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Analysis of Meteorological Data from Three Sites in the Northeastern United States for Application of EPA AIRDOS Code

Frank Gouveia

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MASTER

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Abstract

Meteorological data for the entire year of 1989 were collected at three sites that comprise the Knolls Atomic Power Laboratory: Knolls site, Kesselring site, and Windsor site. These data are 15-min averages of wind speed, wind direction, standard deviation of wind direction, and temperature. Hourly averages were computed and used for all analysis. The Pasquill stability category was computed using procedures established by the Environmental Protection Agency. Joint frequency of wind speed, direction, and stability were computed and displayed as wind roses for each stability. The joint frequency tables are presented in the form that is appropriate as meteorological input for the AIRDOS-EPA dispersion model.

Keywords

Climatology, meteorological data, dispersion data, KAPL, stability class, joint-frequency diagrams, AIRDOS-EPA model.

Introduction

Fifteen-minute-average data were collected at three sites for the 1989 calendar year. The three sites are

Knolls site, 2 miles east of Schenectady, New York,
Kesselring site, 17 miles north of Schenectady, New York, and
Windsor site, in the town of Windsor, Connecticut.

These sites comprise the Knolls Atomic Power Laboratory (KAPL). Table 1 shows the locations and elevations of the three meteorological towers.

The data were collected using HANDAR 540 data-acquisition systems (DAS). Table 2 is a list of instruments used and their specifications. The instruments were placed at 20 m above ground level at Knolls, 10 and 43 m at Kesselring, and 30 m at Windsor. The 10-m level at Kesselring is well below the tree canopy and, therefore, should not be used for dispersion statistics. The analysis of the 10-m data is included in this paper for comparison with previous data from this level.

Table 1 -- Locations of the three KAPL sites.

Site	Longitude	Latitude	Elevation (m)
Knolls	73°52'00" W	42°49'24" N	103
Kesselring	73°56'54" W	43°02'27" N	143
Windsor	72°42'44" W	41°53'16" N	55

Table 2 -- Instruments used at KAPL towers.

Parameter	Instrument	Threshold	Accuracy	Other
Wind Speed	Three-cup Anemometer	0.5 m/s	±0.15 m/s	
Wind Direction	Wind Vane	0.5 m/s	±0.3°	Distance constant 4.5 m
Temperature	Thermistors	---	±0.1°C	

The instruments are polled once every second and averages are computed at 15-min intervals. The standard deviation of horizontal wind direction (σ_{θ}) is computed every 15 min also.

Topography

The Knolls site (2 miles east of Schenectady) is at the southeastern end of the Mohawk River Valley, and near the northern end of the Hudson River Valley, approximately 150 miles from the Atlantic coastline. The Kesselring site is approximately 17 miles north of the Knolls site. The Windsor site is located in the town of Windsor, Connecticut, and is near the middle of the Connecticut River Valley, approximately 5 miles north of the City of Hartford and 50 miles north of Long Island Sound. The general topography at all three sites is low rolling hills with grassy fields and forests of evergreen and deciduous trees. The towers are in clearings containing one- and two-story buildings. The Windsor tower is on the roof of a building. The Hudson and Connecticut Rivers flow from the north to south. The Mohawk River flows from northwest to southeast.

Data Recovery and Quality Check

KAPL personnel transferred the data to IBM-PC compatible ASCII files. Data recovery at the three sites was excellent. From one year of data collection at all three sites, just 1548 15-min averages are missing out of a total possible of 105,120 (1.5% missing). Most of the missing data (1440 data points) comes from the Knolls site, where the data for first 15 days of November are missing.

During the process of checking the quality of data, it was discovered that σ_θ values from Windsor were far too large. The cause of this problem was determined to be the improper calculation of σ_θ by the data-acquisition program in the HANDAR 540 DAS. The Windsor DAS contains version 6.1 of the acquisition program. This version is known to calculate σ_θ improperly. The DAS at Knolls also has version 6.1 of the program, but the σ_θ data do not seem to be as severely affected as the Windsor data. The Kesselring DAS was hit by lightning in August of 1988, so the DAS was replaced with one containing program version 6.9. This improved DAS program calculates σ_θ using an algorithm suggested by Yamartino (1984). Turner (1986) states that the method of estimation of σ_θ by Yamartino gives excellent results over the entire range of possible standard deviations 0° to 103.9° .

It was decided that the σ_θ data from Windsor site would not be used to calculate Pasquill stability class. The wind speed and direction data appear to be unaffected, so wind roses and joint frequency of occurrence of wind speed and direction were computed over all stability classes. Although at the Knolls site we used the same DAS program version as at the Windsor site, the problem with σ_θ was not as severe. The Knolls σ_θ data will be used to calculate Pasquill stability class.

Hourly Averages

Hourly averages were computed by the program HOURK (see appendix for source-code listing). This program was written following guidelines published by the U.S. Environmental Protection Agency (EPA) in EPA (1987). Wind speed and temperature were scalar averaged (equation 6.1.1 and 6.2.2 in EPA 1987). Wind direction was weighted with the wind speed and polar averaged (equation 6.1.14). The hourly value of σ_θ was computed by the root-mean-squared method (equation 6.1.10).

The wind direction and σ_θ should be disregarded during periods when the wind is less than the threshold speed of the anemometer (wind speed < 0.5 m/s). EPA (1987) recommends that the wind direction and σ_θ be taken from the latest non-calm measurement. This guideline was implemented while calculating the hourly averages.

Detail on Pasquill Stability Class Calculations

The hourly values of wind speed and σ_θ were entered into the subroutine SIGCATK (see appendix for listing), which calculates Pasquill stability class A through G according to EPA (1987). The method presented by EPA (1987) was changed to separate class F into classes F and G. The algorithm is often called the Modified Sigma Theta (MST) method and is based on an initial estimate of stability modified by time of day and wind speed (Tables 3 and 4). Unstable classes A through D-Day only occur during the daytime and the stable classes D-Night through G only occur during the night. Table 4 shows the modification of the initial estimate according to wind speed. The higher wind speeds force stability towards neutral. Table 3 gives the lower bounds of σ_θ classes to determine the initial estimate of Pasquill stability category.

