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AN EVALUATION OF A SOLAR RADIATION/DELTA-T METHOD FOR ESTIMATING PASQUILL-GIFFORD (P-G) STABILITY CATEGORIES

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DISCLAIMER

This report has been reviewed by the Office of Air Quality Planning and Standards, EPA, and approved for publication. Mention of trade names or commercial products is not intended to constitute endorsement or recommendation for use.

PREFACE

In this report a comparison is made of two different methods for estimating the hourly Pasquill-Gifford stability categories required for the current generation of regulatory dispersion models. The effects of utilizing the two different methods (referred to as Turner and SRDT in this report) in regulatory applications of a Gaussian dispersion model, ISC2, is also evaluated. A fundamental feature of the SRDT method is the use of on-site meteorological data.

The Environmental Protection Agency must conduct a formal and public review before the Agency can recommend replacement of the Turner method for estimating stability categories with the SRDT method. This report is being released to establish a basis for review of the consequences resulting from use of SRDT-derived stability categories in routine dispersion modeling of air pollution impacts.

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TABLES

1. INTRODUCTION

The *Guideline on Air Quality Models (Revised)*[a] (EPA, 1986) recommends and ranks four alternative schemes for estimating the Pasquill-Gifford (P-G) stability category (Pasquill, 1961; Gifford, 1961) from on-site meteorological measurements. The highest ranking is given to Turner's method (Turner, 1964) which uses on-site wind speed coupled with observations of cloud cover and ceiling height. However, obtaining the data necessary to implement Turner's method requires a full time on-site observer, and may be impractical for use on a routine basis in many circumstances.

At the Fourth Conference on Air Quality Modeling, October 1988 (EPA, 1990), public concerns were presented for a practical alternative to the Turner method for estimating P-G stability categories. A real need was expressed for a method that did not require labor intensive data collection (e.g., hourly human observation of clouds), i.e., one based exclusively on simple on-site meteorological instrumentation. On February 13, 1991, EPA issued a notice of proposed rulemaking to further augment the Guideline via Supplement B (56 FR 5900). Supplement B (Draft) included a new method for estimating the P-G stability category. In this new method, on-site meteorological measurements (10m wind speed in combination with solar radiation during the day and temperature difference, ΔT, at night), are used in lieu of cloud cover and ceiling height for determining the P-G stability category. The proposed method was adapted from Bowen et al. (1983) and is herein referred to as the solar radiation/delta-T (SRDT) method. Public comments presented at the Fifth Conference on Air Quality Modeling, March 1991 (EPA, 1993) regarding the SRDT method focused on two key issues: 1) development of the proposed SRDT method was based on data from only one site (i.e., Kincaid, IL) for a limited time period (i.e., 21 weeks during spring/summer); and 2) the method accommodated ΔT measurements made only at the 2-10m interval, whereas ΔT had been measured at other intervals by many sources.

To address these concerns, an attempt was made to acquire several data bases from diverse geographical areas. In addition, on-site ΔT measurements

[a]Hereinafter, the "Guideline"

from other height intervals were considered for evaluation, as available. Finally, a consequence analysis was needed to document the effect on design concentration ratios if the new method is implemented. This report, presented in seven sections, documents the SRDT evaluation with data from several sites, and the consequence analysis of using the method in regulatory modeling applications. Section 2 of this report presents the rationale behind the Turner and SRDT methods for determining P-G stability categories. Section 3 is a discussion of the methodology used in the analysis. Section 4 presents and discusses the results of the stability classification comparison. Section 5 presents the results from employing the SRDT method in Gaussian dispersion modeling. Section 6 provides a summary and conclusions, and references are listed in Section 7. Appendix A contains results from the randomization procedure used to ascertain the robustness of the SRDT method. Appendix B contains tabulated results of design concentration ratios obtained via Gaussian dispersion modeling.

