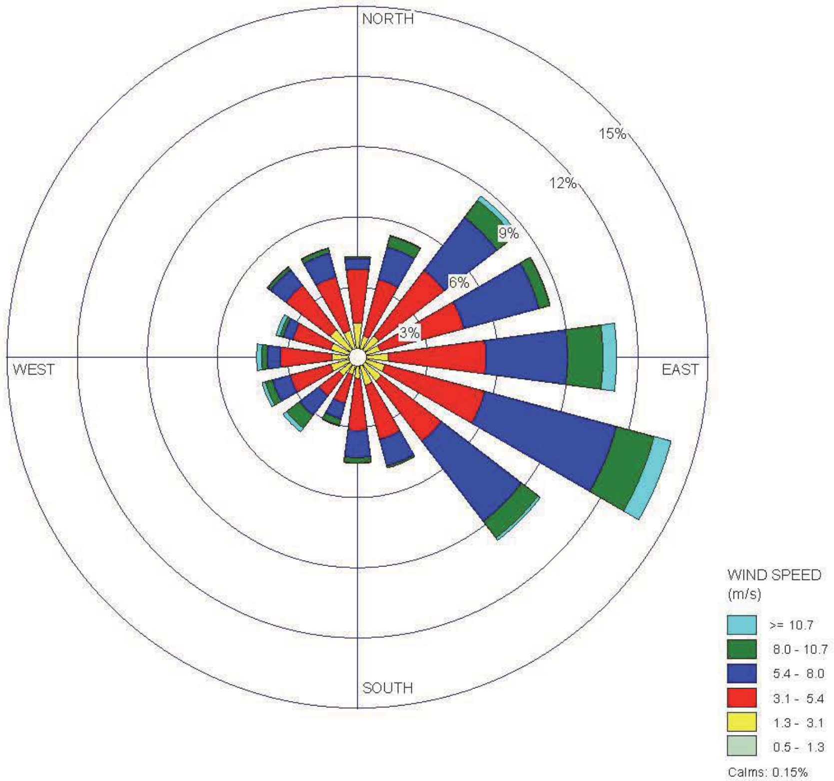
WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:

Seabrook Station - winds measured at 209 feet
2008 Annual Wind Rose (flow vector)

DISPLAY:

Wind Speed
Flow Vector (blowing to)



COMMENTS:	DATA PERIOD:	
	Start Date: 1/1/2008 - 00:00 **End Date: 12/31/2008 - 23:00**	
	CALM WINDS: **0.15%**	TOTAL COUNT: **8256 hrs.**
	AVG. WIND SPEED: **5.10 m/s**	PROJECT NO.:

Epsilon ASSOCIATES INC.

WRPLOT View - Lakes Environmental Software

Appendix B

Annual Wind Roses at All Sites

This appendix contains plots of the 29 annual wind roses that were compared in the study of spatial variations across the SAMA domain for 2005. These wind roses include those from the 13.1 m (43 ft) and 63.7 m (209 ft) levels of the Seabrook Station (SS) meteorological tower, and those from 27 other weather observing sites in the domain.

Table B-1 lists the meteorological stations from which wind data were obtained (Table 1 in the main report). An “R” in column three indicates that the station was used for the annual wind rose comparisons. A “C” in column three indicates that the station was used in the CALMET analysis. Figure B-1 is a map of the area showing the locations of the wind measurement sites. This is the same as Figure 3 in the main report.

All wind roses are from 2005 except for the following sites:

Sanford, Maine: 2006
Wells Beach, Maine: 2011
Wells Reserve, Maine: 2011

The percentage of calms is given in a block at the bottom of each wind rose plot. The average wind speed is also given in a block at the bottom, and is calculated after excluding hours with calms.

The 29 individual annual wind roses are presented in the same order as in Table B-1. On each page, the SS 13.1 m annual wind rose is included next to the other annual wind rose.

Table B-1. Meteorological station site summary. The symbols R and C indicate whether the sites were used in the wind rose and/or CALMET trajectory analyses, respectively. This is the same as Table 1 in the main report.

Station ID		R = Wind rose; C = CALMET		Dir.		Base		
USAF	WBAN	Station Name (ICAO code)	ST	From (SS)	Dist. (mi.)	Elev. (m)	Anem ht (m)	Lat N, Long W
N/A	N/A	RC Seabrook Station (SS)	NH	-	-	3.0	13.1, 63.7	42.898, 70.851
725059	14702	RC Bedford Hanscom Field (KBED)	MA	SW	37.1	40.5	10	42.470, 71.289
725088	54733	RC Beverly Municipal (KBVY)	MA	S	22.3	32.9	10	42.584, 70.916
725090	14739	RC Boston/Logan Internat (KBOS)	MA	SSW	37.9	9.1	10	42.367, 71.017
726050	14745	RC Concord Municipal (KCON)	NH	WNW	38.6	105.5	7.9	43.203, 71.502
744907	14753	RC E. Milton Blue Hill (KMQE)	MA	SSW	49.2	193.5	15.2	42.217, 71.117
725107	04780	RC Fitchburg Municipal (KFIT)	MA	WSW	51.7	106.1	10	42.554, 71.759
726163	54770	RC Jaffrey Municipal (KAFN)	NH	W	58.7	317.0	10	42.805, 72.003
726165	99999	RC Keene Dillant Hopkins (KEEN)	NH	W	71.7	149.0	10	42.898, 72.271
744904	94723	RC Lawrence Municipal (KLWM)	MA	SW	18.5	45.4	10	42.717, 71.123
743945	14710	RC Manchester (KMHT)	NH	W	29.5	70.7	10	42.933, 71.436
743946	54754	RC Nashua Boire (KASH)	NH	WSW	34.7	61.0	10	42.782, 71.515
725098	54704	RC Norwood Memorial (KOWD)	MA	SSW	52.4	15.2	10	42.191, 71.173
726055	04743	RC Pease International (KPSM)	NH	N	12.6	30.5	10	43.078, 70.823
725064	54769	RC Plymouth Municipal (KPYM)	MA	S	68.3	45.4	10	41.917, 70.733
726060	14764	RC Portland Internat Jetport (KPWM)	ME	NNE	58.7	19.2	10	43.646, 70.309
725070	14765	RC Providence/Green State (KPVD)	RI	SSW	87.0	18.9	6.1	41.717, 71.433
997278	99999	RC Providence NOS (FOXR1)	RI	SSW	81.0	10.0	4.2	41.807, 71.402
725073	64708	RC Provincetown AWOS (KPVC)	MA	SSE	66.2	2.4	10	42.067, 70.217
726056	54791	RC Rochester Skyhaven (KDAW)	NH	N	25.4	103.6	10	43.284, 70.929
726064	99999	R Sanford Municipal (KSFM)	ME	NNE	35.1	74.0	10	43.394, 70.708
997707	99999	R Wells Beach (WELM1)	ME	NNE	32.3	6.0	10	43.320, 70.563
998015	99999	R Wells Reserve (WEXM1)	ME	NNE	34.0	19.0	10.4	43.338, 70.550
725095	94746	RC Worcester Regional (KORH)	MA	SW	68.4	310.0	10	42.267, 71.876
744940	14684	C Chatham (KCHH)	MA	SSE	97.0	16.0	-	41.667, 69.950
722790	54762	C Portland/Gray (KGYX)	ME	NNE	74.9	125.9	-	43.900, 70.267
992420	44013	RC Buoy 16 NM East Of Boston, MA (DB242)	MA	S	35.7	0	5	42.346, 70.651
996340	44018	C Buoy 17NM East-Northeast of Provincetown, MA (DB634)	MA	SE	82.3	0	5	42.126, 69.630
992760	44005	RC Buoy Gulf Of Maine 78 NM East Of Portsmouth, NH (DB276)	NH	ENE	87.4	0	5	43.204, 69.128
994270	99999	RC Lighthouse Isle of Shoals, NH (IOSN3)	NH	ENE	12.5	13.1	19.2	42.967, 70.623
726036	99999	C Lighthouse Matinicus Rock, ME (MISM1)	ME	ENE	117.6	16.2	22.9	43.783, 68.855
992780	44007	RC Buoy Portland 12 NM Southeast Of Portland, ME (DB278)	ME	NE	56.3	0	5	43.531, 70.144

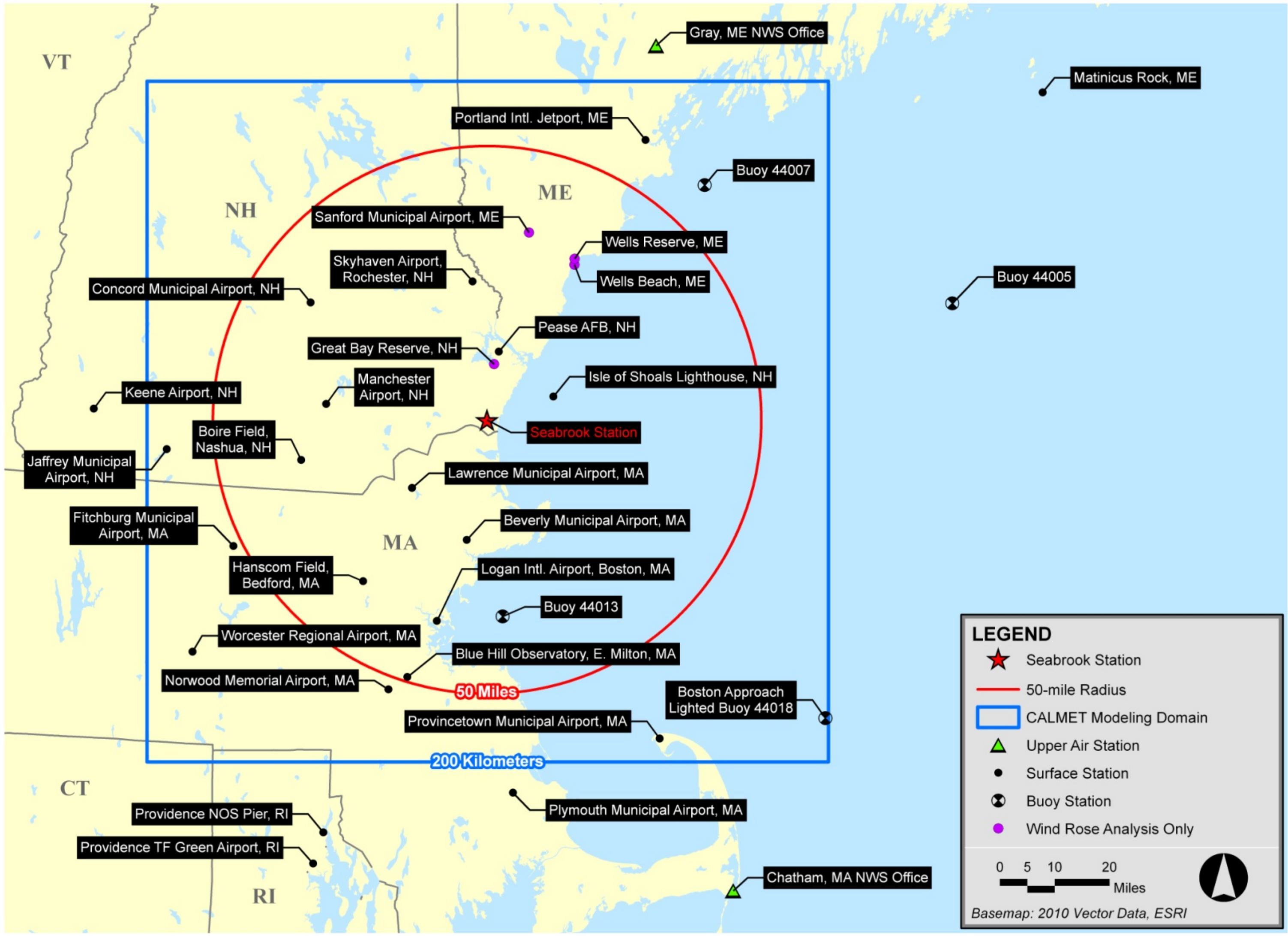


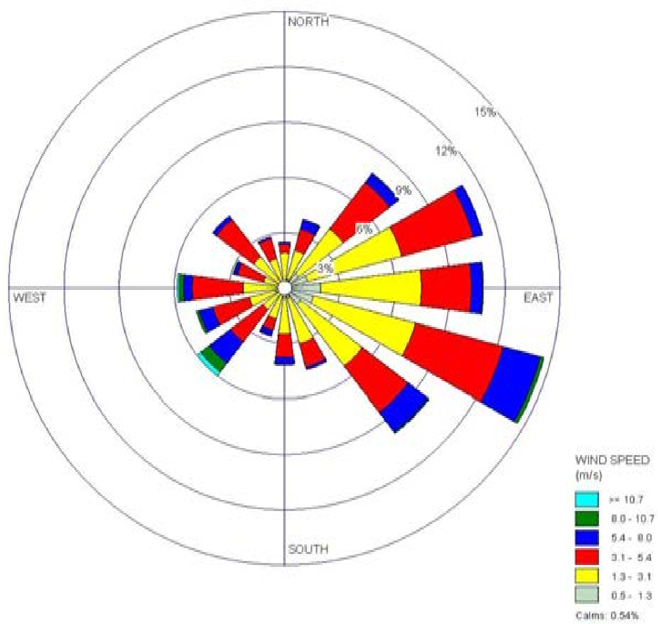
Figure B-1. Locations of meteorological stations used in wind rose analysis and CALMET modeling and listed in Table B-1. Land surface, buoy and upper air station locations are shown. The 50-mile radius circle around Seabrook Station is shown in red and the 200 km by 200 km CALMET modeling domain is shown in blue. This is the same as Figure 3 in the main report.

WIND ROSE PLOT:

Seabrook Station - winds measured at 43 feet
2005 Annual Wind Rose (flow vector)

DISPLAY:

Wind Speed
Flow Vector (blowing to)



COMMENTS:	DATA PERIOD:		
	Start Date: 1/1/2005 - 00:00 End Date: 12/31/2005 - 23:00		
	CALM WINDS: **0.54%**	TOTAL COUNT: **8702 hrs.**	
	AVG. WIND SPEED: **3.21 m/s**		PROJECT NO.:

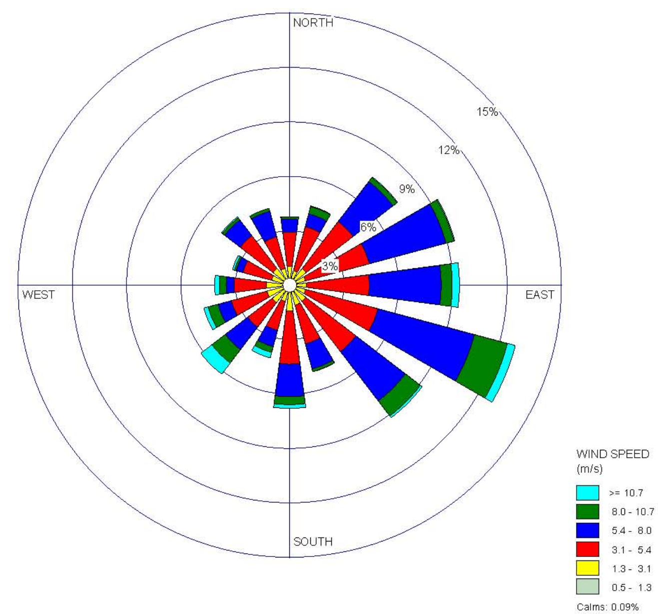
WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:

Seabrook Station - winds measured at 209 feet
2005 Annual Wind Rose (flow vector)

DISPLAY:

Wind Speed
Flow Vector (blowing to)



COMMENTS:	DATA PERIOD:		
	Start Date: 1/1/2005 - 00:00 End Date: 12/31/2005 - 23:00		
	CALM WINDS: **0.09%**	TOTAL COUNT: **8355 hrs.**	
	AVG. WIND SPEED: **5.19 m/s**		PROJECT NO.:

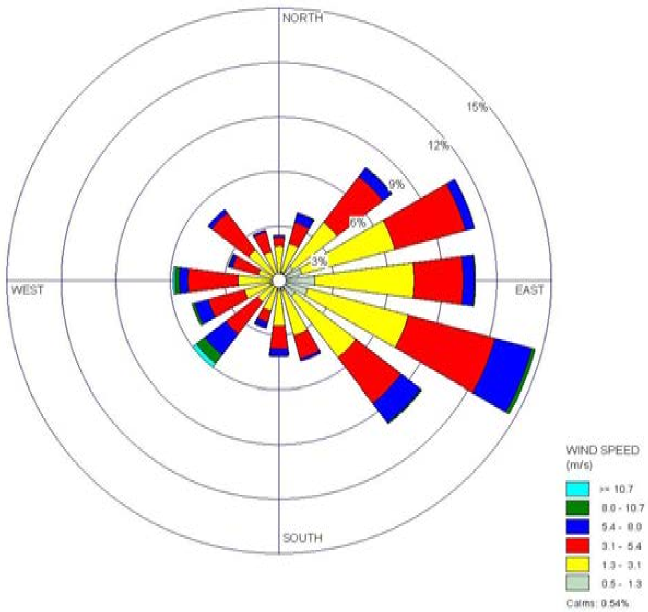
WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:

Seabrook Station - winds measured at 43 feet
2005 Annual Wind Rose (flow vector)

DISPLAY:

Wind Speed
Flow Vector (blowing to)



COMMENTS:

DATA PERIOD:

Start Date: 1/1/2005 - 00:00
End Date: 12/31/2005 - 23:00

CALM WINDS:

0.54%

TOTAL COUNT:

8702 hrs.

AVG. WIND SPEED:

3.21 m/s

PROJECT NO.:

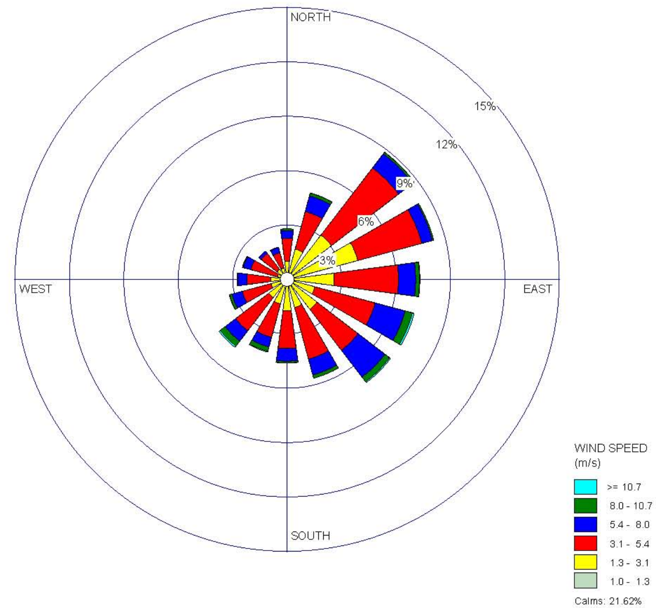
WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:

Hanscom Field, Bedford, MA
2005 Annual Wind Rose (flow vector)

DISPLAY:

Wind Speed
Flow Vector (blowing to)



COMMENTS:

DATA PERIOD:

Start Date: 1/1/2005 - 00:00
End Date: 12/31/2005 - 23:00

CALM WINDS:

21.62%

TOTAL COUNT:

8614 hrs.

AVG. WIND SPEED:

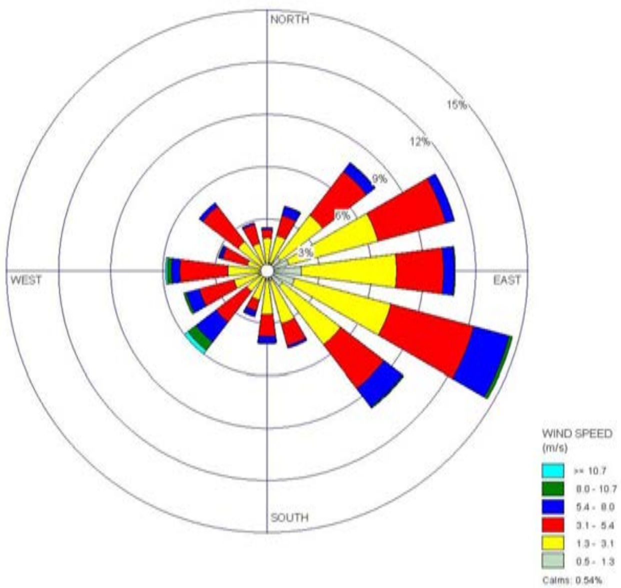
3.08 m/s

PROJECT NO.:

WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:
Seabrook Station - winds measured at 43 feet
2005 Annual Wind Rose (flow vector)

DISPLAY:
Wind Speed
Flow Vector (blowing to)

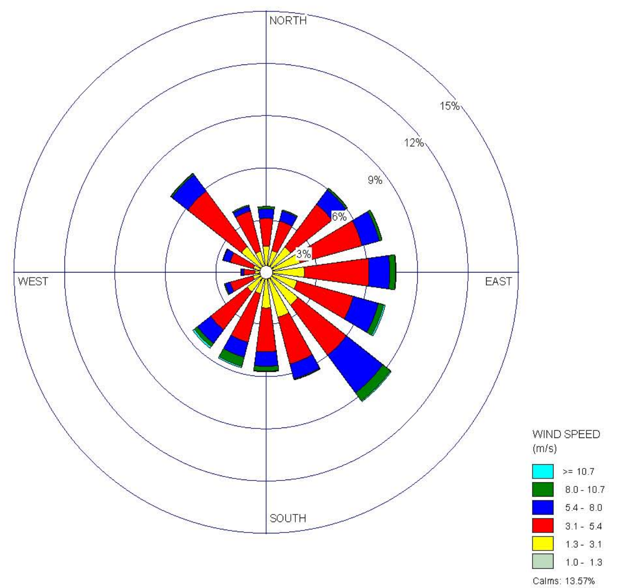


COMMENTS:	DATA PERIOD: **Start Date: 1/1/2005 - 00:00** **End Date: 12/31/2005 - 23:00**		
	CALM WINDS: **0.54%**	TOTAL COUNT: **8702 hrs.**	Epsilon Associates Inc.
	AVG. WIND SPEED: **3.21 m/s**		PROJECT NO.:

WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:
Beverly Municipal Airport, Beverly, MA
2005 Annual Wind Rose (flow vector)

DISPLAY:
Wind Speed
Flow Vector (blowing to)



COMMENTS:	DATA PERIOD: **Start Date: 1/1/2005 - 02:00** **End Date: 12/31/2005 - 23:00**		
	CALM WINDS: **13.57%**	TOTAL COUNT: **8582 hrs.**	Epsilon Associates Inc.
	AVG. WIND SPEED: **3.50 m/s**		PROJECT NO.:

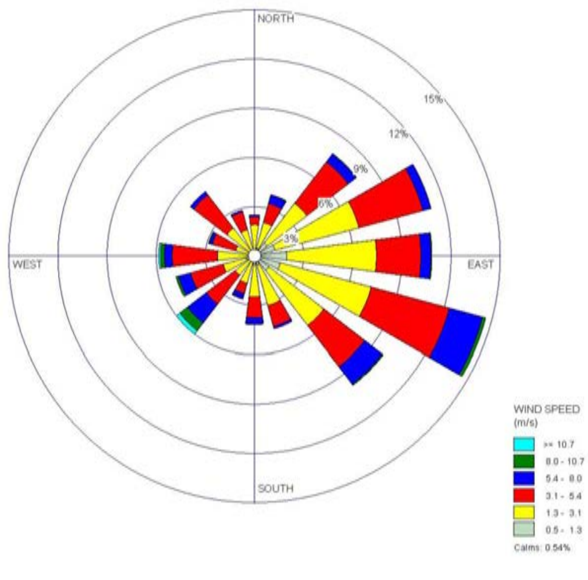
WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:

Seabrook Station - winds measured at 43 feet
2005 Annual Wind Rose (flow vector)

DISPLAY:

Wind Speed
Flow Vector (blowing to)



COMMENTS:	DATA PERIOD:		
	Start Date: 1/1/2005 - 00:00 **End Date: 12/31/2005 - 23:00**		
	CALM WINDS: **0.54%**	TOTAL COUNT: **8702 hrs.**	Epsilon Associates Inc.
	AVG. WIND SPEED: **3.21 m/s**		PROJECT NO.:

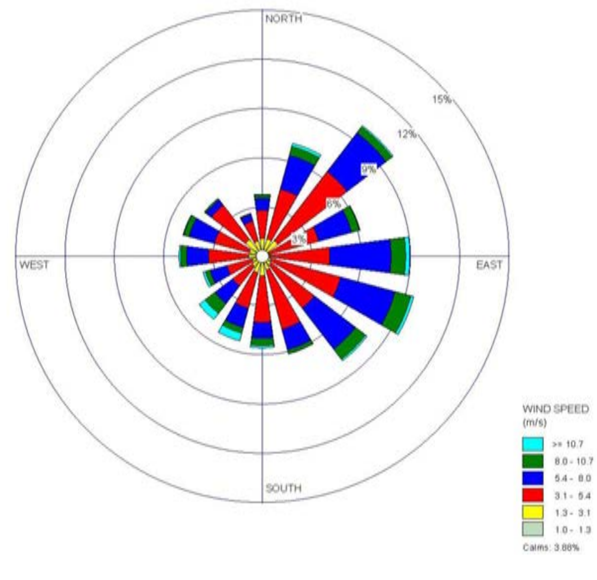
WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:

Logan International Airport, Boston, MA
2005 Annual Wind Rose (flow vector)

DISPLAY:

Wind Speed
Flow Vector (blowing to)

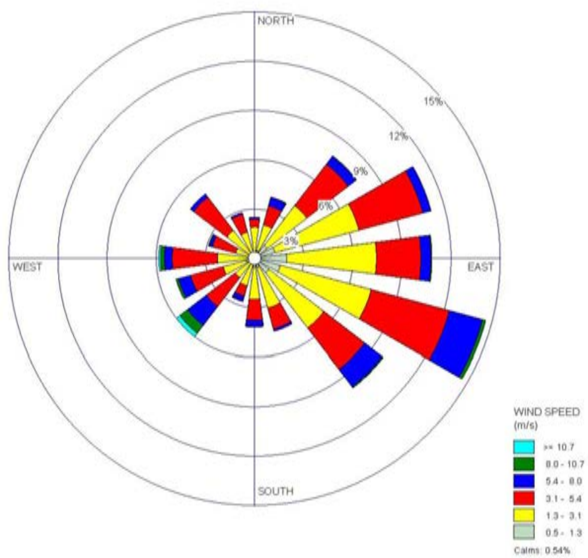


COMMENTS:	DATA PERIOD:		
	Start Date: 1/1/2005 - 00:00 **End Date: 12/31/2005 - 23:00**		
	CALM WINDS: **3.88%**	TOTAL COUNT: **8760 hrs.**	Epsilon Associates Inc.
	AVG. WIND SPEED: **4.93 m/s**		PROJECT NO.:

WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:
Seabrook Station - winds measured at 43 feet
2005 Annual Wind Rose (flow vector)

DISPLAY:
Wind Speed
Flow Vector (blowing to)



COMMENTS:

DATA PERIOD:
Start Date: 1/1/2005 - 00:00
End Date: 12/31/2005 - 23:00

CALM WINDS:
0.54%

TOTAL COUNT:
8702 hrs.

AVG. WIND SPEED:
3.21 m/s

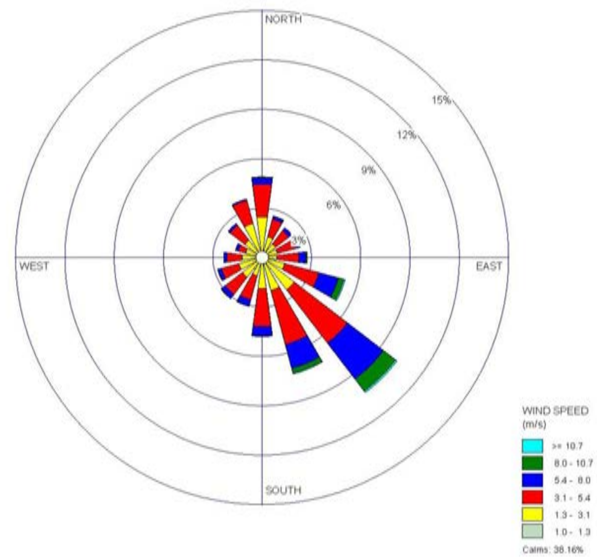
PROJECT NO.:

Epsilon Associates Inc.

WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:
Concord Municipal Airport, Concord, NH
2005 Annual Wind Rose (flow vector)

DISPLAY:
Wind Speed
Flow Vector (blowing to)



COMMENTS:

DATA PERIOD:
Start Date: 1/1/2005 - 00:00
End Date: 12/31/2005 - 23:00

CALM WINDS:
38.16%

TOTAL COUNT:
8737 hrs.

AVG. WIND SPEED:
2.31 m/s

PROJECT NO.:

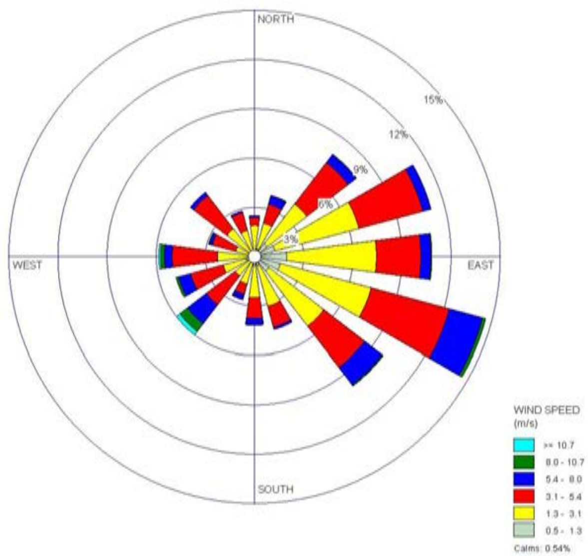
Epsilon Associates Inc.

WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:

Seabrook Station - winds measured at 43 feet
2005 Annual Wind Rose (flow vector)

DISPLAY:
Wind Speed
Flow Vector (blowing to)



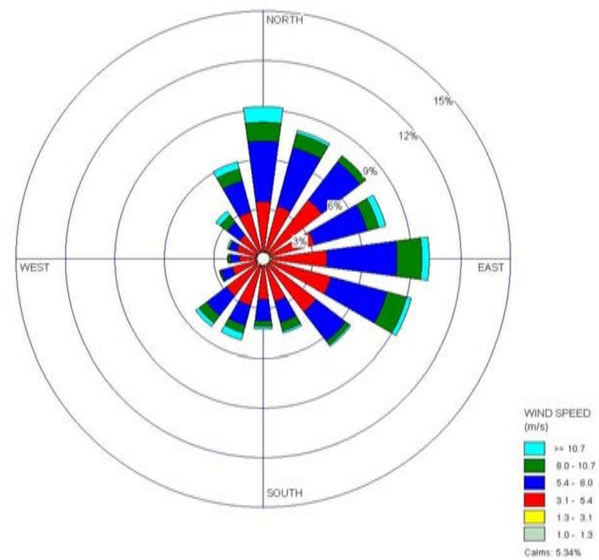
COMMENTS:	DATA PERIOD:		
	Start Date: 1/1/2005 - 00:00 End Date: 12/31/2005 - 23:00		Epsilon ASSOCIATES INC.
	CALM WINDS: **0.54%**	TOTAL COUNT: **8702 hrs.**	
	AVG. WIND SPEED: **3.21 m/s**		PROJECT NO.:

WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:

Blue Hill Observatory, East Milton, MA
2005 Annual Wind Rose (flow vector)

DISPLAY:
Wind Speed
Flow Vector (blowing to)

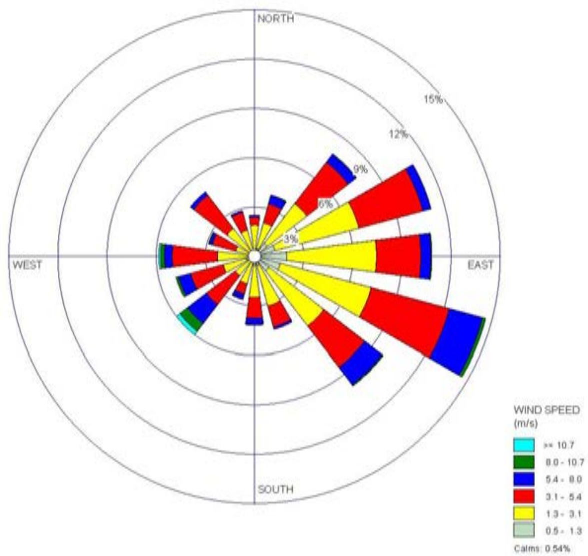


COMMENTS:	DATA PERIOD:		
	Start Date: 1/1/2005 - 01:00 End Date: 12/31/2005 - 23:00		Epsilon ASSOCIATES INC.
	CALM WINDS: **5.34%**	TOTAL COUNT: **8687 hrs.**	
	AVG. WIND SPEED: **5.48 m/s**		PROJECT NO.:

WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:
Seabrook Station - winds measured at 43 feet
2005 Annual Wind Rose (flow vector)

DISPLAY:
Wind Speed
Flow Vector (blowing to)

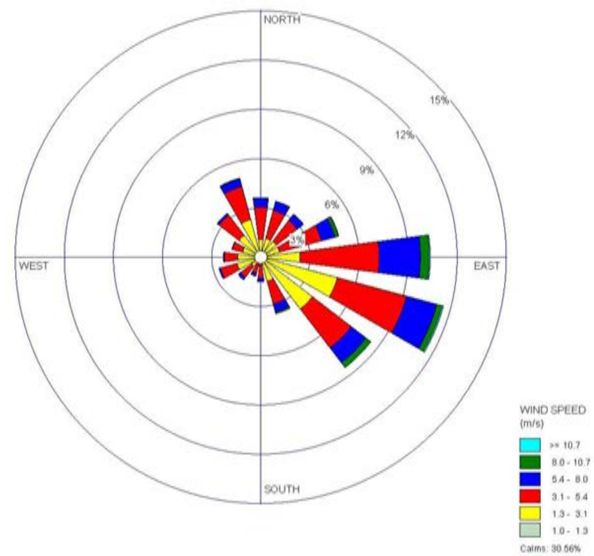


COMMENTS:	DATA PERIOD: **Start Date: 1/1/2005 - 00:00** **End Date: 12/31/2005 - 23:00**		
	CALM WINDS: **0.54%**	TOTAL COUNT: **8702 hrs.**	Epsilon ASSOCIATES INC.
	AVG. WIND SPEED: **3.21 m/s**		PROJECT NO.:

WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:
Fitchburg Municipal Airport, Fitchburg, MA
2005 Annual Wind Rose (flow vector)

DISPLAY:
Wind Speed
Flow Vector (blowing to)



COMMENTS:	DATA PERIOD: **Start Date: 1/1/2005 - 02:00** **End Date: 12/31/2005 - 23:00**		
	CALM WINDS: **30.56%**	TOTAL COUNT: **8539 hrs.**	Epsilon ASSOCIATES INC.
	AVG. WIND SPEED: **2.56 m/s**		PROJECT NO.:

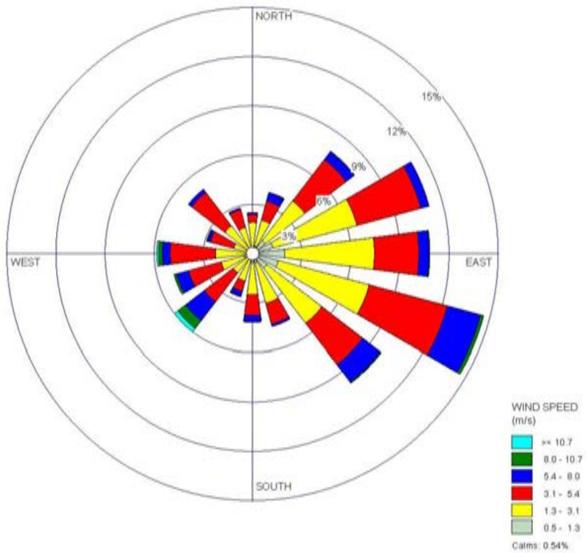
WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:

Seabrook Station - winds measured at 43 feet
2005 Annual Wind Rose (flow vector)

DISPLAY:

Wind Speed
Flow Vector (blowing to)



COMMENTS:	DATA PERIOD:		
	Start Date: 1/1/2005 - 00:00 **End Date: 12/31/2005 - 23:00**		
	CALM WINDS: **0.54%**	TOTAL COUNT: **8702 hrs.**	Epsilon ASSOCIATES INC.
	AVG. WIND SPEED: **3.21 m/s**		PROJECT NO.:

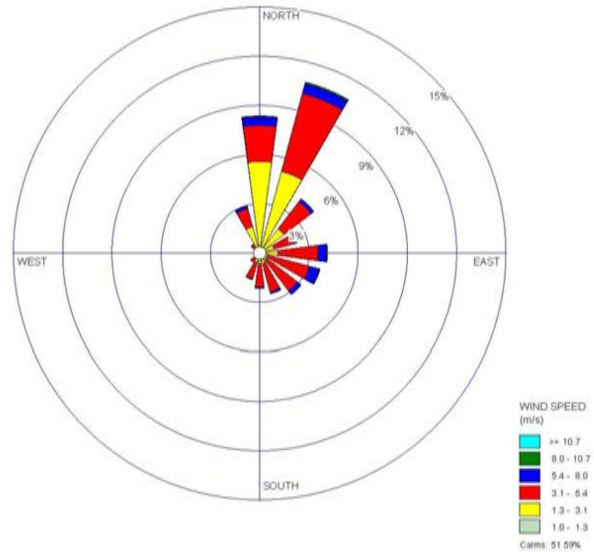
WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:

Jaffrey Municipal Silver Ranch Airport, Jaffrey, NH
2005 Annual Wind Rose (flow vector)

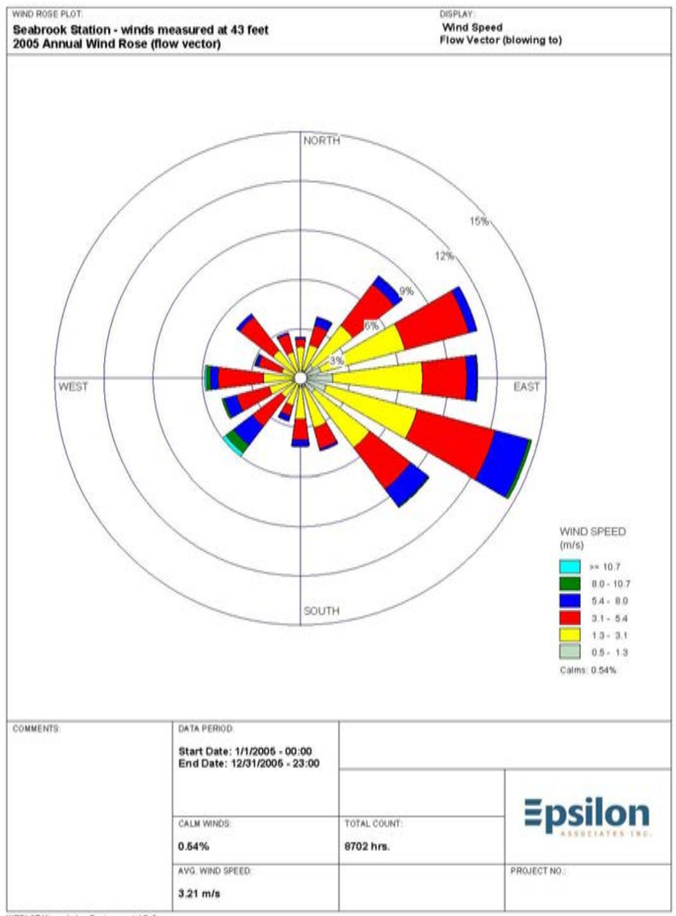
DISPLAY:

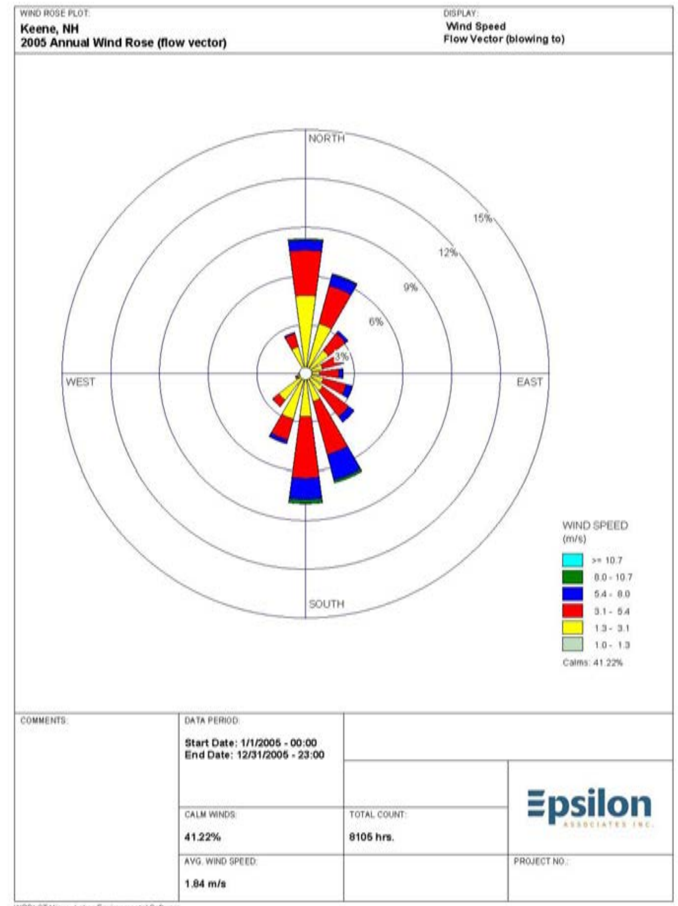
Wind Speed
Flow Vector (blowing to)



COMMENTS:	DATA PERIOD:		
	Start Date: 1/1/2005 - 02:00 **End Date: 12/31/2005 - 23:00**		
	CALM WINDS: **51.59%**	TOTAL COUNT: **8654 hrs.**	Epsilon ASSOCIATES INC.
	AVG. WIND SPEED: **1.60 m/s**		PROJECT NO.:

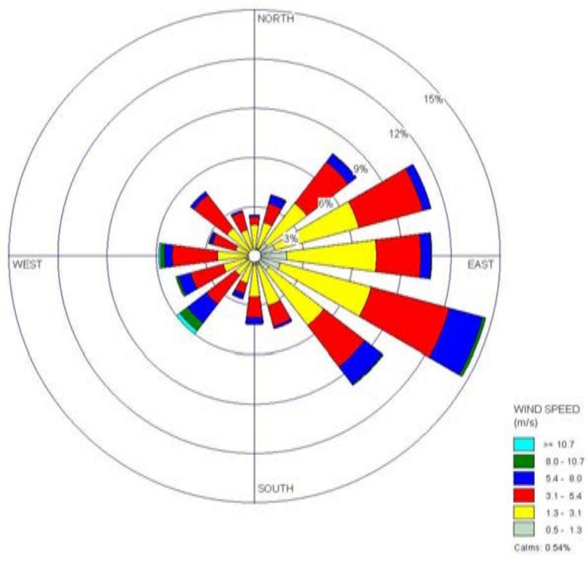
WRPLOT View - Lakes Environmental Software


WIND ROSE PLOT:
Seabrook Station - winds measured at 43 feet
2005 Annual Wind Rose (flow vector)
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
0.5 - 1.3
Calms: 0.54%
COMMENTS:
DATA PERIOD:
Start Date: 1/1/2005 - 00:00
End Date: 12/31/2005 - 23:00
CALM WINDS:
0.54%
TOTAL COUNT:
8702 hrs.
AVG. WIND SPEED:
3.21 m/s
PROJECT NO.:
WRPLOT View - Lakes Environmental Software


WIND ROSE PLOT:
Keene, NH
2005 Annual Wind Rose (flow vector)
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: 41.22%
COMMENTS:
DATA PERIOD:
Start Date: 1/1/2005 - 00:00
End Date: 12/31/2005 - 23:00
CALM WINDS:
41.22%
TOTAL COUNT:
8105 hrs.
AVG. WIND SPEED:
1.84 m/s
PROJECT NO.:
WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:
Seabrook Station - winds measured at 43 feet
2005 Annual Wind Rose (flow vector)

DISPLAY:
Wind Speed
Flow Vector (blowing to)



COMMENTS:

DATA PERIOD:
Start Date: 1/1/2005 - 00:00
End Date: 12/31/2005 - 23:00

CALM WINDS:
0.54%

TOTAL COUNT:
8702 hrs.