Night refers to the period from one hour before sunset to one hour after sunrise. Sunrise and sunset times are calculated by,

$$t = \cos^{-1} \left(- \frac{\sin \phi \sin \delta}{\cos \phi \cos \delta} \right),$$

where t is the time of day, ϕ is the latitude and δ is the declination of the sun. The sunrise and sunset times are adjusted for the equation of time and longitude.

Table 3 -- Lateral wind direction turbulence criteria for initial estimate of Pasquill stability category. Based on surface roughness of 40 cm and various instrument heights. Use with Table 4.

Initial estimate of Pasquill stability category	Lower bound of standard deviation of horizontal wind direction fluctuations, σ_θ , in degrees			
	Instrument height in meters			
	10	20	30	43
A	27.4	26.3	25.6	25.1
B	21.3	19.2	18.1	17.1
C	15.2	13.5	12.6	11.9
D	9.1	7.8	7.1	6.5
E	4.6	3.6	3.0	2.7
F	2.6	1.9	1.6	1.4

Table 4 -- Wind speed adjustments for determining final estimate of Pasquill stability category from σ_z . Use with Table 3.

	Initial estimated category	10-m scalar wind speed (WS) (m/s)	Final estimate of stability category
Daytime	A	WS < 3	A
		3 ≤ WS < 4	B
		4 ≤ WS < 6	C
		6 ≤ WS	D
	B	WS < 4	B
		4 ≤ WS < 6	C
		6 ≤ WS	D
	C	WS < 6	C
		6 ≤ WS	D
	D, E, F or G	ANY	D
Nighttime	A	WS < 2.4	G
		2.4 ≤ WS < 2.9	F
		2.9 ≤ WS < 3.6	E
		3.6 ≤ WS	D
	B	WS < 2.4	F
		2.4 ≤ WS < 3.0	E
		3.0 ≤ WS	D
	C	WS < 2.4	E
		2.4 ≤ WS	D
	D	ANY	D
	E	WS < 5.0	E
		5.0 ≤ WS	D
	F	WS < 3.0	E
		3.0 ≤ WS < 5.0	E
		5.0 ≤ WS	D
	G	WS < 3.0	G
		3.0 ≤ WS < 5.0	E
		5.0 ≤ WS	D

Wind Roses

Joint frequency of occurrence of wind speed and direction for all 7 stability classes were constructed. The neutral stability classes of D-Day and D-Night were combined into one neutral class. Wind direction was separated into 16 classes of 22.5°, centered on the compass direction. Following the meteorological convention, the labeled wind direction is the direction the wind is coming from. Wind speed was separated into 5 classes according to Table 5.

The joint-frequency tables are graphically displayed as wind roses in Appendix B. There are 8 wind roses for each site, one for each of the seven stability classes (A through G) and one for all stabilities together.

Analysis for AIRDOS-EPA

AIRDOS-EPA (AIR DOSe) is a computer model for annual radiological dose assessment (EPA 1989). EPA has mandated that AIRDOS-EPA be used to calculate offsite dose from all emissions. Summaries of meteorological data are necessary input data for this model. There are four major meteorological inputs required for the AIRDOS-EPA model. These are mixing depth, the frequency of wind directions, the frequency of each Pasquill stability class for each wind direction, and the average wind speeds in meters per second.

Mixing depth is sometimes called atmospheric lid or mixing height. This is the distance from the ground to the top of a layer of vigorous vertical mixing. The value is site specific and changes through the day. It can be estimated from the contour maps in Holtzworth (1972). On a warm, summer day, mixing depth may be as high as 4,000 m. At night, the mixing depth may be lower than 200 m. Although it changes with time of day, mixing depth does not affect pollutant concentrations until the plume is many kilometers downwind. It is prudent to choose a mixing depth that is lower than the average daily depth.

Joint-Frequency Tables

Table 5 -- Wind speed classifications used to construct the wind roses in Appendix B

Class name	Wind speed (WS) (m/s)
Calm	WS ≤ 1.0
Weak	1.0 < WS ≤ 3.0
Moderate	3.0 < WS ≤ 5.0
Strong	5.0 < WS ≤ 7.0
Very Strong	7.0 < WS

The AIRDOS-EPA model requires that wind directions be defined as blowing TOWARD the 16 compass directions. This convention is opposite to that of the joint-frequency tables. The frequency of each wind direction class must be determined as well as the frequency of wind direction class over all eight stabilities. The sum of the frequencies for categories A through G will be equal to 1 for each of the 16 wind directions.

Average wind speed is determined for each wind direction and stability. Reciprocal-averaged wind speeds are also determined. These values are calculated by averaging reciprocals of wind speeds and then inverting the reciprocal averages. The AIRDOS-EPA manual (EPA 1989) warns that all values of average and reciprocal-averaged wind speed for each direction and stability used for calculations in the model must be greater than zero or AIRDOS-EPA will stop with a division-by-zero error.

The appendix has summaries of the data files necessary for the meteorological input for AIRDOS-EPA for the three KAPL sites. Also, the same data are displayed in the appendix with the columns and rows appropriately labeled.