2. RATIONALE

Turbulence, which drives dispersion within the mixed layer of the atmosphere, is a result of thermal and mechanical processes. The P-G stability classification method parameterized these processes using observations of wind speed and subjective estimates of incoming solar radiation (insolation). Turner (1964) provided an objective means for implementing the P-G method using routine airport observations available from the National Weather Service (NWS). Stability class, using Turner's method, is a function of wind speed, the insolation class (objectively determined based on the sun's position in the sky), cloud cover, and ceiling height.

Uncertainty in the P-G method arises, in part, from the subjectivity in the classification of insolation. For example, as indicated in Table 2-1, Pasquill (1961) defined strong insolation as: "... sunny, midday, midsummer conditions in England." Based on measurements at Kew Observatory in England, these conditions correspond to insolation values of about 700 Wm^{-2}, (Chandler, 1965; Ludwig and Dabberdt, 1972, 1976). Similarly, Pasquill's definition of slight insolation: "... sunny, midday, midwinter conditions in England" corresponds to insolation values of about 420 Wm^{-2}.

Insolation flux intensity varies diurnally, seasonally, and spatially. There can be significant microscale influences on the amount of insolation received at the ground surface. The intensity and spectral composition of the insolation are also highly influenced by the amount and type of cloud cover (Miller, 1981). Objective methods for classifying insolation (Table 2-1) include those of Turner (1964), Ludwig and Dabberdt (1972), Smith (1972) and Bowen et al. (1983). Turner's method requires calculation of the solar elevation angle based on location and time. The other methods require either estimates or on-site measurements of insolation. Strong insolation is equated with solar elevations exceeding 60 degrees (Turner, 1964) and insolation values exceeding 560 Wm^{-2} (Ludwig and Dabberdt, 1976) to 700 Wm^{-2} (Bowen et al., 1983). Slight insolation is equated with solar elevations between 15 and 35 degrees (Turner, 1964) and insolation values less than 280 Wm^{-2} (Ludwig and Dabberdt, 1976) to 350 Wm^{-2} (Bowen et al., 1983).

Table 2-1. Comparison of incoming solar radiation (insolation) classifications.

Source	Strong	Moderate	Slight	Weak
Pasquill, 1961	sunny, midday, midsummer conditions in England		sunny, midday, midwinter conditions in England	
Chandler, 1965 Insolation (Wm^{-2})	700[a]		420[a]	
Turner, 1964 Solar elevation (degrees)	>60	35 - 60	15 - 35	<15
Ludwig and Dabberdt, 1972 Insolation (Wm^{-2})	>560	280 - 560	<280	
Smith, 1972 Insolation (Wm^{-2})	>600	300 - 600	<300	
Bowen et al., 1983 Insolation (Wm^{-2})	>700	350 - 700	<350	

[a] Measurements made at Kew Observatory for conditions corresponding to Pasquill's definitions.

Table 2-2. Conceptual matrix for insolation-based key to Pasquill-Gifford (P-G) stability categories.

DAYTIME					NIGHTTIME		
Wind Speed (ms^{-1})	Solar Radiation (Wm^{-2})				Wind Speed (ms^{-1})	2-10m ΔT ($°Cm^{-1}$)	
	$\geq E_1$	$E_1 \rightarrow E_2$	$E_2 \rightarrow E_3$	$<E_3$		$<\Delta T_L$	$\geq \Delta T_L$
$<u_1$	A	A	B	D	$<u_5$	E	F
$u_1 \rightarrow u_2$	A	B	C	D	$u_5 \rightarrow u_6$	D	E
$u_2 \rightarrow u_3$	B	B	C	D	$\geq u_6$	D	D
$u_3 \rightarrow u_4$	C	C	D	D			
$\geq u_4$	C	D	D	D			