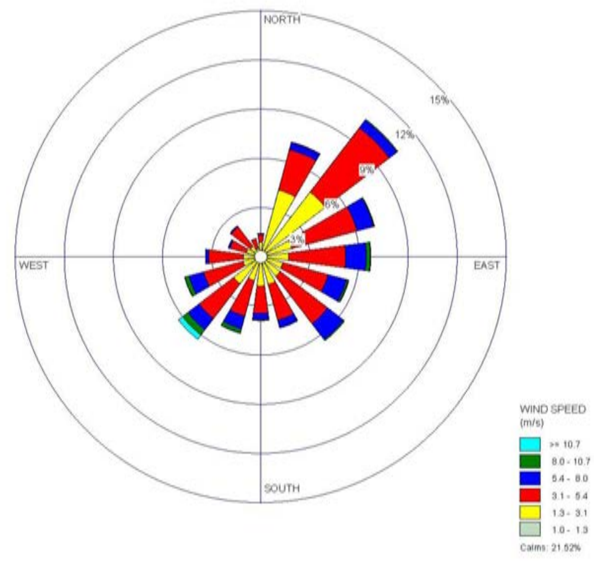
AVG. WIND SPEED:
3.21 m/s

PROJECT NO.:

WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:
Lawrence Municipal Airport, Lawrence, MA
2005 Annual Wind Rose (flow vector)

DISPLAY:
Wind Speed
Flow Vector (blowing to)



COMMENTS:

DATA PERIOD:
Start Date: 1/1/2005 - 02:00
End Date: 12/31/2005 - 23:00

CALM WINDS:
21.52%

TOTAL COUNT:
8660 hrs.

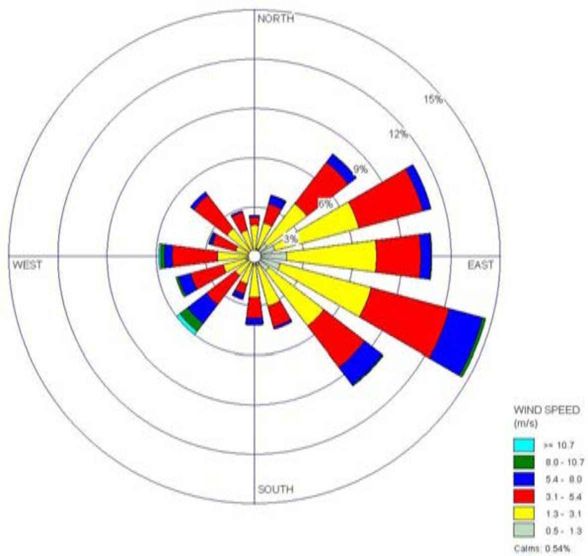
AVG. WIND SPEED:
2.91 m/s

PROJECT NO.:

WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:
Seabrook Station - winds measured at 43 feet
2005 Annual Wind Rose (flow vector)

DISPLAY:
Wind Speed
Flow Vector (blowing to)

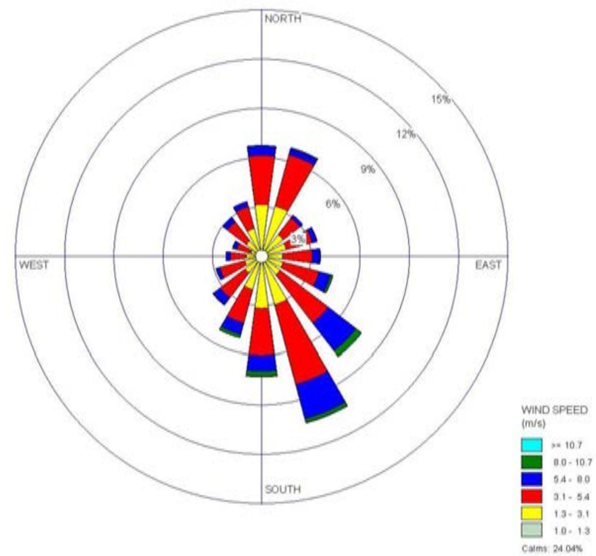


COMMENTS:	DATA PERIOD:		
	Start Date: 1/1/2005 - 00:00 End Date: 12/31/2005 - 23:00		
	CALM WINDS: 0.54%	TOTAL COUNT: 8702 hrs.	Epsilon Associates Inc.
	AVG. WIND SPEED: 3.21 m/s		PROJECT NO.:

WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:
Manchester Airport, Manchester, NH
2005 Annual Wind Rose (flow vector)

DISPLAY:
Wind Speed
Flow Vector (blowing to)



COMMENTS:	DATA PERIOD:		
	Start Date: 1/1/2005 - 02:00 End Date: 12/31/2005 - 23:00		
	CALM WINDS: 24.04%	TOTAL COUNT: 8676 hrs.	Epsilon Associates Inc.
	AVG. WIND SPEED: 2.79 m/s		PROJECT NO.:

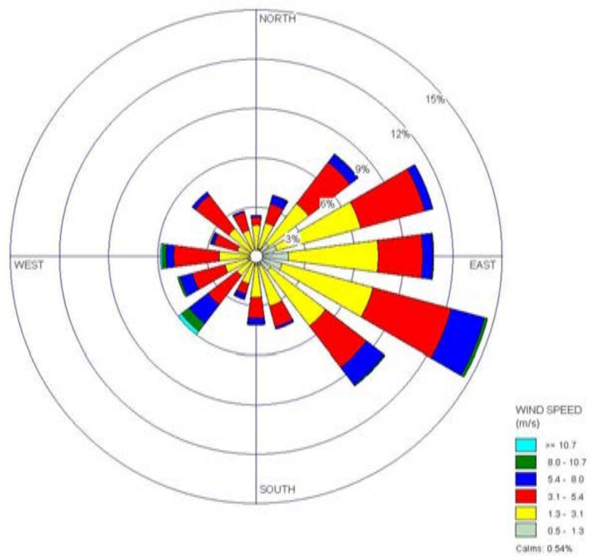
WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:

Seabrook Station - winds measured at 43 feet
2005 Annual Wind Rose (flow vector)

DISPLAY:

Wind Speed
Flow Vector (blowing to)



COMMENTS:	DATA PERIOD: **Start Date: 1/1/2005 - 00:00** **End Date: 12/31/2005 - 23:00**		
	CALM WINDS: **0.54%**	TOTAL COUNT: **8702 hrs.**	Epsilon ASSOCIATES INC.
	AVG. WIND SPEED: **3.21 m/s**		PROJECT NO.:

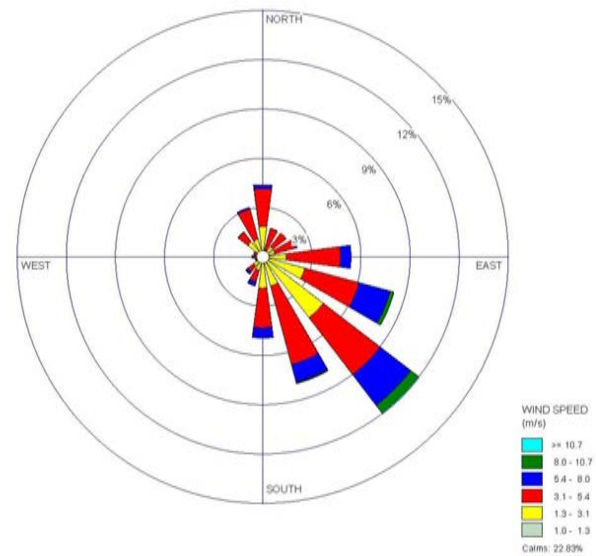
WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:

Boire Field, Nashua, NH
2005 Annual Wind Rose (flow vector)

DISPLAY:

Wind Speed
Flow Vector (blowing to)

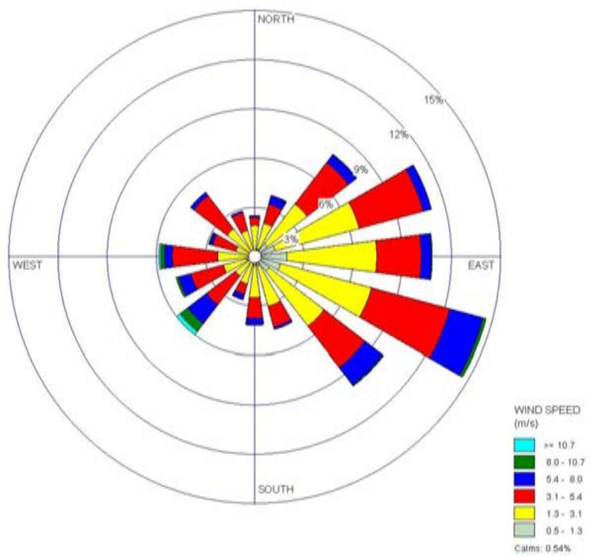


COMMENTS:	DATA PERIOD: **Start Date: 1/1/2005 - 15:00** **End Date: 12/31/2005 - 23:00**		
	CALM WINDS: **22.83%**	TOTAL COUNT: **2899 hrs.**	Epsilon ASSOCIATES INC.
	AVG. WIND SPEED: **2.28 m/s**		PROJECT NO.:

WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:
Seabrook Station - winds measured at 43 feet
2005 Annual Wind Rose (flow vector)

DISPLAY:
Wind Speed
Flow Vector (blowing to)



COMMENTS:

DATA PERIOD:
Start Date: 1/1/2005 - 00:00
End Date: 12/31/2005 - 23:00

CALM WINDS:
0.54%

TOTAL COUNT:
8702 hrs.

AVG. WIND SPEED:
3.21 m/s

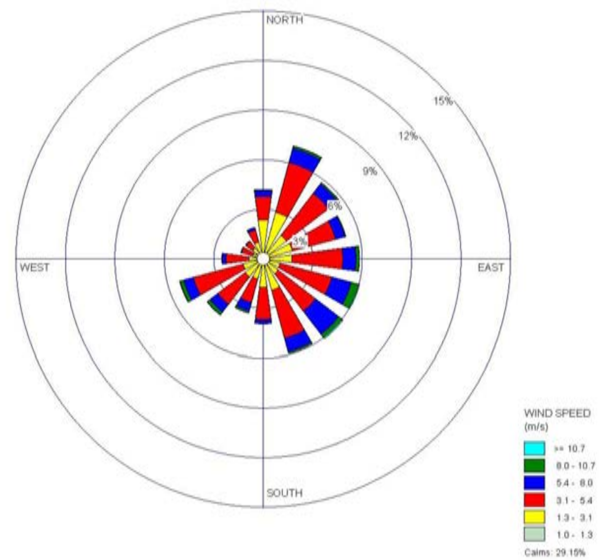
PROJECT NO.:

Epsilon ASSOCIATES INC.

WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:
Norwood Memorial Airport, Norwood, MA
2005 Annual Wind Rose (flow vector)

DISPLAY:
Wind Speed
Flow Vector (blowing to)



COMMENTS:

DATA PERIOD:
Start Date: 1/1/2005 - 02:00
End Date: 12/31/2005 - 23:00

CALM WINDS:
29.15%

TOTAL COUNT:
8641 hrs.

AVG. WIND SPEED:
2.68 m/s

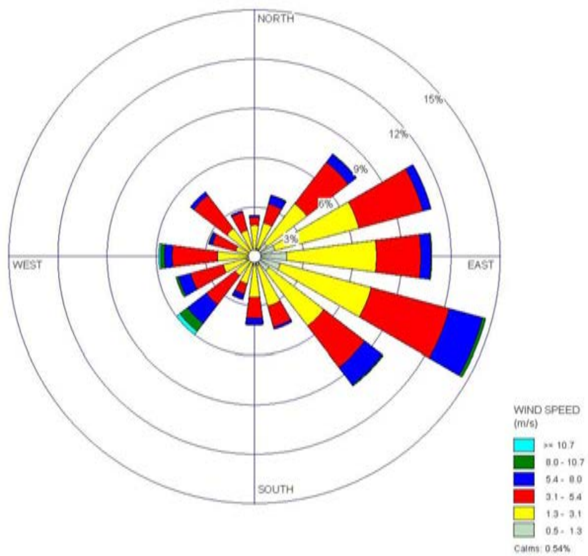
PROJECT NO.:

Epsilon ASSOCIATES INC.

WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:
Seabrook Station - winds measured at 43 feet
2005 Annual Wind Rose (flow vector)

DISPLAY:
Wind Speed
Flow Vector (blowing to)



COMMENTS:

DATA PERIOD:
Start Date: 1/1/2005 - 00:00
End Date: 12/31/2005 - 23:00

CALM WINDS:
0.54%

TOTAL COUNT:
8702 hrs.

AVG. WIND SPEED:
3.21 m/s

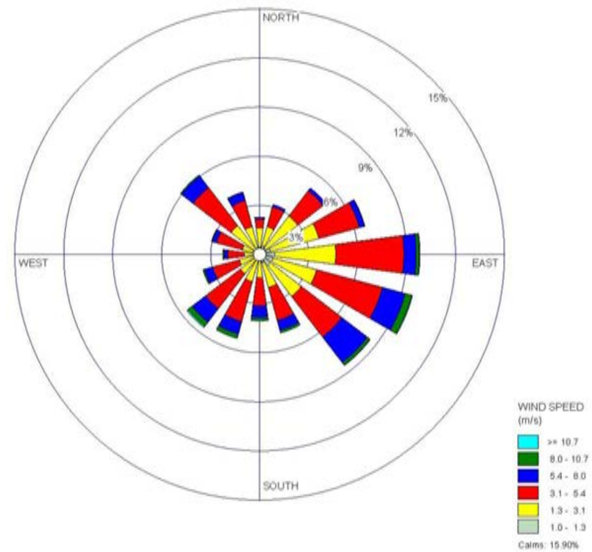
Epsilon Associates Inc.

PROJECT NO.:

WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:
Pease Air Force Base, Portsmouth, NH
2005 Annual Wind Rose (flow vector)

DISPLAY:
Wind Speed
Flow Vector (blowing to)



COMMENTS:

DATA PERIOD:
Start Date: 1/1/2005 - 00:00
End Date: 12/31/2005 - 23:00

CALM WINDS:
15.90%

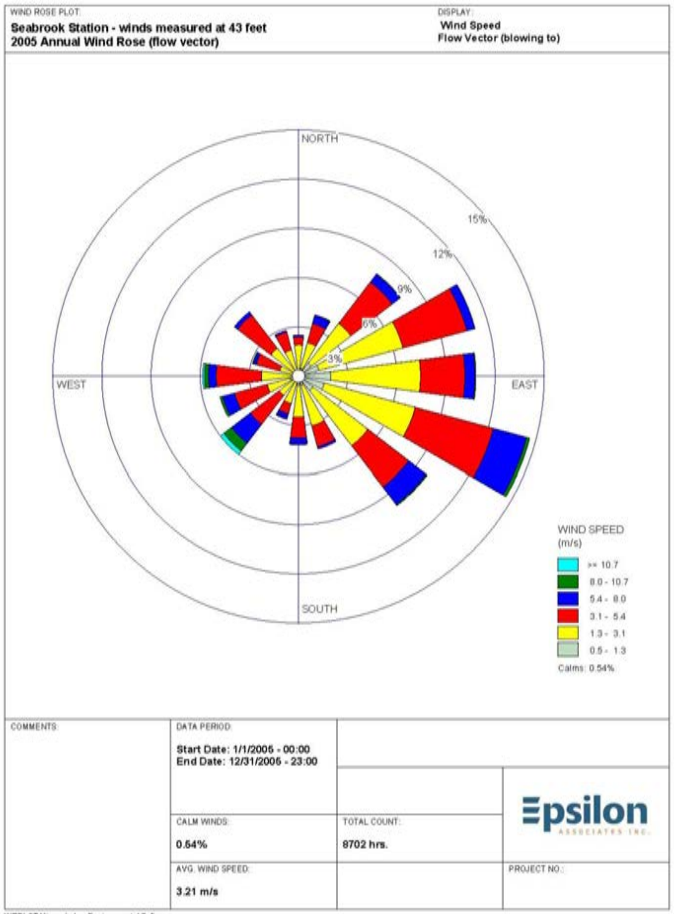
TOTAL COUNT:
8653 hrs.

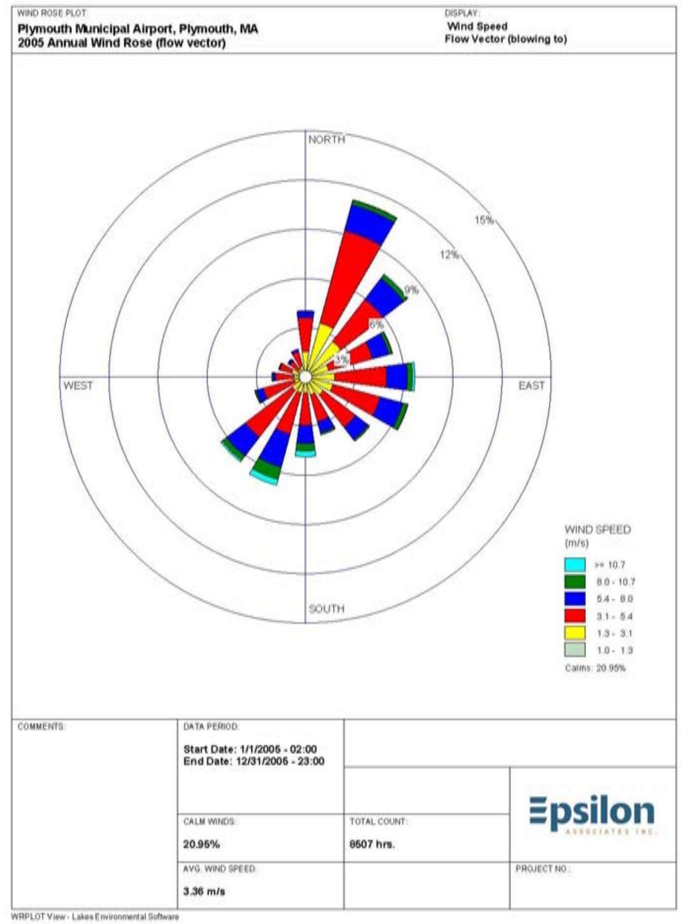
AVG. WIND SPEED:
2.94 m/s

Epsilon Associates Inc.

PROJECT NO.:

WRPLOT View - Lakes Environmental Software


WIND ROSE PLOT:
Seabrook Station - winds measured at 43 feet
2005 Annual Wind Rose (flow vector)
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
0.5 - 1.3
Calms: 0.54%
COMMENTS:
DATA PERIOD:
Start Date: 1/1/2005 - 00:00
End Date: 12/31/2005 - 23:00
CALM WINDS:
0.54%
TOTAL COUNT:
8702 hrs.
AVG. WIND SPEED:
3.21 m/s
PROJECT NO.:
WRPLOT View - Lakes Environmental Software

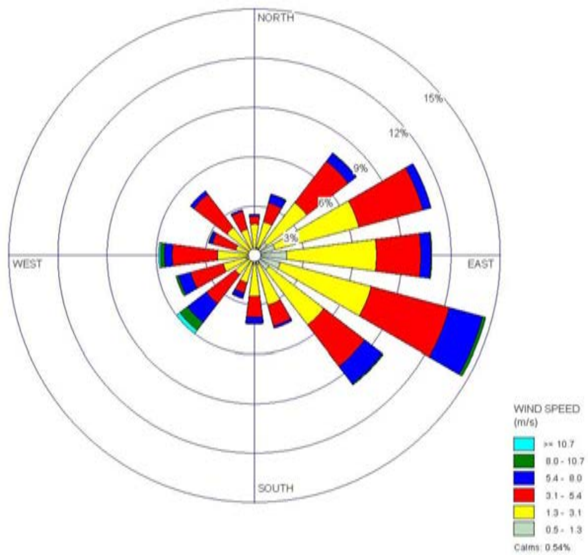

WIND ROSE PLOT:
Plymouth Municipal Airport, Plymouth, MA
2005 Annual Wind Rose (flow vector)
DISPLAY:
Wind Speed
Flow Vector (blowing to)
NORTH
WEST
EAST
SOUTH
3%
6%
9%
12%
15%
WIND SPEED
(m/s)
>= 10.7
8.0 - 10.7
5.4 - 8.0
3.1 - 5.4
1.3 - 3.1
1.0 - 1.3
Calms: 20.95%
COMMENTS:
DATA PERIOD:
Start Date: 1/1/2005 - 02:00
End Date: 12/31/2005 - 23:00
CALM WINDS:
20.95%
TOTAL COUNT:
8507 hrs.
AVG. WIND SPEED:
3.36 m/s
PROJECT NO.:
WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:

Seabrook Station - winds measured at 43 feet
2005 Annual Wind Rose (flow vector)

DISPLAY:

Wind Speed
Flow Vector (blowing to)



COMMENTS:	DATA PERIOD: **Start Date: 1/1/2005 - 00:00** **End Date: 12/31/2005 - 23:00**		
	CALM WINDS: **0.54%**	TOTAL COUNT: **8702 hrs.**	Epsilon ASSOCIATES INC.
	AVG. WIND SPEED: **3.21 m/s**		PROJECT NO.:

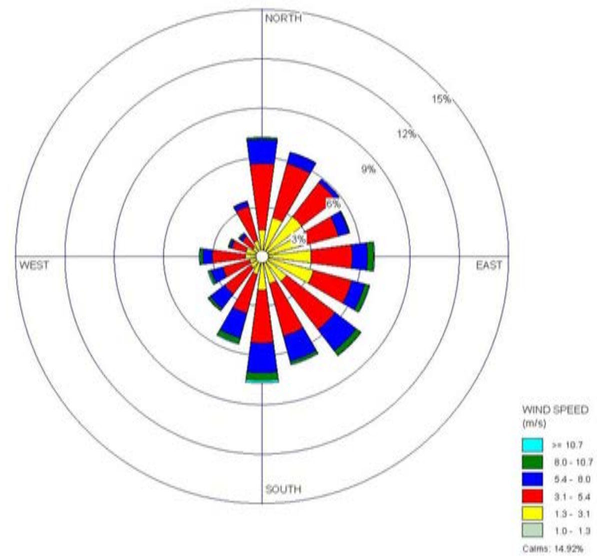
WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:

Portland International Jetport, Portland, ME
2005 Annual Wind Rose (flow vector)

DISPLAY:

Wind Speed
Flow Vector (blowing to)



COMMENTS:	DATA PERIOD: **Start Date: 1/1/2005 - 00:00** **End Date: 12/31/2005 - 23:00**		
	CALM WINDS: **14.92%**	TOTAL COUNT: **8764 hrs.**	Epsilon ASSOCIATES INC.
	AVG. WIND SPEED: **3.42 m/s**		PROJECT NO.:

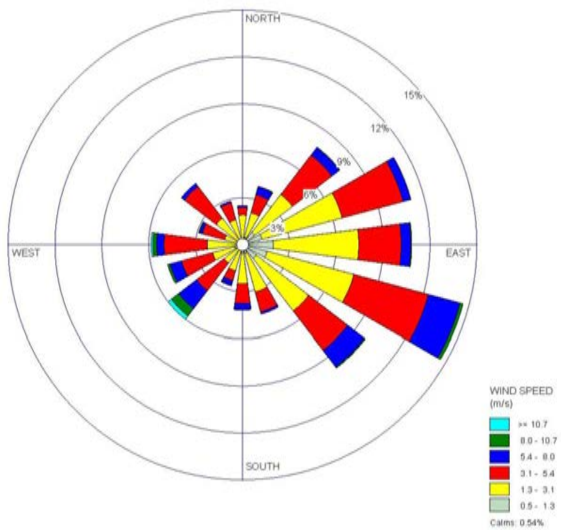
WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:

Seabrook Station - winds measured at 43 feet
2005 Annual Wind Rose (flow vector)

DISPLAY:

Wind Speed
Flow Vector (blowing to)



COMMENTS:	DATA PERIOD:			
	Start Date: 1/1/2005 - 00:00 **End Date: 12/31/2005 - 23:00**			
	CALM WINDS: **0.54%**	TOTAL COUNT: **8702 hrs.**	Epsilon ASSOCIATES INC.	
	AVG. WIND SPEED: **3.21 m/s**		PROJECT NO.:	

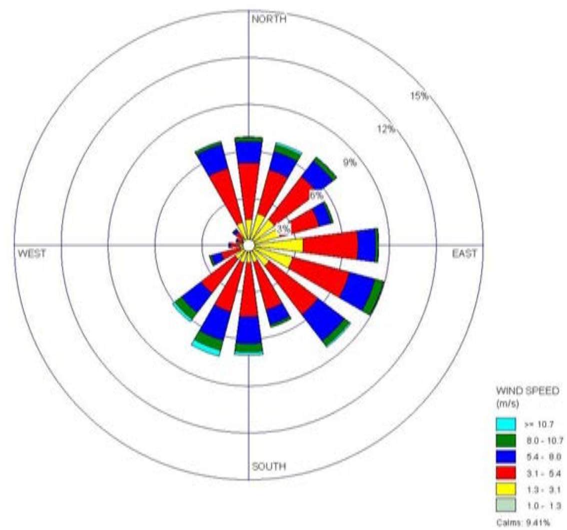
WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:

Providence TF Green International Airport, Warwick, RI
2005 Annual Wind Rose (flow vector)

DISPLAY:

Wind Speed
Flow Vector (blowing to)

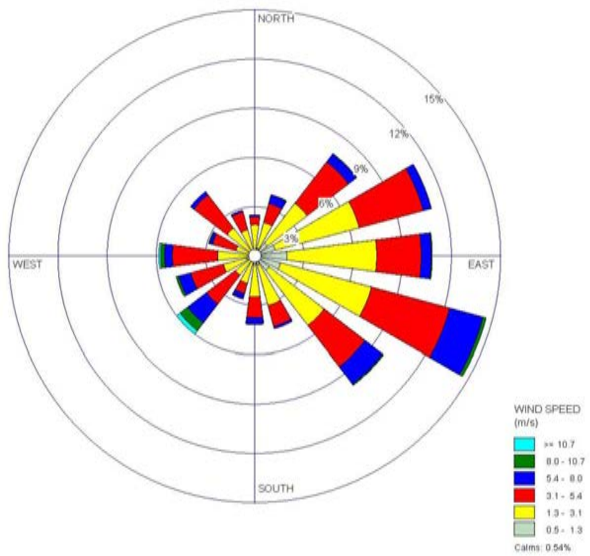


COMMENTS:	DATA PERIOD:			
	Start Date: 1/1/2005 - 00:00 **End Date: 12/31/2005 - 23:00**			
	CALM WINDS: **9.41%**	TOTAL COUNT: **8760 hrs.**	Epsilon ASSOCIATES INC.	
	AVG. WIND SPEED: **3.98 m/s**		PROJECT NO.:	

WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:
Seabrook Station - winds measured at 43 feet
2005 Annual Wind Rose (flow vector)

DISPLAY:
Wind Speed
Flow Vector (blowing to)

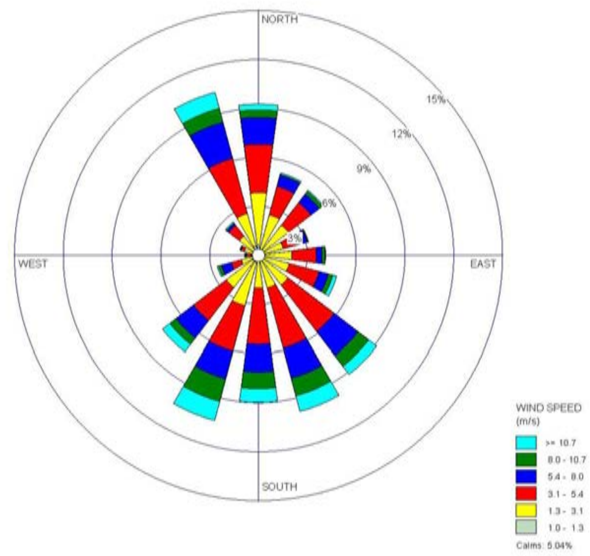


COMMENTS:	DATA PERIOD:		
	Start Date: 1/1/2005 - 00:00 **End Date: 12/31/2005 - 23:00**		
	CALM WINDS: **0.54%**	TOTAL COUNT: **8702 hrs.**	Epsilon ASSOCIATES INC.
	AVG. WIND SPEED: **3.21 m/s**		PROJECT NO.:

WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:
National Ocean Service FOXR1, Providence, RI
2005 Annual Wind Rose (flow vector)

DISPLAY:
Wind Speed
Flow Vector (blowing to)



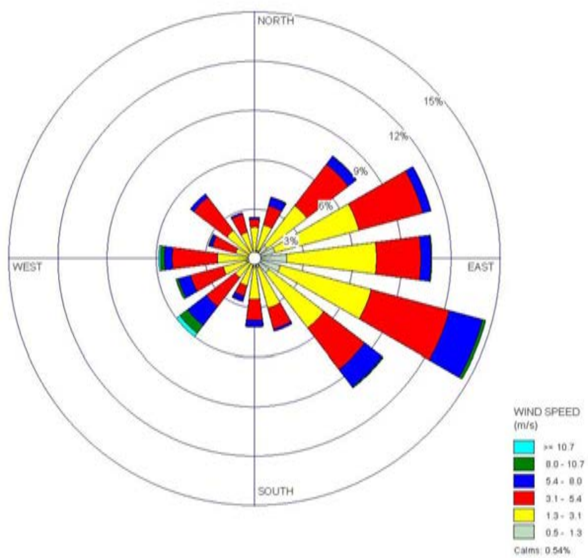
COMMENTS:	DATA PERIOD:		
	Start Date: 1/4/2005 - 21:00 **End Date: 12/31/2005 - 23:00**		
	CALM WINDS: **5.04%**	TOTAL COUNT: **6272 hrs.**	Epsilon ASSOCIATES INC.
	AVG. WIND SPEED: **4.50 m/s**		PROJECT NO.:

WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:

Seabrook Station - winds measured at 43 feet
2005 Annual Wind Rose (flow vector)

DISPLAY:
Wind Speed
Flow Vector (blowing to)



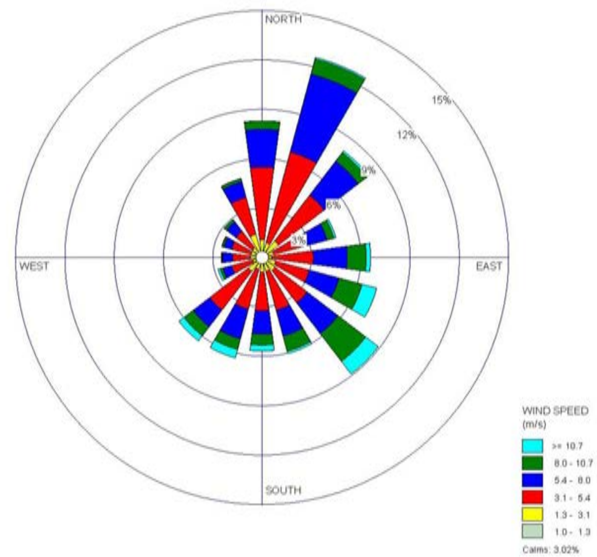
COMMENTS:	DATA PERIOD: **Start Date: 1/1/2005 - 00:00** **End Date: 12/31/2005 - 23:00**		
	CALM WINDS: **0.54%**	TOTAL COUNT: **8702 hrs.**	Epsilon ASSOCIATES INC.
	AVG. WIND SPEED: **3.21 m/s**		PROJECT NO.:

WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:

Provincetown Municipal Airport, Provincetown, MA
2005 Annual Wind Rose (flow vector)

DISPLAY:
Wind Speed
Flow Vector (blowing to)

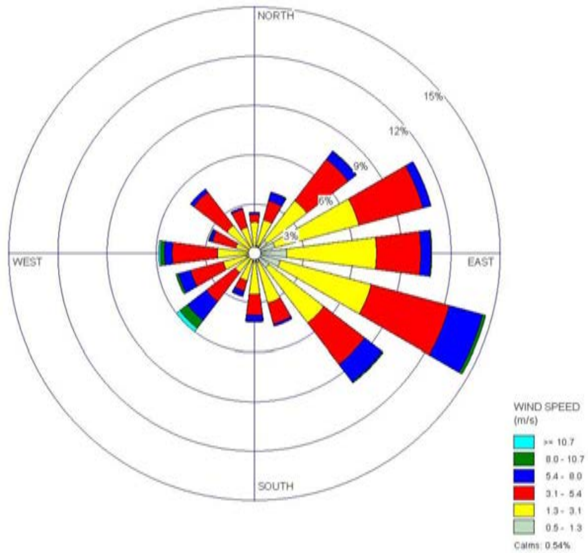


COMMENTS:	DATA PERIOD: **Start Date: 1/1/2005 - 00:00** **End Date: 12/31/2005 - 23:00**		
	CALM WINDS: **3.02%**	TOTAL COUNT: **7026 hrs.**	Epsilon ASSOCIATES INC.
	AVG. WIND SPEED: **5.20 m/s**		PROJECT NO.:

WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:
Seabrook Station - winds measured at 43 feet
2005 Annual Wind Rose (flow vector)

DISPLAY:
Wind Speed
Flow Vector (blowing to)



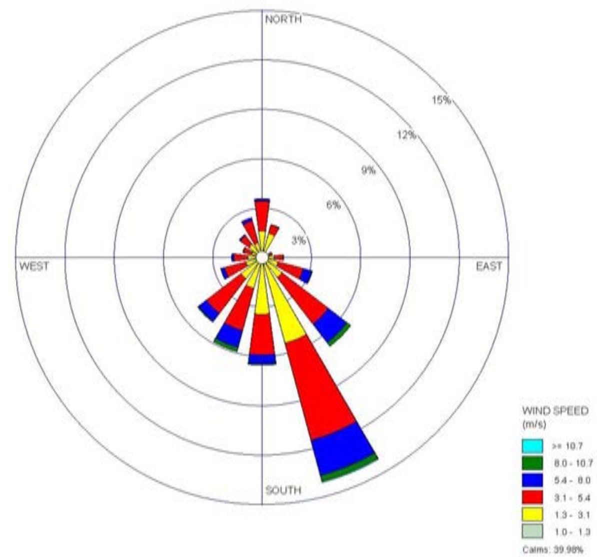
COMMENTS:	DATA PERIOD: **Start Date: 1/1/2005 - 00:00** **End Date: 12/31/2005 - 23:00**	
	CALM WINDS: **0.54%**	TOTAL COUNT: **8702 hrs.**
	AVG. WIND SPEED: **3.21 m/s**	PROJECT NO.:

Epsilon ASSOCIATES INC.

WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:
Skyhaven Airport, Rochester, NH
2005 Annual Wind Rose (flow vector)

DISPLAY:
Wind Speed
Flow Vector (blowing to)



COMMENTS:	DATA PERIOD: **Start Date: 1/1/2005 - 02:00** **End Date: 12/31/2005 - 23:00**	
	CALM WINDS: **39.98%**	TOTAL COUNT: **8672 hrs.**
	AVG. WIND SPEED: **2.12 m/s**	PROJECT NO.:

Epsilon ASSOCIATES INC.