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APPENDIX A
JOINT-FREQUENCY TABLES FOR INPUT TO AIRDOS-EPA PROGRAM

FREQUENCY TABLES FOR 1989 ALL HOURS 8399 DATA POINTS KNOLLS SITE

FREQUENCY OF EACH STABILITY CLASS FOR EACH WIND DIRECTION								
WIND TOWARD	FRACTION OF TIME IN EACH STABILITY CLASS							
	A	B	C	D	E	F	G	ALL
N	0.0226	0.0293	0.1618	0.6125	0.1332	0.0158	0.0248	0.1582
NNW	0.0397	0.0269	0.2103	0.5603	0.1103	0.0167	0.0359	0.0929
NW	0.1564	0.1401	0.3550	0.1792	0.0912	0.0326	0.0456	0.0366
WNW	0.2541	0.1676	0.2595	0.1351	0.1027	0.0378	0.0432	0.0220
W	0.2929	0.1500	0.2071	0.1000	0.1429	0.0429	0.0643	0.0167
WSW	0.2214	0.1357	0.2000	0.1286	0.1786	0.0643	0.0714	0.0167
SW	0.1520	0.1094	0.2584	0.2462	0.1398	0.0456	0.0486	0.0392
SSW	0.0893	0.0470	0.2038	0.3793	0.2006	0.0455	0.0345	0.0760
S	0.1161	0.0580	0.1071	0.3728	0.1920	0.0603	0.0938	0.0533
SSE	0.1129	0.0538	0.1478	0.4005	0.1452	0.0618	0.0780	0.0443
SE	0.0815	0.0599	0.2030	0.4243	0.1564	0.0483	0.0266	0.0716
ESE	0.0287	0.0271	0.2670	0.5653	0.0801	0.0138	0.0180	0.2243
E	0.0549	0.0248	0.1788	0.5381	0.0991	0.0389	0.0655	0.0673
ENE	0.0460	0.0460	0.1632	0.3556	0.2176	0.0628	0.1088	0.0285
NE	0.0846	0.0498	0.1393	0.3582	0.1741	0.0896	0.1045	0.0239
NNE	0.0664	0.0373	0.1245	0.3817	0.2282	0.0539	0.1079	0.0287

RECIPROCAL-AVERAGED WIND SPEEDS								
WIND TOWARD	WIND SPEED (METERS/SEC)							
	A	B	C	D	E	F	G	
N	1.490	1.698	2.733	2.351	1.394	1.120	1.124	
NNW	1.474	1.601	2.422	2.006	1.231	1.112	1.070	
NW	1.291	1.564	1.730	1.480	1.096	1.298	1.138	
WNW	1.329	1.420	1.451	1.399	1.200	1.057	1.011	
W	1.227	1.235	1.326	1.222	1.094	1.062	1.091	
WSW	1.237	1.304	1.556	1.177	1.234	1.037	1.120	
SW	1.327	1.511	2.089	2.324	1.313	1.216	1.046	
SSW	1.427	1.704	2.594	2.760	1.414	1.153	1.168	
S	1.357	1.499	1.721	1.648	1.403	1.440	1.220	
SSE	1.682	1.908	2.651	1.736	1.345	1.173	1.136	
SE	1.575	2.300	3.404	2.746	1.638	1.373	1.230	
ESE	1.783	2.691	4.098	3.876	1.783	1.400	1.231	
E	1.545	2.252	3.897	2.430	1.537	1.332	1.145	
ENE	1.839	1.806	3.468	1.931	1.276	1.346	1.133	
NE	1.851	1.742	2.433	1.602	1.254	1.230	1.108	
NNE	1.510	1.775	2.183	1.527	1.357	1.086	1.060	

AVERAGE WIND SPEEDS								
WIND TOWARD	WIND SPEED (METERS/SEC)							
	A	B	C	D	E	F	G	
N	1.610	2.028	3.272	3.268	1.677	1.176	1.194	
NNW	1.590	1.833	2.938	2.700	1.362	1.146	1.107	
NW	1.398	1.805	1.963	1.689	1.139	1.510	1.214	
WNW	1.423	1.523	1.577	1.556	1.300	1.071	1.013	
W	1.285	1.329	1.393	1.329	1.165	1.067	1.111	
WSW	1.294	1.400	2.025	1.378	1.332	1.044	1.180	
SW	1.426	1.775	2.676	3.221	1.443	1.273	1.081	
SSW	1.561	1.957	3.395	3.460	1.573	1.231	1.268	
S	1.510	1.608	2.160	2.013	1.619	1.633	1.305	
SSE	1.810	2.310	3.495	2.358	1.491	1.261	1.197	
SE	1.720	2.672	3.845	3.575	1.798	1.555	1.325	
ESE	1.987	2.890	4.409	4.751	1.926	1.588	1.347	
E	1.729	2.707	4.307	3.338	1.723	1.541	1.214	
ENE	1.973	2.282	3.997	2.744	1.448	1.413	1.177	
NE	1.982	2.140	3.007	2.128	1.389	1.333	1.162	
NNE	1.731	2.211	2.680	1.968	1.611	1.115	1.092	

FREQUENCY TABLES FOR 1989 ALL HOURS 8736 DATA POINTS KESSELRING
 SITE FREQUENCY OF EACH STABILITY CLASS FOR EACH WIND DIRECTION
 WIND TOWARD FRACTION OF TIME IN EACH STABILITY CLASS

	A	B	C	D	E	F	G	ALL
N	0.2389	0.2340	0.1527	0.1897	0.0862	0.0690	0.0296	0.0465
NNW	0.1625	0.2688	0.2021	0.2292	0.0583	0.0562	0.0229	0.0549
NW	0.2818	0.2887	0.1134	0.1031	0.1100	0.0756	0.0275	0.0333
WNW	0.3120	0.2120	0.1040	0.1600	0.1080	0.0600	0.0440	0.0286
W	0.1574	0.1636	0.1543	0.2130	0.1821	0.0679	0.0617	0.0371
WSW	0.1056	0.1767	0.1487	0.2522	0.1703	0.0948	0.0517	0.0531
SW	0.0202	0.1271	0.2000	0.3519	0.1690	0.0791	0.0527	0.0738
SSW	0.0464	0.1000	0.0393	0.3250	0.2679	0.1357	0.0857	0.0321
S	0.0508	0.0621	0.0056	0.1356	0.3051	0.2316	0.2090	0.0203
SSE	0.0688	0.0688	0.0212	0.1958	0.2328	0.1799	0.2328	0.0216
SE	0.0345	0.0822	0.1008	0.3077	0.1645	0.1247	0.1857	0.0432
ESE	0.0165	0.0321	0.1251	0.5098	0.1551	0.0693	0.0920	0.1107
E	0.0183	0.0336	0.1103	0.6192	0.1281	0.0397	0.0508	0.2252
ENE	0.0310	0.0877	0.2451	0.3981	0.1075	0.0696	0.0610	0.1331
NE	0.1101	0.2026	0.1630	0.2159	0.1322	0.0903	0.0859	0.0520
NNE	0.1921	0.1623	0.1192	0.1987	0.1126	0.1424	0.0728	0.0346