A desire to retain the basic rationale of Turner's method was an important consideration in the selection of objective procedures for use with on-site data. Table 2-2 shows the structural matrix conceived for the insolation-based P-G stability classification procedure. As explained later, the specific SRDT "cutpoints" (limits for on-site meteorological parameters, i.e., u_1 - u_6, E_1 - E_3, ΔT_L, used to estimate stability categories) were derived empirically. The SRDT method is based on a development by Bowen et al. (1983), with modifications as necessary to retain as much as possible of the structure and behavior of Turner's method as implemented in the EPA meteorological preprocessors for regulatory models (EPA, 1986). The first modification was to replace Bowen's method for determining nighttime (insolation less than 35 Wm^{-2}) with the procedure which is based on calculations of sunrise and sunset. This modification was necessary to maintain consistency in the SRDT method and that used in EPA's meteorological preprocessors. Another modification was to include an additional daytime insolation class ($<E_3$) corresponding to Turner's "weak" insolation class. Bowen et al. (1983) used fewer daytime wind speed categories (5) than did Turner (9); however, the extreme wind speed categories for the two methods are essentially identical: 12 knots (6.2 ms^{-1}) for Turner versus 6.0 ms^{-1} for Bowen et al. (1983). The nighttime stability classification matrix, stratified by two lapse rate classes differentiated by some critical value, ΔT_L, is taken directly from Bowen et al. (1983), but uses fewer wind speed classes. This replaces the Turner method for estimating nighttime stability which requires observations of cloud cover and ceiling height. A third modification was to use fewer and slightly different wind speed categories during nighttime versus daytime. A modification to the Turner method was to combine P-G "F" and "G" classes.[a]

[a]Classification of "G" stability via the Turner method was rare among all data bases, which are described in Section 3.1.

3. METHODS

3.1 Data Selection

A search produced 10 potentially suitable data bases. Of these, 3 were selected as best meeting the requirements for this evaluation (Table 3-1). The requirements for individual data bases included the following attributes: 1) hourly average values for 2-10m temperature difference,[a] 10m wind speed and direction, and total solar radiation; 2) available cloud cover and ceiling height data from a nearby, representative NWS station; 3) a continuous monitoring record of sufficient length (preferably, at least one full year); 4) on-site meteorological monitoring having been done in accordance with EPA guidance (EPA, 1987a); and 5) on-site meteorological data having been quality assured. There was also a desire to acquire data bases that, in the aggregate, were geographically within the contiguous United States.

3.2 Approach

As mentioned above, the method with which to compare the SRDT system is that prescribed by Turner (1964), as implemented in the Meteorological Processor for Regulatory Models (MPRM)(Irwin et al., 1988), hereafter referred to as the "Turner method". The Turner method uses on-site wind speed coupled with cloud cover and ceiling height observed on-site. Because on-site data for cloud cover were unavailable, surface observations from a nearby, representative NWS station were used as surrogates. Accordingly, on-site data bases were carefully selected (see Section 3.1) to ensure the integrity of their use with surrogate NWS data. Determination of P-G stability categories was made using MPRM (Version 1.3), configured to implement the Turner method. Consistent procedures were used for all sites. For stabilities determined using either the Turner method (via MPRM[b]) or the SRDT method, "smoothing" (i.e., disallowing stability to change by more than one class per hour) was disabled in this evaluation in an effort to make a direct comparison of the stability categories generated by both methods. In all evaluations, quality control measures were implemented to ensure that only data valid for joint

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[a]Other intervals were also of interest.

[b]A special version of MPRM 1.3 (MPRMRUFF) was configured to output "rough" hourly stability classes.

Table 3-1. Selected on-site meteorological data bases for the SRDT evaluation.

						ΔT Height Interval (m)	
Source	Location	NWS Station	Distance[a]	Period	Insolation	2-10	Other
EPRI[b]	Kincaid, IL	Springfield, IL	~25	4/80 - 8/80	Yes	Yes	10-50, 10-100
ENSR[c]	Longview, WA	Portland, OR	~55	1/91 - 12/91	Yes	Yes	2-50
ENSR	Bloomington, IN	Indianapolis, IN	~70	7/91 - 7/92	Yes	Yes	

[a]Kilometers from nearest NWS station.

[b]Electric Power Research Institute; data base used in original SRDT evaluation by EPA (see Section 1.0).

[c]ENSR, Inc.; data were collected at a pulp and paper mill operated by Weyerhauser, Inc.

stability comparison were used. All other data were bypassed but otherwise accounted for (in all comparisons, valid data ranged from 83 to 94 percent).