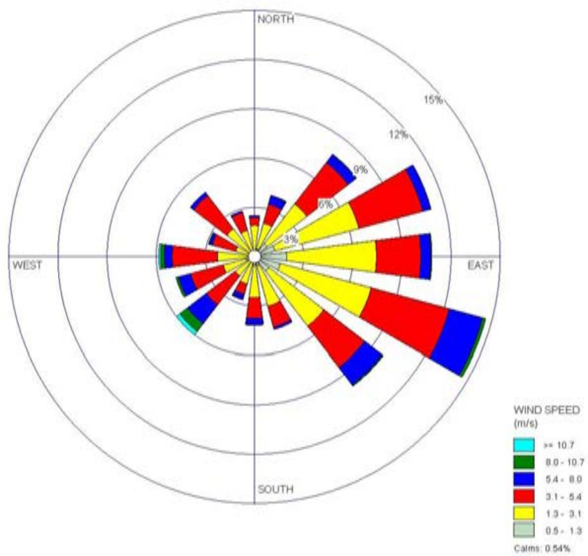
WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:

Seabrook Station - winds measured at 43 feet
2005 Annual Wind Rose (flow vector)

DISPLAY:

Wind Speed
Flow Vector (blowing to)



COMMENTS:	DATA PERIOD:		
	Start Date: 1/1/2005 - 00:00 **End Date: 12/31/2005 - 23:00**		
	CALM WINDS: **0.54%**	TOTAL COUNT: **8702 hrs.**	Epsilon ASSOCIATES INC.
	AVG. WIND SPEED: **3.21 m/s**		PROJECT NO.:

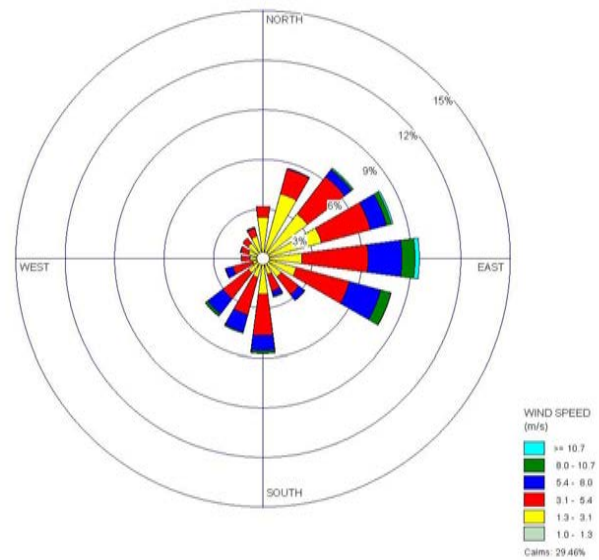
WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:

Sanford Municipal Airport, Sanford, ME
2006 Annual Wind Rose (flow vector)

DISPLAY:

Wind Speed
Flow Vector (blowing to)

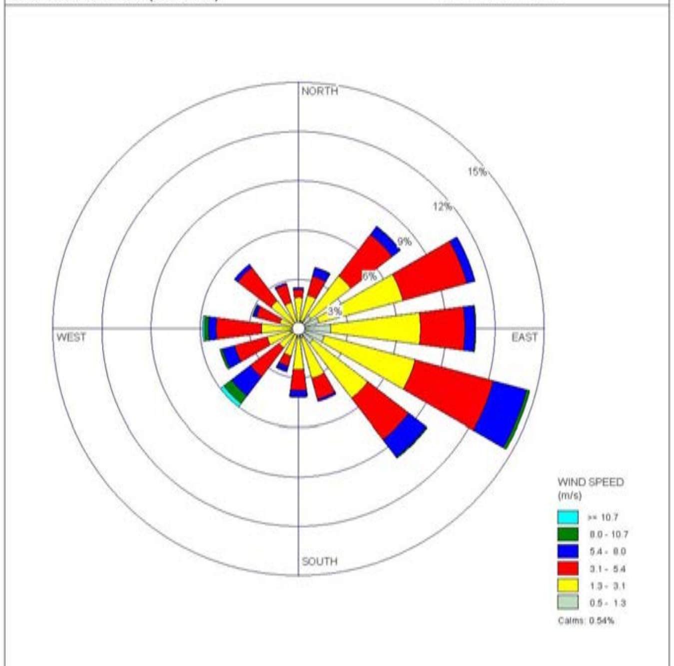


COMMENTS:	DATA PERIOD:		
	Start Date: 1/1/2006 - 00:00 **End Date: 12/31/2006 - 23:00**		
	CALM WINDS: **29.46%**	TOTAL COUNT: **8674 hrs.**	Epsilon ASSOCIATES INC.
	AVG. WIND SPEED: **2.62 m/s**		PROJECT NO.:

WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:
Seabrook Station - winds measured at 43 feet
2005 Annual Wind Rose (flow vector)

DISPLAY:
Wind Speed
Flow Vector (blowing to)

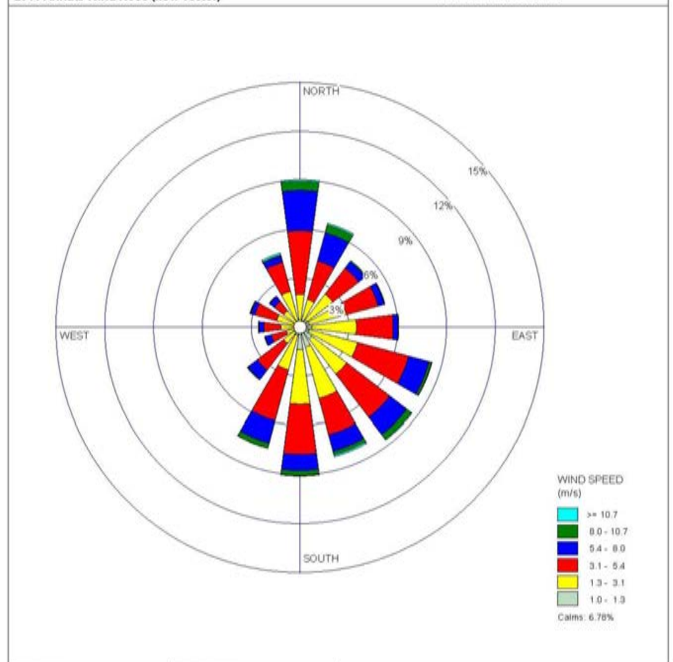


COMMENTS:	DATA PERIOD:		
	Start Date: 1/1/2005 - 00:00 End Date: 12/31/2005 - 23:00		Epsilon ASSOCIATES INC.
	CALM WINDS: 0.54%	TOTAL COUNT: 8702 hrs.	
	AVG. WIND SPEED: 3.21 m/s		PROJECT NO.:

WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:
Wells Beach, ME
2011 Annual Wind Rose (flow vector)

DISPLAY:
Wind Speed
Flow Vector (blowing to)

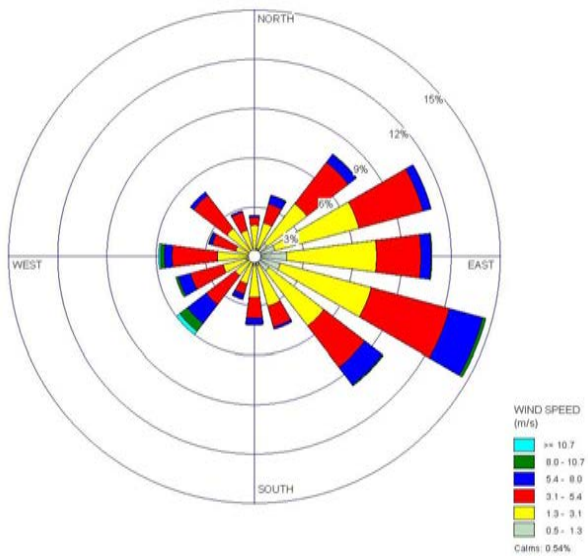


COMMENTS:	DATA PERIOD:		
	Start Date: 1/20/2011 - 14:00 End Date: 12/31/2011 - 23:00		Epsilon ASSOCIATES INC.
	CALM WINDS: 6.78%	TOTAL COUNT: 8080 hrs.	
	AVG. WIND SPEED: 3.38 m/s		PROJECT NO.:

WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:
Seabrook Station - winds measured at 43 feet
2005 Annual Wind Rose (flow vector)

DISPLAY:
Wind Speed
Flow Vector (blowing to)



COMMENTS:

DATA PERIOD:
Start Date: 1/1/2005 - 00:00
End Date: 12/31/2005 - 23:00

CALM WINDS:
0.54%

TOTAL COUNT:
8702 hrs.

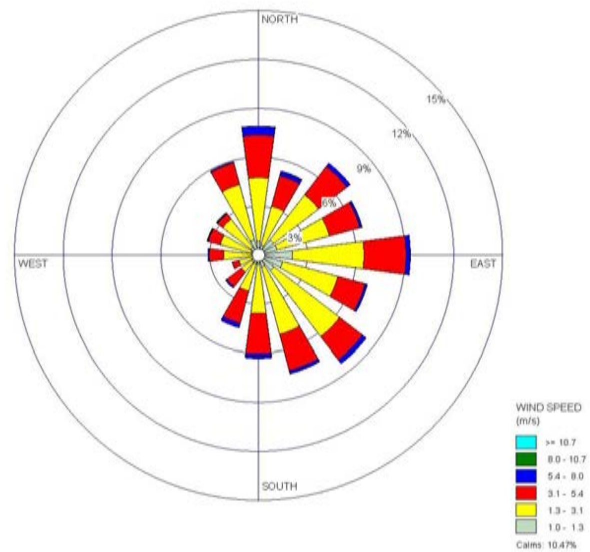
AVG. WIND SPEED:
3.21 m/s

PROJECT NO.:

WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:
Wells Reserve, ME
2011 Annual Wind Rose (flow vector)

DISPLAY:
Wind Speed
Flow Vector (blowing to)



COMMENTS:

DATA PERIOD:
Start Date: 1/1/2011 - 04:00
End Date: 12/31/2011 - 23:00

CALM WINDS:
10.47%

TOTAL COUNT:
8650 hrs.

AVG. WIND SPEED:
2.29 m/s

PROJECT NO.:

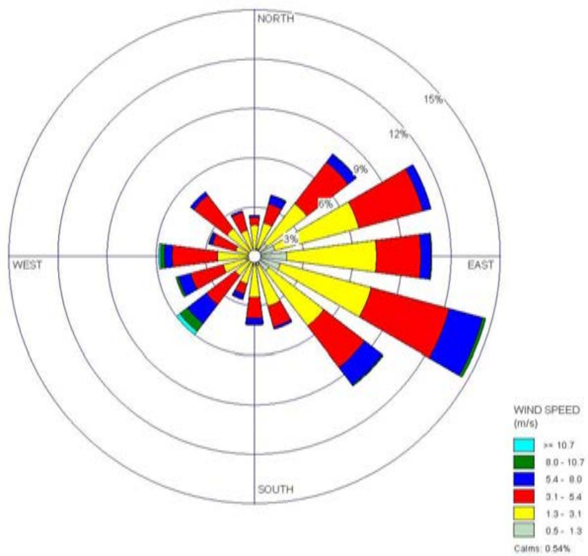
WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:

Seabrook Station - winds measured at 43 feet
2005 Annual Wind Rose (flow vector)

DISPLAY:

Wind Speed
Flow Vector (blowing to)



COMMENTS:	DATA PERIOD: **Start Date: 1/1/2005 - 00:00** **End Date: 12/31/2005 - 23:00**		
	CALM WINDS: **0.54%**	TOTAL COUNT: **8702 hrs.**	Epsilon Associates Inc.
	AVG. WIND SPEED: **3.21 m/s**		PROJECT NO.:

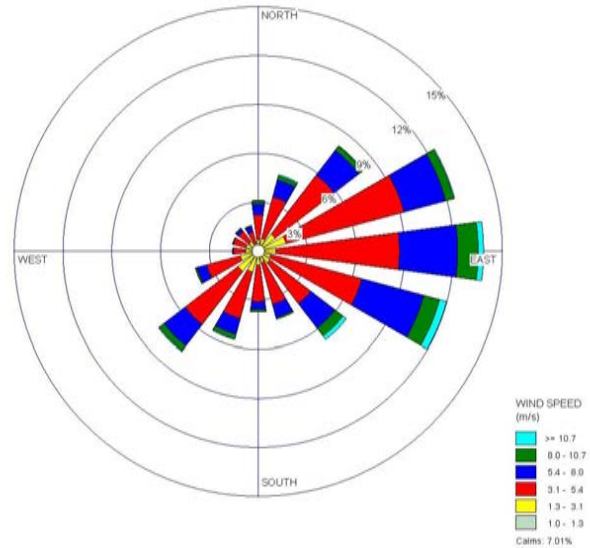
WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:

Worcester Regional Airport, Worcester, MA
2005 Annual Wind Rose (flow vector)

DISPLAY:

Wind Speed
Flow Vector (blowing to)

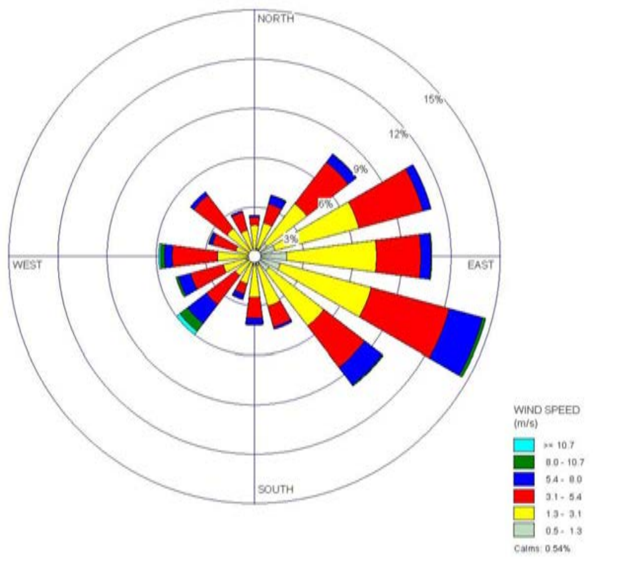


COMMENTS:	DATA PERIOD: **Start Date: 1/1/2005 - 02:00** **End Date: 12/31/2005 - 23:00**		
	CALM WINDS: **7.01%**	TOTAL COUNT: **8752 hrs.**	Epsilon Associates Inc.
	AVG. WIND SPEED: **4.37 m/s**		PROJECT NO.:

WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:
Seabrook Station - winds measured at 43 feet
2005 Annual Wind Rose (flow vector)

DISPLAY:
Wind Speed
Flow Vector (blowing to)

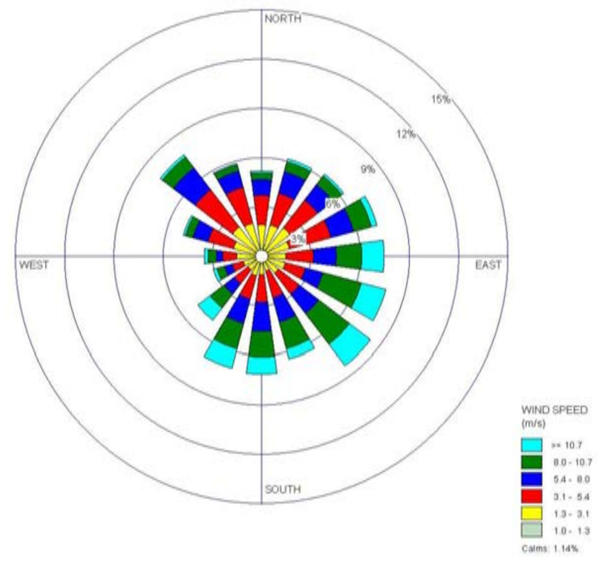


COMMENTS:	DATA PERIOD: **Start Date: 1/1/2005 - 00:00** **End Date: 12/31/2005 - 23:00**		
	CALM WINDS: **0.54%**	TOTAL COUNT: **8702 hrs.**	Epsilon Associates Inc.
	AVG. WIND SPEED: **3.21 m/s**		PROJECT NO.:

WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:
Buoy 44013 - 16 NM East of Boston, MA
2005 Annual Wind Rose (flow vector)

DISPLAY:
Wind Speed
Flow Vector (blowing to)

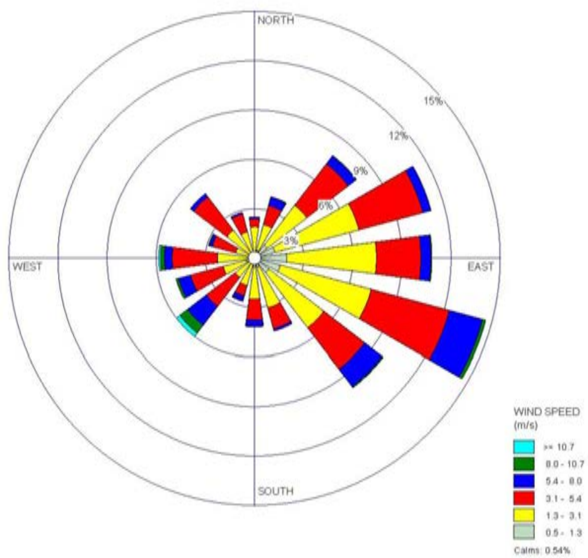


COMMENTS:	DATA PERIOD: **Start Date: 1/1/2005 - 00:00** **End Date: 12/31/2005 - 23:00**		
	CALM WINDS: **1.14%**	TOTAL COUNT: **8602 hrs.**	Epsilon Associates Inc.
	AVG. WIND SPEED: **5.87 m/s**		PROJECT NO.:

WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:
Seabrook Station - winds measured at 43 feet
2005 Annual Wind Rose (flow vector)

DISPLAY:
Wind Speed
Flow Vector (blowing to)

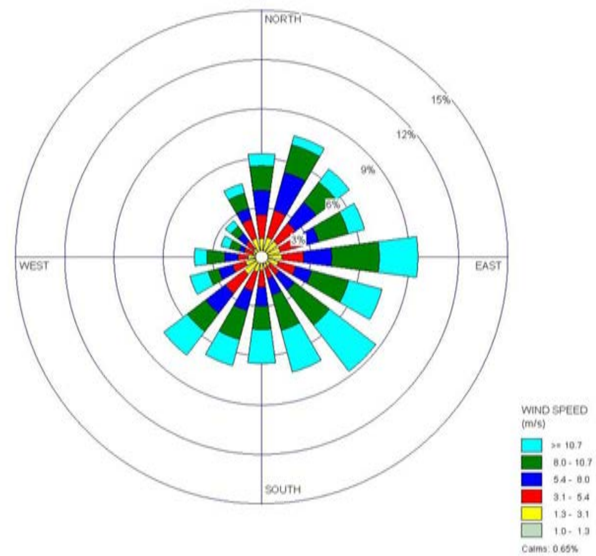


COMMENTS:	DATA PERIOD:		
	Start Date: 1/1/2005 - 00:00 **End Date: 12/31/2005 - 23:00**		
	CALM WINDS: **0.54%**	TOTAL COUNT: **8702 hrs.**	Epsilon ASSOCIATES INC.
	AVG. WIND SPEED: **3.21 m/s**		PROJECT NO.:

WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:
Buoy 44005 - East of Portsmouth, NH
2005 Annual Wind Rose (flow vector)

DISPLAY:
Wind Speed
Flow Vector (blowing to)

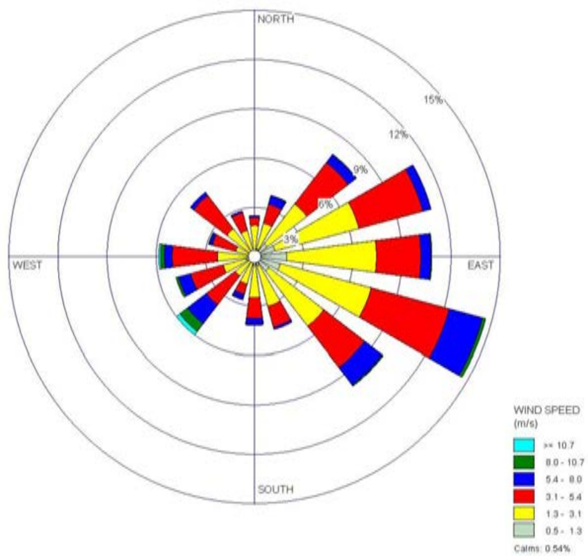


COMMENTS:	DATA PERIOD:		
	Start Date: 1/1/2005 - 00:00 **End Date: 12/31/2005 - 23:00**		
	CALM WINDS: **0.65%**	TOTAL COUNT: **4769 hrs.**	Epsilon ASSOCIATES INC.
	AVG. WIND SPEED: **7.53 m/s**		PROJECT NO.:

WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:
Seabrook Station - winds measured at 43 feet
2005 Annual Wind Rose (flow vector)

DISPLAY:
Wind Speed
Flow Vector (blowing to)



COMMENTS:

DATA PERIOD:
Start Date: 1/1/2005 - 00:00
End Date: 12/31/2005 - 23:00

CALM WINDS:
0.54%

TOTAL COUNT:
8702 hrs.

AVG. WIND SPEED:
3.21 m/s

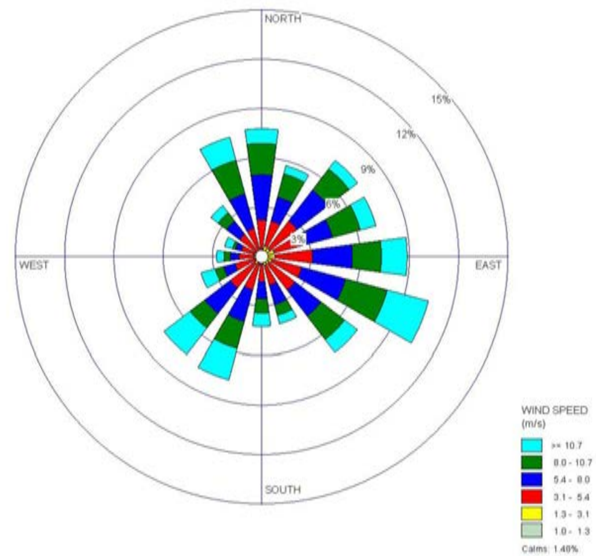
PROJECT NO.:

Epsilon ASSOCIATES INC.

WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:
Isle of Shoals Lighthouse, NH
2005 Annual Wind Rose (flow vector)

DISPLAY:
Wind Speed
Flow Vector (blowing to)



COMMENTS:

DATA PERIOD:
Start Date: 1/1/2005 - 00:00
End Date: 12/31/2005 - 23:00

CALM WINDS:
1.48%

TOTAL COUNT:
8585 hrs.

AVG. WIND SPEED:
7.26 m/s

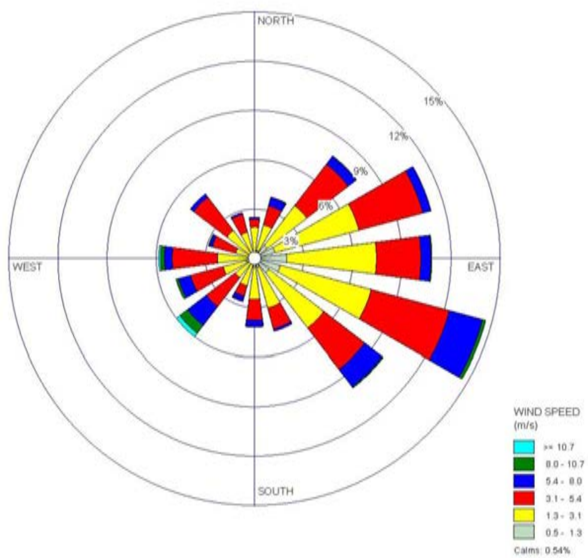
PROJECT NO.:

Epsilon ASSOCIATES INC.

WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:
Seabrook Station - winds measured at 43 feet
2005 Annual Wind Rose (flow vector)

DISPLAY:
Wind Speed
Flow Vector (blowing to)



COMMENTS:

DATA PERIOD:
Start Date: 1/1/2005 - 00:00
End Date: 12/31/2005 - 23:00

CALM WINDS:
0.54%

TOTAL COUNT:
8702 hrs.

AVG. WIND SPEED:
3.21 m/s

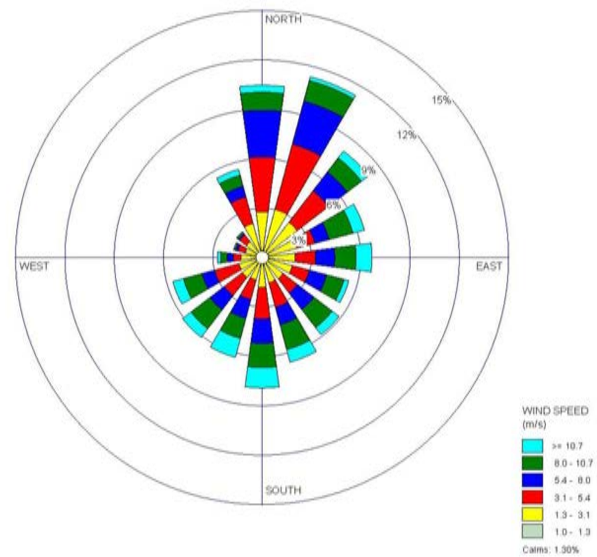
PROJECT NO.:

Epsilon ASSOCIATES INC.

WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:
Buoy 44007, Portland, ME
2005 Annual Wind Rose (flow vector)

DISPLAY:
Wind Speed
Flow Vector (blowing to)



COMMENTS:

DATA PERIOD:
Start Date: 1/1/2005 - 01:00
End Date: 12/31/2005 - 23:00

CALM WINDS:
1.30%

TOTAL COUNT:
6008 hrs.

AVG. WIND SPEED:
5.59 m/s

PROJECT NO.:

Epsilon ASSOCIATES INC.

WRPLOT View - Lakes Environmental Software

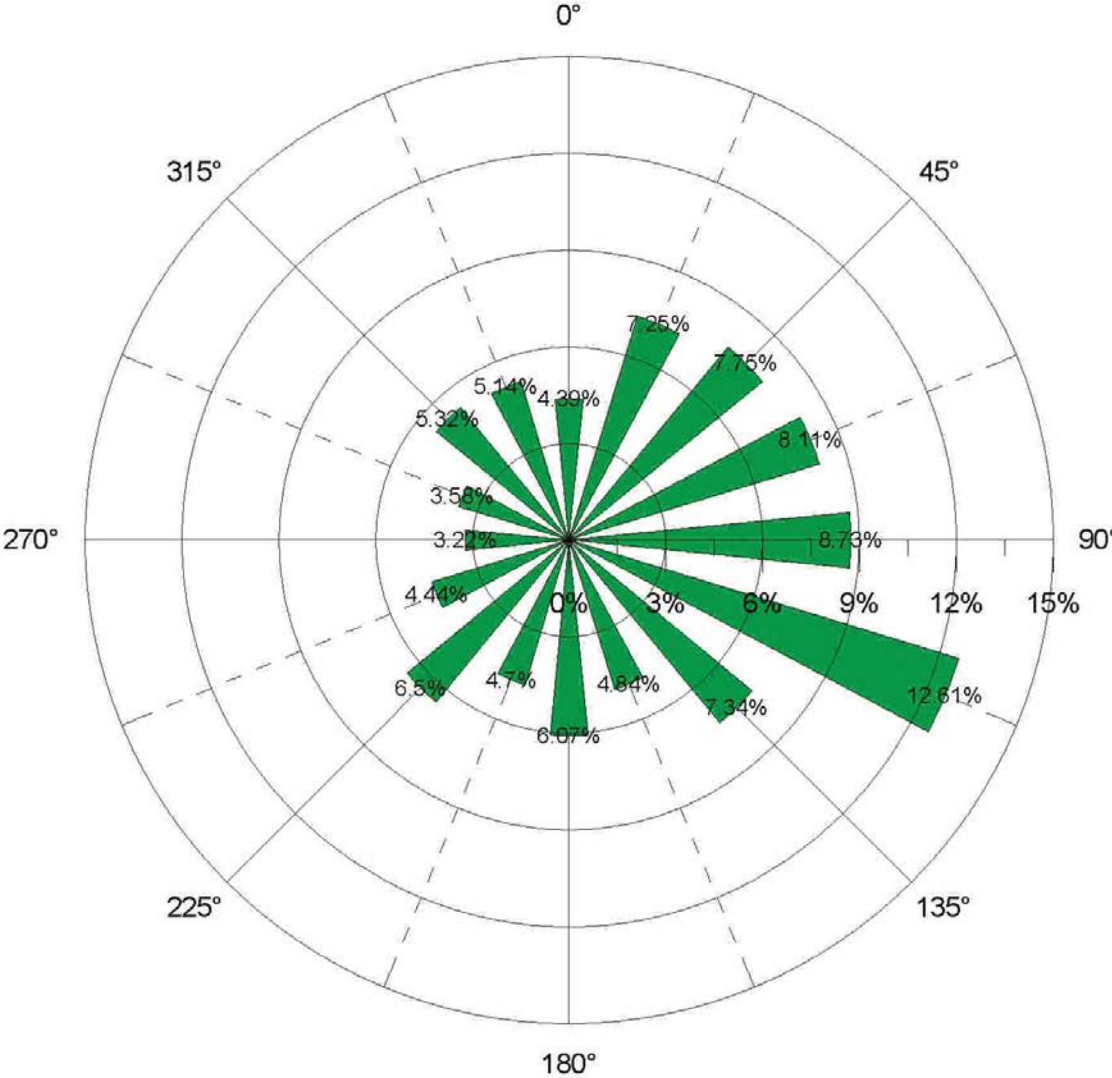
Appendix C
CALMET Trajectory Roses for 100 m Elevation

This appendix contains 14 plots of annual CALMET trajectory roses for 2005, for trajectories initiated at Seabrook 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:

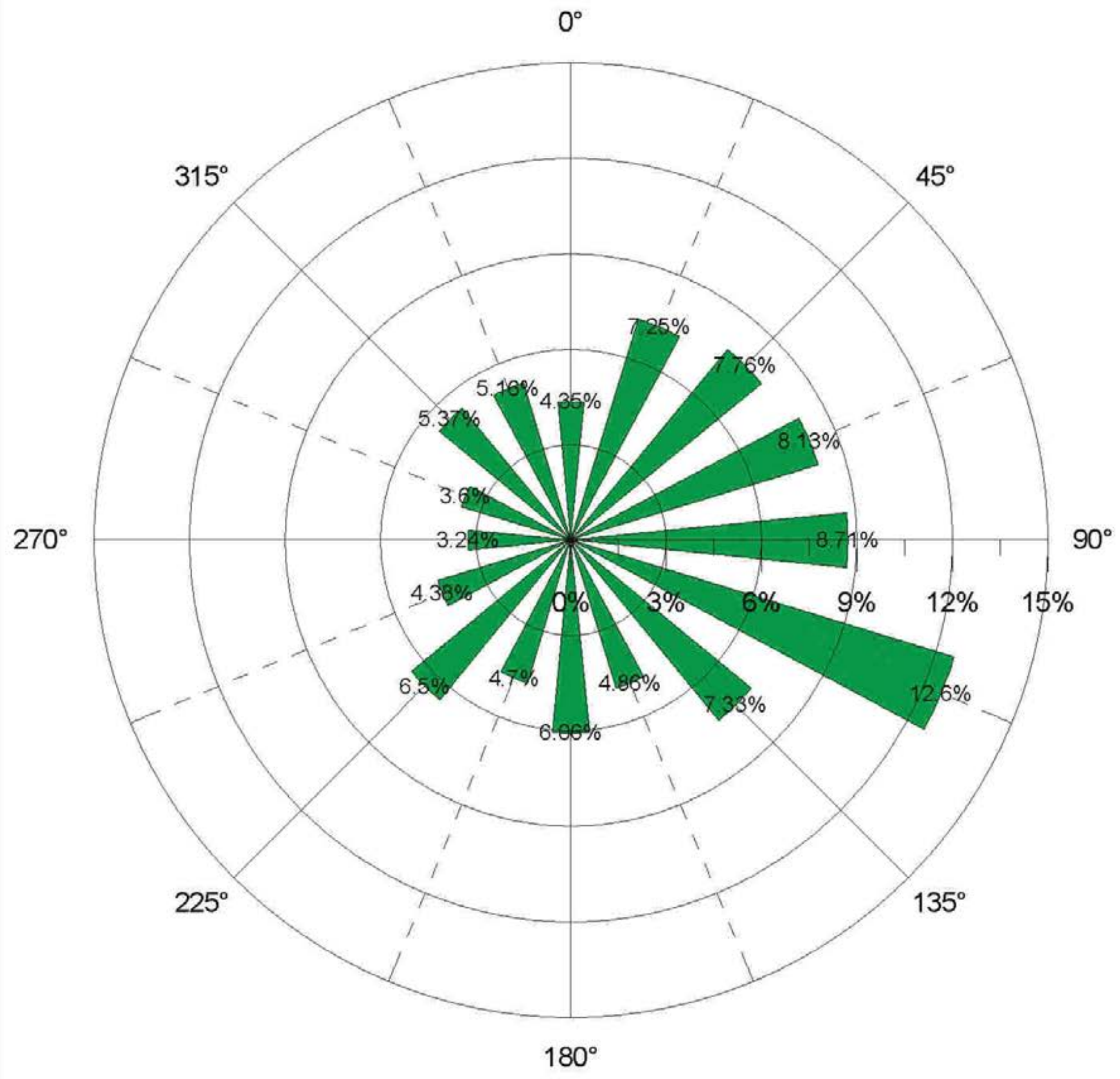
Seabrook Station Trajectories



COMMENTS:	MODELING OPTIONS:		
Figure 1 Trajectory Frequency Distribution 100 meter height 1 mile downwind	2005 CALMET Wind Fields		Epsilon Associates Inc.
	OUTPUT TYPE: FREQ		
	UNITS: Count	DATE: July 20, 2012	PROJECT NO.: 3396

PROJECT TITLE:

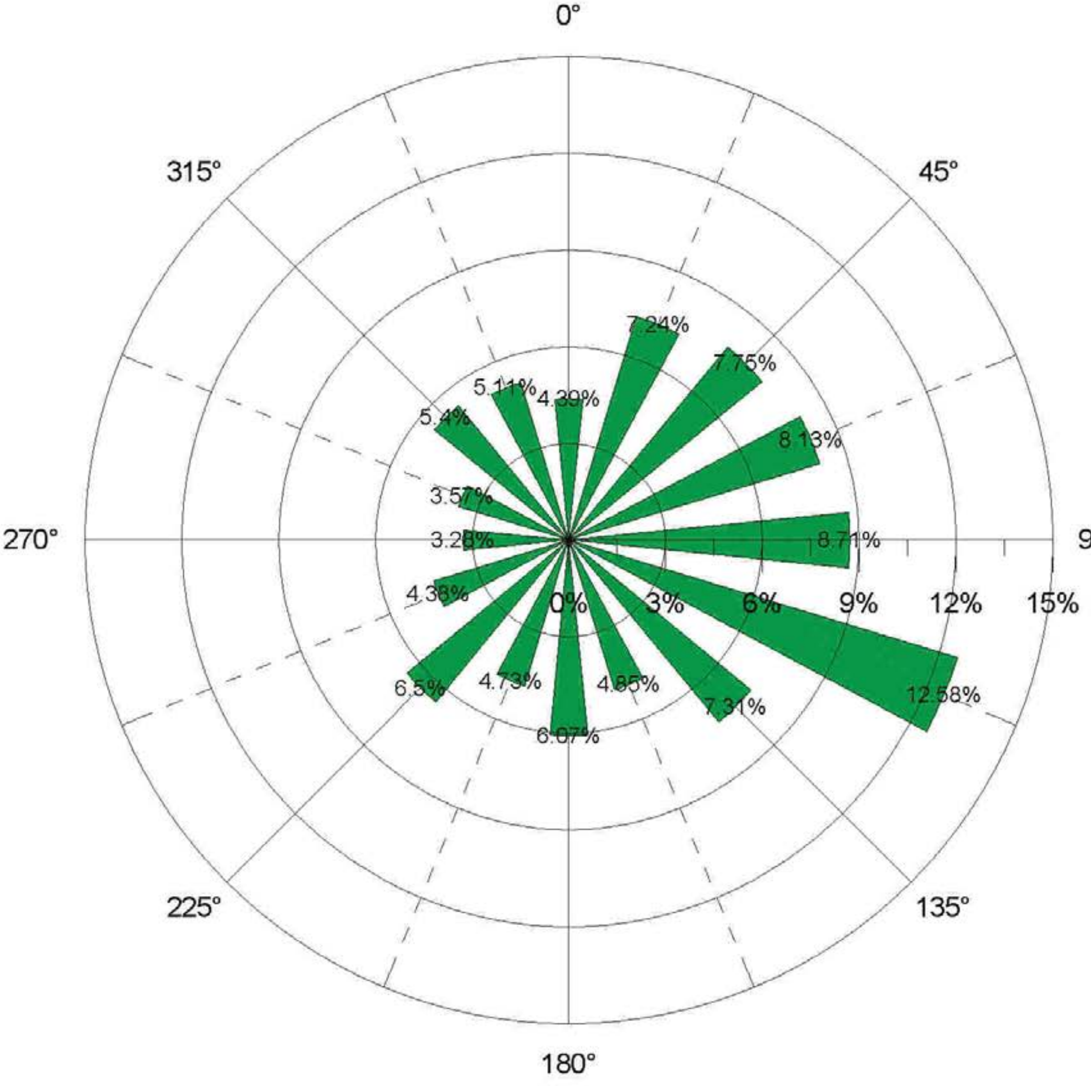
Seabrook Station Trajectories



COMMENTS:	MODELING OPTIONS:		
Figure 2 Trajectory Frequency Distribution 100 meter height 2 mile downwind	2005 CALMET Wind Fields		Epsilon ASSOCIATES INC.
	OUTPUT TYPE: FREQ		
	UNITS: Count	DATE: July 20, 2012	PROJECT NO.: 3396

PROJECT TITLE:

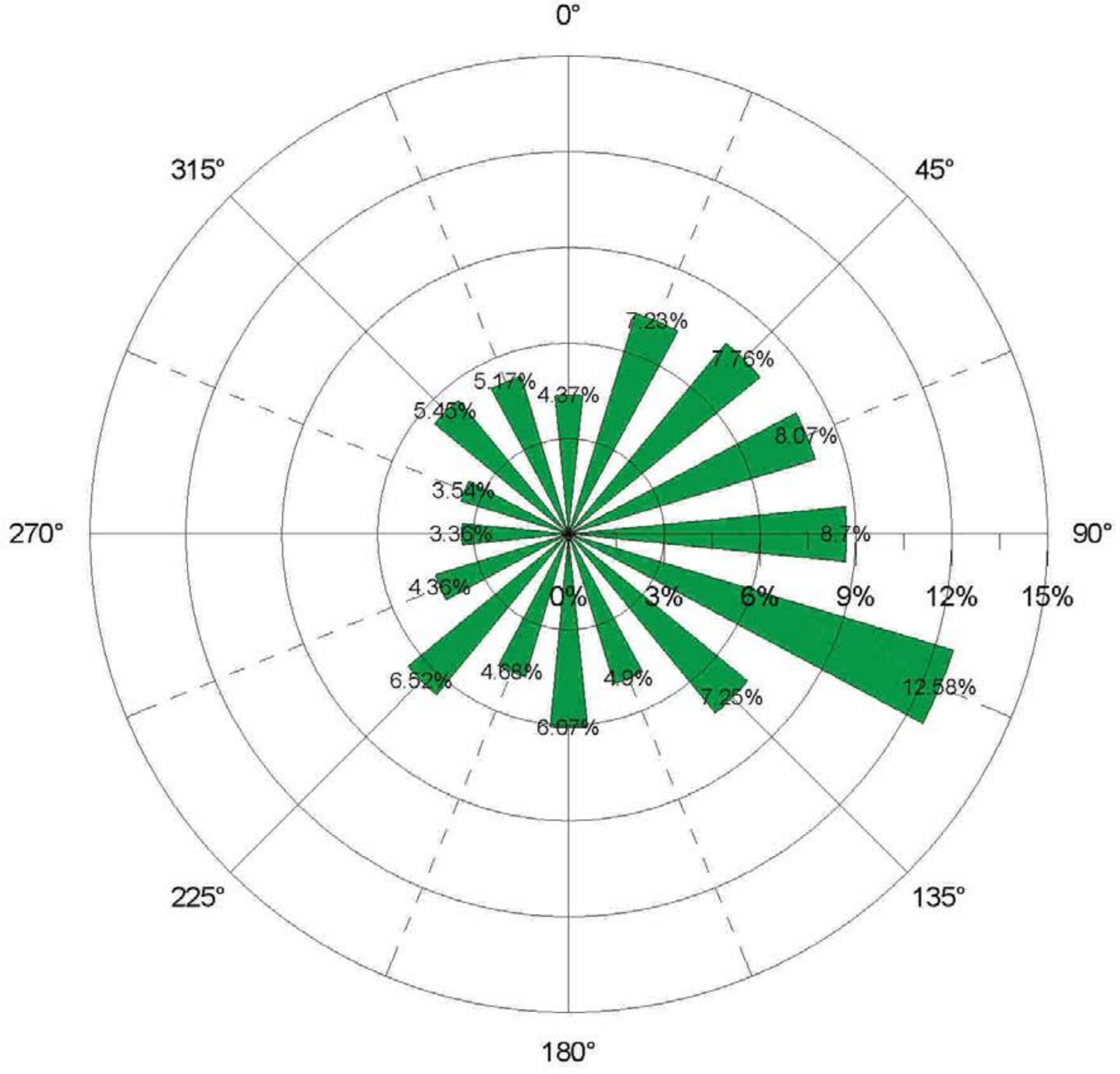
Seabrook Station Trajectories



COMMENTS:	MODELING OPTIONS:		
Figure 3 Trajectory Frequency Distribution 100 meter height 3 mile downwind	2005 CALMET Wind Fields OUTPUT TYPE: FREQ		Epsilon ASSOCIATES INC.
	UNITS: Count	DATE: July 20, 2012	PROJECT NO.: 3396