RECIPROCAL-AVERAGED WIND SPEEDS

WIND TOWARD	WIND SPEED (METERS/SEC)						
	A	B	C	D	E	F	G
N	1.526	2.013	1.863	1.835	1.389	1.466	1.240
NNW	1.391	2.152	2.669	2.667	1.410	1.400	1.223
NW	1.436	1.663	1.762	1.622	1.400	1.179	1.172
WNW	1.412	1.453	1.288	1.238	1.284	1.445	1.127
W	1.404	1.707	1.917	1.464	1.274	1.232	1.164
WSW	1.444	1.852	2.102	1.974	1.551	1.353	1.182
SW	1.573	2.103	2.707	2.545	1.456	1.367	1.155
SSW	1.211	1.763	1.858	1.462	1.233	1.389	1.140
S	1.136	1.499	1.000	1.389	1.082	1.049	1.171
SSE	1.350	2.436	1.548	1.136	1.096	1.118	1.179
SE	1.740	2.492	3.252	2.089	1.208	1.187	1.129
ESE	1.568	2.191	3.798	2.036	1.275	1.210	1.161
E	1.534	2.293	3.906	2.968	1.421	1.261	1.219
ENE	1.741	2.357	3.495	2.669	1.585	1.385	1.260
NE	1.710	2.187	2.533	2.218	1.402	1.268	1.286
NNE	1.447	1.739	1.921	1.754	1.508	1.182	1.235

AVERAGE WIND SPEEDS

WIND TOWARD	WIND SPEED (METERS/SEC)						
	A	B	C	D	E	F	G
N	1.703	2.322	2.461	2.764	1.531	1.621	1.333
NNW	1.569	2.544	3.424	3.829	1.657	1.519	1.345
NW	1.595	1.946	2.376	2.683	1.603	1.264	1.275
WNW	1.553	1.700	1.596	1.538	1.433	1.580	1.218
W	1.537	2.011	2.306	2.196	1.397	1.368	1.240
WSW	1.614	2.259	2.712	2.531	1.768	1.502	1.254
SW	1.738	2.491	3.593	3.204	1.681	1.520	1.250
SSW	1.385	2.054	2.545	2.011	1.423	1.568	1.196
S	1.211	1.936	1.000	2.312	1.167	1.085	1.257
SSE	1.623	2.877	2.300	1.373	1.184	1.229	1.266
SE	1.985	2.981	4.253	3.645	1.448	1.379	1.181
ESE	1.813	2.832	4.510	3.754	1.497	1.390	1.246
E	1.769	2.818	4.540	4.557	1.648	1.421	1.305
ENE	1.997	2.803	4.061	3.695	1.885	1.609	1.363
NE	1.922	2.560	3.170	3.278	1.618	1.398	1.428
NNE	1.603	2.086	2.517	2.258	1.682	1.274	1.391

FREQUENCY TABLES FOR 1983 ALL HOURS 8759 DATA POINTS WINDSOR

SITE FREQUENCY OF EACH STABILITY CLASS FOR EACH WIND DIRECTION

WIND TOWARD	FRACTION OF TIME IN EACH STABILITY CLASS							
	A	B	C	D	E	F	G	ALL
N	0.1654	0.0888	0.1021	0.1964	0.3019	0.0522	0.0932	0.1029
NNW	0.2742	0.1018	0.0705	0.1253	0.1984	0.0757	0.1540	0.0437
NW	0.2930	0.0806	0.0879	0.1429	0.1062	0.0806	0.2088	0.0312
WNW	0.3516	0.0989	0.0714	0.0495	0.1429	0.0879	0.1978	0.0208
W	0.3077	0.1231	0.0615	0.0821	0.1436	0.0564	0.2256	0.0223
WSW	0.2941	0.1629	0.1357	0.0905	0.0950	0.0860	0.1357	0.0252
SW	0.2140	0.0996	0.1845	0.1181	0.1882	0.0664	0.1292	0.0309
SSW	0.1250	0.1039	0.2306	0.1849	0.1180	0.0616	0.1761	0.0648
S	0.0985	0.0913	0.1876	0.2344	0.1733	0.0546	0.1603	0.1588
SSE	0.1346	0.0850	0.1442	0.1615	0.1927	0.0689	0.2131	0.1061
SE	0.0901	0.0732	0.1625	0.3047	0.1843	0.0556	0.1296	0.1356
ESE	0.1191	0.0867	0.1300	0.2915	0.1599	0.0762	0.1360	0.0764
E	0.1699	0.0919	0.0891	0.2006	0.1894	0.0585	0.2006	0.0410
ENE	0.1623	0.0830	0.1283	0.2226	0.0943	0.0755	0.2340	0.0303
NE	0.1635	0.1099	0.1475	0.1796	0.1501	0.0509	0.1984	0.0426
NNE	0.1574	0.1303	0.1201	0.2352	0.1861	0.0355	0.1354	0.0675