Once the requisite P-G stability categories were determined via MPRM for each site, the SRDT system was applied. The SRDT system uses on-site wind speed, total solar radiation (daytime) and temperature difference (ΔT) (nighttime). The temperature differences were measured with reliable thermocouple systems. Cutpoints for the solar radiation and ΔT parameters were derived iteratively to obtain optimal fits for the entire time period at each site. The observed range of direct solar radiation intensities reported for contiguous U.S. locations (Miller, 1981) was investigated in an effort to develop a daytime scale that would be geographically robust. Initial evaluations indicated some site-to-site variations in the derived cutpoints. Therefore, it was decided to pool the data from all three sites to determine cutpoints from the composite data set. The occurrence of residuals (category differences) on an hourly basis was minimized; attention was paid to the distribution of those residuals by category and a systematic effort was employed in the choice of cutpoints to evenly allocate those residuals across all stability categories in an attempt to make the system as robust as possible. These cutpoints were then applied to each individual data base to assess site-specific residuals in the behavior of the SRDT method.

As a further effort to investigate the sensitivity of the results, the composite data were randomly stratified into two complementary (mutually exclusive) subsets; hourly records for which information was valid for joint stability classification were randomly sorted into two bins. Records from each bin were then used independently to evaluate the SRDT method. Cutpoints determined for the pooled data were applied individually to each bin. This approach allowed for an assessment of the sensitivity of the SRDT results to the specific data employed in the analyses. Thus, for the composite data base, results could be assessed as random fluctuations over many iterations.

Finally, a consequence analysis showing effects on design concentration ratios was performed using three hypothetical sources, a hypothetical receptor array on flat terrain, and a suitable Gaussian dispersion model (ISC2; see Section 5).

4. STABILITY COMPARISON RESULTS

4.1 Composite Results

For the pooled analysis from the three data bases (i.e., Kincaid, Longview, and Bloomington), 19,540 hours (89.6% of those potentially available for 909 days) were valid for making the joint comparison of stability classes. As indicated in Table 4-1, the optimum cutpoints for solar radiation were 925, 675, and 175 Wm^{-2}. Daytime wind speed cutpoints were 2.0, 3.0, 5.0, and 6.0 ms^{-1}; those for nighttime wind speed were 2.0 and 2.5 ms^{-1}. Using these cutpoints, comparison of hourly stability categories for both methods showed reasonable agreement (Table 4-2). The joint frequency distribution of hourly stability categories modulated via the SRDT method was examined (Table 4-3). Of most interest was the discrimination made at night as a function of wind speed and ΔT. Most of the category "sorting skill" is being made on the basis of wind speed, with ΔT adding a refinement. The weak discrimination seen with nighttime ΔT has been observed by others (Bowen et al., 1983; Bowen and Pamp, 1994). To check this phenomenon, the nominal value for the ΔT cutpoint (ΔT_L) was varied iteratively from 0.0, -0.01, -0.02, -0.03, +0.01, +0.02, and +0.03. No systematic improvement was seen over that using ΔT_L = 0.0, the value employed

Table 4-1. Insolation-based key to Pasquill-Gifford (P-G) stability categories based on composite data from three sites.

DAYTIME[a]					NIGHTTIME[a]		
Wind Speed[b] (ms^{-1})	Solar Radiation (Wm^{-2})				Wind Speed[b] (ms^{-1})	2-10m ΔT ($^\circ Cm^{-1}$)	
	≥925	925 → 675	675 → 175	<175		<Δ0.0	≥Δ0.0
<2.0	A	A	B	D	<2.0	E	F
2.0 → 3.0	A	B	C	D	2.0 → 2.5	D	E
3.0 → 5.0	B	B	C	D	≥2.5	D	D
5.0 → 6.0	C	C	D	D			
≥6.0	C	D	D	D			

[a] As implemented in MPRM (Irwin et al., 1988), daytime begins at the start of the first full block hour that includes the calculated time of sunrise. Likewise, nighttime begins at the start of the first full block hour that includes the calculated time of sunset.

[b] Average wind speed, measured at 10m above ground level.