PROJECT TITLE:

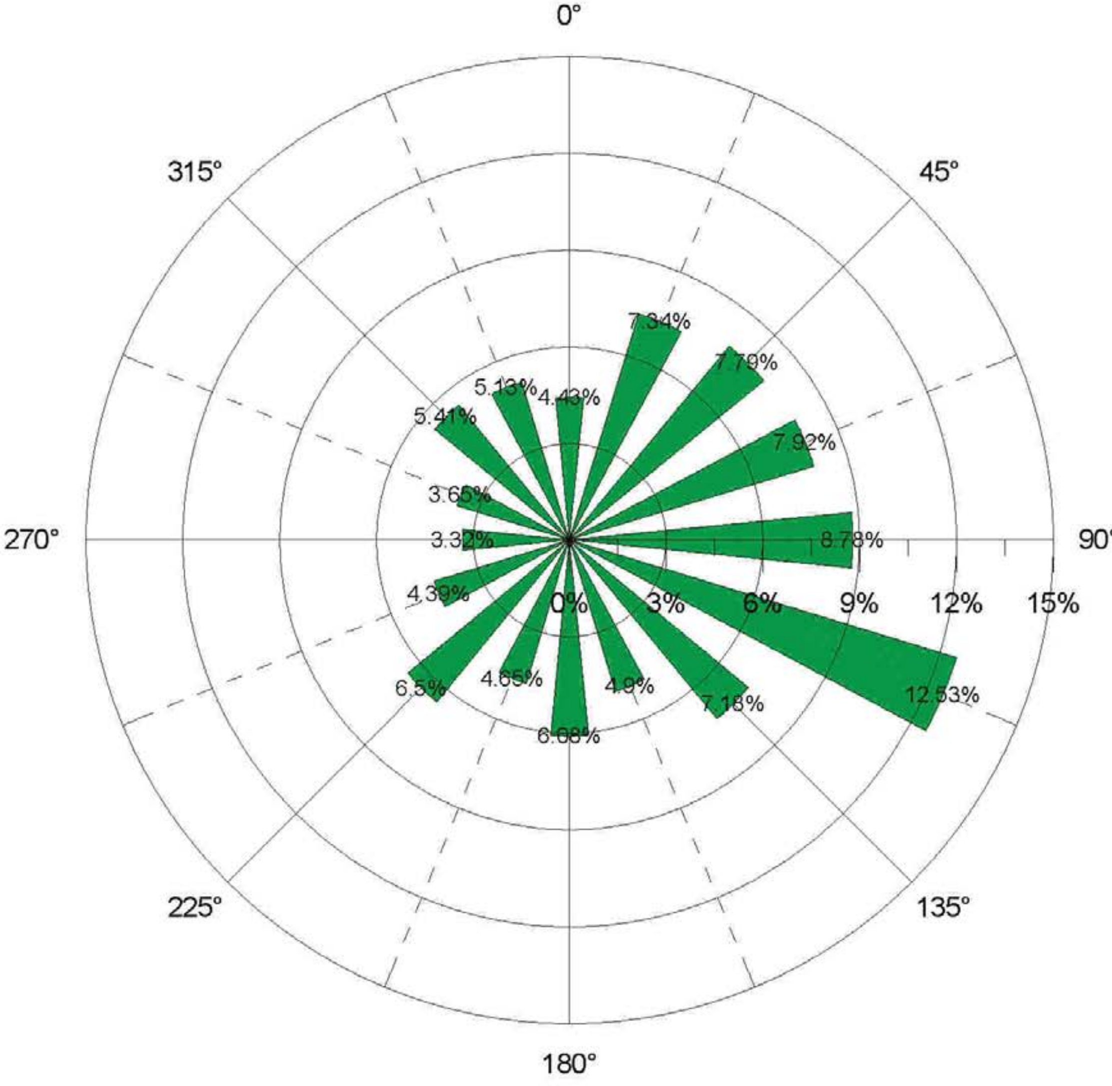
Seabrook Station Trajectories



COMMENTS:	MODELING OPTIONS:		
Figure 4 Trajectory Frequency Distribution 100 meter height 4 mile downwind	2005 CALMET Wind Fields		Epsilon ASSOCIATES INC.
	OUTPUT TYPE: FREQ		
	UNITS: Count	DATE: July 20, 2012	PROJECT NO.: 3396

PROJECT TITLE:

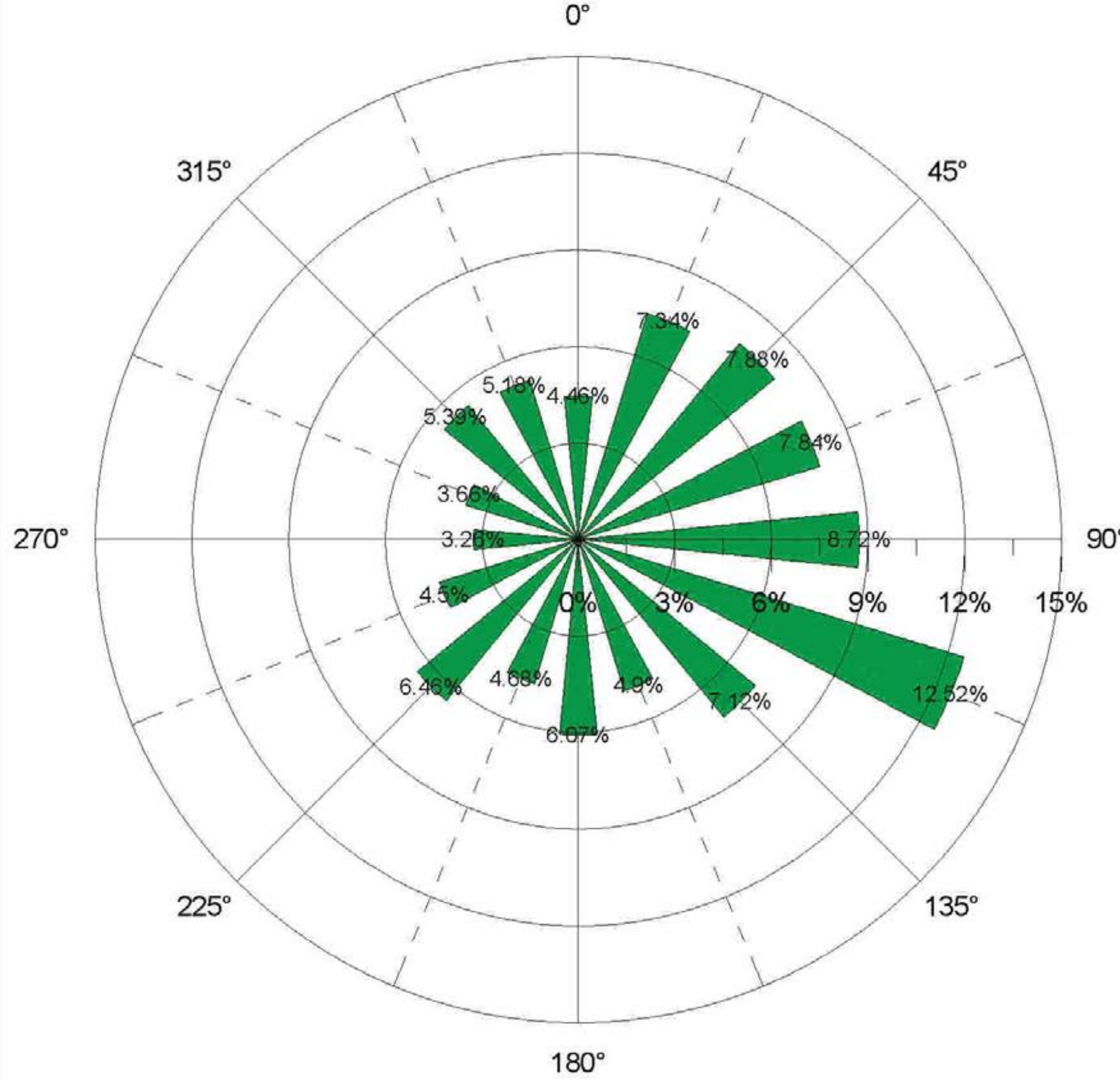
Seabrook Station Trajectories



COMMENTS:	MODELING OPTIONS:		
Figure 5 Trajectory Frequency Distribution 100 meter height 5 mile downwind	2005 CALMET Wind Fields		Epsilon ASSOCIATES INC.
	OUTPUT TYPE: FREQ		
	UNITS: Count	DATE: July 20, 2012	PROJECT NO.: 3396

PROJECT TITLE:

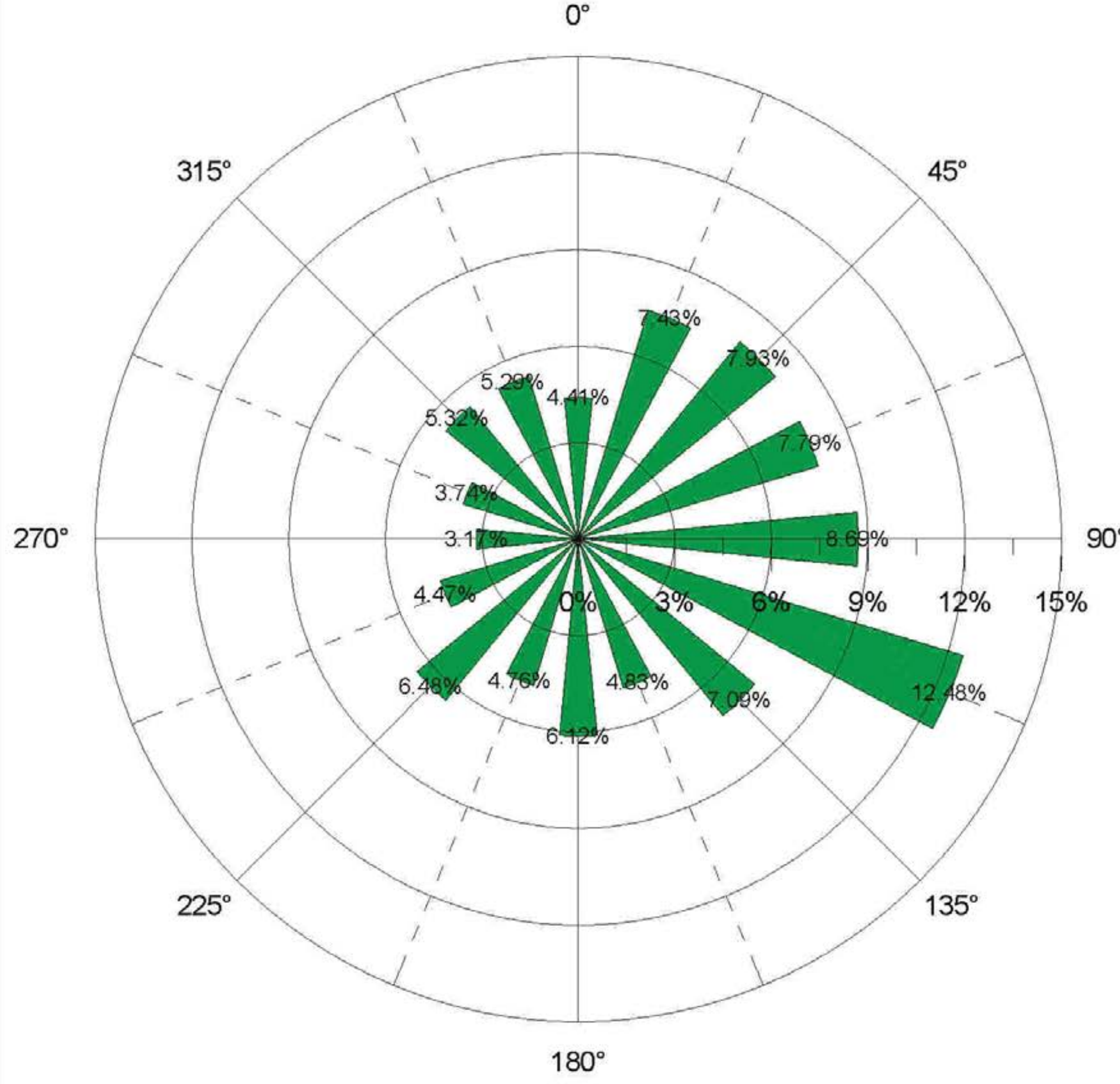
Seabrook Station Trajectories



COMMENTS:	MODELING OPTIONS:		
Figure 6 Trajectory Frequency Distribution 100 meter height 6 mile downwind	2005 CALMET Wind Fields		Epsilon ASSOCIATES INC.
	OUTPUT TYPE: FREQ		
	UNITS: Count	DATE: July 20, 2012	PROJECT NO.: 3396

PROJECT TITLE:

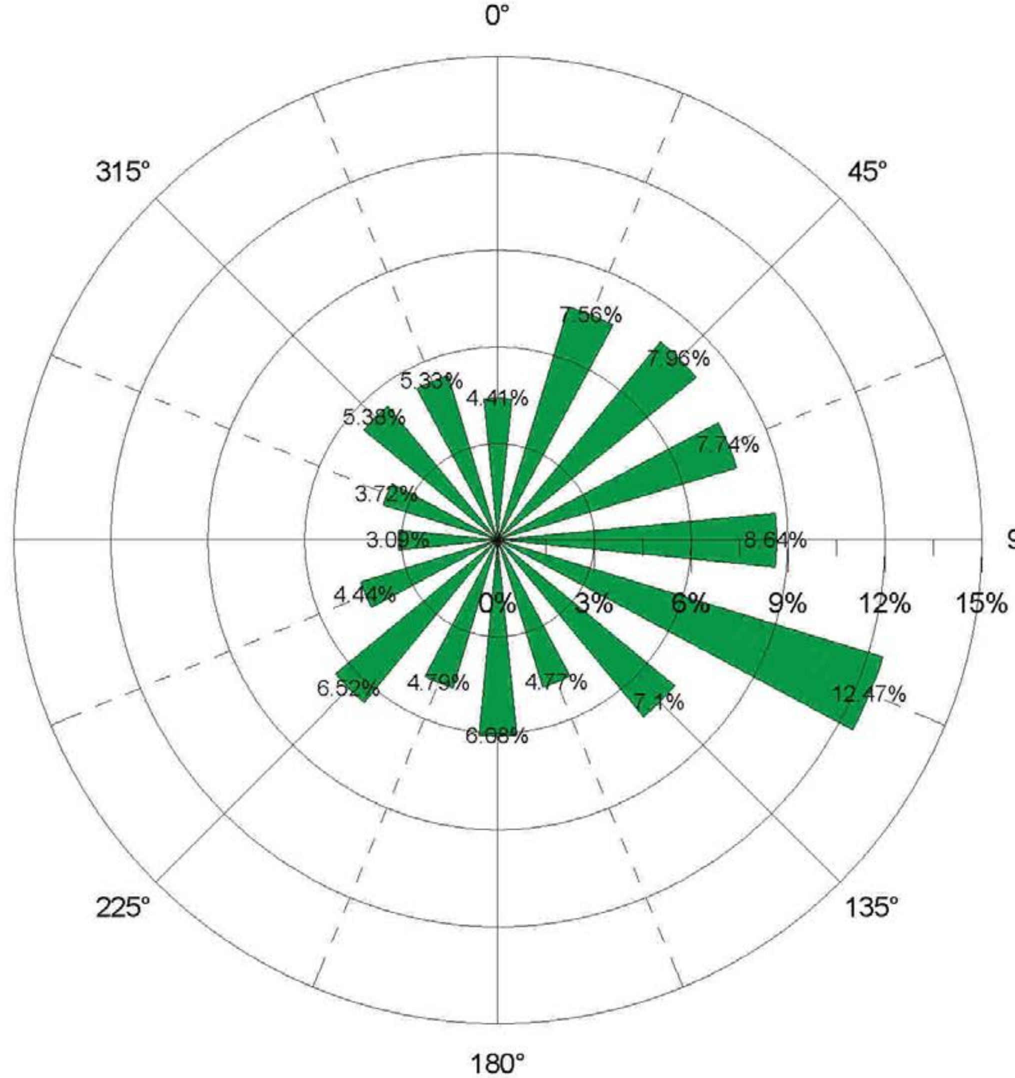
Seabrook Station Trajectories



COMMENTS:	MODELING OPTIONS:		
Figure 7 Trajectory Frequency Distribution 100 meter height 7 mile downwind	2005 CALMET Wind Fields		Epsilon ASSOCIATES INC.
	OUTPUT TYPE: FREQ		
	UNITS: Count	DATE: July 20, 2012	PROJECT NO.: 3396

PROJECT TITLE:

Seabrook Station Trajectories



COMMENTS:

Figure 8
Trajectory Frequency Distribution

100 meter height
8 mile downwind

MODELING OPTIONS:

2005 CALMET Wind Fields

OUTPUT TYPE:

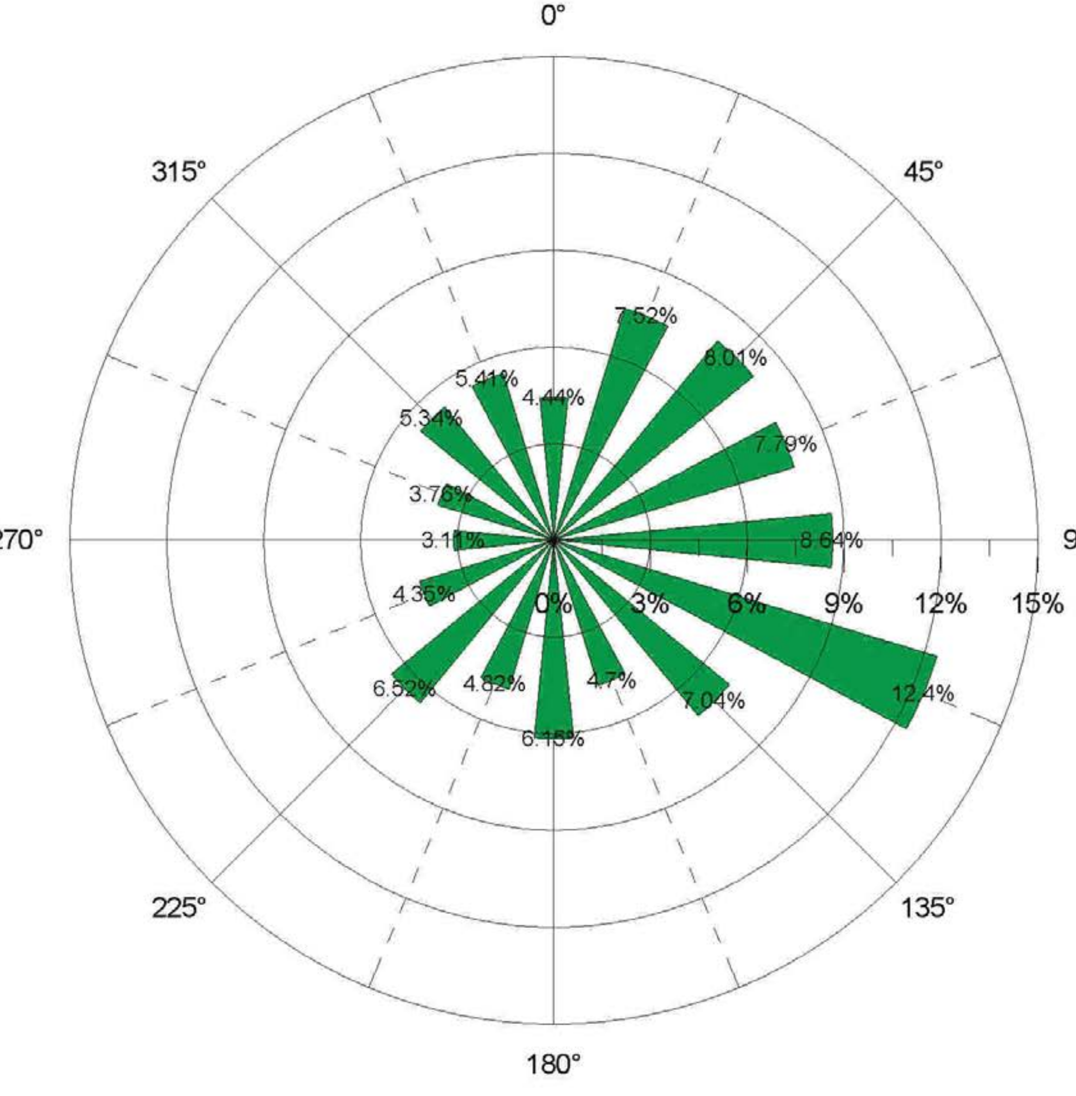
FREQ

Epsilon ASSOCIATES INC.

UNITS:	DATE:	PROJECT NO.:
Count	July 20, 2012	3396

PROJECT TITLE:

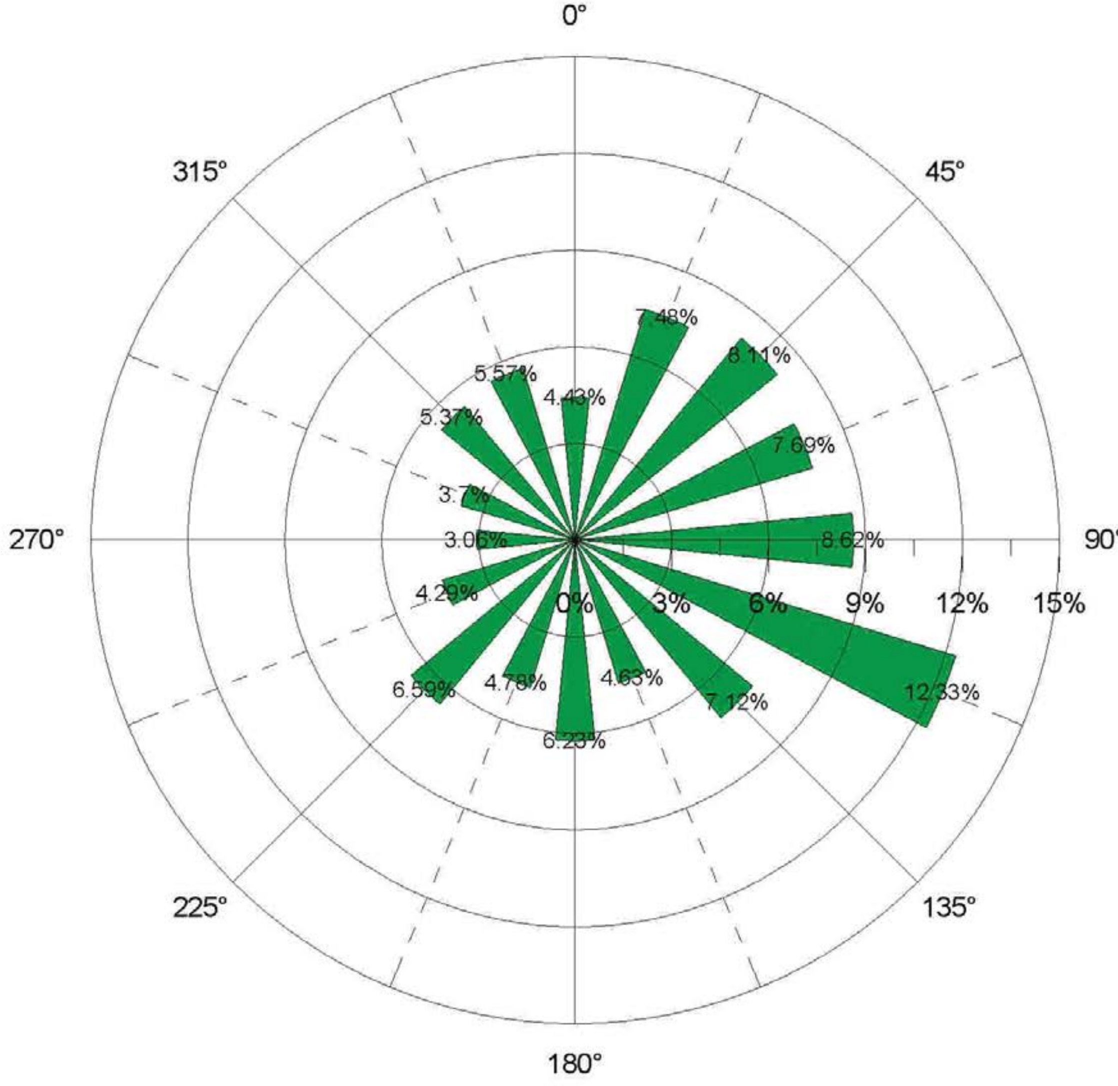
Seabrook Station Trajectories



COMMENTS:	MODELING OPTIONS:		
Figure 9 Trajectory Frequency Distribution 100 meter height 9 mile downwind	2005 CALMET Wind Fields		Epsilon ASSOCIATES INC.
	OUTPUT TYPE: FREQ		
	UNITS: Count	DATE: July 20, 2012	PROJECT NO.: 3396

PROJECT TITLE:

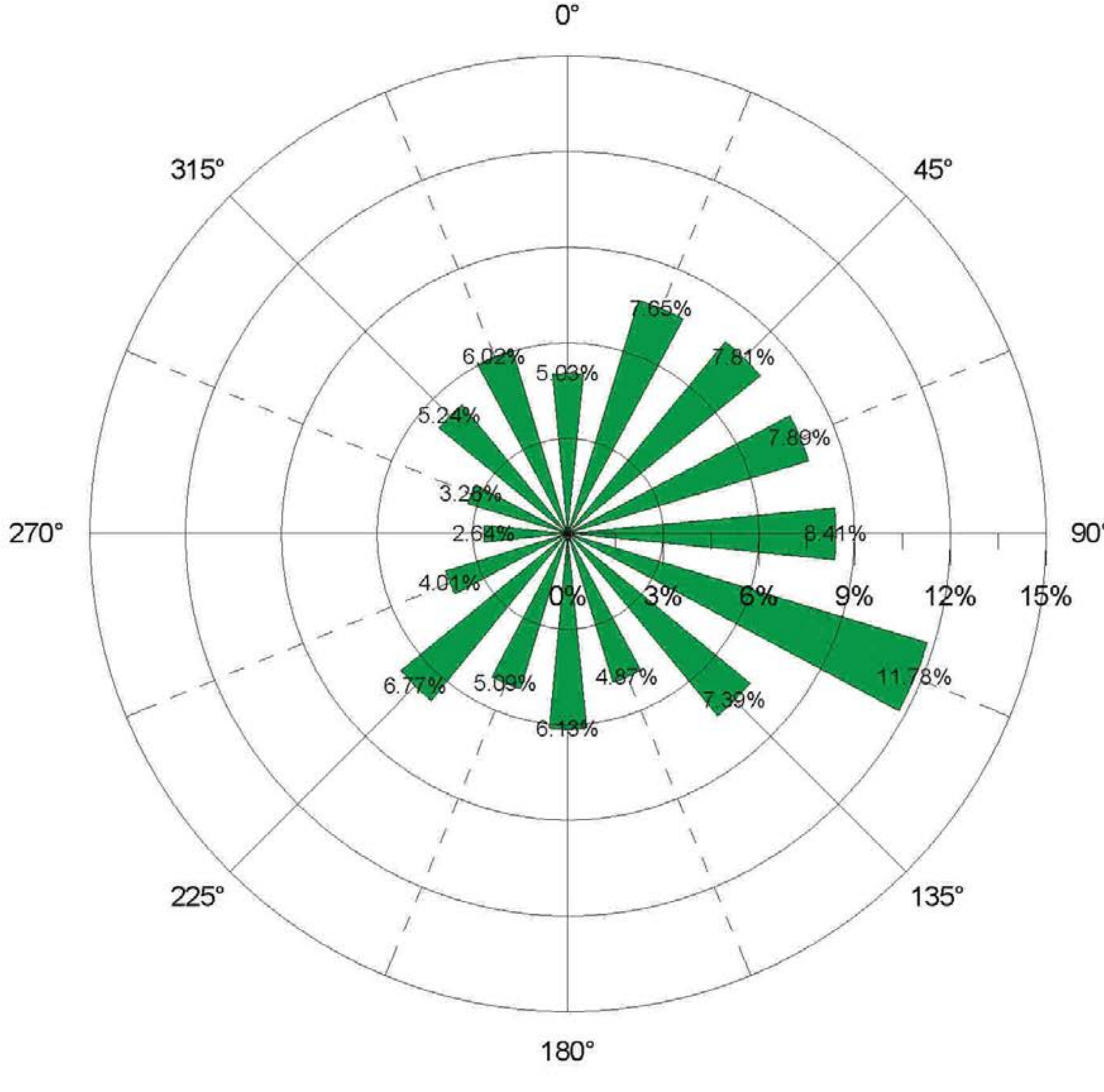
Seabrook Station Trajectories



COMMENTS:	MODELING OPTIONS:		
Figure 10 Trajectory Frequency Distribution 100 meter height 10 mile downwind	2005 CALMET Wind Fields OUTPUT TYPE: FREQ		Epsilon ASSOCIATES INC.
	UNITS: Count	DATE: July 20, 2012	PROJECT NO.: 3396

PROJECT TITLE:

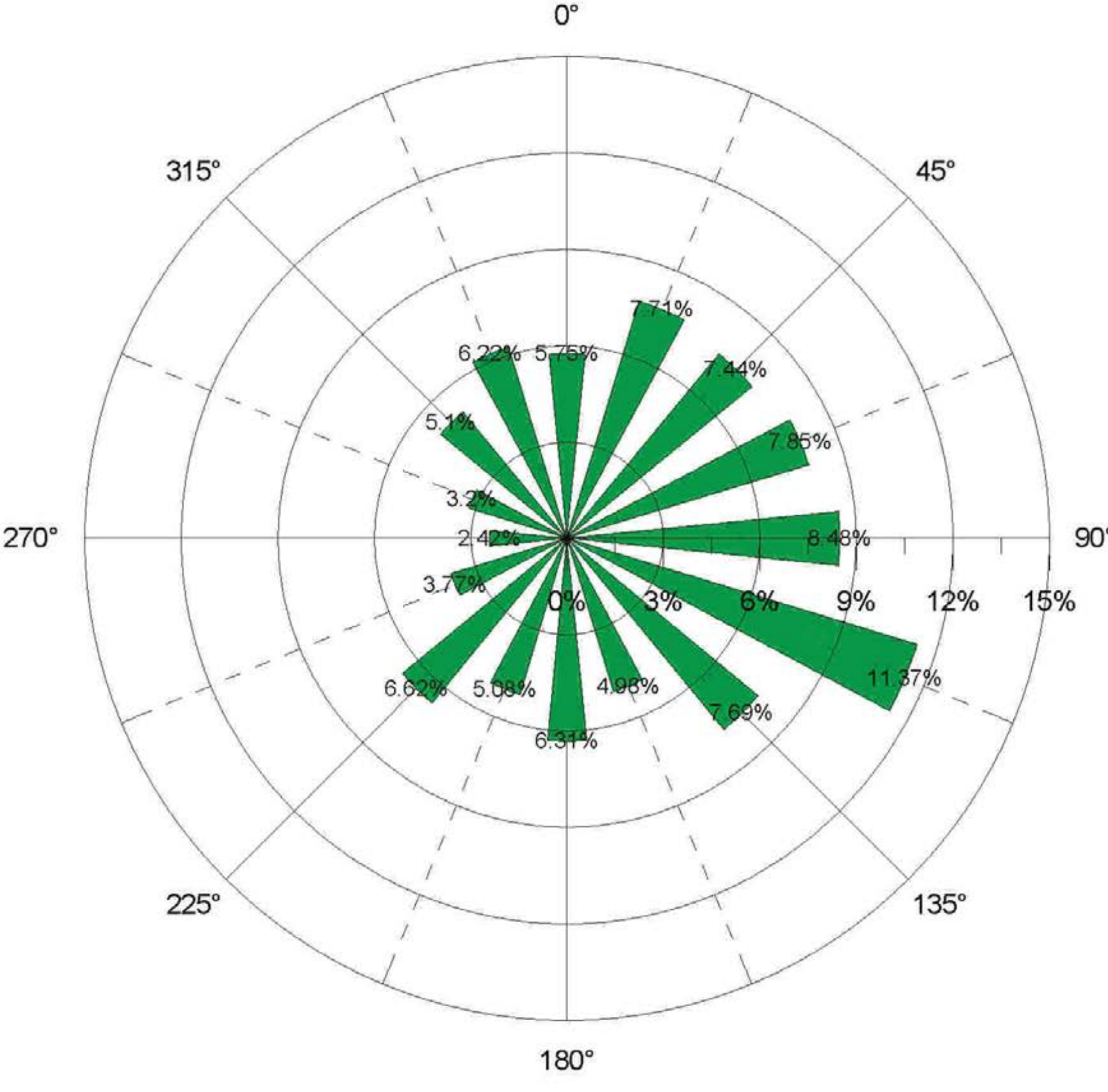
Seabrook Station Trajectories



COMMENTS: Figure 11 Trajectory Frequency Distribution 100 meter height 20 mile downwind	MODELING OPTIONS: **2005 CALMET Wind Fields**		
	OUTPUT TYPE: **FREQ**		Epsilon ASSOCIATES INC.
	UNITS: **Count**	DATE: **July 20, 2012**	PROJECT NO.: **3396**

PROJECT TITLE:

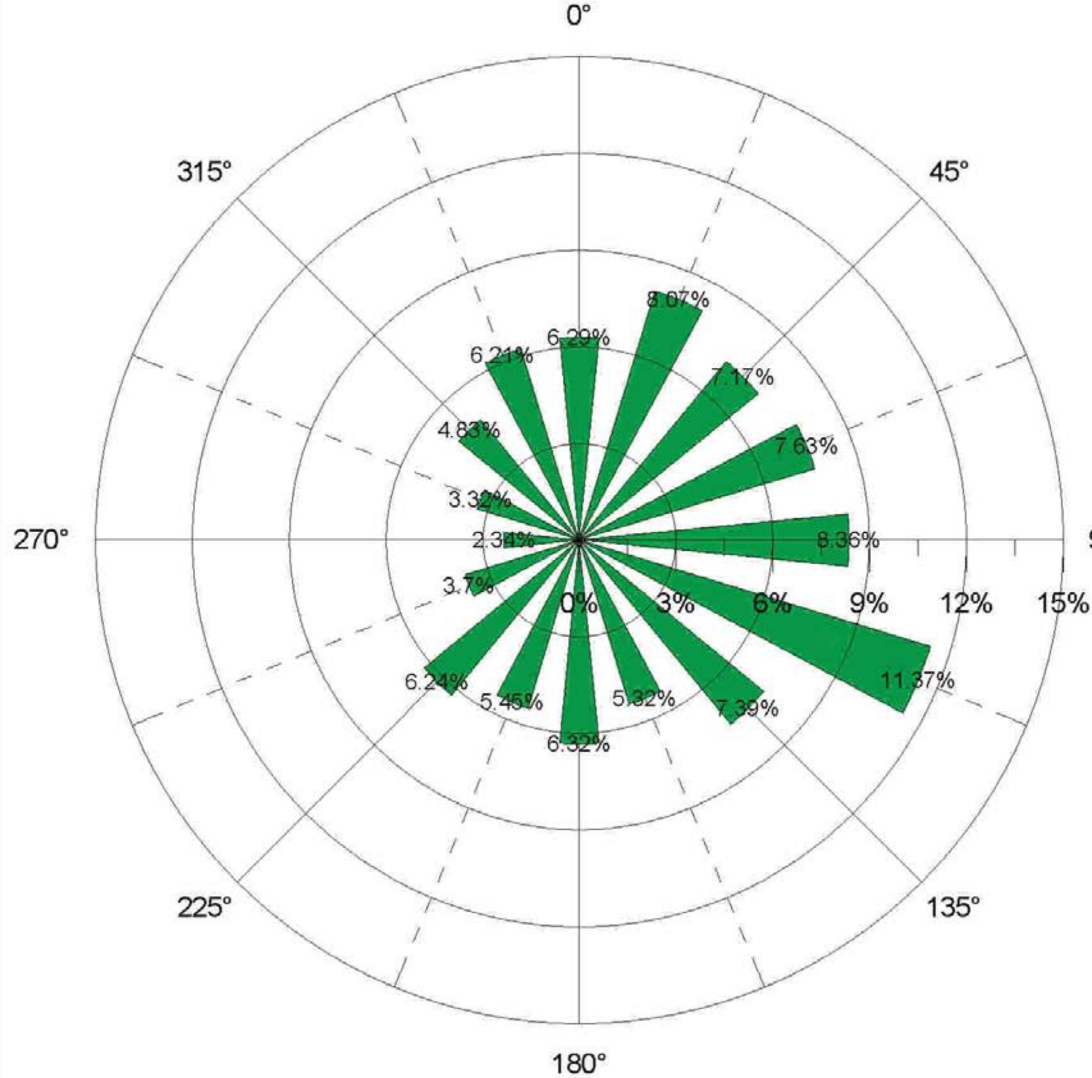
Seabrook Station Trajectories



COMMENTS:	MODELING OPTIONS:		
Figure 12 Trajectory Frequency Distribution 100 meter height 30 mile downwind	2005 CALMET Wind Fields		Epsilon ASSOCIATES INC.
	OUTPUT TYPE: FREQ		
	UNITS: Count	DATE: July 20, 2012	PROJECT NO.: 3396

PROJECT TITLE:

Seabrook Station Trajectories



COMMENTS:	MODELING OPTIONS:		
Figure 13 Trajectory Frequency Distribution 100 meter height 40 mile downwind	2005 CALMET Wind Fields		
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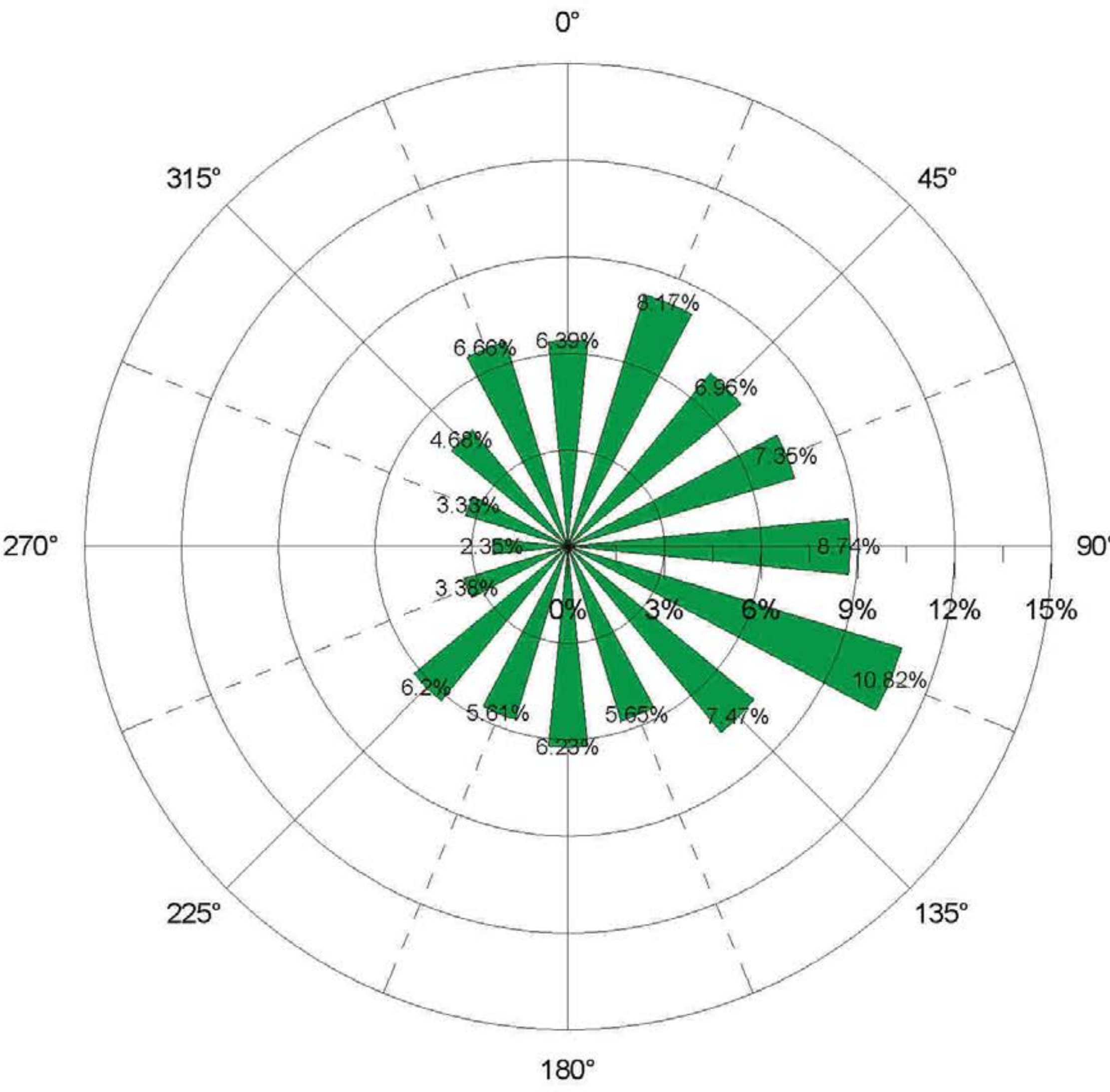
	UNITS: Count	DATE: July 20, 2012	PROJECT NO.: 3396

PROJECT TITLE:

Seabrook Station Trajectories



COMMENTS:	MODELING OPTIONS:		
Figure 14 Trajectory Frequency Distribution 100 meter height 50 mile downwind	2005 CALMET Wind Fields		Epsilon ASSOCIATES INC.
	OUTPUT TYPE: FREQ		
	UNITS: Count	DATE: July 20, 2012	PROJECT NO.: 3396

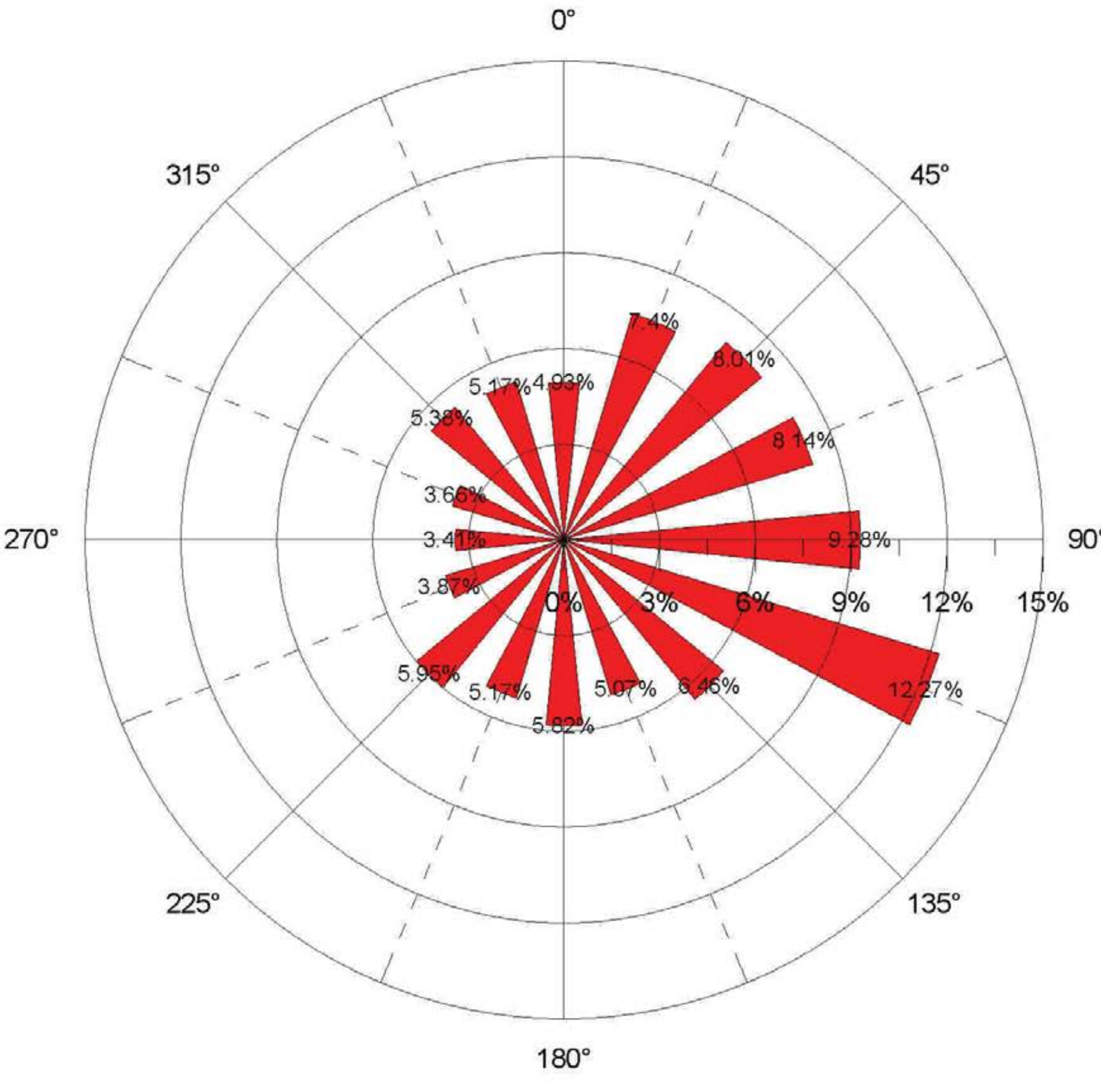
Appendix D
CALMET Trajectory Roses for 200 m Elevation

This appendix contains 14 plots of annual CALMET trajectory roses for 2005, for trajectories initiated at Seabrook 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:

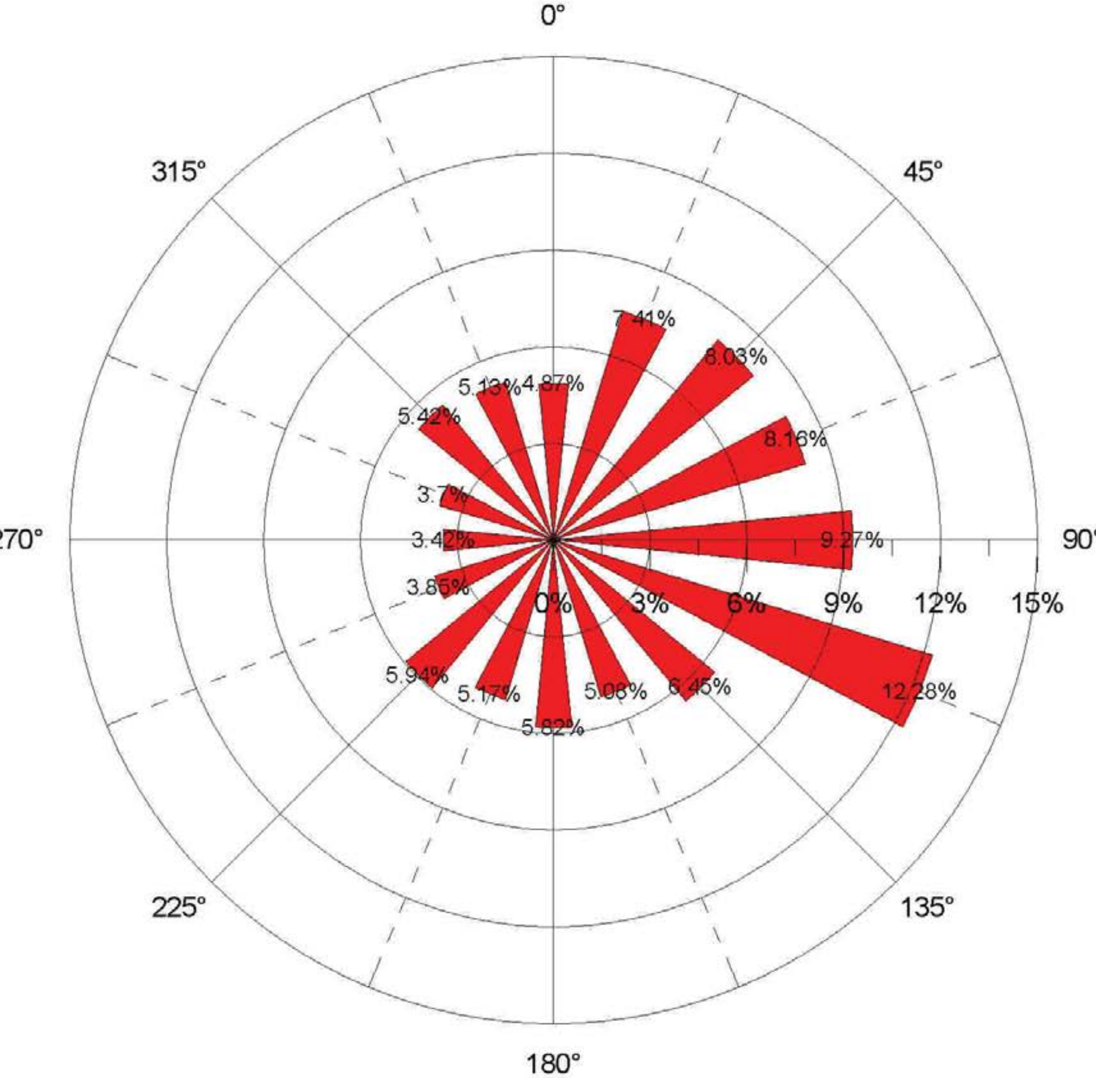
Seabrook Station Trajectories



COMMENTS:	MODELING OPTIONS:		
Figure 1 Trajectory Frequency Distribution 200 meter height 1 mile downwind	2005 CALMET Wind Fields		Epsilon ASSOCIATES INC.
	OUTPUT TYPE: FREQ		
	UNITS: Count	DATE: July 20, 2012	PROJECT NO.: 3396

PROJECT TITLE:

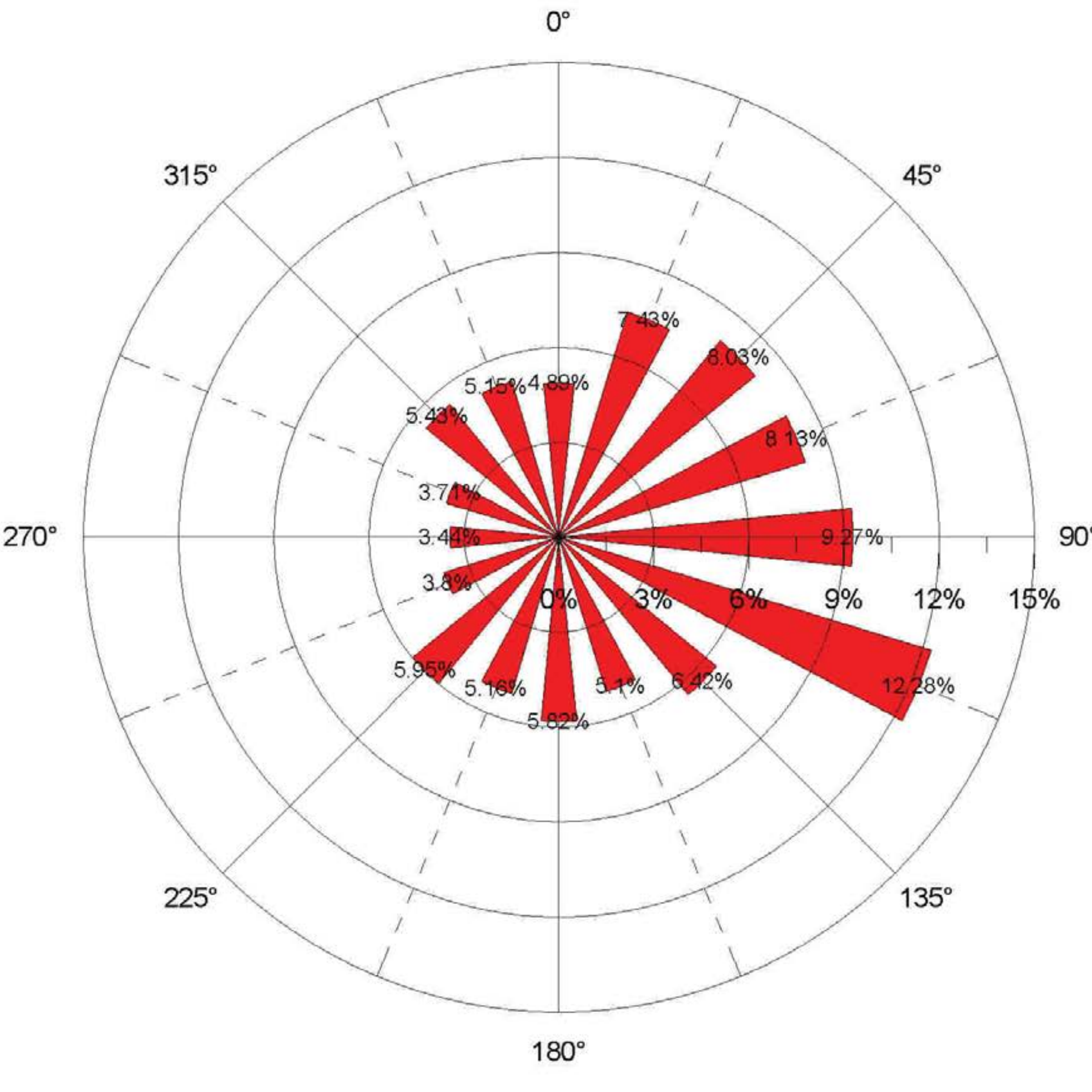
Seabrook Station Trajectories



COMMENTS:	MODELING OPTIONS:		
Figure 2 Trajectory Frequency Distribution 200 meter height 2 mile downwind	2005 CALMET Wind Fields		Epsilon ASSOCIATES INC.
	OUTPUT TYPE: FREQ		
	UNITS: Count	DATE: July 20, 2012	PROJECT NO.: 3396

PROJECT TITLE:

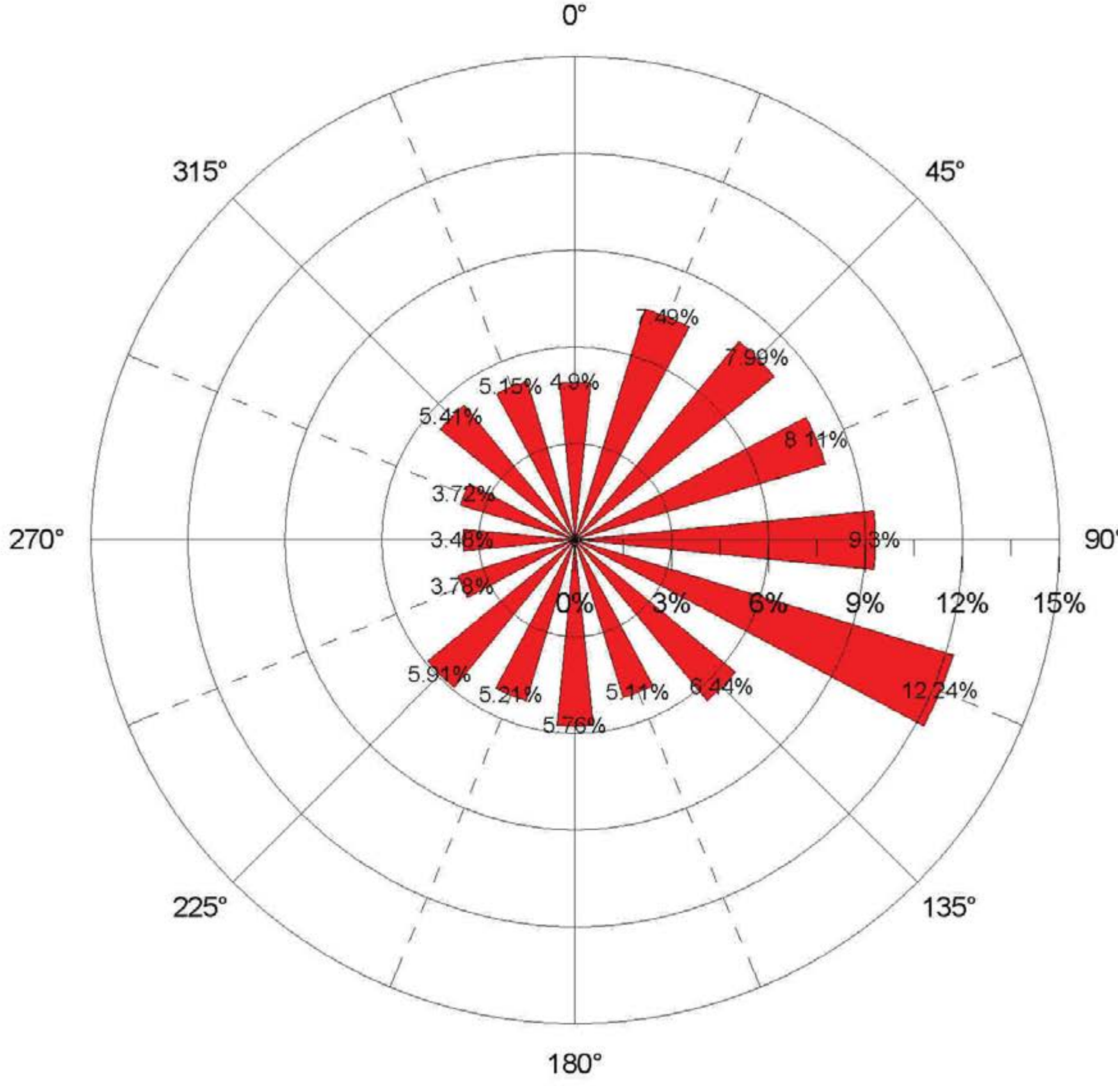
Seabrook Station Trajectories



COMMENTS:	MODELING OPTIONS:		
Figure 3 Trajectory Frequency Distribution 200 meter height 3 mile downwind	2005 CALMET Wind Fields		Epsilon ASSOCIATES INC.
	OUTPUT TYPE: FREQ		
	UNITS: Count	DATE: July 20, 2012	PROJECT NO.: 3396

PROJECT TITLE:

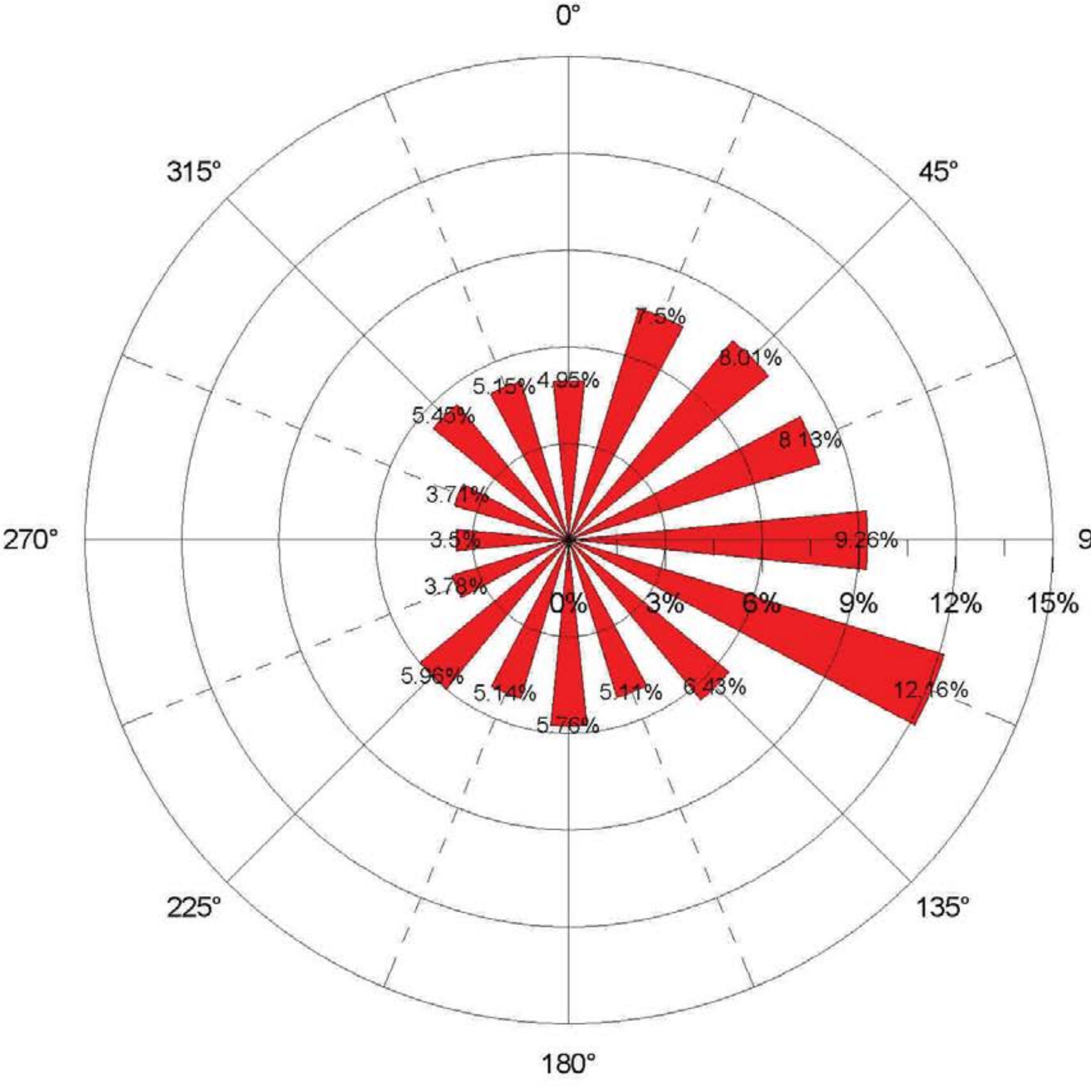
Seabrook Station Trajectories



COMMENTS:	MODELING OPTIONS:		
Figure 4 Trajectory Frequency Distribution 200 meter height 4 mile downwind	2005 CALMET Wind Fields OUTPUT TYPE: FREQ		Epsilon ASSOCIATES INC.
	UNITS: Count	DATE: July 20, 2012	PROJECT NO.: 3396

PROJECT TITLE:

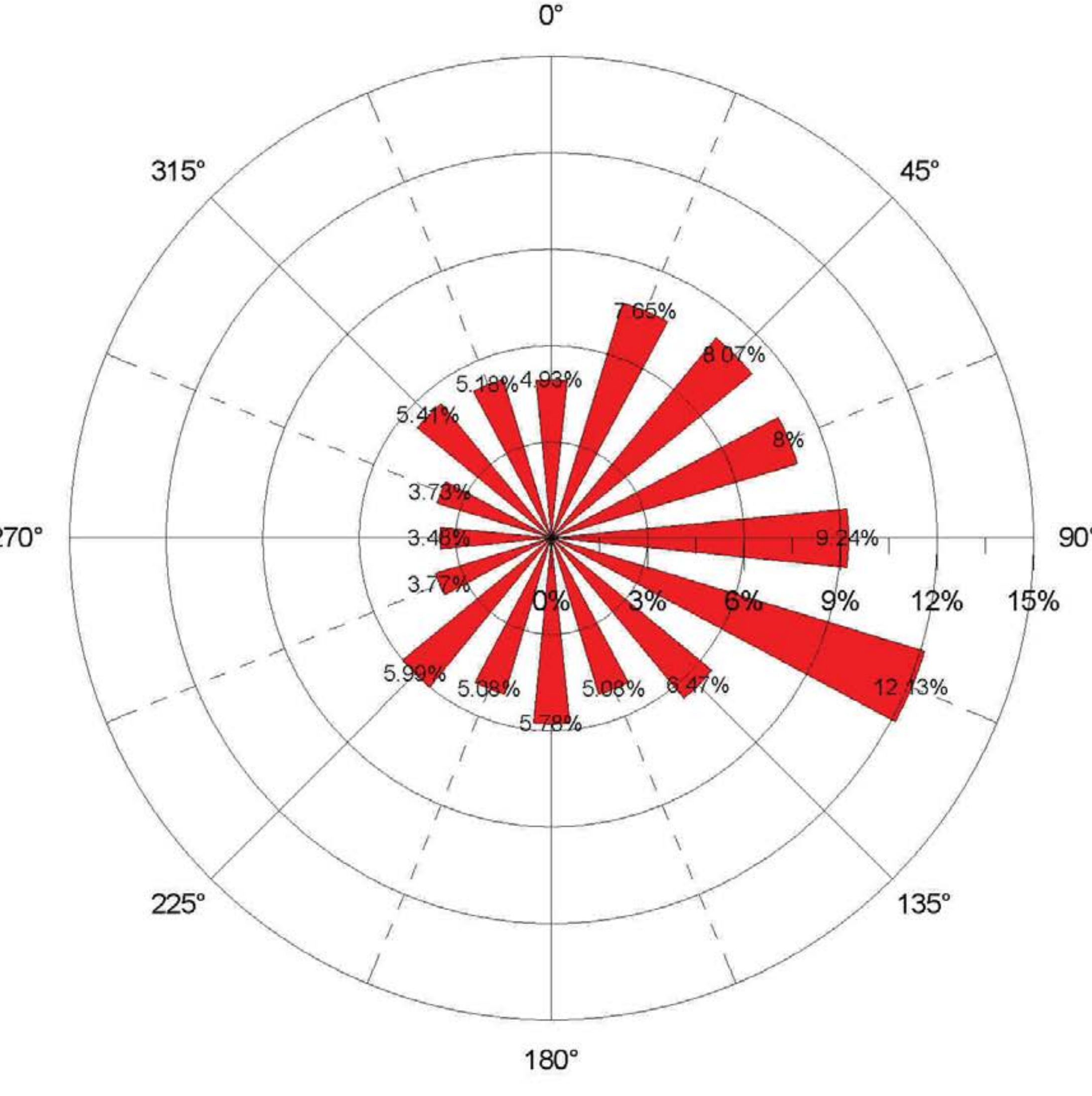
Seabrook Station Trajectories



COMMENTS:	MODELING OPTIONS:		
Figure 5 Trajectory Frequency Distribution 200 meter height 5 mile downwind	**2005 CALMET Wind Fields**		Epsilon ASSOCIATES INC.
	OUTPUT TYPE: **FREQ**		
	UNITS: **Count**	DATE: **July 20 2012**	PROJECT NO.: **3396**

PROJECT TITLE:

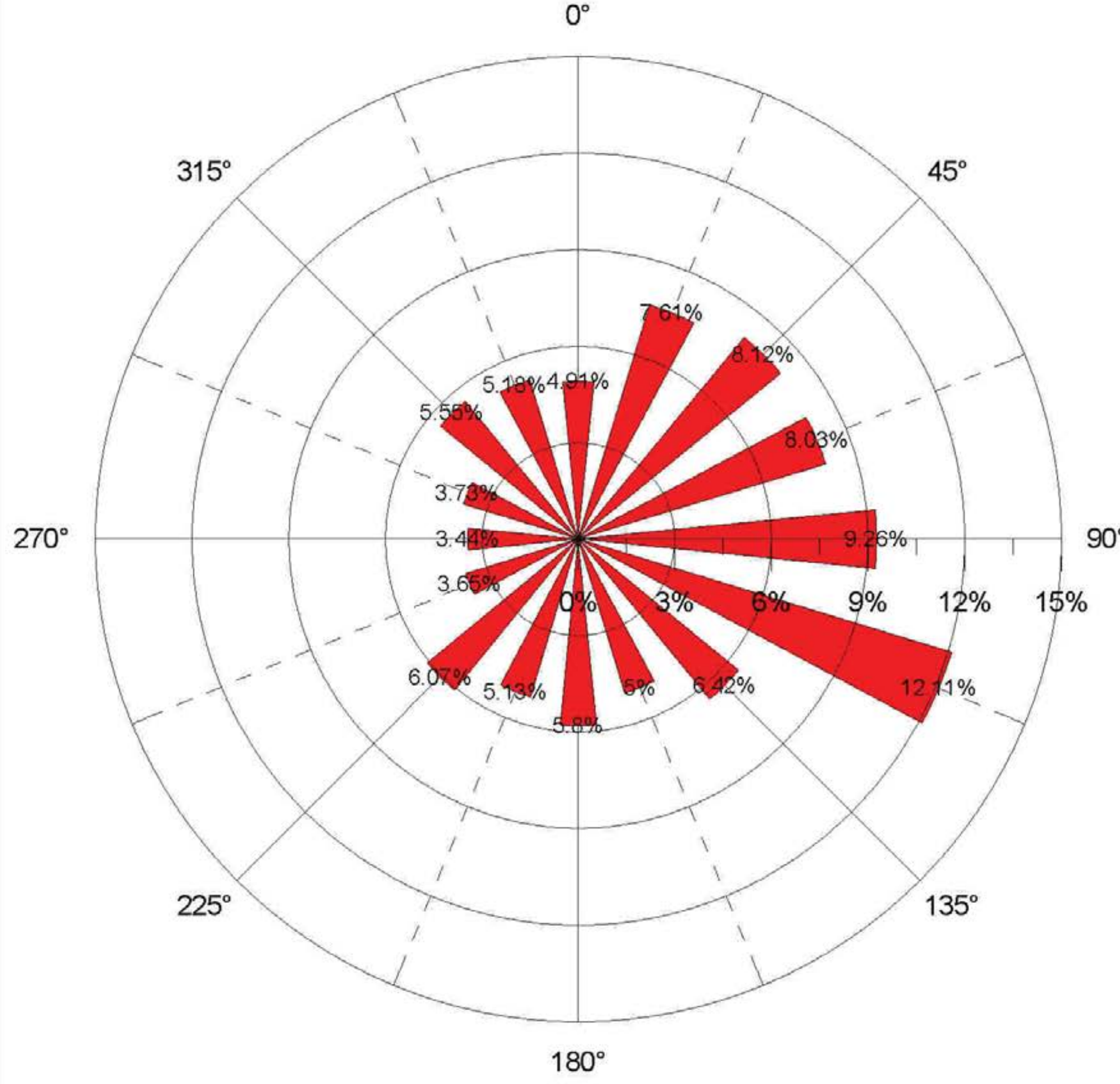
Seabrook Station Trajectories



COMMENTS:	MODELING OPTIONS:		
Figure 6 Trajectory Frequency Distribution 200 meter height 6 mile downwind	2005 CALMET Wind Fields		Epsilon ASSOCIATES INC.
	OUTPUT TYPE: FREQ		
	UNITS: Count	DATE: July 20, 2012	PROJECT NO.: 3396

PROJECT TITLE:

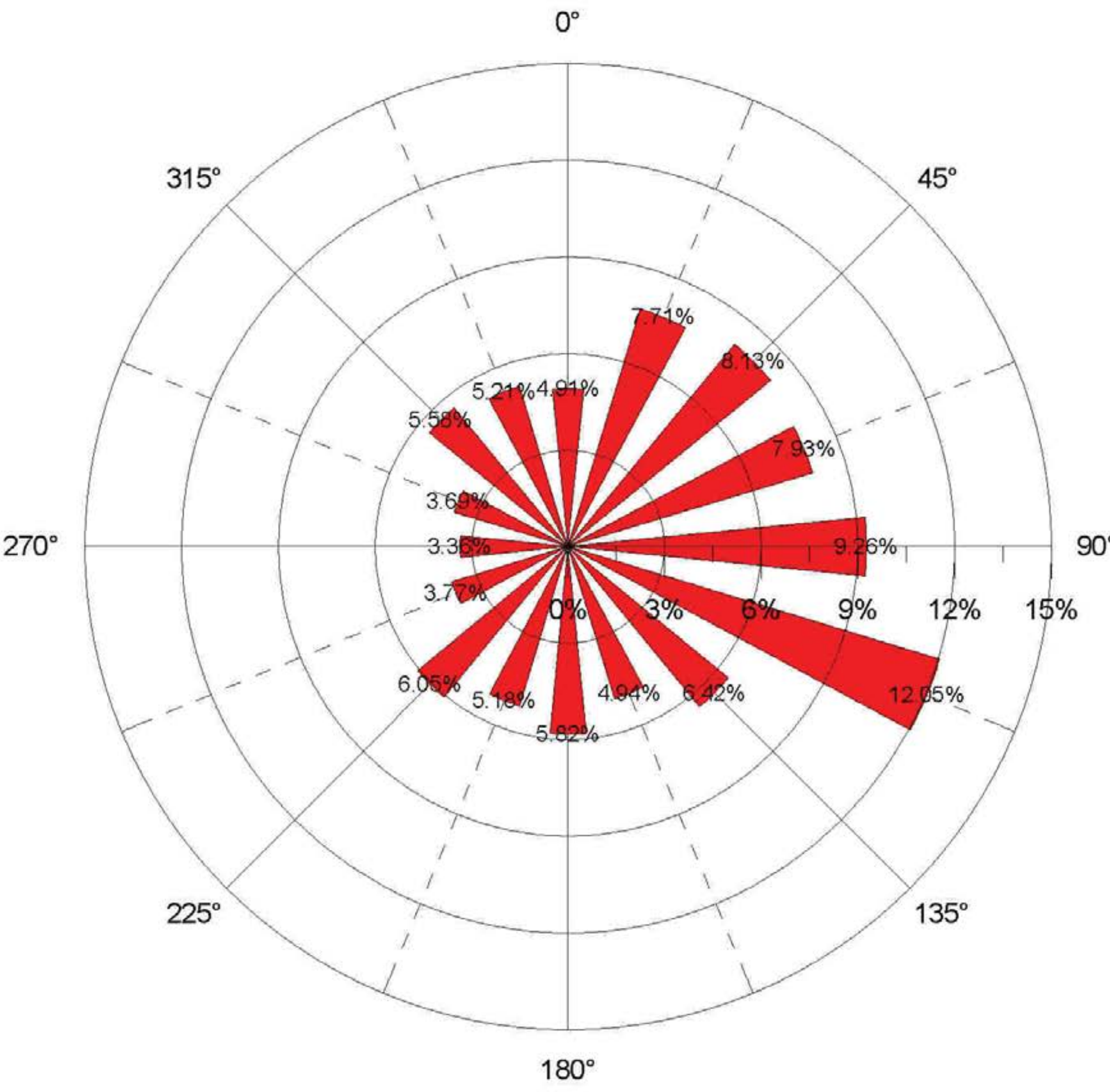
Seabrook Station Trajectories



COMMENTS:	MODELING OPTIONS:		
Figure 7 Trajectory Frequency Distribution 200 meter height 7 mile downwind	2005 CALMET Wind Fields		Epsilon ASSOCIATES INC.
	OUTPUT TYPE: FREQ		
	UNITS: Count	DATE: July 20, 2012	PROJECT NO.: 3396

PROJECT TITLE:

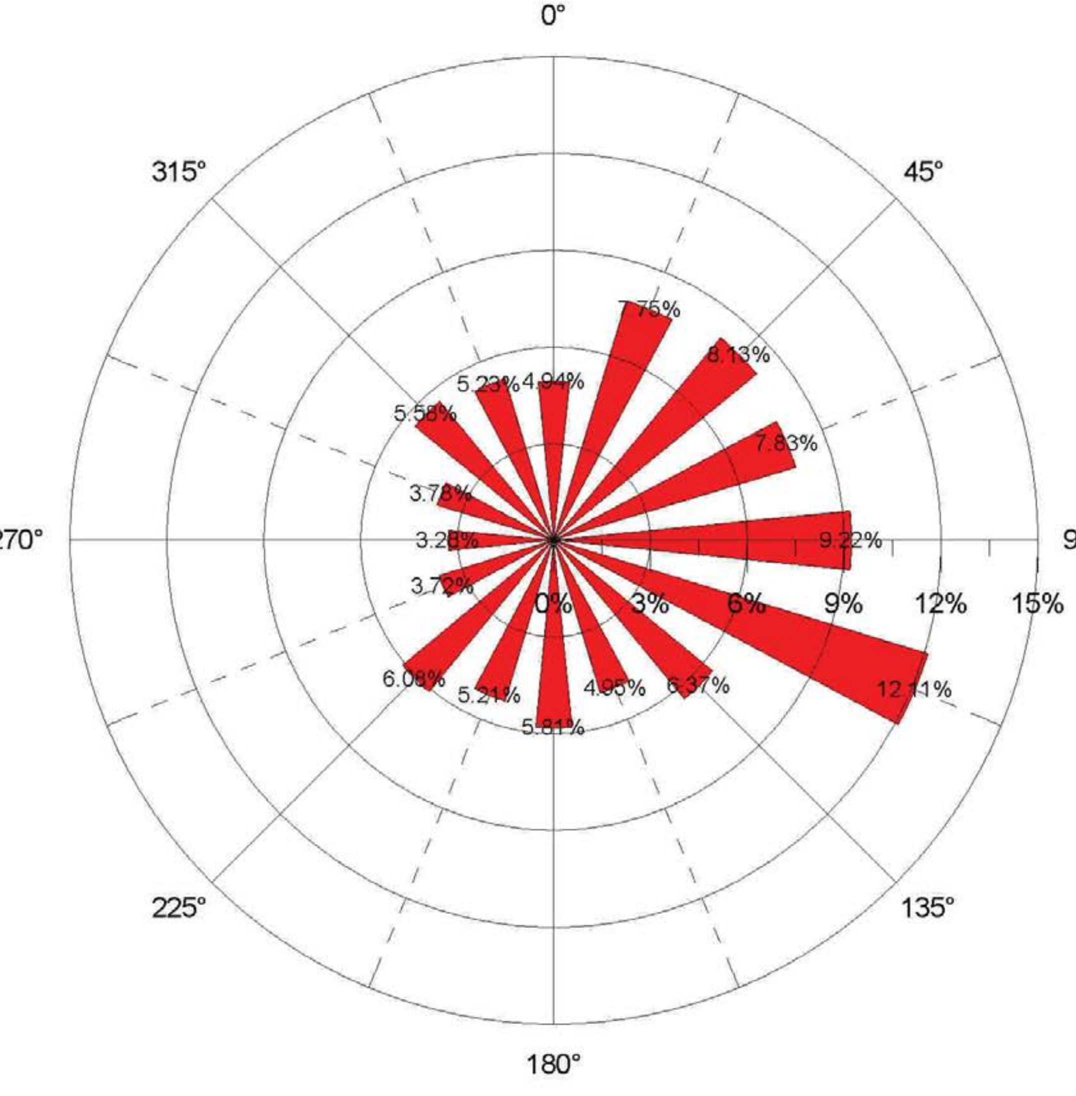
Seabrook Station Trajectories



COMMENTS:	MODELING OPTIONS:		
Figure 8 Trajectory Frequency Distribution 200 meter height 8 mile downwind	2005 CALMET Wind Fields		Epsilon ASSOCIATES INC.
	OUTPUT TYPE: FREQ		
	UNITS: Count	DATE: July 20, 2012	PROJECT NO.: 3396