RECIPROCAL-AVERAGED WIND SPEEDS

WIND TOWARD	WIND SPEED (METERS/SEC)						
	A	B	C	D	E	F	G
N	1.603	2.263	2.427	2.329	1.404	1.548	1.381
NNW	1.669	2.474	2.444	1.861	1.437	1.712	1.382
NW	1.412	1.814	2.406	1.059	1.402	1.695	1.271
WNW	1.484	2.034	1.724	1.607	1.588	1.754	1.303
W	1.496	1.882	1.870	1.562	1.380	1.555	1.267
WSW	1.517	2.295	1.768	2.449	1.553	1.774	1.433
SW	1.432	1.786	2.007	1.874	1.573	1.989	1.286
SSW	1.433	2.249	2.660	2.415	1.542	1.805	1.413
S	1.666	2.576	2.750	2.854	1.755	1.892	1.362
SSE	1.528	2.555	2.900	2.114	1.454	1.736	1.334
SE	1.668	2.882	3.162	2.502	1.487	1.673	1.276
ESE	1.629	2.919	3.493	2.560	1.497	1.544	1.288
E	1.638	2.623	3.187	1.455	1.191	1.535	1.224
ENE	1.638	2.750	2.642	2.019	1.390	1.542	1.235
NE	1.622	2.960	2.591	2.150	1.360	1.432	1.171
NNE	1.669	2.645	2.539	1.838	1.341	1.313	1.276

AVERAGE WIND SPEEDS

WIND TOWARD	WIND SPEED (METERS/SEC)						
	A	B	C	D	E	F	G
N	1.816	2.673	3.093	3.193	1.565	1.764	1.494
NNW	1.885	2.874	3.030	2.900	1.642	2.021	1.515
NW	1.610	2.477	3.353	1.179	1.748	2.036	1.407
WNW	1.656	2.650	2.854	2.367	2.050	2.081	1.411
W	1.757	2.408	2.917	2.319	1.829	1.891	1.373
WSW	1.743	2.714	2.103	2.955	1.895	2.021	1.590
SW	1.614	2.233	2.562	2.719	1.969	2.228	1.377
SSW	1.638	2.693	3.248	3.313	1.791	2.114	1.559
S	1.888	2.892	3.379	3.468	2.020	2.139	1.486
SSE	1.736	2.953	3.729	2.845	1.691	2.005	1.439
SE	1.878	3.205	4.062	3.725	1.779	1.920	1.388
ESE	1.850	3.126	4.101	3.898	1.802	1.788	1.414
E	1.872	2.948	3.694	2.017	1.338	1.776	1.328
ENE	1.826	3.036	3.482	2.985	1.628	1.850	1.334
NE	1.838	3.210	3.484	2.842	1.600	1.616	1.258
NNE	1.877	2.979	3.389	2.568	1.551	1.505	1.370

APPENDIX B
WIND ROSES

10

$$1.1-3 \quad 3.1-5 \quad 5.1-7 \quad >7$$

calms: 19.8%

KNOLLS SITE
1989
Stability B

KNOLLS SITE 1989 Stability C

A circular wind rose diagram showing wind frequency by direction and speed. The diagram has concentric circles labeled 10%, 20%, and 30%. The cardinal directions are labeled N, E, S, and W. Wind vectors are shown as lines with rectangular markers at their ends. The longest vector points towards the West-Northwest, extending beyond the 30% circle. Other significant vectors point towards the East and North. The label 'B-5' is at the bottom.

Wind Speed (m/s)

1.1-3 3.1-5 5.1-7 >7

calms: 9.6%

1.1-3 3.1-5 5.1-7 >7

calms: 31.7%

KNOLLS SITE
1989
Stability F

KNOLLS SITE

1989

Stability G

Wind Speed (m/s)

1.1 - 3 3.1 - 5 5.1 - 7 > 7

calms: 63.1%

KNOLLS SITE 1989 All Stabilities

KESSELRING SITE 10 m --- 1989 Stability A

KESSELRING SITE
10 m -- 1989
Stability B

Wind Speed (m/s)

1.1-3 3.1-5 5.1-7 >7

calms: 39.7%

KESSELRING SITE 10 m --- 1989 Stability C

Wind Speed (m/s)

calms: 23.1%

KESSELRING SITE 10 m -- 1989 Stability D

Wind Speed (m/s)

1.1-3 3.1-5 5.1-7 >7

calms: 50.1%

KESSELRING SITE 10 m --- 1989 Stability E

B-14

Wind Speed (m/s)

11-3 3.1-5 5.1-7 >7

calms: 78.5%

KESSELRING SITE 10 m --- 1989 Stability F

Wind Speed (m/s)

calms: 82.5%

KESSELRING SITE 10 m --- 1989 Stability G

Wind Speed (m/s)

1.1 - 3 3.1 - 5 5.1 - 7 > 7

calms: 84.5%

All Stabilities

1.1-3 3.1-5 5.1-7 >7

calms: 63.1%

Wind Speed (m/s)

1.1-3 3.1-5 5.1-7 >7

calms: 24.9%

KESSELRING SITE 43 m -- 1989 Stability B

KESSELRING SITE
43 m --- 1989
Stability C

KESSELRING SITE
43 m --- 1989
Stability D

Wind Speed (m/s)

1.1 - 3	3.1 - 5	5.1 - 7	> 7
---------	---------	---------	-----

calms: 15.1%

KESSELRING SITE 43 m — 1989 Stability F

Wind Speed (m/s)

1.1 - 3 3.1 - 5 5.1 - 7 > 7

calms: 48.0%

KESSELRING SITE 43 m --- 1989 Stability G

Wind Speed (m/s)

1.1 - 3 3.1 - 5 5.1 - 7 > 7

calms: 52.1%

KESSELRING SITE 43 m --- 1989 All Stabilities

WINDSOR SITE 1989 Stability A

B-26

Wind Speed (m/s)

1.1 - 3 3.1 - 5 5.1 - 7 > 7

calms: 20.1%

WINDSOR SITE
1989
Stability B

Wind Speed (m/s)

1.1 - 3 3.1 - 5 5.1 - 7 > 7

calms: 7.0%

WINDSOR SITE

1989

Stability C

Wind Speed (m/s)

11-3 3.1-5 5.1-7 >7

calms: 7.4%

A wind rose diagram showing the frequency of wind blowing from various directions. The diagram is circular with concentric rings at 10% and 20% frequency. The cardinal directions are labeled: N (North), E (East), S (South), and W (West). The wind frequency is highest from the North-Northwest (NNW) direction, reaching approximately 25%.