Table 4-2. **Comparison of hourly stability classification via Turner versus SRDT for composite data from all three sites using key described in Table 4-1; ΔT values are from 2-10m.**

		P-G Stability Categories as Estimated via Turner							
		A	B	C	D_{day}	D_{night}	E	F&G	TOTAL
SRDT	A	108	160	3	2	0	0	0	273
	B	118	1230	393	252	0	0	0	1993
	C	31	429	970	996	0	0	0	2426
	D_{day}	4	244	1037	3787	0	0	0	5072
	D_{night}	0	0	0	0	2085	905	651	3641
	E	0	0	0	0	659	250	662	1571
	F	0	0	0	0	892	55	3617	4564
	TOTAL	261	2063	2403	5037	3636	1210	4930	19540
	%[a]	41.4	59.6	40.4	75.2	57.3	20.7	73.4	

[a] Percent coincidence of the hourly stability categories based on the distribution derived via Turner (see Section 3.2).

Table 4-3. **Joint frequency distribution matrix for all SRDT stability categories appearing in Table 4-2.**[b]

	SOLAR RADIATION (Wm^{-2})					ΔT/ΔZ (°Cm^{-1})		
WS	≥925	925-675	675-175	<175	WS	<0.0	≥0.0	
<2.0	25	198	1087	1676				
2.0 - 3.0	50	341	826	925	<2.0	549	4564	
3.0 - 5.0	72	493	1471	1156	2.0 - 2.5	188	1022	
5.0 - 6.0	12	114	401	246	≥2.5	773	2680	
≥6.0	3	86	349	233				
TOTAL	162	1232	4134	4236		1510	8266	19540

[b] The composite data valid for comparison comprised 9764 daytime hours and 9776 nighttime hours.

in the SRDT method examined by Bowen et al. (1983). It was therefore decided to retain the cutpoint at 0.0°Cm^{-1}. The nighttime wind speed cutpoints were likewise varied iteratively over reasonable values. The proximity of the chosen cutpoints (0.5 ms^{-1} apart) was necessary to get the required sorting skill in concert with ΔT, and no alternative ΔT cutpoint (ΔT_L) allowed the two nighttime wind speed cutpoints to be any further apart than 0.5 ms^{-1}.

Overall, the stability classifications for the two methods coincided for 62% of the hours, and were within one category for 89% of the hours (Table 4-4; Fig. 4-1). Absolute residuals ($|\Delta|$) expressed as a percentage of hours allocated to each category, were analyzed by stability category, and by day versus night. Across all categories, the mean residual was less than one percent. The mean absolute residual was greater for nighttime hours than for daytime hours. As indicated in Table 4-2, however, the coincidence of categories by both methods varied as a function of stability category. The greatest coincidence (75%) occurred with daytime D's, while the least (21%) occurred with E's. As these results were considered to be optimum for the pooled data, the cutpoints were applied to the individual sites to assess their residuals.

The results of the randomization analysis are presented in Appendix A. The SRDT method was not seen to be sensitive to random variations in the data. The results for complementary subsets of the pooled data were virtually identical.

4.2 Results for the Kincaid Site

The first data base examined[a] was from the Electric Power Research Institute (EPRI) Plume Model Validation and Development Program (PMVDP) for the plains site, Kincaid, Illinois. The meteorological monitoring site is located in central Illinois; the surrounding terrain is flat and uniform ($z_0 \approx 10$cm). The site and its environs have been extensively described elsewhere (EPRI, 1983). Though meteorological measurements were made from March through November, 1980, data for a 21-week period (7 April - 31 August 1980) were considered to be of highest quality. On-site measurements of interest included those of 10m wind speed and direction, 2-10m, 10-50m and 10-100m ΔT, and total

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[a]These data were used in the analysis for EPA's initial proposal to adopt SRDT.

Table 4-4. Stability classification results for composite data from all three sites using key described in Table 4-1 and ΔT values from 2-10m (19,540 valid hours).