PROJECT TITLE:

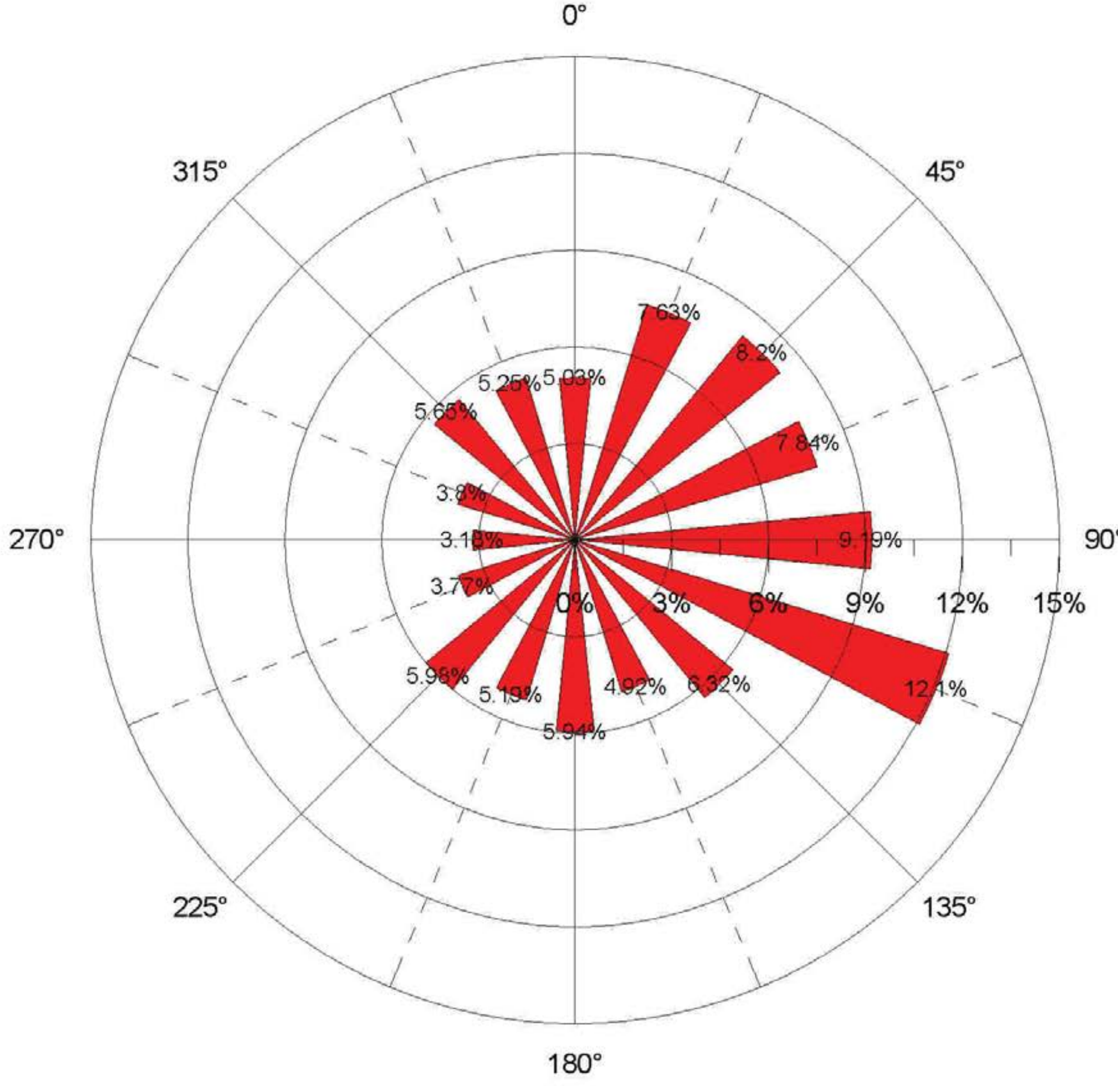
Seabrook Station Trajectories



COMMENTS:	MODELING OPTIONS:		
Figure 9 Trajectory Frequency Distribution 200 meter height 9 mile downwind	**2005 CALMET Wind Fields**		Epsilon ASSOCIATES INC.
	OUTPUT TYPE: **FREQ**		
	UNITS: **Count**	DATE: **July 20, 2012**	PROJECT NO.: **3396**

PROJECT TITLE:

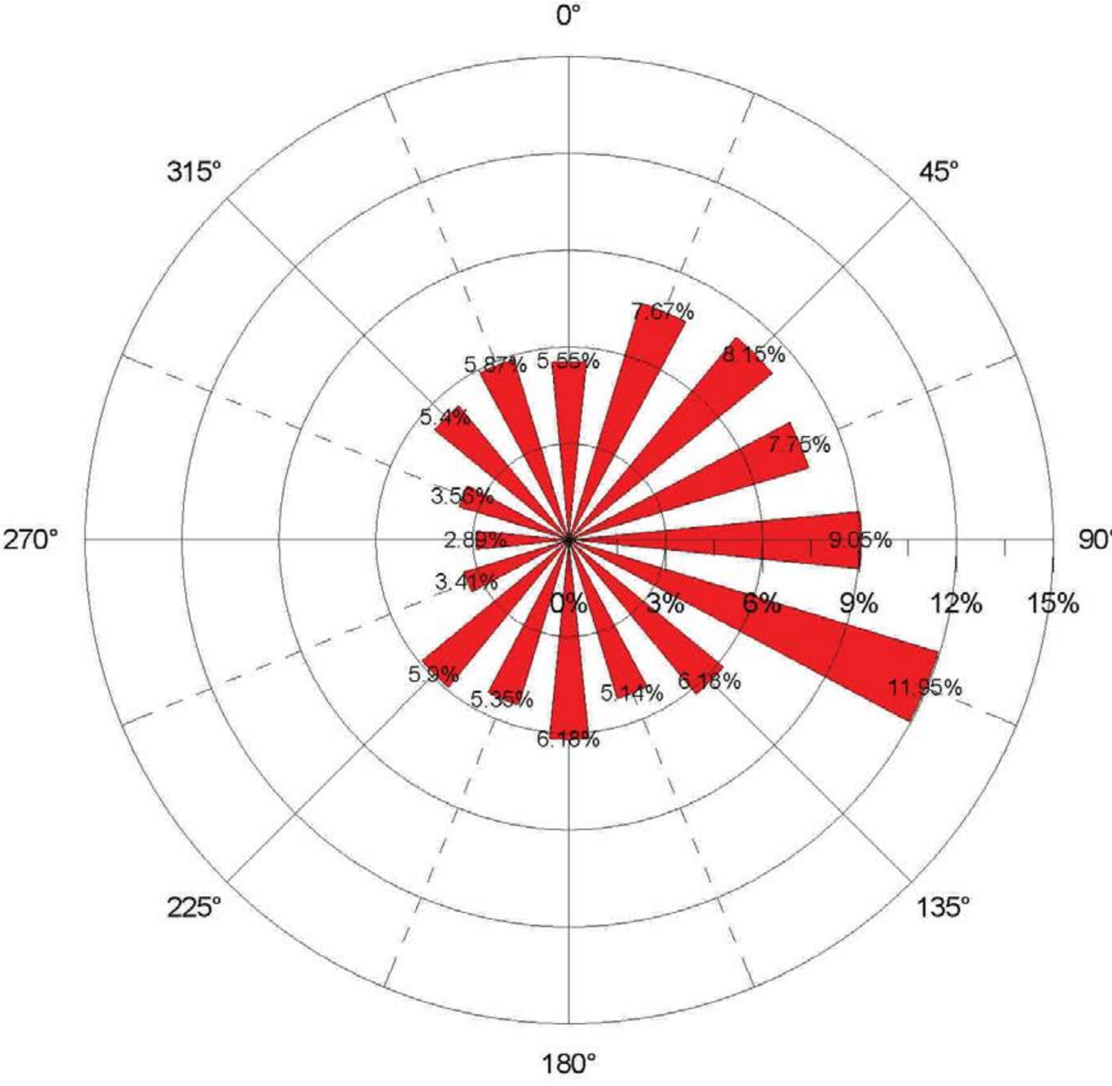
Seabrook Station Trajectories



COMMENTS:	MODELING OPTIONS:		
Figure 10 Trajectory Frequency Distribution 200 meter height 10 mile downwind	2005 CALMET Wind Fields		Epsilon Associates Inc.
	OUTPUT TYPE: FREQ		
	UNITS: Count	DATE: July 20, 2012	PROJECT NO.: 3396

PROJECT TITLE:

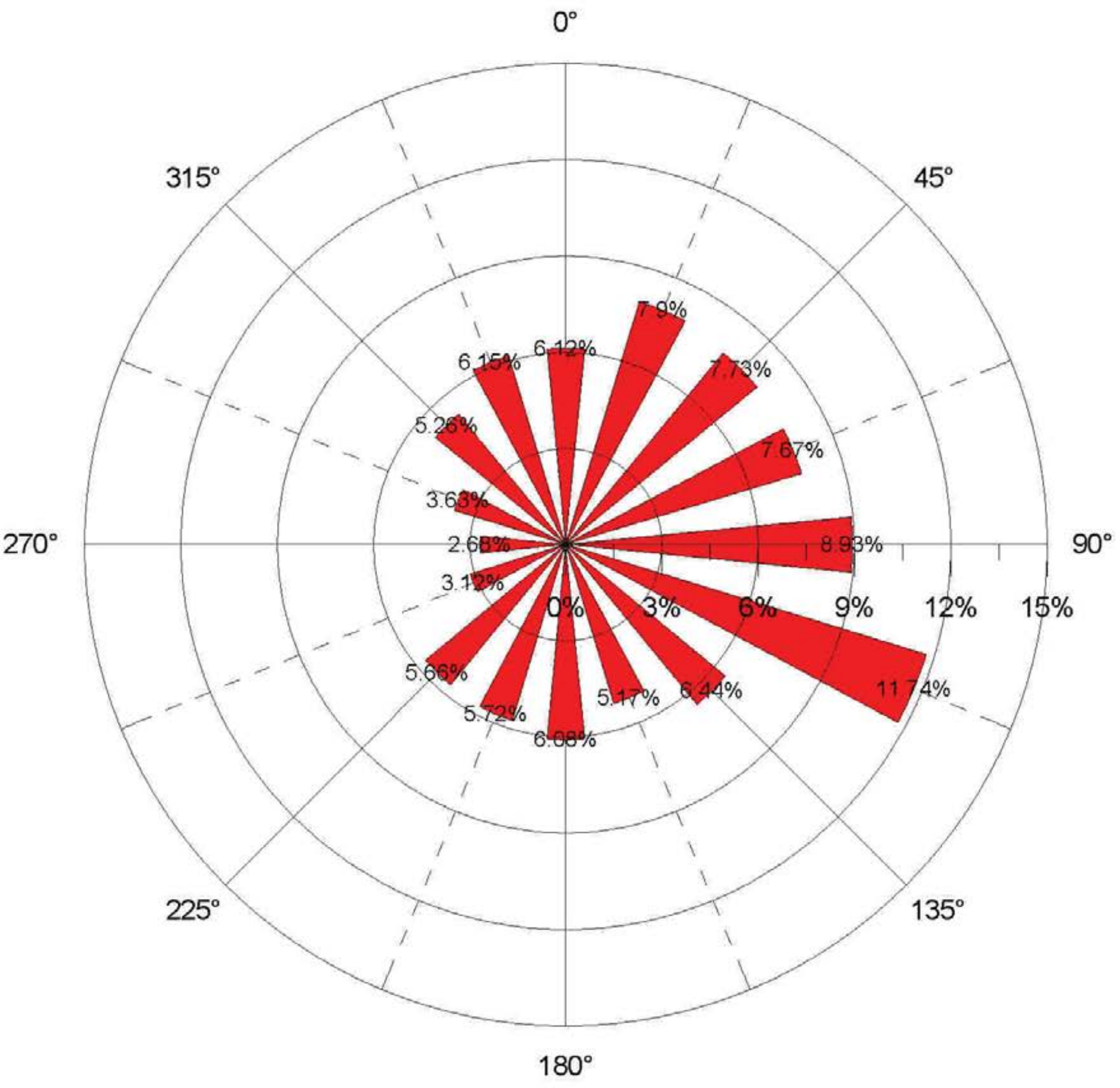
Seabrook Station Trajectories



COMMENTS:	MODELING OPTIONS:		
Figure 11 Trajectory Frequency Distribution 200 meter height 20 mile downwind	**2005 CALMET Wind Fields**		Epsilon ASSOCIATES INC.
	OUTPUT TYPE: **FREQ**		
	UNITS: **Count**	DATE: **July 20, 2012**	PROJECT NO.: **3396**

PROJECT TITLE:

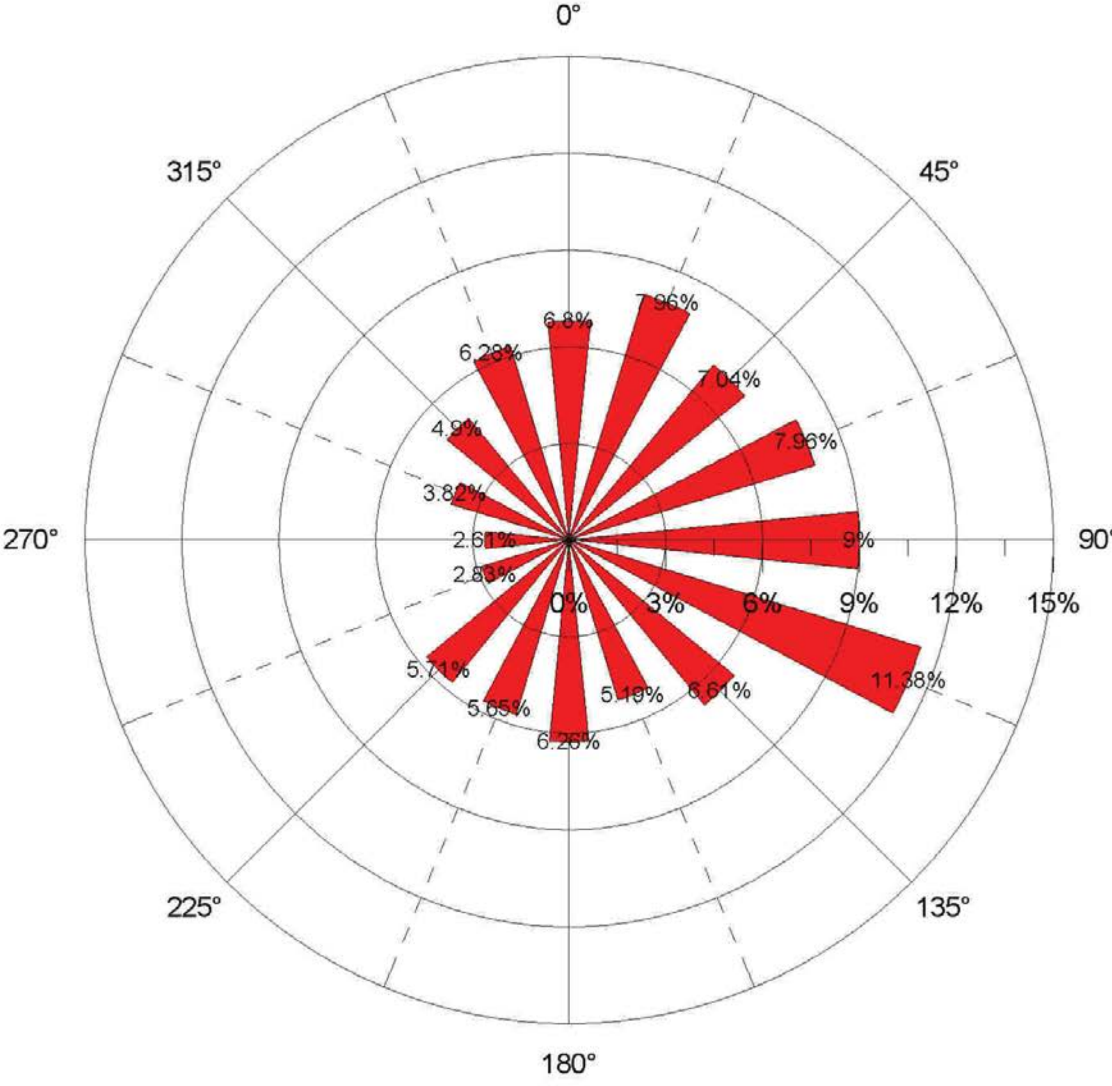
Seabrook Station Trajectories



COMMENTS:	MODELING OPTIONS:		
Figure 12 Trajectory Frequency Distribution 200 meter height 30 mile downwind	2005 CALMET Wind Fields		Epsilon ASSOCIATES INC.
	OUTPUT TYPE: FREQ		
	UNITS: Count	DATE: July 20, 2012	PROJECT NO.: 3396

PROJECT TITLE:

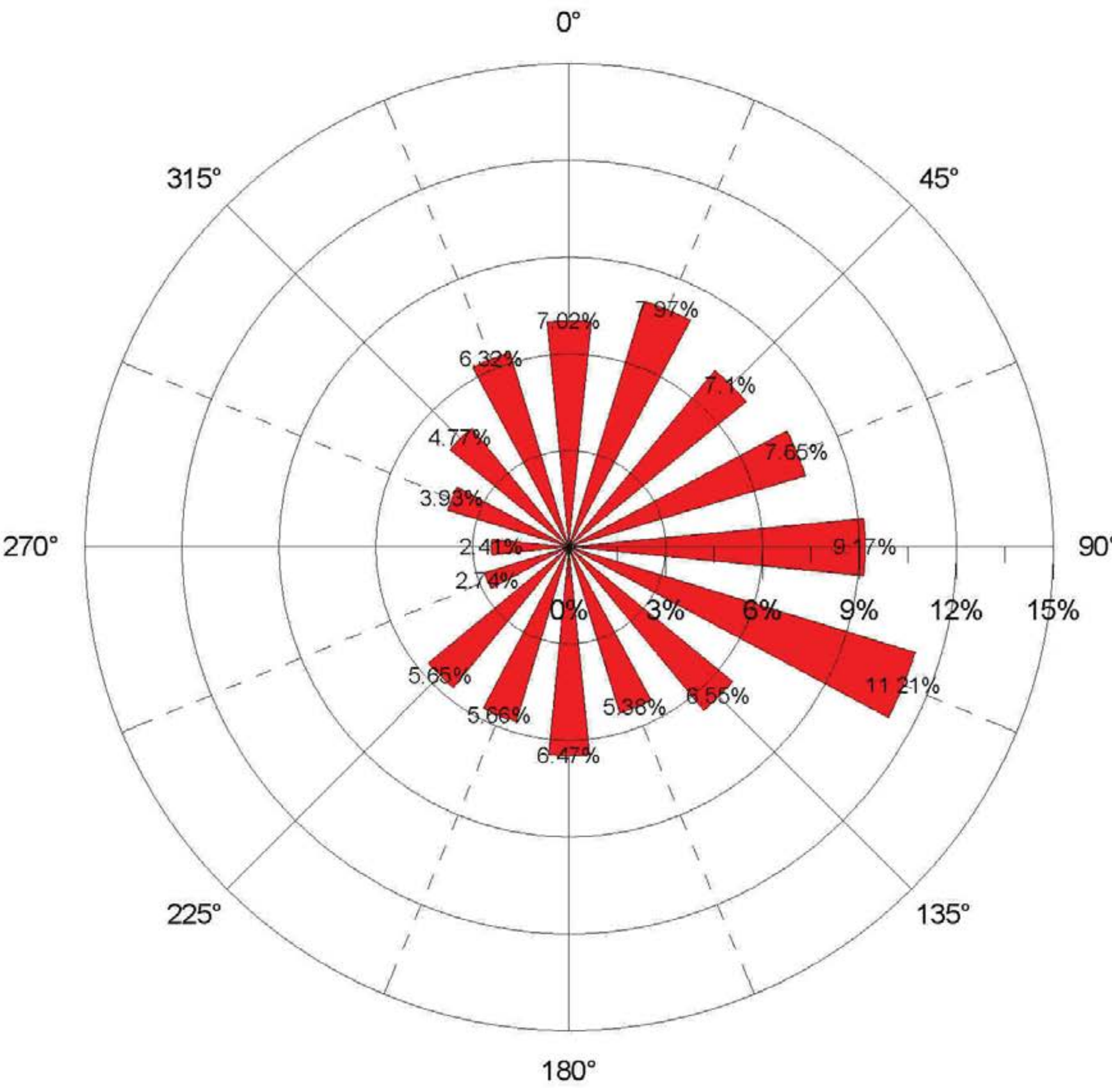
Seabrook Station Trajectories



COMMENTS:	MODELING OPTIONS:		
Figure 13 Trajectory Frequency Distribution 200 meter height 40 mile downwind	2005 CALMET Wind Fields		Epsilon ASSOCIATES INC.
	OUTPUT TYPE: FREQ		
	UNITS: Count	DATE: July 20, 2012	PROJECT NO.: 3396

PROJECT TITLE:

Seabrook Station Trajectories



COMMENTS:	MODELING OPTIONS:		
Figure 14 Trajectory Frequency Distribution 200 meter height 50 mile downwind	2005 CALMET Wind Fields		Epsilon ASSOCIATES INC.
	OUTPUT TYPE: FREQ		
	UNITS: Count	DATE: July 20, 2012	PROJECT NO.: 3396

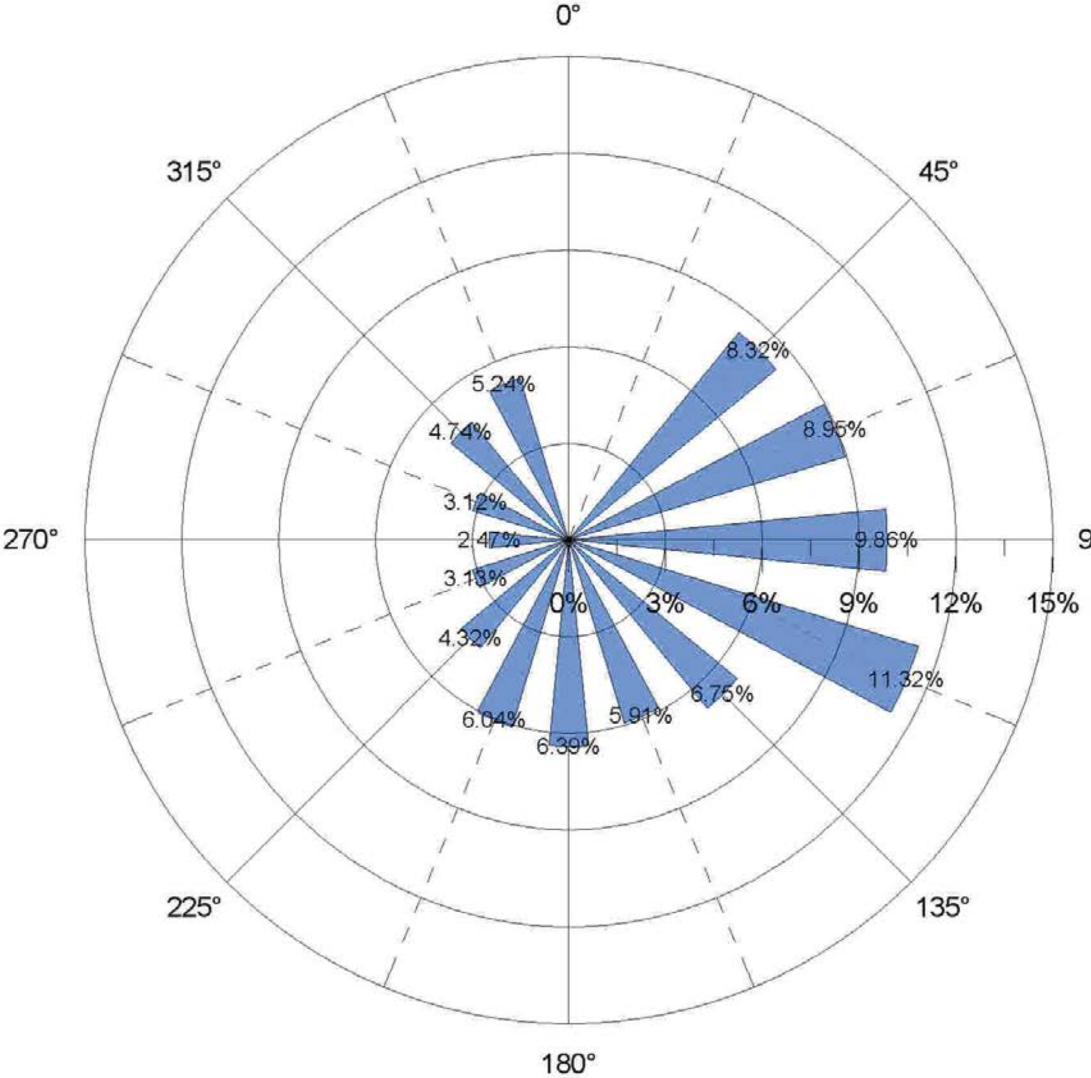
Appendix E
CALMET Trajectory Roses for 500 m Elevation

This appendix contains 14 plots of annual CALMET trajectory roses for 2005, for trajectories initiated at Seabrook 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:

Seabrook Station Trajectories



COMMENTS:	MODELING OPTIONS:		
Figure 1 Trajectory Frequency Distribution 500 meter height 1 mile downwind	2005 CALMET Wind Fields		Epsilon ASSOCIATES INC.
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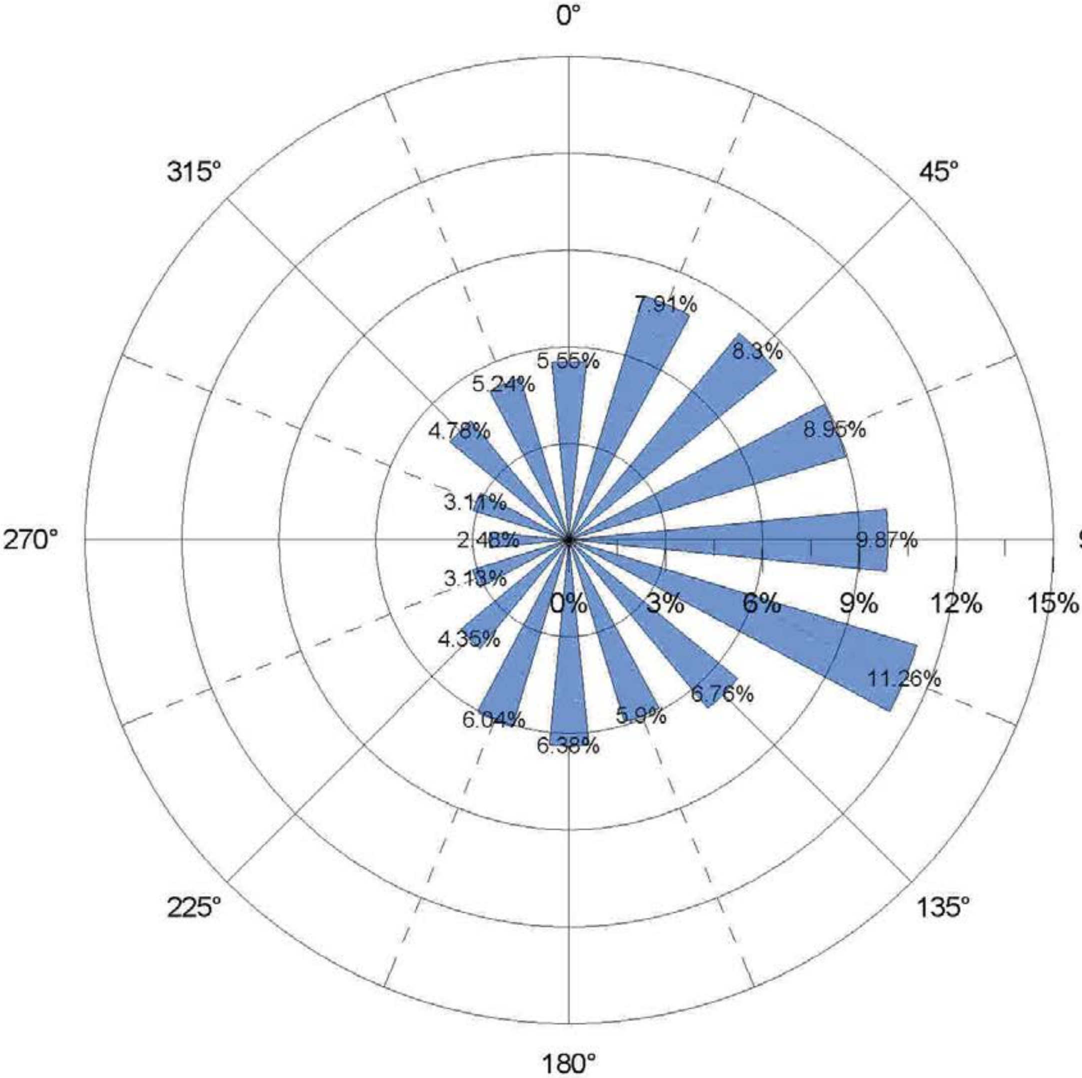
PROJECT TITLE:

Seabrook Station Trajectories



COMMENTS:	MODELING OPTIONS:		
Figure 2 Trajectory Frequency Distribution 500 meter height 2 mile downwind	2005 CALMET Wind Fields		
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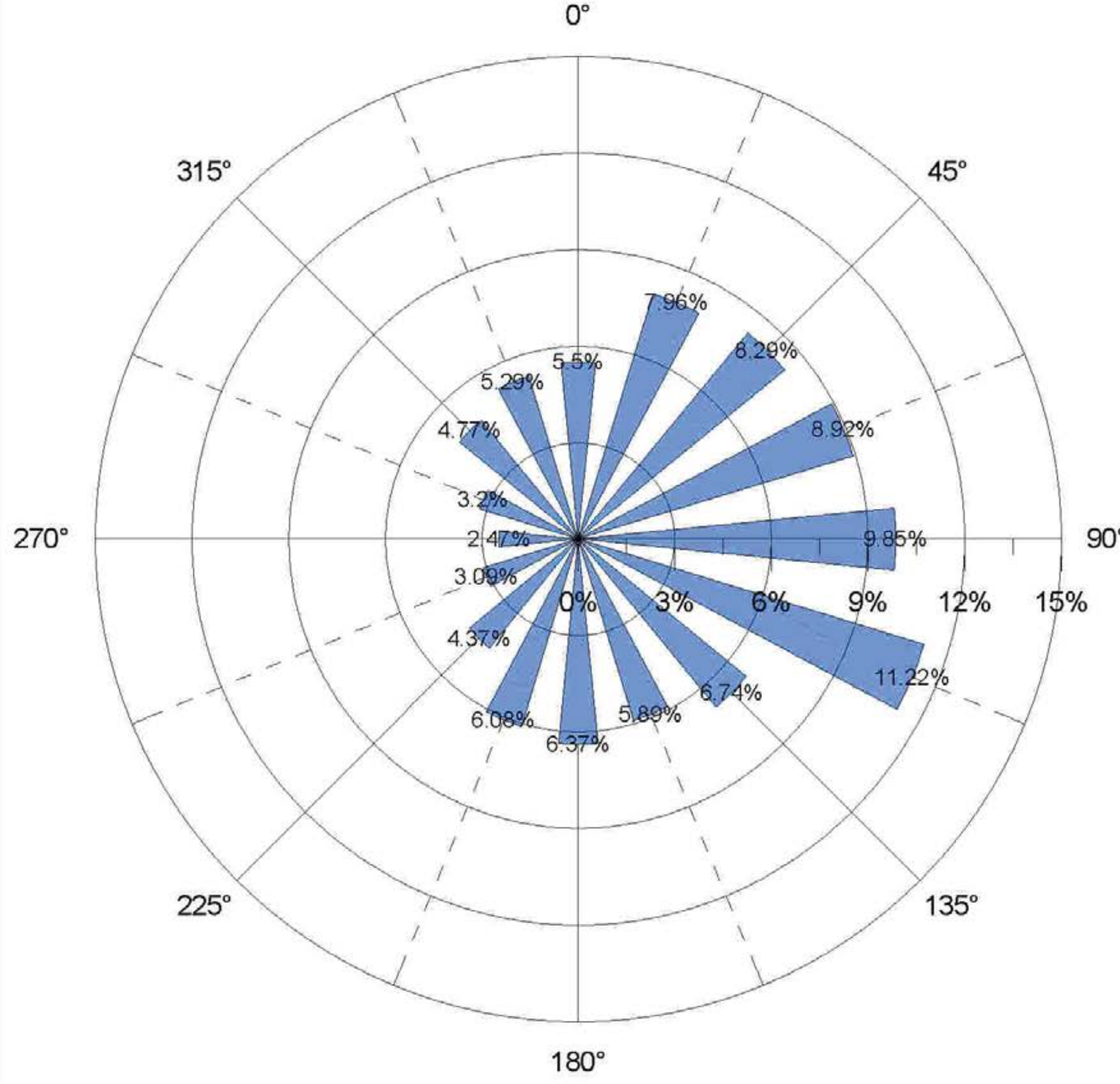
	UNITS: Count	DATE: July 20, 2012	PROJECT NO.: 3396

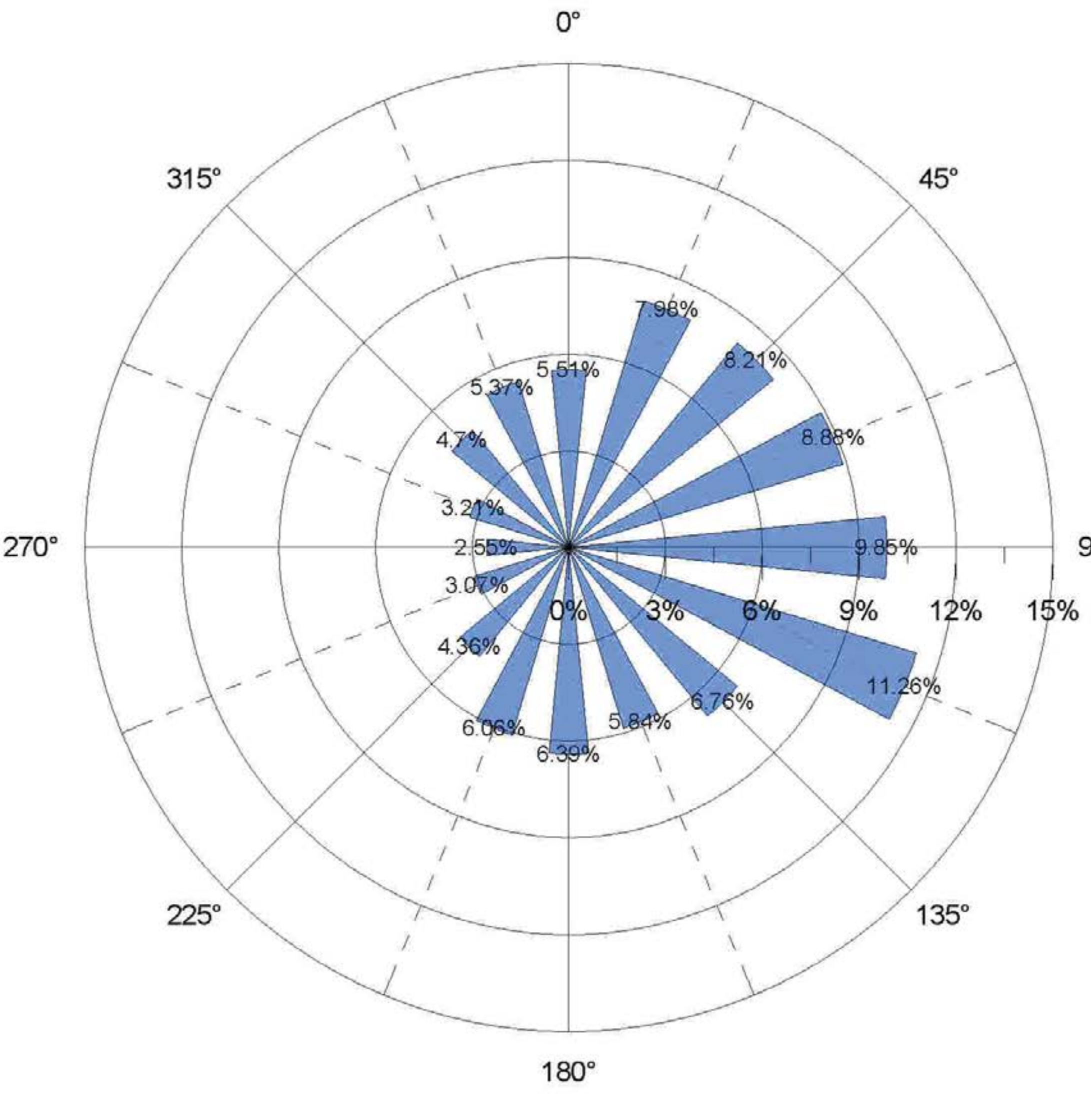
PROJECT TITLE:
Seabrook Station Trajectories



COMMENTS:	MODELING OPTIONS:		
Figure 3 Trajectory Frequency Distribution 500 meter height 3 mile downwind	2005 CALMET Wind Fields		Epsilon ASSOCIATES INC.
	OUTPUT TYPE: FREQ		
	UNITS: Count	DATE: July 20, 2012	PROJECT NO.: 3396

PROJECT TITLE:

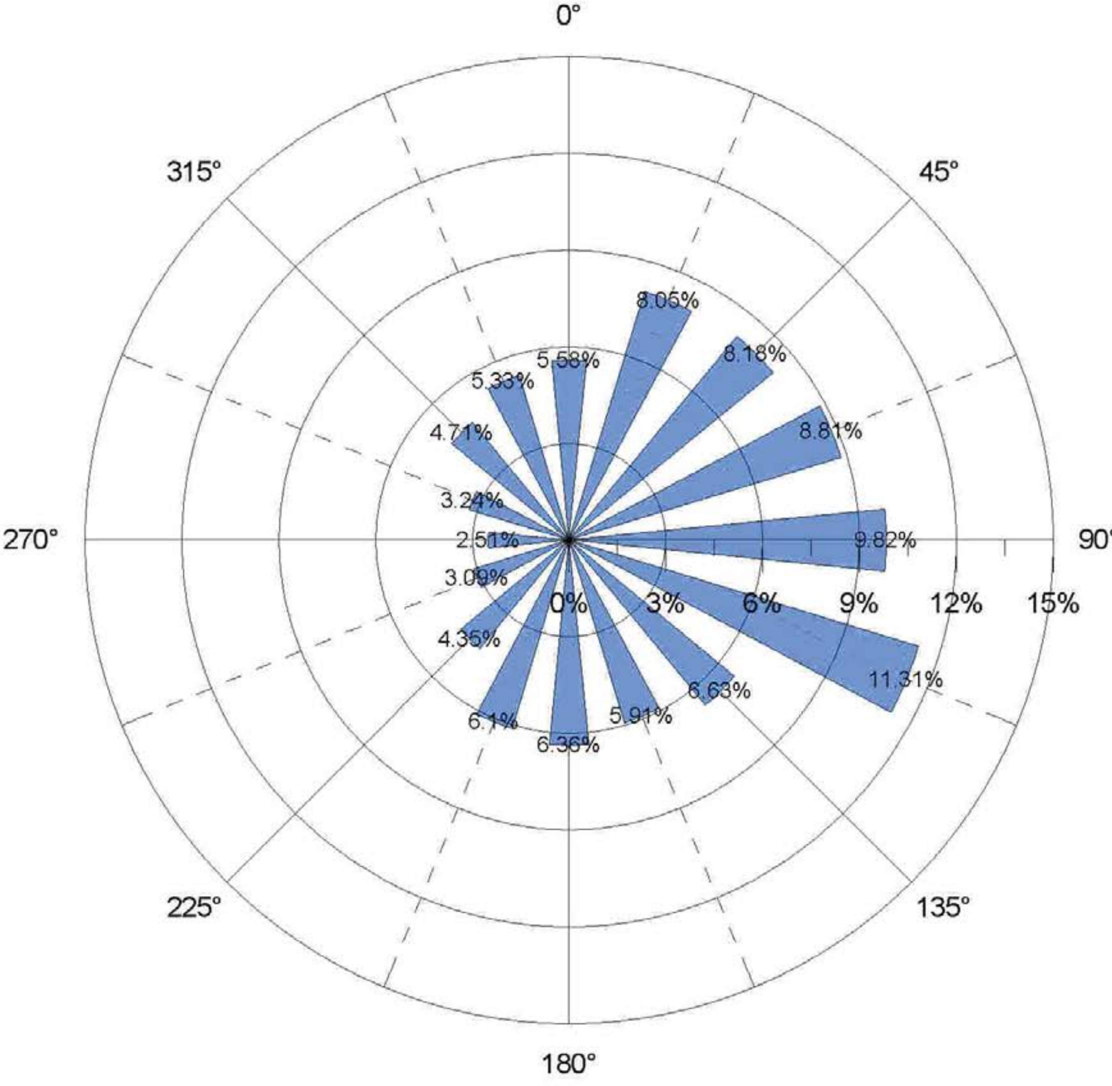
Seabrook Station Trajectories



COMMENTS:	MODELING OPTIONS:		
Figure 4 Trajectory Frequency Distribution 500 meter height 4 mile downwind	2005 CALMET Wind Fields OUTPUT TYPE: FREQ		Epsilon ASSOCIATES INC.
	UNITS: Count	DATE: July 20, 2012	PROJECT NO.: 3396

PROJECT TITLE:

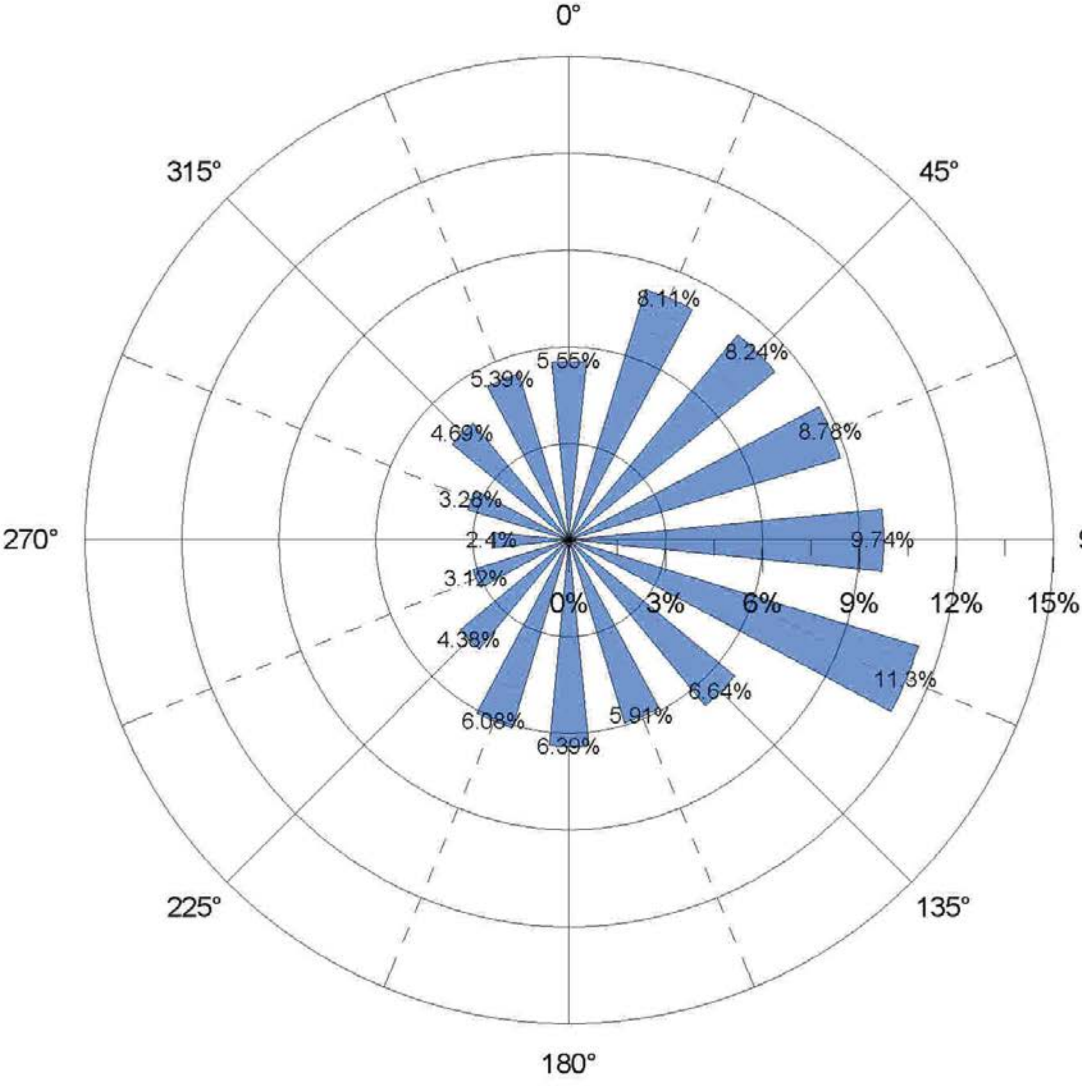
Seabrook Station Trajectories



COMMENTS:	MODELING OPTIONS:		
Figure 5 Trajectory Frequency Distribution 500 meter height 5 mile downwind	2005 CALMET Wind Fields OUTPUT TYPE: FREQ		Epsilon ASSOCIATES INC.
	UNITS: Count	DATE: July 20, 2012	PROJECT NO.: 3396

PROJECT TITLE:

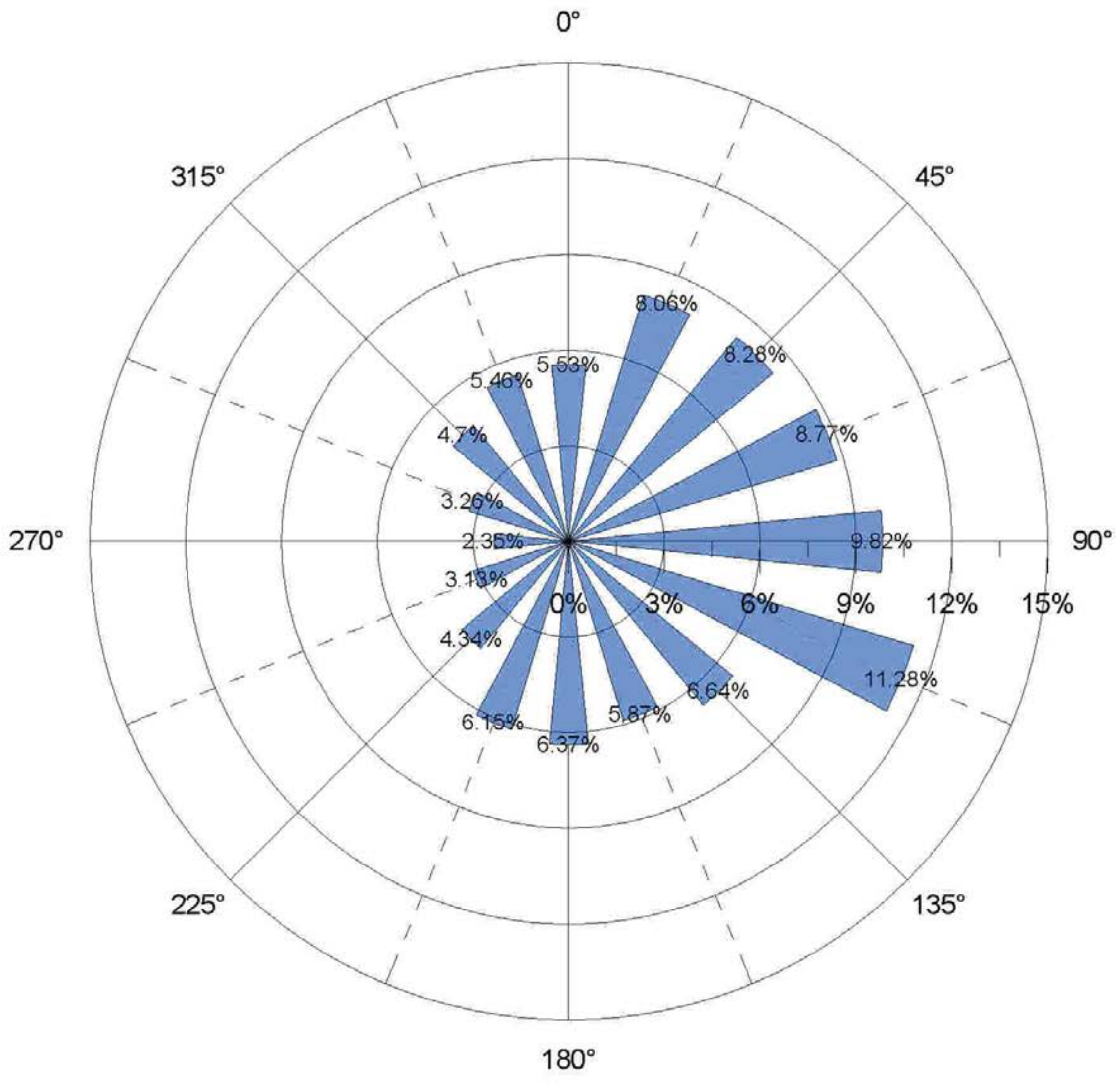
Seabrook Station Trajectories



COMMENTS:	MODELING OPTIONS:		
Figure 6 Trajectory Frequency Distribution 500 meter height 6 mile downwind	2005 CALMET Wind Fields		Epsilon ASSOCIATES INC.
	OUTPUT TYPE: FREQ		
	UNITS: Count	DATE: July 20, 2012	PROJECT NO.: 3396

PROJECT TITLE:

Seabrook Station Trajectories



COMMENTS:	MODELING OPTIONS:		
Figure 7 Trajectory Frequency Distribution 500 meter height 7 mile downwind	2005 CALMET Wind Fields		Epsilon ASSOCIATES INC.
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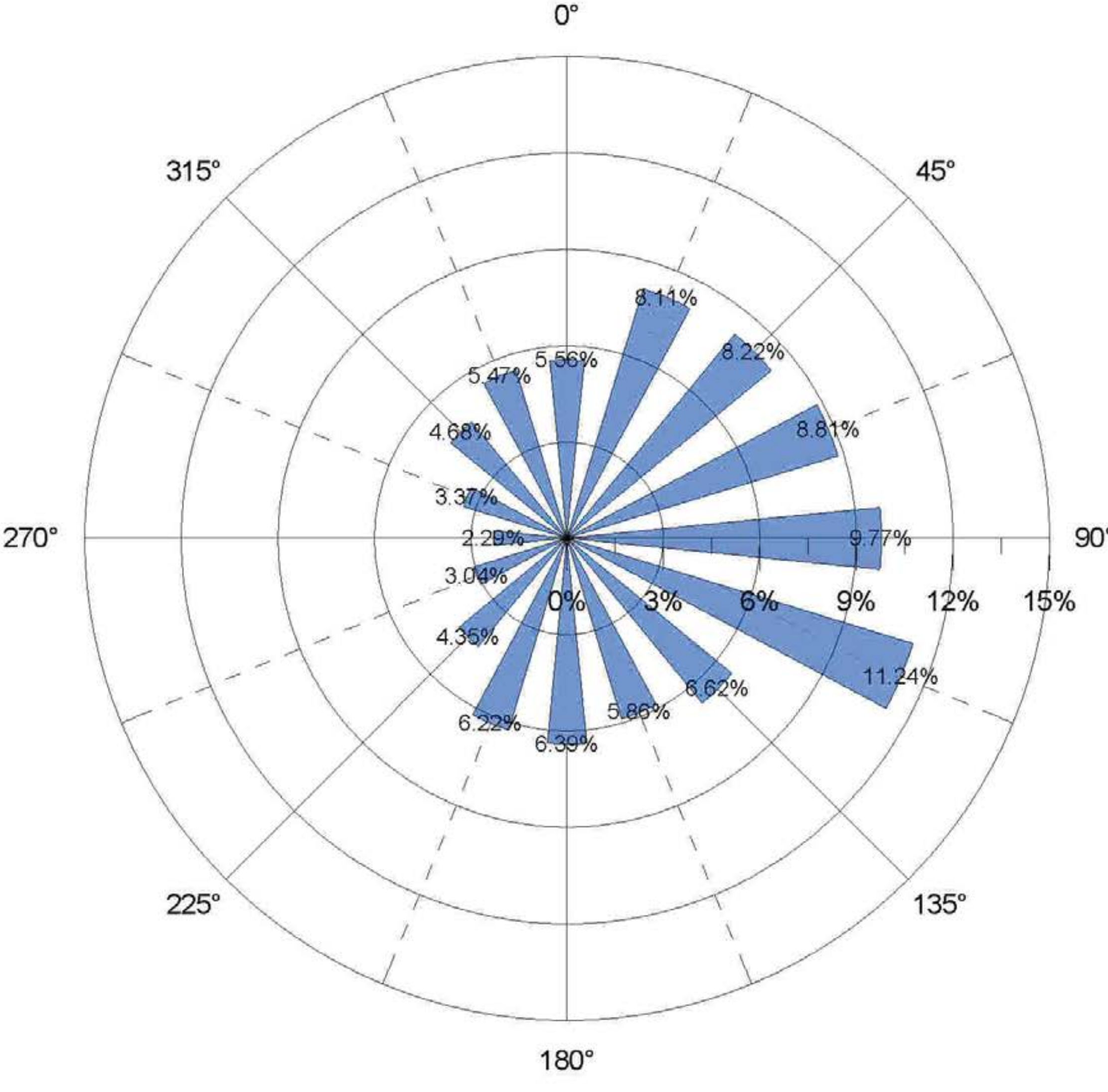
	UNITS: Count	DATE: July 20, 2012	PROJECT NO.: 3396

PROJECT TITLE:

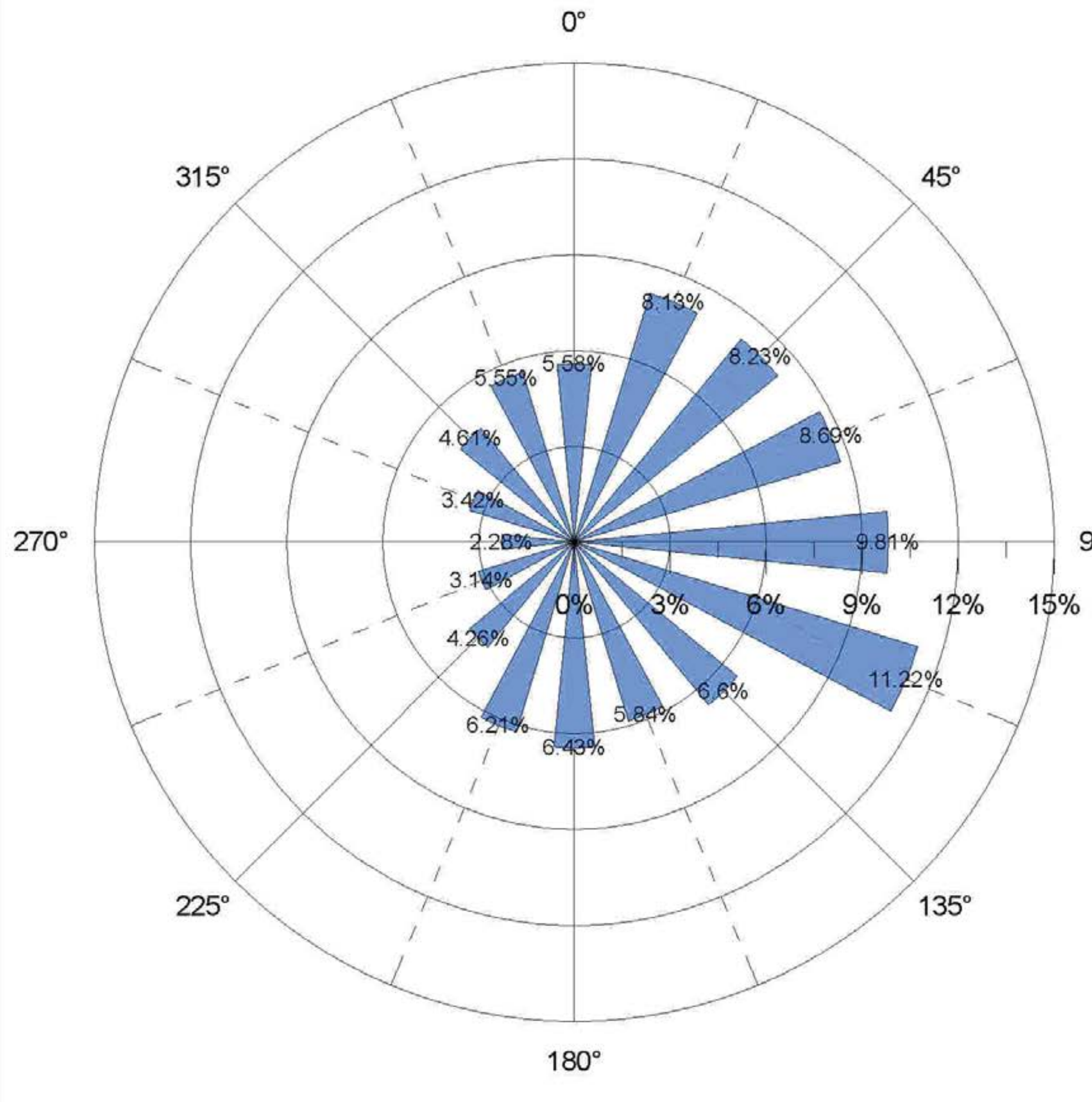
Seabrook Station Trajectories



COMMENTS:	MODELING OPTIONS:		
Figure 8 Trajectory Frequency Distribution 500 meter height 8 mile downwind	2005 CALMET Wind Fields OUTPUT TYPE: FREQ		Epsilon ASSOCIATES INC.
	UNITS: Count	DATE: July 20, 2012	PROJECT NO.: 3396

PROJECT TITLE:

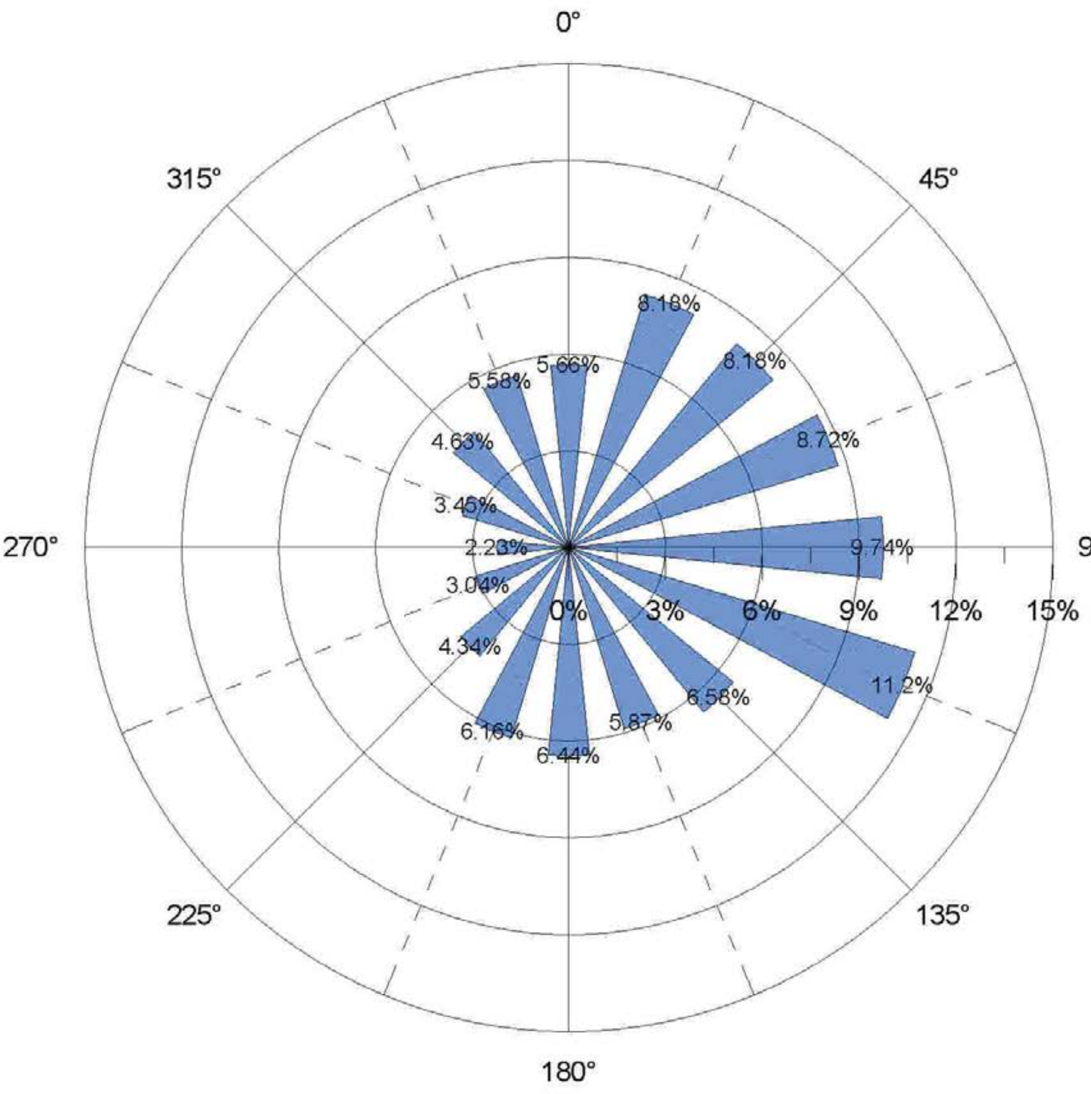
Seabrook Station Trajectories



COMMENTS:	MODELING OPTIONS:		
Figure 9 Trajectory Frequency Distribution 500 meter height 9 mile downwind	2005 CALMET Wind Fields		Epsilon ASSOCIATES INC.
	OUTPUT TYPE: FREQ		
	UNITS: Count	DATE: July 20, 2012	PROJECT NO.: 3396

PROJECT TITLE:

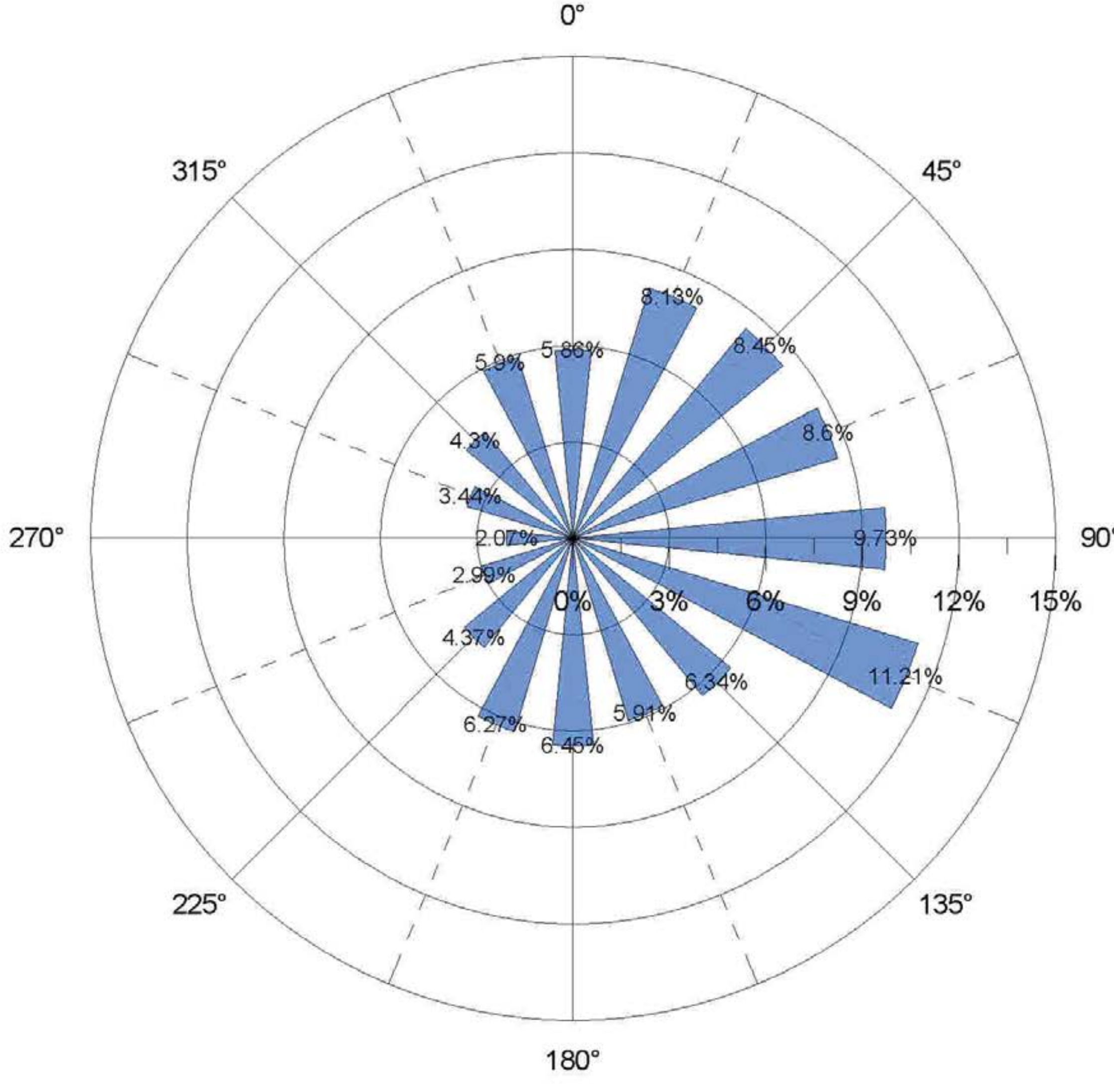
Seabrook Station Trajectories



COMMENTS:	MODELING OPTIONS:		
Figure 10 Trajectory Frequency Distribution 500 meter height 10 mile downwind	2005 CALMET Wind Fields		Epsilon ASSOCIATES INC.
	OUTPUT TYPE: FREQ		
	UNITS: Count	DATE: July 20, 2012	PROJECT NO.: 3396

PROJECT TITLE:

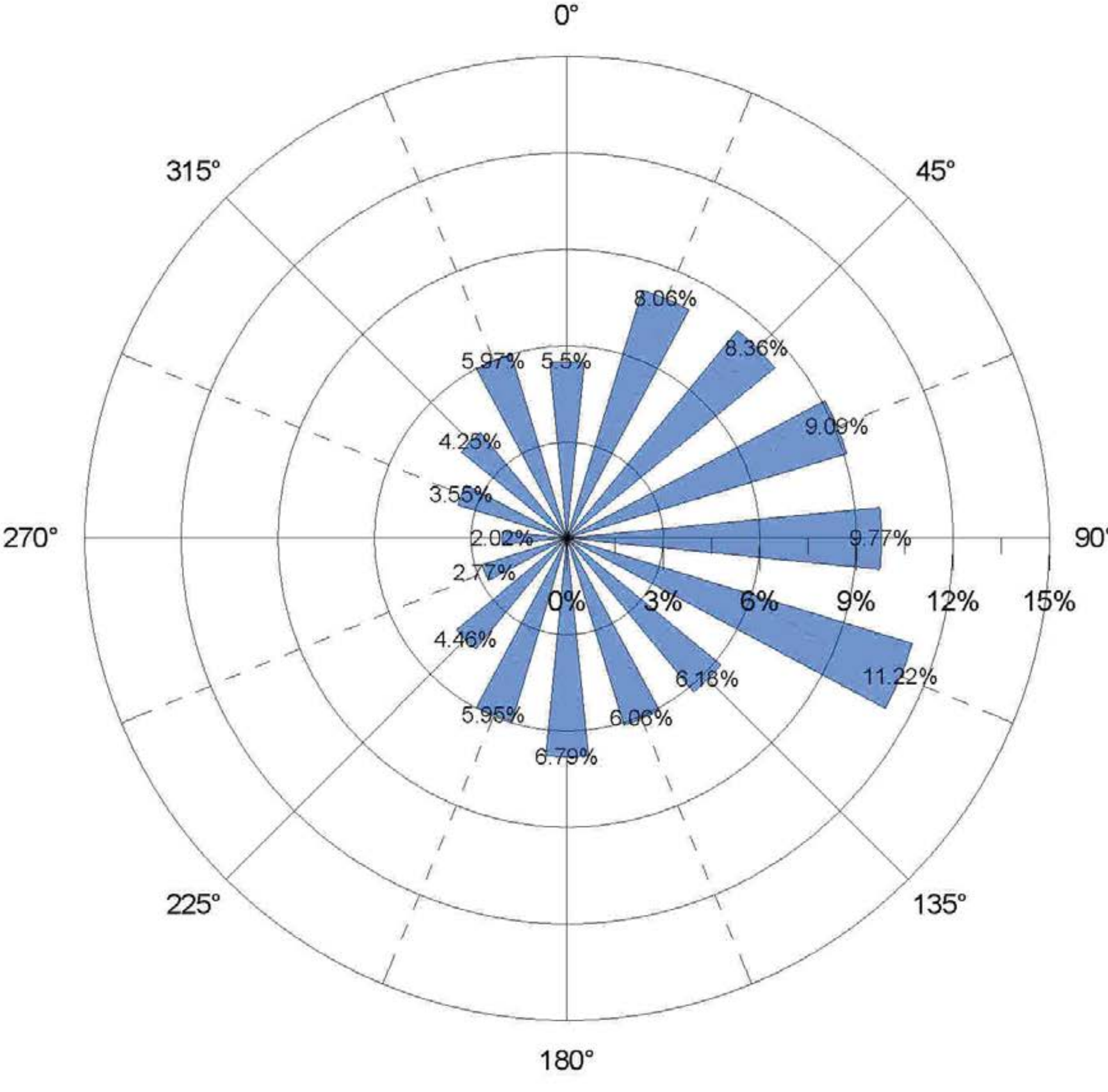
Seabrook Station Trajectories



COMMENTS:	MODELING OPTIONS:		
Figure 11 Trajectory Frequency Distribution 500 meter height 20 mile downwind	2005 CALMET Wind Fields		Epsilon Associates Inc.
	OUTPUT TYPE: FREQ		
	UNITS: Count	DATE: July 20, 2012	PROJECT NO.: 3396

PROJECT TITLE:

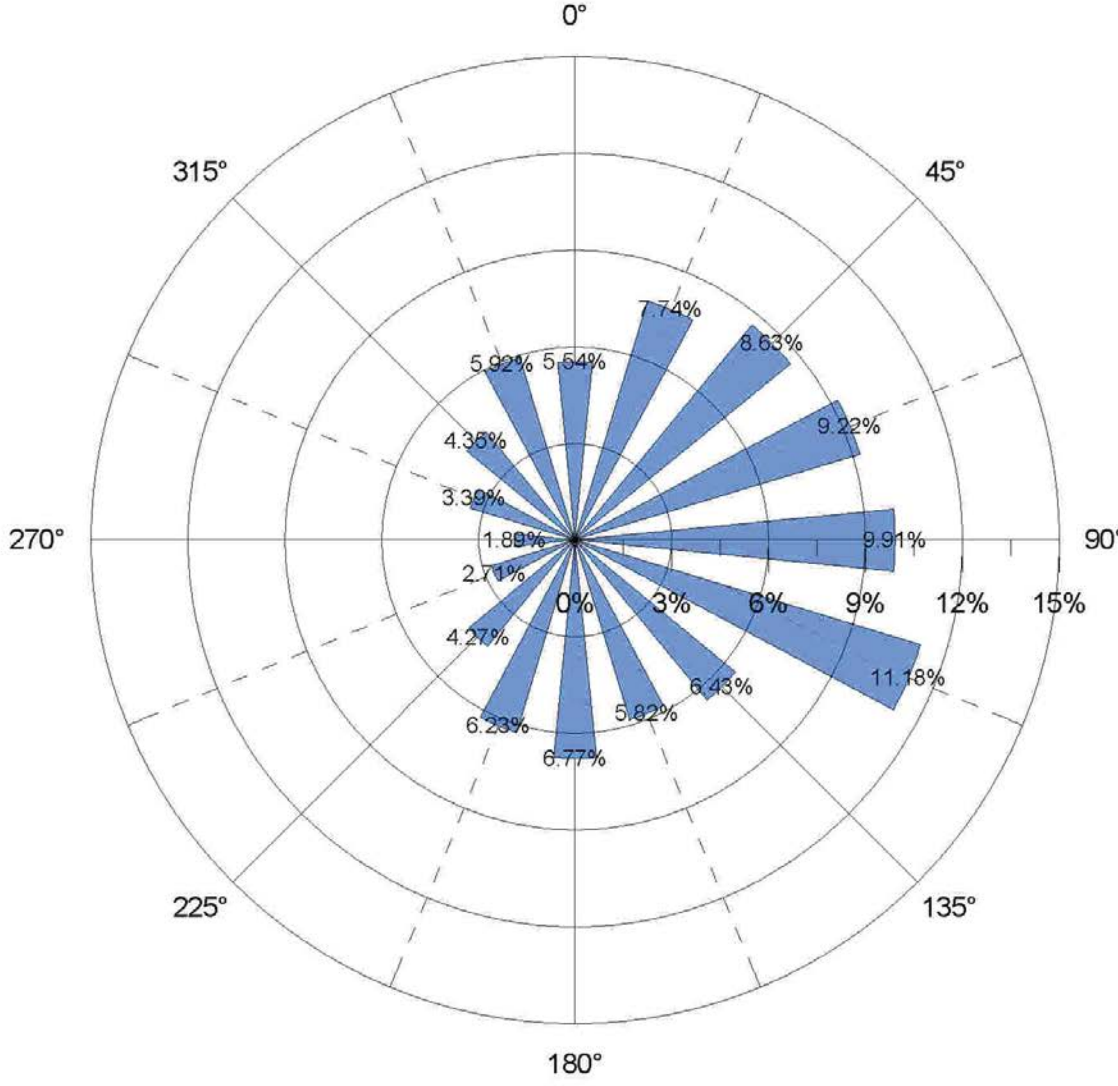
Seabrook Station Trajectories



COMMENTS:	MODELING OPTIONS:		
Figure 12 Trajectory Frequency Distribution 500 meter height 30 mile downwind	2005 CALMET Wind Fields		Epsilon ASSOCIATES INC.
	OUTPUT TYPE: FREQ		
	UNITS: Count	DATE: July 20, 2012	PROJECT NO.: 3396

PROJECT TITLE:

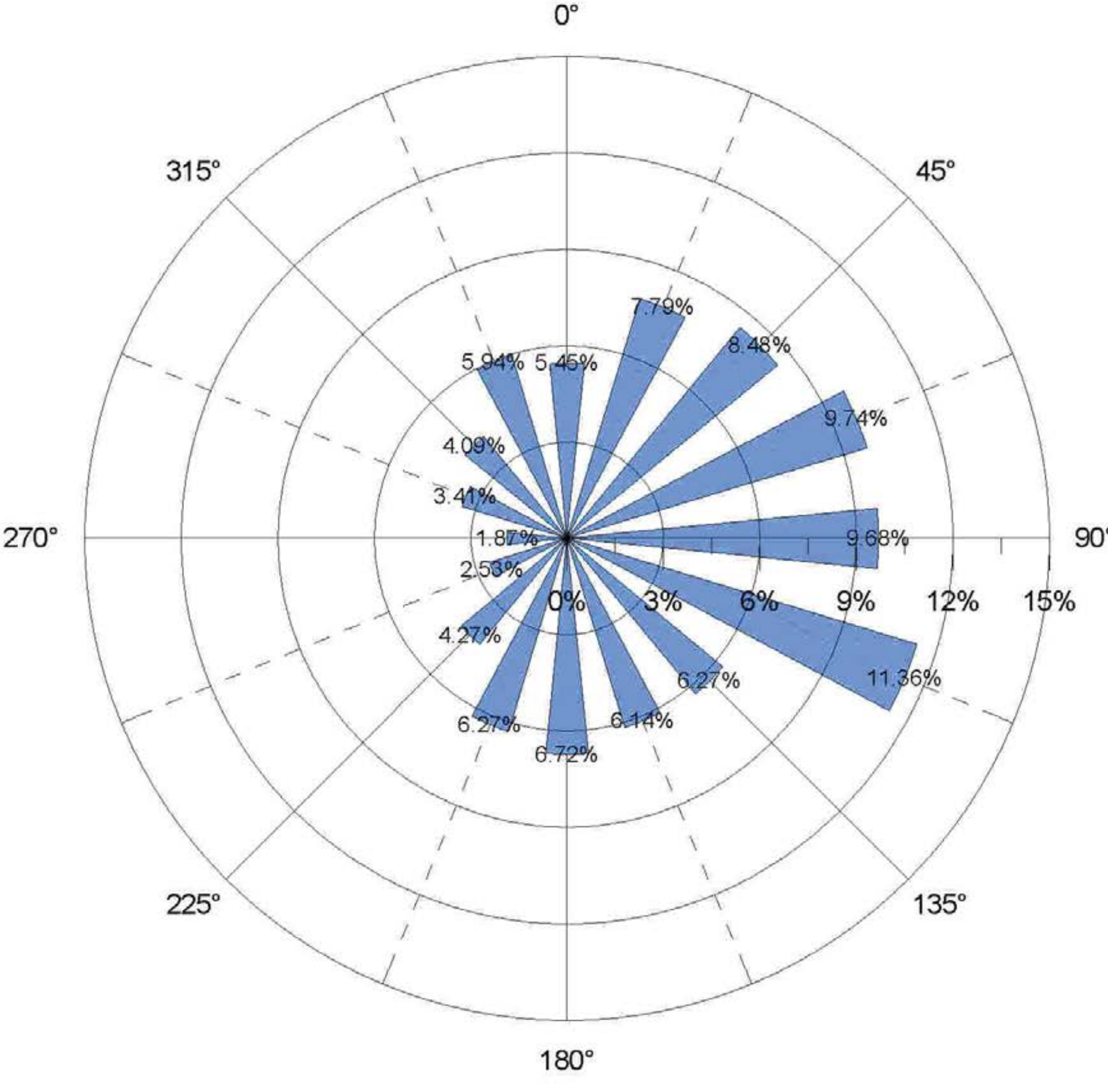
Seabrook Station Trajectories



COMMENTS:	MODELING OPTIONS:		
Figure 13 Trajectory Frequency Distribution 500 meter height 40 mile downwind	2005 CALMET Wind Fields		Epsilon ASSOCIATES INC.
	OUTPUT TYPE: FREQ		
	UNITS: Count	DATE: July 20, 2012	PROJECT NO.: 3396

PROJECT TITLE:

Seabrook Station Trajectories



COMMENTS:	MODELING OPTIONS:		
Figure 14 Trajectory Frequency Distribution 500 meter height 50 mile downwind	2005 CALMET Wind Fields OUTPUT TYPE: FREQ		Epsilon ASSOCIATES INC.
	UNITS: Count	DATE: July 20, 2012	PROJECT NO.: 3396

URS

ATTACHMENT 4

URS-PS-TR-13-0003

Exposure Index Study Using MACCS2 and CALMET: A Sensitivity Study Supporting the Seabrook Station SAMA Analysis

Revision 0

March 2013

Revision History

Revision	Date	Major Change(s)
0	March 2013	Original Issue

Exposure Index Study Using MACCS2 and CALMET:

A Sensitivity Study Supporting the Seabrook Station SAMA Analysis

Executive Summary

The Exposure Index is a metric used by the U.S. Nuclear Regulatory Commission in the Generic Environmental Impact Statement for License Renewal of Nuclear Plants, and is applied in the assessment of future plant operation risk impacts from atmospheric release pathways. In a License Renewal Application's Severe Accident Mitigation Alternatives (SAMA) analysis, two of the metrics of interest are annual- and spatially-averaged consequences, the offsite population dose and the offsite economic consequences, that are dependent on wind-directed radiological exposures to the population distributed in a 50-mile radius domain around the subject plant. The Exposure Index (EI) is calculated in the present study as a surrogate for the SAMA analysis metrics to better understand the sensitivity of using localized wind trajectories throughout the 50-mile radius domain around the Seabrook Station, as compared to a single set of annual wind trajectories based on measurements for the Seabrook Station site. For this analysis, the single set of wind trajectories is based on the 2005 annual wind rose for the Seabrook Station as processed by Version 1.13.1 of the MACCS2 computer model, and the localized trajectory roses are calculated using the Version 5 of the CALMET model.