B-29

WINDSOR SITE

1989

Stability E

WINDSOR SITE

1989

Stability F

WINDSOR SITE

1989

Stability G

Wind Speed (m/s)

1.1-3 3.1-5 5.1-7 >7

calms: 36.5%

1.1-3 3.1-5 5.1-7 >7
calms: 210%

APPENDIX C
SOURCE LISTINGS

HOURLK

This program reads the 15-min average data and produces a listing of hourly averages.

\$NOFLOATCALLS

\$STORAGE:2

\$DEBUG

PROGRAM HOURLY

REAL DATA (50)

COMMON /SUMS/ SSPD, SSIN, SCOS, SIG2, STP, NUM

COMMON /LINES/ LINEIN, LINEOUT

COMMON /CHAN/ ICHAN(7), NCHAN

C ICHAN(1) - DATE

C ICHAN(2) - HOUR

C ICHAN(3) - WIND SPEED

C ICHAN(4) - WIND DIRECTION

C ICHAN(5) - SIGMA THETA

C ICHAN(7) - TEMPERATURE

OPEN (6, FILE='HOURLK.XXX', STATUS='NEW')

CALL RDINIT

3 CONTINUE

CALL OPENFILE

CALL READONE (ISTAT, DATA)

NOWDA = DATA(ICHAN(1))

NOWHR = DATA(ICHAN(2))

CALL CLEAR

5 CONTINUE

TIME = DATA(1) + DATA(2)/24.

TNOW = NOWDA + NOWHR /24.

IF (TIME .LT. TNOW) THEN

WRITE (*,*) 'TIMES ARE OUT OF SEQUENCE'

WRITE (*,*) 'TIMES=', TNOW, TIME

WRITE (*,*) 'INPUT LINE NUMBER=', LINEIN

WRITE (6,*) 'TIMES ARE OUT OF SEQUENCE'

WRITE (6,*) 'TIMES=', TNOW, TIME

WRITE (6,*) 'INPUT LINE NUMBER=', LINEIN

STOP

ENDIF

IF (NOWDA .NE. DATA(1) .OR.

1 NOWHR .NE. DATA(2)) THEN

CALL COMPWRT (NOWDA, NOWHR)

CALL CLEAR

ENDIF

NOWDA = DATA(ICHAN(1))

NOWHR = DATA(ICHAN(2))

WS = DATA (ICHAN(3))

C USE PREVIOUS WD AND SIGMA THETA WHEN WS IS CALM

```
IF (WS .GE. 0.5) THEN
  WD = DATA (ICHAN(4))
  SI = DATA (ICHAN(5))
```

ENDIF

```
TP = DATA (ICHAN(7))
```

```
IF ((WS .EQ. 99.9) .OR.
1   (WD .EQ. 999.) .OR.
2   (SI .EQ. 999.9) .OR.
4   (TP .EQ. 99.9)) THEN
```

GOTO 8

ENDIF

```
IF ((WS .LT. 0) .OR. (WS .GT. 30) .OR.
1   (WD .LT. 0) .OR. (WD .GT. 360) .OR.
2   (SI .LT. 0) .OR. (SI .GT. 360) .OR.
4   (TP .LT.-30) .OR. (TP .GT. 50)) THEN
```

```
WRITE (*,*) 'DATA OUT OF RANGE', WS, WD, SI, TP
WRITE (*,*) 'LINE=', LINEIN
WRITE (6,*) 'DATA OUT OF RANGE', WS, WD, SI, TP
WRITE (6,*) 'LINE=', LINEIN
STOP
```

ENDIF

```
CALL ADDTOSUM (WS, WD, SI, TP)
```

8 CONTINUE

```
CALL READONE (ISTAT, DATA)
```

```
IF (ISTAT .LT. 0) THEN
  CALL COMPWRT (NOWDA, NOWHR)
  GOTO 3
```

ENDIF

GOTO 5

END

\$PAGE

```
SUBROUTINE RDINIT
COMMON /CHAN/ ICHAN(7), NCHAN
COMMON /ZEES/ Z0, Z
```

```
OPEN (3, FILE='HOURK.INI', STATUS='OLD')
```

```
NCHAN = 0
READ (3,*)
READ (3,*) Z0
WRITE (6,*) 'Surface roughness (cm) = ', Z0
READ (3,*) Z
WRITE (6,*) 'Height of instruments (cm) = ', Z
```

```
DO 5 I = 1, 7
  READ (3,*, END=6) ICHAN (I)
  NCHAN = MAX (NCHAN, ICHAN(I))
```

```

5  CONTINUE
6  CONTINUE
   WRITE (6,*) 'CHANNELS=', ICHAN

```

```

   CLOSE (3)
   RETURN
END

```

\$PAGE

```

SUBROUTINE CLEAR
COMMON /SUMS/ SSPD, SSIN, SCOS, SIG2, STP, NUM

```

```

SSPD = 0.
SSIN = 0.
SCOS = 0.
SIG2 = 0.
STP  = 0.
NUM  = 0

```

```

RETURN
END

```

\$PAGE

```

SUBROUTINE ADDTOSUM (WS, WD, SIG, TP)
COMMON /SUMS/ SSPD, SSIN, SCOS, SIG2, STP, NUM
DATA PI180/.017453/

```

```

IF (WS .GT. 50) RETURN
IF (WD .GT. 360) RETURN
IF (SIG .GT. 900) RETURN
IF (TP .GT. 50) RETURN

```

```

SSPD = SSPD + WS
RAD  = WD * PI180
WS2  = MAX (WS, .1)
SSIN = SSIN + WS2 * SIN(RAD)
SCOS = SCOS + WS2 * COS(RAD)
SIG2 = SIG2 + SIG * SIG
STP  = STP  + TP
NUM  = NUM + 1
RETURN
END