STABILITY	Turner (%)	SRDT (%)	|Δ| (%)	Mean (%)
A	261 (1.3)	273 (1.4)	(0.1)	
B	2063 (10.6)	1993 (10.2)	(0.4)	
C	2403 (12.3)	2426 (12.4)	(0.1)	
D_{day}	5037 (25.8)	5072 (26.0)	(0.2)	
			→	(0.193)
D_{night}	3636 (18.6)	3641 (18.6)	(0.0)	
E	1210 (6.2)	1571 (8.0)	(1.8)	
F	4930 (25.2)	4564 (23.4)	(1.8)	
			→	(1.20)
				(0.62)

Hourly coincidence of stability categories: 61.7%
Hourly categories ± one class: 89.4%

Table 4-5. Stability classification results for Kincaid, IL data using key described in Table 4-1 and ΔT values from 2-10m (2916 valid hours; 83% of the period).

STABILITY	Turner (%)	SRDT (%)	|Δ| (%)	Mean (%)
A	61 (2.1)	42 (1.4)	(0.7)	
B	376 (12.9)	301 (10.3)	(2.6)	
C	497 (17.0)	432 (14.8)	(2.2)	
D_{day}	618 (21.2)	777 (26.6)	(5.4)	
			→	(2.7)
D_{night}	322 (11.0)	611 (21.0)	(10.0)	
E	237 (8.1)	257 (8.8)	(0.7)	
F	805 (27.6)	496 (17.0)	(10.6)	
			→	(7.1)
				(4.6)

Hourly coincidence of stability categories: 56.4%
Hourly categories ± one class: 89.7%

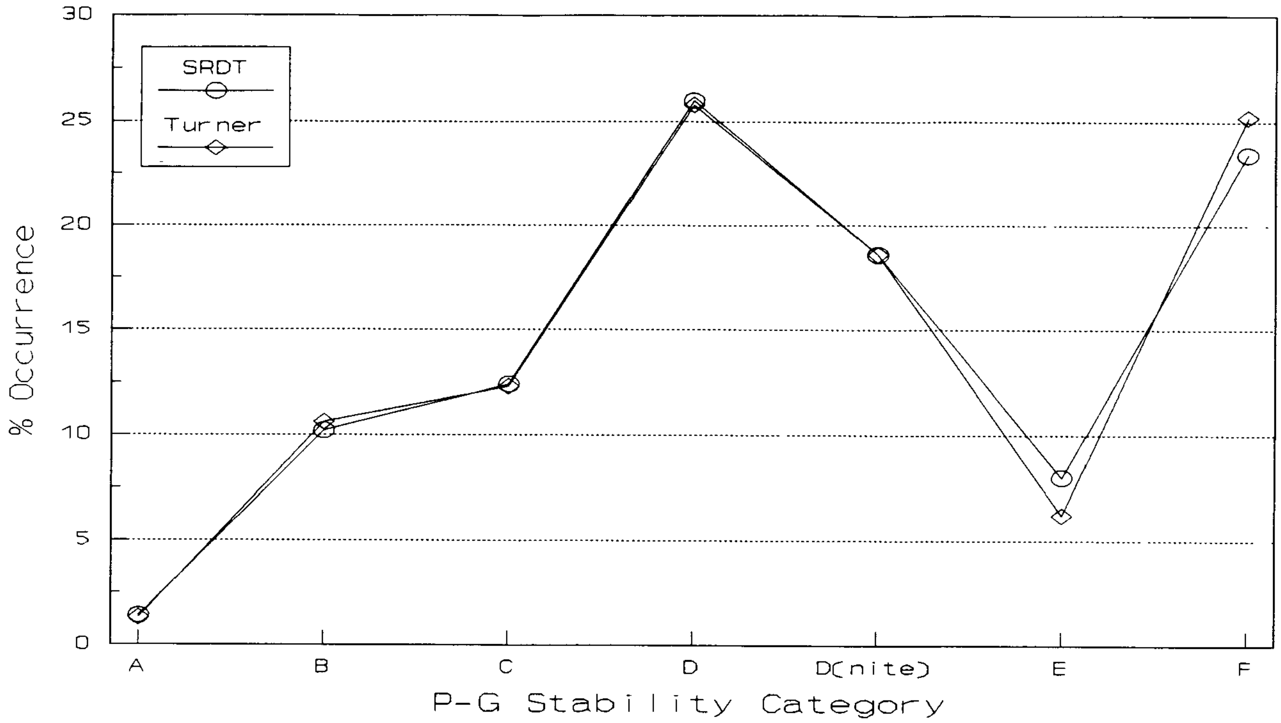

Figure 4-1. **Stability classification plot for composite data using key described in Table 4-1; 2-10m ΔT values (19,540 valid hours).**