Using the same population distribution projected to the year 2050 for the fifty-mile spatial domain around the Seabrook Station, the total EI is calculated for three cases: 1) the MACCS2-based wind rose; 2) the CALMET-based 500 m trajectory rose; and 3) the CALMET-based 100 m trajectory rose. The Case 1, MACCS2-based EI, is calculated to be 198,080. The two CALMET-based EIs are nearly the same, with the 100-m EI being about one percent larger than the 500-m EI, and both are larger than that based on data from the Seabrook Station. The total EI based on the CALMET trajectory roses for the 500-m elevation is equal to 265,314, or approximately 34% larger than the MACCS2, single location-based EI. The total EI based on the CALMET trajectory roses for the 100-m elevation is equal to 266,641, or 35% larger than the MACCS2-based EI (198,080). The source of this difference is largely due to the Seabrook Station wind rose for the South by Southwest (SSW) direction compared to the multiple-station trajectory rose.

Table of Contents

1. Introduction

The Exposure Index (EI) is a metric used by the U.S. Nuclear Regulatory Commission (NRC) in the Generic Environmental Impact Statement (GEIS) for License Renewal of Nuclear Plants, and is applied in the assessment of future plant operation risk impacts from atmospheric release pathways (NUREG-1437, Vol. 1, page 5-19). As described in NUREG-1437, this pathway includes the exposure of individuals directly from the passage of the cloud of radioactive material released from an accident and from material deposited on the ground, as well as the longer-term effects from other terrestrial pathways such as through food ingestion of crops. The EI is a function of the population distribution surrounding the plant of interest weighted by the site-specific wind direction frequencies for the 16 different principal compass directions. Other factors, such as terrain, precipitation, and stability class may have some effect on these risks, but their impact is secondary.

In a nuclear power plant Severe Accident Mitigation Alternatives (SAMA) analysis, the two consequence metrics of interest are the off-site population dose and the off-site economic costs. Both of these two metrics are evaluated as mean annual consequences, i.e., using the mean or average of a distribution of possible results that vary in magnitude based on hourly data taken from a representative year of data from the plant site being evaluated. The calculated population- and spatially-averaged consequences are strongly dependent on wind-directed radiological exposures to the population distributed in a 50-mile radius spatial domain around the subject plant.

For the Seabrook Station SAMA analysis, meteorological data are taken from the year 2005 and the on-site tower. In the present SAMA analysis for the Seabrook Station, the MACCS2 computer code (SNL, 1998a and 1998b) based on a Gaussian plume segment atmospheric transport and dispersion (ATD) model, is applied to calculate off-site population dose and economic cost consequences in the 50-mile domain around Seabrook Station. In this report, the EI based on the single-site, Seabrook Station 2005 meteorological data is compared to an alternative basis using the CALMET model (Scire et al., 2000). The EIs calculated between MACCS2 and the alternative CALMET model can thus provide an approximate comparison of likely differences in SAMA analysis impacts if an alternative model were available. In other words, if population and regional economic characteristics are held constant, the relative change in EI, from the MACCS2-based SAMA wind rose in one case to the CALMET based trajectory rose case in the other will indicate the relative change in SAMA PDR and OECR that would result from if a CALMET-based, trajectory rose basis model was available for use with MACCS2.

The present analysis uses the Seabrook Station, single station calculated EI, i.e., that obtained from the processed meteorological Seabrook Station data for 2005 and the 2050 population distribution developed for the SAMA analysis (NextEra, 2011). This exposure index is compared to that obtained using the CALMET model (Hanna and Hendrick, 2013), specifically a set of trajectory rose data evaluated at the 100-m (Appendix C, Trajectory Roses for 100 m Elevation), and the 500-m (Appendix D, Trajectory Roses for 500 m Elevation) elevations for different sites within the same Seabrook Station 50-mile radius domain.

2. Methodology

For the Seabrook Station Plant exposure index analysis, the same methodology is followed as is described in NUREG-1437, Volume 1, where the exposure index is the product of the wind rose for sector i, interval j, and the population for the corresponding grid element in sector i, interval j.

$$\text{Exposure Index} = \sum_{i=1}^{16} \sum_{j=1}^{5} \text{Wind rose (sector i, interval j} \times \text{Population in grid element (sector i, interval j)}, \quad \text{(Eqn. 1)}$$

where i is the directional sector index that ranges from 1 to 16 denoting principal compass directions N, NNE, NE, ENE, E, ESE, SE, SSE, S, SSW, SW, WSW, W, WNW, NW, and NNW, and j is the 10-mile interval index that ranges from 1 to 5 for 0-10 miles, 10 miles to 20 miles, 20 miles to 30 miles, 30 miles to 40 miles, and 40 miles to 50 miles intervals, respectively.

The tables in this document support the exposure index calculation shown above using a Seabrook Station, single location-based method with one set of wind roses, and then using a set of CALMET, multiple location-based wind roses, or trajectory roses. In both the Seabrook Station analysis rand the CALMET analysis, the same population data are used in the EI calculation.

2.1 Population

The same population distribution is used in the exposure index analysis by both Seabrook Station-based and CALMET based methods. The population data are taken from pages76-79 of SBK-L-11001 (NextEra, 2011). Table 1 shows the population for the 50-mile radius around the Seabrook Station. Column 3 of Table 1 shows the population for each of the 16 wind direction sectors and column 4 shows the percentage of the total population within each of the 16 different wind direction sectors. The next five columns list population data for 80 polar grid elements composed of five ten-mile intervals (0-10 miles, 10 miles to 20 miles, 20 miles to 30 miles, 30 miles to 40 miles, and 40 miles to 50 miles) and 16 radial sectors of 22.5^{o} width center in each of the principal compass directions (N, NNE, NE, ENE, E, ESE, SE, SSE, S, SSW, SW, WSW, W, WNW, NW, and NNW). The last column gives the 20 – 50 mile population by sector. Summary statistics are given in the last row of Table 1 showing the percentage of population by 10-mile increment from 0 to 50 miles of the total population of 4,991,412.

2.2 Wind Rose and Trajectory Rose Data

Two sources of data were applied in the EI study as described in Section 1.2 of Hanna and Hendrick (2013). The first are the primary meteorological inputs to the Seabrook Station SAMA analysis calculations were the 2005 wind data from the 43 ft. (13.1 m) level onsite tower at the Seabrook Station. Additional measurements included the temperature difference between the 209 ft. (63.7 m) and 43 ft. (13.1 m) levels, plus the precipitation observations from a rain gauge near the base of the meteorological tower. The on-site meteorological tower is located about 100 m from the marsh and about 2 km from the ocean. The second set of data are from 31 National Climatic Data Center (NCDC) and other sites and are summarized in Table 1 of the trajectory roses study (Hanna and Hendrick, 2013)

3. Exposure Index Results

3.1 MACCS2-Based Calculation of Exposure Index

Table 2 shows the single, Seabrook Station-based wind rose and resulting exposure index calculation.[1] The first three columns contain the same index, polar direction, and total population by sector as Table 1. The fourth column shows the Seabrook Station wind rose as processed by the code after reading in 8,760 hours of Seabrook Station site-specific weather data at the 13.1-m height including wind direction. The MACCS2 model processes all input data from 8,760 hourly records into a set of annual wind direction frequencies, shown in the fourth column, and is based on Seabrook Station data for the 2005 calendar year. The fifth through ninth column contain the EI product of the wind rose (fourth column) for that sector and the population for the grid element, for that direction sector and that interval. For example, the fifth column lists the EI calculation for the 0 to 10-mile interval beginning with the N sector. The population of that sector and interval (Table 1) is 11,405 and this is multiplied by the wind rose for this sector and interval, which is 0.0251. The product is 11,405 x 0.0251 = 286 persons. The process continues for each of 16 direction sectors for the 0 to 10-mile interval and the outcome listed in the fifth column. The sum for this column is 14,000 persons.[2] The process continues for the next four intervals of 10 to 20 miles (sixth column), 20 to 30 miles (seventh column), 30 to 40 miles (eighth column), and 40 to 50 miles (ninth column). The corresponding interval sums by interval are: 19,827 (10-20 miles), 47,621 (20-30 miles), 63,549 (30-40 miles), and 53,083 (40-50 miles). The total EI for the MACCS2-based calculation is 198,080, with percentages of the five intervals shown in the last line of Table 2.

Table 2's final column indicates the component of the EI made up of the population in the 20 to 50 mile region of the SAMA analysis by principal direction. The EI of this region, 164,253 is about 83% of the total EI of 198,080.

3.2 CALMET-Based Calculation of Exposure Index

Two sets of CALMET data were used to obtain two separate calculations of the EI based, i.e., one specific to the 500-m elevation and another specific to the 100-m elevation. Tables 3 and 4 show the information used in the trajectory rose input data processing and subsequent output for the EI analysis specific to the <u>500-m</u> elevation. Tables 5 and 6 show the information used in the trajectory rose input data processing and subsequent output for the EI analysis specific to the <u>100-m</u> elevation. The basis calculation performed again uses Eqn. 1, with the exception of the trajectory rose term being substituted for the wind rose term for interval i, and sector j.

[1] Although referred to as the "MACCS2-based wind rose" this wind rose is actually what is observed from the 43-ft (13.1 m) meteorological data at the Seabrook Station.
[2] For the remainder of this report, persons as the unit of the exposure index is implied, and will be omitted in text and tables to improve the readability.

3.2.1 CALMET-based Exposure Index at 500 m

The CALMET-based calculation of the exposure index uses the same population distribution (Table 1) as does the MACCS2-based EI analysis but incorporates additional, finer resolution measures of wind directions provided by the trajectory roses. Before applying the CALMET trajectory roses to the five-interval, 16-sector population grid an averaging process is used. CALMET trajectory roses are averaged for the 10-mile interval in question as follows:

- 0 – 10 mile interval: wind trajectories at 1 mile, 2 miles, 3 miles, 4 miles, 5 miles, 6 miles, 7 miles, 8 miles, 9 miles, and 10 miles (The 0 to 10 mile range is the only one where trajectory roses are available every 1-mile increment).
- 10 – 20 mile interval: wind trajectories at 10 miles and 20 miles
- 20 – 30 mile interval; wind trajectories at 20 miles and 30 miles
- 30 – 40 mile interval; wind trajectories at 30 miles and 40 miles; and
- 40 – 50 mile interval; wind trajectories at 40 miles and 50 miles.

The first set of CALMET trajectory rose data are for the 500-m elevation and are taken from Appendix E of Hanna and Hendrick (2013). The data for 1 mile, 2 miles, 3 miles, 4 miles, 5 miles, 6 miles, 7 miles, 8 miles, 9 miles, and 10 miles are listed by direction in Table 3. The 0 to 10 mile interval average by direction is shown in the row with the label, "0-10 ave.". For example, the ten entries under the North direction are summed and divided by 10 to yield the 0 – 10 mile interval average of 0.0500. Other direction averages for this interval follow from NNE through NNW.

The 10 - 20 mile interval averages are then computed by averaging the trajectory roses at 10 miles and 20 miles. For example, for the North direction, the 10-mile and 20-mile trajectory roses are 0.0566 and 0.0586, respectively, are averaged to obtain the value of 0.0.0576. Other values for this same interval are calculated in the same manner for each direction and the results are listed in the row "10-20 ave.". The same process is repeated for the 20- and 30-mile, the 30- and 40-mile, and 40- and 50-mile trajectory roses to obtain trajectory rose interval averages for the 20 – 30 mile, 30 – 40 mile, and 40 – 50 miles intervals, that are listed in rows with the labels of "20-30 ave.", "30-40 ave." and "40-50 ave.", respectively.

The five rows of direction-specific, ten-mile interval average trajectory rose data ("0-10 ave.", "10-20 ave.", "20-30 ave.", "30-40 ave." and "40-50 ave.") are carried forward into the following table (Table 4) as the fourth column (CALMET average of 1-, 2-, 3-, 4-, 5-, 6-, 7-, 8-, 9-, and 10-mile trajectory roses), sixth column (CALMET average of 10-mile and 20-mile trajectory rose), eighth column (CALMET average of 20-mile and 30-mile trajectory rose), tenth column (CALMET average of 30-mile and 40-mile trajectory rose), and twelfth column (CALMET average of 40-mile and 50-mile trajectory rose) for calculation of the exposure index based on the 500-m elevation CALMET trajectory rose data. The same Equation 1 product of trajectory rose (for that sector and interval) and population from Table 1 (for the same sector and interval) was taken for the CALMET case as was performed for the MACCS2 wind rose by ten-mile interval for the following intervals: 1.) 0 to 10 miles Population Exposure Index (fifth column), 10 miles to 20 miles Population Exposure Index (seventh column), 20 miles to 30 miles Population Exposure Index (ninth column), 30 miles to 40 miles Population Exposure Index, and thirteenth column (40 miles to 50 miles Population Exposure Index). For example, for the North direction in the 40- to 50-mile interval, the trajectory rose is 0.1123 and the population from Table 1 is 80,474, with the product then being

0.1123 x 80,474 = 9,033. This process is completed for all 16 directions for each ten-mile interval. The final exposure indices by ten-mile interval are listed in the Total Exposure Index row in Table 4 and are:

0 – 10 miles EI:	14,783
10 – 20 miles EI:	21,142
20 – 30 miles EI:	53,068
30 – 40 miles EI:	88,506
40 – 50 miles EI:	87,815.

The total EI based on the CALMET trajectory roses is the sum of these five interval EIs and is equal to 265,314. This is larger by the Seabrook Station, MACCS2-based EI (198,080) by 33.9%. This ratio is shown at the bottom of Table 4 as well as the (CALMET EI)/(MACCS2 EI) ratio by ten-mile intervals, and are shown in the row with the label, "CALMET/MACCS2 Ratio for Interval".

3.2.2 CALMET-based Exposure Index at 100 m

The second set of CALMET trajectory rose data are for the 100-m elevation and are taken from Appendix C of Hanna and Hendrick (2013). The data for 1 mile, 2 miles, 3 miles, 4 miles, 5 miles, 6 miles, 7 miles, 8 miles, 9 miles, and 10 miles are listed by direction in Table 5. The 0 to 10 mile interval average by direction is shown in the row with the label, "0-10 ave.". For example, the ten entries under the North direction are summed and divided by 10 to yield the 0 – 10 mile interval average of 0.0441. Other direction averages for this interval follow from NNE through NNW.

The 10 - 20 mile interval averages are then computed by averaging the trajectory roses at 10 miles and 20 miles. For example, for the North direction, the 10-mile and 20-mile trajectory roses are 0.0443 and 0.0503, respectively are averaged to obtain the value of 0.0474. Other values for this same interval are calculated in the same manner for each direction and the results are listed in the row "10-20 ave.". The same process is repeated for the 20- and 30-mile, the 30- and 40-mile, and 40- and 50-mile trajectory roses to obtain trajectory rose interval averages for the 20 – 30 mile, 30 – 40 mile, and 40 – 50 miles intervals, that are listed in rows with the labels of "20-30 ave.", "30-40 ave." and "40-50 ave.", respectively.

The five rows of direction-specific, ten-mile interval average trajectory rose data ("0-10 ave.", "10-20 ave.", "20-30 ave.", "30-40 ave." and "40-50 ave.") are carried forward into the following table (Table 6) as the fourth column (CALMET average of 1-, 2-, 3-, 4-, 5-, 6-, 7-, 8-, 9-, and 10-mile trajectory roses), sixth column (CALMET average of 10-mile and 20-mile trajectory rose), eighth column (CALMET average of 20-mile and 30-mile trajectory rose), tenth column (CALMET average of 30-mile and 40-mile trajectory rose), and twelfth column (CALMET average of 40-mile and 50-mile trajectory rose) for calculation of the exposure index based on the 500-m elevation CALMET trajectory rose data. The same Equation 1 product of trajectory rose (for that sector and interval) and population from Table 1 (for the same sector and interval) was calculated for the CALMET 100-m elevation case as was performed for the CALMET 500-m trajectory rose by ten-mile interval for the following intervals: 1.) 0 to 10 miles Population Exposure Index (fifth column), 10 miles to 20 miles Population Exposure Index (seventh column), 20 miles to 30 miles Population Exposure Index (ninth column), 30 miles to 40 miles Population Exposure Index, and thirteenth column (40 miles to 50 miles Population Exposure Index). For example, for the North direction in

the 40- to 50-mile interval, the trajectory rose is 0.0634 and the population from Table 1 is 14,999, with the product then being 0.0634 x 14,999 = 951. This process is completed for all 16 directions for each ten-mile interval. The final exposure indices by ten-mile interval are listed in the Total Exposure Index row in Table 6 and are:

0 – 10 miles EI:	14,773
10 – 20 miles EI:	23,696
20 – 30 miles EI:	57,623
30 – 40 miles EI:	86,226
40 – 50 miles EI:	84,323.

The total EI based on the CALMET trajectory roses is the sum of these five interval EIs and is equal to 266,641. This is larger by the MACCS2-based EI (198,080) by 34.6%. This ratio is shown at the bottom of Table 6 as well as the (CALMET EI)/(MACCS2 EI) ratio by ten-mile intervals, and are shown in the row with the label, “CALMET/MACCS2 Ratio for Interval”.

4. Result Summary and Conclusions

Using the same population distribution for the fifty-mile spatial domain around the Seabrook Station in each case, the total EI is calculated using the single, Seabrook Station-based wind rose, the CALMET-based 500 m trajectory roses, and the CALMET-based 100 m trajectory roses. The Seabrook Station-based EI is calculated to be 198,080. The total EI based on the CALMET trajectory roses for the 500-m elevation is equal to 265,314, or larger than the Seabrook Station-based EI by nearly 34% (33.9%). The total EI based on the CALMET trajectory roses for the 100-m elevation is equal to 266,641, or larger than the Seabrook Station-based EI by nearly 35% (34.6%). In comparing the two CALMET EI results, they are remarkably close, i.e., within approximately one percent (0.7%) of each other.

The chief reason for the difference appears to be the relatively lower wind direction fraction towards the south by southwest (SSW) direction in the single station Seabrook Station wind rose compared to other stations included in the SAMA analysis domain for either the 500-m or 100-m elevation. This is the highest population sector in the 50-mile SAMA analysis domain from the Seabrook Station and therefore a factor or two to three difference in the trajectory rose to wind rose ratio has an appreciable influence in the overall EI result.

While either CALMET set of results is about the same difference compared to that obtained with the single, Seabrook Station-based set results, the 500-m elevation results provided by CALMET are judged to be a better comparison over those calculated for the 100-m elevation, also with CALMET. This is because most atmospheric plumes released from the Seabrook Station will mix vertically as they move downwind and generally will extend to the full mixing layer height after twenty miles of travel downwind where most of the population is found in the 50-mile domain around the Seabrook Station site. Thus, the CALMET 500 m result is more appropriate as a mid-plume height basis than 100-m basis elevation for the trajectory roses.

Table 1. Population Distribution Used in the Seabrook Station SAMA Analysis

Index	Direction	Total Population by Sector	Sector Population as Percentage of Total	0 to 10 mile Population	10 miles to 20 mile	20 miles to 30 miles	30 miles to 40 miles	40 miles to 50 miles	20 to 50 mile Sector Population
1	N	153,558	3.08%	11,405	25,561	64,004	37,589	14,999	116,592
2	NNE	182,805	3.66%	24,257	47,033	16,372	29,567	65,576	111,515
3	NE	16,170	0.32%	13,919	1,562	498	1	190	689
4	ENE	21,292	0.43%	21,292	0	0	0	0	0
5	E	6,076	0.12%	6,076	0	0	0	0	0
6	ESE	7,227	0.14%	7,227	0	0	0	0	0
7	SE	12,099	0.24%	3,677	3,265	5,157	0	0	5,157
8	SSE	76,349	1.53%	33,393	8,618	34,338	0	0	34,338
9	S	575,775	11.54%	15,871	30,269	242,194	69,289	218,152	529,635
10	SSW	2,030,003	40.67%	21,296	31,868	154,381	942,784	879,674	1,976,839
11	SW	691,294	13.85%	19,171	104,555	272,808	163,980	130,780	567,568
12	WSW	414,291	8.30%	20,034	75,952	88,542	170,127	59,636	318,305
13	W	318,608	6.38%	13,985	32,733	94,038	140,850	37,002	271,890
14	WNW	253,972	5.09%	6,075	23,826	30,253	139,943	53,875	224,071
15	NW	109,710	2.20%	19,450	12,859	11,298	28,890	37,213	77,401
16	NNW	122,183	2.45%	10,962	36,792	36,455	22,046	15,928	74,429
Total Population		4,991,412	100.00%	248,090	434,893	1,050,338	1,745,066	1,513,025	4,991,412
									4,308,429
		Percent of Total Population		5.0%	8.7%	21.0%	35.0%	30.3%	100.0%
		4,991,412					20 - 50 mile population	86.3%	

Table 2. MACCS2-Based Wind Rose and Exposure Index

Index	Direction	Total Population by Sector	MACCS2 Wind Rose	0 to 10 miles Population Exposure Index	10 miles to 20 miles Population Exposure Index	20 miles to 30 miles Population Exposure Index	30 miles to 40 miles Population Exposure Index	40 miles to 50 miles Population Exposure Index	20 to 50 mile Population Exposure Index
1	N	153,558	0.0251	286	642	1,607	943	376	2,926
2	NNE	182,805	0.0387	939	1,820	634	1,144	2,538	4,316
3	NE	16,170	0.0787	1,095	123	39	0	15	54
4	ENE	21,292	0.1120	2,385	0	0	0	0	0
5	E	6,076	0.1086	660	0	0	0	0	0
6	ESE	7,227	0.1465	1,059	0	0	0	0	0
7	SE	12,099	0.0991	364	324	511	0	0	511
8	SSE	76,349	0.0461	1,539	397	1,583	0	0	1,583
9	S	575,775	0.0421	668	1,274	10,196	2,917	9,184	22,298
10	SSW	2,030,003	0.0274	584	873	4,230	25,832	24,103	54,165
11	SW	691,294	0.0602	1,154	6,294	16,423	9,872	7,873	34,168
12	WSW	414,291	0.0497	996	3,775	4,401	8,455	2,964	15,820
13	W	318,608	0.0586	820	1,918	5,511	8,254	2,168	15,933
14	WNW	253,972	0.0291	177	693	880	4,072	1,568	6,520
15	NW	109,710	0.0493	959	634	557	1,424	1,835	3,816
16	NNW	122,183	0.0288	316	1,060	1,050	635	459	2,144
Total Population		4,991,412							
Total Exposure Index		**198,080**	1.0000	14,000	19,827	47,621	63,549	53,083	164,253
Percentage of Total Exposure				7.1%	10.0%	24.0%	32.1%	26.8%	82.9%
								100.0%	

Table 3. CALMET Trajectory Rose by Direction and Distance (Based on 500-m elevation)

Distance or Ave.	Trajectory Rose at Distance																
	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Total
1 mile	0.0000	0.0000	0.0832	0.0895	0.0986	0.1132	0.0675	0.0591	0.0639	0.0604	0.0432	0.0313	0.0240	0.0312	0.0474	0.0524	0.8649
2 miles	0.0555	0.0791	0.0830	0.0895	0.0987	0.1126	0.0676	0.0590	0.0638	0.0604	0.0435	0.0313	0.0248	0.0311	0.0478	0.0524	1.0001
3 miles	0.0550	0.0796	0.0829	0.0892	0.0985	0.1122	0.0674	0.0589	0.0637	0.0608	0.0437	0.0309	0.0247	0.0320	0.0477	0.0529	1.0001
4 miles	0.0551	0.0798	0.0821	0.0888	0.0985	0.1126	0.0676	0.0584	0.0639	0.0606	0.0436	0.0307	0.0255	0.0321	0.0470	0.0537	1.0000
5 miles	0.0558	0.0805	0.0818	0.0881	0.0982	0.1131	0.0663	0.0591	0.0636	0.0610	0.0435	0.0309	0.0251	0.0324	0.0471	0.0533	0.9998
6 miles	0.0555	0.0811	0.0824	0.0878	0.0974	0.1130	0.0664	0.0591	0.0639	0.0608	0.0438	0.0312	0.0240	0.0328	0.0469	0.0539	1.0000
7 miles	0.0553	0.0806	0.0828	0.0877	0.0982	0.1128	0.0664	0.0587	0.0637	0.0615	0.0434	0.0313	0.0235	0.0326	0.0470	0.0546	1.0001
8 miles	0.0556	0.0811	0.0822	0.0881	0.0977	0.1124	0.0662	0.0586	0.0639	0.0622	0.0435	0.0304	0.0229	0.0337	0.0468	0.0547	1.0000
9 miles	0.0558	0.0813	0.0823	0.0869	0.0981	0.1122	0.0660	0.0584	0.0643	0.0621	0.0426	0.0314	0.0228	0.0342	0.0461	0.0555	1.0000
10 miles	0.0566	0.0818	0.0818	0.0872	0.0974	0.1120	0.0658	0.0587	0.0644	0.0616	0.0434	0.0304	0.0223	0.0345	0.0463	0.0558	1.0000
0-10 ave.	0.0500	0.0725	0.0825	0.0883	0.0981	0.1126	0.0667	0.0588	0.0639	0.0611	0.0434	0.0310	0.0240	0.0327	0.0470	0.0539	0.9865
10 miles	0.0566	0.0818	0.0818	0.0872	0.0974	0.1120	0.0658	0.0587	0.0644	0.0616	0.0434	0.0304	0.0223	0.0345	0.0463	0.0558	1.0000
20 miles	0.0586	0.0813	0.0845	0.0860	0.0973	0.1121	0.0634	0.0591	0.0645	0.0627	0.0437	0.0299	0.0207	0.0344	0.0430	0.0590	1.0002
10-20 ave.	0.0576	0.0816	0.0832	0.0866	0.0974	0.1121	0.0646	0.0589	0.0645	0.0622	0.0436	0.0302	0.0215	0.0345	0.0447	0.0574	1.0001
20 miles	0.0586	0.0813	0.0845	0.0860	0.0973	0.1121	0.0634	0.0591	0.0645	0.0627	0.0437	0.0299	0.0207	0.0344	0.0430	0.0590	1.0002
30 miles	0.0550	0.0806	0.0836	0.0909	0.0977	0.1122	0.0618	0.0606	0.0679	0.0595	0.0446	0.0277	0.0202	0.0355	0.0425	0.0597	1.0000
20-30 ave.	0.0568	0.0810	0.0841	0.0885	0.0975	0.1122	0.0626	0.0599	0.0662	0.0611	0.0442	0.0288	0.0205	0.0350	0.0428	0.0594	1.0001
30 miles	0.0550	0.0806	0.0836	0.0909	0.0977	0.1122	0.0618	0.0606	0.0679	0.0595	0.0446	0.0277	0.0202	0.0355	0.0425	0.0597	1.0000
40 miles	0.0554	0.0774	0.0863	0.0922	0.0991	0.1118	0.0643	0.0582	0.0677	0.0623	0.0427	0.0271	0.0189	0.0339	0.0435	0.0592	1.0000
30-40 ave.	0.0552	0.0790	0.0850	0.0916	0.0984	0.1120	0.0631	0.0594	0.0678	0.0609	0.0437	0.0274	0.0196	0.0347	0.0430	0.0595	1.0000
40 miles	0.0554	0.0774	0.0863	0.0922	0.0991	0.1118	0.0643	0.0582	0.0677	0.0623	0.0427	0.0271	0.0189	0.0339	0.0435	0.0592	1.0000
50 miles	0.0545	0.0779	0.0848	0.0974	0.0968	0.1136	0.0627	0.0614	0.0672	0.0627	0.0427	0.0253	0.0187	0.0341	0.0409	0.0594	1.0001
40-50 ave.	0.05495	0.07765	0.08555	0.0948	0.09795	0.1127	0.0635	0.0598	0.06745	0.0625	0.0427	0.0262	0.0188	0.034	0.0422	0.0593	1.0001

Table 4. CALMET -Based Exposure Index (Based on 500-m elevation data)

Index	Direction	Total Population by Sector	CALMET average of 1-, 2-, 3-, 4-, 5-, 6-, 7-, 8-, 9-, and 10-mile trajectory roses	0 to 10 miles Population Exposure Index	CALMET average of 10-mile and 20-mile trajectory rose	10 miles to 20 miles Population Exposure Index	CALMET average of 20-mile and 30-mile trajectory rose	20 miles to 30 miles Population Exposure Index	CALMET average of 30-mile and 40-mile trajectory rose	30 miles to 40 miles Population Exposure Index	CALMET average of 40-mile and 50-mile trajectory rose	40 miles to 50 miles Population Exposure Index
1	N	153,558	0.0500	570	0.0576	1,472	0.0568	3,635	0.0552	2,075	0.0550	824
2	NNE	182,805	0.0725	1,758	0.0816	3,836	0.0810	1,325	0.0790	2,336	0.0777	5,092
3	NE	16,170	0.0825	1,148	0.0832	130	0.0841	42	0.0850	0	0.0856	16
4	ENE	21,292	0.0883	1,880	0.0866	0	0.0885	0	0.0916	0	0.0948	0
5	E	6,076	0.0981	596	0.0974	0	0.0975	0	0.0984	0	0.0980	0
6	ESE	7,227	0.1126	814	0.1121	0	0.1122	0	0.1120	0	0.1127	0
7	SE	12,099	0.0667	245	0.0646	211	0.0626	323	0.0631	0	0.0635	0
8	SSE	76,349	0.0588	1,964	0.0589	508	0.0599	2,055	0.0594	0	0.0598	0
9	S	575,775	0.0639	1,014	0.0645	1,951	0.0662	16,033	0.0678	4,698	0.0675	14,714
10	SSW	2,030,003	0.0611	1,302	0.0622	1,981	0.0611	9,433	0.0609	57,416	0.0625	54,980
11	SW	691,294	0.0434	832	0.0436	4,553	0.0442	12,044	0.0437	7,158	0.0427	5,584
12	WSW	414,291	0.0310	621	0.0302	2,290	0.0288	2,550	0.0274	4,661	0.0262	1,562
13	W	318,608	0.0240	335	0.0215	704	0.0205	1,923	0.0196	2,754	0.0188	696
14	WNW	253,972	0.0327	198	0.0345	821	0.0350	1,057	0.0347	4,856	0.0340	1,832
15	NW	109,710	0.0470	914	0.0447	574	0.0428	483	0.0430	1,242	0.0422	1,570
16	NNW	122,183	0.0539	591	0.0574	2,112	0.0594	2,164	0.0595	1,311	0.0593	945
		4,991,412										
Total Exposure Index		265,314	0.9865	14,783	1.0001	21,142	1.0001	53,068	1.0000	88,506	1.00005	87,815
MACCS2 EI (Table 2)		198,080		14,000		19,827		47,621		63,549		53,083
Interval				1.056		1.066		1.114		1.393		1.654
(CALMET EI)/ (MACCS2 EI)		**1.34**		**33.9%**								

Table 5. CALMET Trajectory Rose by Direction and Distance (Based on 100-m elevation)

N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Total
0.0439	0.0725	0.0775	0.0811	0.0873	0.1261	0.0734	0.0484	0.0607	0.0470	0.0650	0.0444	0.0322	0.0358	0.0532	0.0514	0.9999
0.0435	0.0725	0.0776	0.0813	0.0871	0.1260	0.0733	0.0486	0.0606	0.0470	0.0650	0.0438	0.0324	0.0360	0.0537	0.0516	0.9998
0.0439	0.0724	0.0775	0.0813	0.0871	0.1258	0.0731	0.0485	0.0607	0.0473	0.0650	0.0438	0.0328	0.0357	0.0540	0.0511	1.0002
0.0437	0.0723	0.0776	0.0807	0.0870	0.1258	0.0725	0.0490	0.0607	0.0468	0.0652	0.0436	0.0336	0.0354	0.0545	0.0517	1.0000
0.0443	0.0734	0.0779	0.0792	0.0878	0.1253	0.0718	0.0490	0.0608	0.0465	0.0650	0.0439	0.0332	0.0365	0.0541	0.0513	0.9999
0.0446	0.0734	0.0788	0.0784	0.0872	0.1252	0.0712	0.0490	0.0607	0.0468	0.0646	0.0450	0.0326	0.0366	0.0539	0.0518	0.9999
0.0441	0.0743	0.0793	0.0779	0.0869	0.1248	0.0709	0.0483	0.0612	0.0476	0.0648	0.0447	0.0317	0.0374	0.0532	0.0529	0.9999
0.0441	0.0756	0.0796	0.0774	0.0864	0.1247	0.0710	0.0477	0.0608	0.0479	0.0652	0.0444	0.0309	0.0372	0.0538	0.0533	1.0000
0.0444	0.0752	0.0801	0.0779	0.0864	0.1240	0.0704	0.0470	0.0615	0.0482	0.0652	0.0435	0.0311	0.0376	0.0534	0.0541	1.0000
0.0443	0.0748	0.0811	0.0769	0.0862	0.1233	0.0712	0.0463	0.0623	0.0478	0.0659	0.0429	0.0306	0.0370	0.0537	0.0557	1.0002
0.0441	0.0736	0.0787	0.0792	0.0869	0.1251	0.0719	0.0482	0.0610	0.0473	0.0651	0.0440	0.0321	0.0365	0.0538	0.0525	1.0000
0.0443	0.0748	0.0811	0.0769	0.0862	0.1233	0.0712	0.0463	0.0623	0.0478	0.0659	0.0429	0.0306	0.037	0.0537	0.0557	1.0000
0.0503	0.0765	0.0781	0.0789	0.0841	0.1178	0.0739	0.0487	0.0613	0.0509	0.0677	0.0401	0.0264	0.0328	0.0524	0.0602	1.0001
0.0473	0.0757	0.0796	0.0779	0.0852	0.1206	0.0726	0.0475	0.0618	0.0494	0.0668	0.0415	0.0285	0.0349	0.0531	0.0580	1.0001
0.0503	0.0765	0.0781	0.0789	0.0841	0.1178	0.0739	0.0487	0.0613	0.0509	0.0677	0.0401	0.0264	0.0328	0.0524	0.0602	1.0001
0.0575	0.0771	0.0744	0.0785	0.0848	0.1137	0.0769	0.0498	0.0631	0.0508	0.0662	0.0377	0.0242	0.0320	0.0510	0.0622	0.9999
0.0539	0.0768	0.0763	0.0787	0.0845	0.1158	0.0754	0.0493	0.0622	0.0509	0.0670	0.0389	0.0253	0.0324	0.0517	0.0612	1.0000
0.0575	0.0771	0.0744	0.0785	0.0848	0.1137	0.0769	0.0498	0.0631	0.0508	0.0662	0.0377	0.0242	0.0320	0.0510	0.0622	0.9999
0.0629	0.0807	0.0717	0.0763	0.0836	0.1137	0.0739	0.0532	0.0632	0.0545	0.0624	0.037	0.0234	0.0332	0.0483	0.0621	1.0001
0.0602	0.0789	0.0731	0.0774	0.0842	0.1137	0.0754	0.0515	0.0632	0.0527	0.0643	0.0374	0.0238	0.0326	0.0497	0.0622	1.0000
0.0629	0.0807	0.0717	0.0763	0.0836	0.1137	0.0739	0.0532	0.0632	0.0545	0.0624	0.037	0.0234	0.0332	0.0483	0.0621	1.0001
0.0639	0.0817	0.0696	0.0735	0.0874	0.1082	0.0747	0.0565	0.0623	0.0561	0.062	0.0338	0.0235	0.0333	0.0468	0.0666	0.9999
0.0634	0.0812	0.07065	0.0749	0.0855	0.11095	0.0743	0.05485	0.06275	0.0553	0.0622	0.0354	0.02345	0.03325	0.04755	0.0644	1.0000

Table 6. CALMET -Based Exposure Index (Based on 100-m elevation data)

Index	Direction	Total Population by Sector	CALMET average of 1-, 2-, 3-, 4-, 5-, 6-, 7-, 8-, 9-, and 10-mile trajectory rose	0 to 10 mile Population Exposure Index	CALMET average of 10-mile and 20-mile trajectory rose	10 miles to 20 mile Population Exposure Index	CALMET average of 20-mile and 30-mile trajectory rose	20 miles to 30 mile Population Exposure Index	CALMET average of 30-mile and 40-mile trajectory rose	30 miles to 40 miles Population Exposure Index	CALMET average of 40-mile and 50-mile trajectory rose	40 miles to 50 miles Population Exposure Index
1	N	153,558	0.0441	503	0.0473	1,209	0.0539	3,450	0.0602	2,263	0.0634	951
2	NNE	182,805	0.0736	1,786	0.0757	3,558	0.0768	1,257	0.0789	2,333	0.0812	5,325
3	NE	16,170	0.0787	1,095	0.0796	124	0.0763	38	0.0731	0	0.0707	13
4	ENE	21,292	0.0792	1,687	0.0779	0	0.0787	0	0.0774	0	0.0749	0
5	E	6,076	0.0869	528	0.0852	0	0.0845	0	0.0842	0	0.0855	0
6	ESE	7,227	0.1251	904	0.1206	0	0.1158	0	0.1137	0	0.1110	0
7	SE	12,099	0.0719	264	0.0726	237	0.0754	389	0.0754	0	0.0743	0
8	SSE	76,349	0.0482	1,609	0.0475	409	0.0493	1,691	0.0515	0	0.0549	0
9	S	575,775	0.0610	968	0.0618	1,871	0.0622	15,064	0.0632	4,376	0.0628	13,689
10	SSW	2,030,003	0.0473	1,007	0.0494	1,573	0.0509	7,850	0.0527	49,638	0.0553	48,646
11	SW	691,294	0.0651	1,248	0.0668	6,984	0.0670	18,264	0.0643	10,544	0.0622	8,135
12	WSW	414,291	0.0440	881	0.0415	3,152	0.0389	3,444	0.0374	6,354	0.0354	2,111
13	W	318,608	0.0321	449	0.0285	933	0.0253	2,379	0.0238	3,352	0.0235	868
14	WNW	253,972	0.0365	222	0.0349	832	0.0324	980	0.0326	4,562	0.0333	1,791
15	NW	109,710	0.0538	1,045	0.0531	682	0.0517	584	0.0497	1,434	0.0476	1,769
16	NNW	122,183	0.0525	575	0.0580	2,132	0.0612	2,231	0.0622	1,370	0.0644	1,025
		4,991,412										
Total Exposure		**266,641**	1.0000	14,773	1.0001	23,696	1.0000	57,623	1.0000	86,226	1.0000	84,323
MACCS2 EI		**198,080**		14,000		19,827		47,621		63,549		53,083
(CALMET EI)/(MACCS2 EI) Ratio for Interval				1.055		1.195		1.210		1.357		1.589
(CALMET EI)/ (MACCS2 EI)		**1.35**		**34.6%**								

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