```

\$PAGE

```

SUBROUTINE COMPWRT (DAY, HOUR)
INTEGER DAY, HOUR

```

```

COMMON /SUMS/ SSPD, SSIN, SCOS, SIG2, STP, NUM
COMMON /LINES/ LINEIN, LINEOUT
COMMON /CHAN/ ICHAN(7), NCHAN

```

```

DATA PI180/.017453/

```

```

IF (NUM .LE. 0) THEN
   WRITE (6,*) 'NUM LE ZERO LINE=', LINEIN
   RETURN

```

```

ENDIF

```

```

SSPD = SSPD / NUM

IF (SCOS.EQ.0) SCOS = SSIN / .0001
IF (SSIN.EQ.0) SSIN = SCOS / .0001
ANG = ATAN2 (SSIN, SCOS) / PI180
IF (ANG .LT. 0) ANG = ANG + 360

SIG2 = SQRT (SIG2/NUM)

STP = STP / NUM

C TIME IS THE MID-POINT OF THE INTERVAL
C 5-HOUR CORRECTION FOR EST, AND 1/2 HOUR TO THE MIDPOINT
TIME = HOUR - 4.5
CALL SIGCAT (DAY, TIME, SSPD, SIG2, IUS)

LINEOUT = LINEOUT + 1
WRITE (2,500) DAY, HOUR, SSPD, ANG, SIG2, IUS, STP
IF (HOUR .EQ. 0) THEN
    WRITE (6,500) DAY, HOUR, SSPD, ANG, SIG2, IUS, STP
    WRITE (*,500) DAY, HOUR, SSPD, ANG, SIG2, IUS, STP
ENDIF
500 FORMAT (2I4, F7.1, F7.0, F7.1, I4, F7.1)

RETURN
END

$PAGE

SUBROUTINE OPENFILE

COMMON /LINES/ LINEIN, LINEOUT

CHARACTER*15 INFILE, OUTFILE
CHARACTER*1 OUTF(15)
EQUIVALENCE (OUTFILE, OUTF)
INTEGER OPT
LOGICAL BATCH
DATA BATCH/.FALSE./

IF (BATCH) GOTO 6

1 CONTINUE
WRITE (*,*)
WRITE (*,*)
1 'YOU HAVE THESE OPTIONS'
WRITE (*,*)
1 ' ENTER FILE NAMES SINGLY (1)'
WRITE (*,*)
1 ' FROM A BATCH FILE (2)'
WRITE (*,*)
1 ' OR STOP (3)'
WRITE (*,*)
WRITE (*,*) 'ENTER 1, 2 OR 3'
READ (*,*, ERR=1) OPT

```

```

IF (OPT .EQ. 3) THEN
    STOP
ENDIF
IF (OPT .LT. 1 .OR. OPT .GT. 2) GOTO 1

IF (OPT .EQ. 2) GOTO 5

    BATCH = .FALSE.
2   CONTINUE
    WRITE (*,*) 'ENTER INPUT FILE NAME'
    READ (*,100) INFILE
    IF (INFILE .EQ. 'STOP') STOP

3   CONTINUE
    OPEN (1, FILE=INFILE, STATUS='OLD')
    WRITE (*,*) 'READ ', INFILE
    WRITE (6,*) 'OPEN INPUT ', INFILE
    LINEIN = 0

    OUTFILE = INFILE
    WRITE (OUTF(11:14), '(A4)') '.HLY'

    OPEN (2, FILE=OUTFILE, STATUS='NEW')
    WRITE (6,*) 'OPEN OUTPUT ', OUTFILE
    LINEOUT = 0

    RETURN

5   CONTINUE
    OPEN (3, FILE='HOURK.BAT', STATUS='OLD', ERR=93)
    WRITE (6,*) 'OPEN BATCH FILE'

    READ (3,*)
    BATCH = .TRUE.

6   CONTINUE
    READ (3,*,END=7,ERR=6) INFILE
    GOTO 3

7   CONTINUE
    BATCH = .FALSE.
    WRITE (*,*) 'END OF BATCH FILE REACHED'
    WRITE (6,*) 'END OF BATCH FILE REACHED'
    GOTO 1

9   CONTINUE
    WRITE (*,*)
    WRITE (*,*) 'CANNOT FIND FILE ', INFILE
    WRITE (*,*) 'TRY AGAIN'
    WRITE (*,*) 'ENTER STOP TO EXIT'
    WRITE (6,*)
    WRITE (6,*) 'CANNOT FIND FILE ', INFILE
    WRITE (6,*) 'TRY AGAIN'

```

```

        GOTO 2

93      CONTINUE
        WRITE (*,*)
        WRITE (*,*) 'CANNOT FIND FILE HOURK.BAT'
        WRITE (*,*) 'TRY AGAIN'
        GOTO 1

100     FORMAT (A15)
        END

$PAGE   SUBROUTINE READONE (ISTAT, DATA)

        COMMON /CHAN/ ICHAN(7), NCHAN
        COMMON /LINES/ LINEIN, LINEOUT

        REAL DATA(50)

        LINEIN = LINEIN + 1
5        CONTINUE
        READ (1,*, ERR=8, END=9) (DATA(I), I=1, NCHAN)

        ISTAT = 0
        RETURN

8        CONTINUE
        WRITE (6,*) 'ERROR READING UNIT 1  LINE=', LINEIN
        GOTO 5
C        WRITE (*,*) 'ERROR READING UNIT 1  LINE=', LINEIN
C        STOP

9        CONTINUE
        ISTAT = -1
        LINEIN = LINEIN - 1
        WRITE (6,*) LINEIN, '  LINES READ'
        WRITE (*,*) LINEIN, '  LINES READ'
        RETURN

        END

```

SIGCATK

\$NOFLOATCALLS

\$STORAGE:2

\$DEBUG

SUBROUTINE SIGCAT (JUL, TIME, WS, SIGTHT, ISTB)

C This subroutine converts a given value of sigma theta
C ("SIGTHT")

C to a Pasquill stability category.