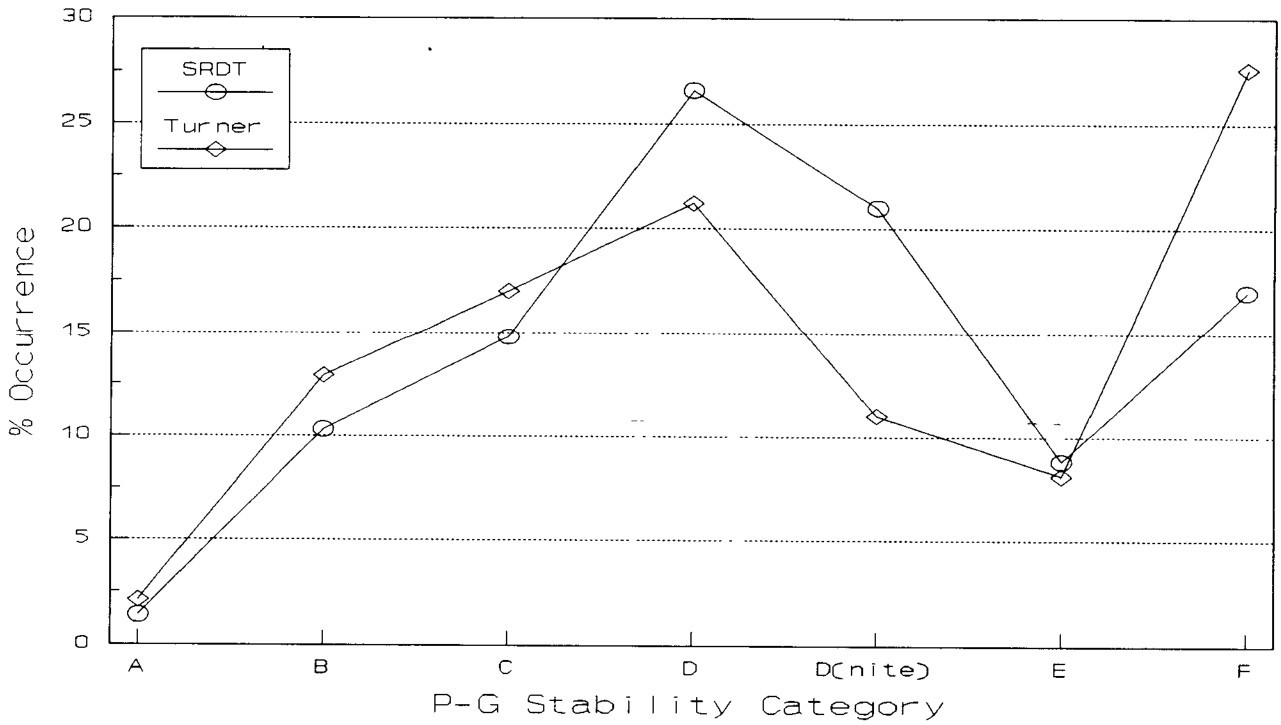

Figure 4-2. **Stability classification plot for Kincaid, IL data using key described in Table 4-1; 2-10m ΔT values (2916 valid hours; 83% of the period).**

solar radiation. In addition to the on-site data, concurrent surface observations from the NWS station at Springfield, IL (WBAN #93822), about 25km northwest of the site, were obtained.