C This conversion was first quoted in Nuclear Safety 17(1):72

C (F.A. Gifford, 1976) and can be found in the Handbook on

C Atmospheric Diffusion, S.R. Hanna, G.A. Briggs, R.P.
C Hosker, Jr.,

C U.S. DOE (1982), NTIS # DOE/TIC-11223 (DE82002045), Table
C 4.3.

COMMON /ZEES/ Z0, Z

REAL RISET(2,365), LOWLIM(7), EXP(7)

LOGICAL HERE

DATA HERE/.FALSE./

DATA LOWLIM/22.5, 17.5, 12.5, 7.5, 3.8, 2.1,
0.0/

DATA EXP /-0.06, -0.15, -0.17, -0.23, -0.38, -0.43, -
0.43/

IF (.NOT.HERE) THEN

OPEN (4, FILE='SUNRISET.DAT', STATUS='OLD')

READ (4,*)

DO 3 I = 1, 365

READ (4,*) J, RISET(1,I), RISET(2,I)

3 CONTINUE

CLOSE (4)

HERE = .TRUE.

WRITE (6,*) 'Z0, Z=', Z0, Z

DO 35 I = 1, 7

FACTOR = (Z0/15)**(0.2) * (Z/10) ** EXP(I)

LOWLIM (I) = LOWLIM (I) * FACTOR

35 CONTINUE

WRITE (6,*) 'LOW LIMITS', LOWLIM

ENDIF

C IF THE WIND SPEED IS GREATER THAN 6m/s STABILITY IS NEUTRAL

IF (WS .GT. 6) THEN

ISTB = 4

GOTO 5

ENDIF

C CONVERT SIGMA THETA TO A DAYTIME STABILITY CLASS

ISTB = 0

```

4      CONTINUE
      ISTB = ISTB + 1
      IF (SIGTHT .LT. LOWLIM(ISTB)) GOTO 4

C  MAKE ROOM FOR THE NIGHTIME NEUTRAL CASE (ISTB = 5)
      IF (ISTB .GE. 5) THEN
          ISTB = ISTB + 1
      ENDIF

5      CONTINUE
C  TEST FOR NIGHTIME CONDITIONS
C  NIGHTIME IS CONSIDERED TO BE FROM 1 HOUR BEFORE SUNSET
C  TO 1 HOUR AFTER SUNRISE.

      IF (TIME .GT. (RISET(2,JUL)-1) .OR.
1      TIME .LT. (RISET(1,JUL)+1)) THEN

          CALL NIGHT (WS, ISTB)
      ELSE
          CALL DAY (WS, ISTB)
      ENDIF

      RETURN
      END

$PAGE      SUBROUTINE NIGHT (WS, ISTB)

C  NIGHTIME
C      STAB = A B C D D E F G
      GOTO ( 1, 2, 3, 4, 5, 6, 7, 8) ISTB
      WRITE (*,*) 'ILLEGAL VALUE FOR ISTAB', ISTB
      ISTB = 4
      GOTO 9

1      CONTINUE
C  'A' goes to 'G', 'F', 'E' or 'D'
      ISTB = 8
      IF (WS .GE. 2.4) ISTB = 7
      IF (WS .GE. 2.9) ISTB = 6
      IF (WS .GE. 3.6) ISTB = 5
      GOTO 9

2      CONTINUE
C  'B' goes to 'F', 'E' or 'D'
      ISTB = 7
      IF (WS .GE. 2.4) ISTB = 6
      IF (WS .GE. 3.0) ISTB = 5
      GOTO 9

3      CONTINUE
C  'C' goes to 'E' or 'D'
      ISTB = 6
      IF (WS .GE. 2.4) ISTB = 5
      GOTO 9

```



```

4      CONTINUE
C 'D' at night
      ISTB = 5
      GOTO 9

5      CONTINUE
C 'D' at night
      GOTO 9

6      CONTINUE
C 'E'
      ISTB = 6
      IF (WS .GE. 5.0) ISTB = 5
      GOTO 9

7      CONTINUE
C 'F'
      ISTB = 7
      IF (WS .GE. 3.0) ISTB = 6
      IF (WS .GE. 5.0) ISTB = 5

8      CONTINUE
C 'G'
      ISTB = 8
      IF (WS .GE. 3.0) ISTB = 6
      IF (WS .GE. 5.0) ISTB = 5

9      RETURN
      END

$PAGE      SUBROUTINE DAY (WS, ISTB)

C DAYTIME
C      STAB = A B C D D E F G
      GOTO ( 1, 2, 3, 4, 5, 6, 7, 8) ISTB
      WRITE (*,*) 'ILLEGAL VALUE FOR ISTAB', ISTB
      ISTB = 4
      GOTO 9

1      CONTINUE
C 'A' goes to 'A', 'B', 'C' or 'D'
      IF (WS .GE. 3.0) ISTB = 2
      IF (WS .GE. 4.0) ISTB = 3
      IF (WS .GE. 6.0) ISTB = 4
      GOTO 9

2      CONTINUE
C 'B' goes to 'B', 'C' or 'D'
      IF (WS .GE. 4.0) ISTB = 3
      IF (WS .GE. 6.0) ISTB = 4
      GOTO 9

3      CONTINUE

```

```
C  'C' goes to 'C' or 'D'
    IF (WS .GE. 6.0) ISTB = 4
    GOTO 9

    4  CONTINUE
C  'D' in the day
    5  CONTINUE
C  'D' at night NOT USED
    6  CONTINUE
C  'E'
    7  CONTINUE
C  'F'
    8  CONTINUE
C  'G'
C  'D', 'E', 'F', AND 'G' ALL GO TO NEUTRAL
    ISTB = 4

    9  RETURN
    END
```

-END-

DATE FILMED

01 / 29 / 91