For the Kincaid data base, 2616 hours (83% of those potentially available for 147 days) were valid for making the joint comparison of stability classes. Overall, the stability classifications for the two methods coincided for 56% of the hours, and were within one category for 90% of the hours (Table 4-5; Fig. 4-2). Unstable and E categories were comparable. The SRDT method overrepresented the nighttime D category and underrepresented the F category.

4.3 Results for the Longview Site

ENSR Consulting and Engineering provided the next data base. The meteorological monitoring site is located in Longview, in southwest Washington, along the Columbia River approximately 65km inland from the Pacific Ocean. While the terrain within the local proximity of the city of Longview is relatively flat ($z_0 \approx 10$cm), the terrain immediately across the Columbia River in Oregon and just outside the Longview city limits in Washington ascends quickly into a series of ridges and hills. The city itself (and the monitoring site) is approximately 5m above mean sea level (msl) due to its low-lying position along the Columbia River. Terrain extends 60m above msl within 3km of the monitoring site. Data for calendar year 1991 were available for this analysis and were collected and quality assured according to EPA guidance (EPA, 1987a), as well as ENSR's own internal standard operating procedures. On-site measurements of interest included those of 10m wind speed and direction, 2-10m and 2-50m ΔT, and total solar radiation. In addition to the on-site data, surface observations from the NWS station at Portland, OR (WBAN #24229), about 65km southeast of the site, were obtained. The topographical setting for the site, unique among the three sites examined in this analysis, is such that local micrometeorologial effects are possible. Preliminary analyses of nighttime wind speeds indicated that the site is influenced by nighttime drainage flows, resulting in relatively low (33% ≤ 1 ms^{-1}; 62% ≤ 2 ms^{-1}; $\bar{u}$ = 1.9 ms^{-1}) and uniform velocities.

For the Longview data base, 8187 hours (94% of those potentially available for 365 days) were valid for making the joint comparison of stability classes.

Overall, the stability classifications for the two methods coincided for 58% of the hours, and were within one category for 85% of the hours (Table 4-6; Fig. 4-3). Unstable categories generally compared better, while (as with Kincaid) some disparity occurred for the nighttime D category.

4.4 Results for the Bloomington Site

ENSR Consulting and Engineering also provided the third data base. The meteorological monitoring site, equipped with a 10m tower, is located in a rural area with slightly rough terrain ($z_0 \approx 25$cm) about 70km south of Indianapolis, near Bloomington, IN. To compensate for several days of missing data due to frequent lightning-caused outages, data for the 13-month period July 1991 - July 1992 were provided. These data were collected and quality assured according to the provisions of EPA guidance (EPA, 1987b), and ENSR's own internal standard operating procedures. On-site measurements of interest included those of 10m wind speed and direction, 2-10m ΔT, and total solar radiation. In addition to the on-site data, concurrent surface observations from the NWS station at Indianapolis, IN (WBAN #93819) were obtained.

For the Bloomington data base, 8437 hours (89% of those potentially available for 397 days) were valid for making the joint comparison of stability classes. Overall, the stability classifications for the two methods coincided for 67% of the hours, and were within one category for 94% of the hours (Table 4-7; Fig. 4-4). As with Kincaid, but to a lesser extent, the SRDT method underrepresented the F stability category.

4.5 Results for a ΔT Interval Other than 2-10m

There was interest to investigate the performance of the SRDT method for ΔT values measured at intervals above 10m. On-site meteorological data collected at Kincaid and Longview afforded just such an opportunity, as they included 10-50m ΔT values. As a group, the 10-50m ΔT values at both sites were less variable in absolute magnitude and less frequently in the isothermal/positive range as compared with their 2-10m counterparts.[a] Therefore, it was anticipated that a ΔT cutpoint of slightly less than 0.0 $°Cm^{-1}$ (e.g., -0.01 or

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[a]For Kincaid, 95% of the 2-10m ΔT values were in the isothermal/positive range, versus 79% of those from 10-50m. Likewise, for Longview, 89% of the 2-10m ΔT values were in the isothermal/positive range, versus 46% of those from 10-50m.

Table 4-6. Stability classification results for Longview, WA data using key described in Table 4-1 and ΔT values from 2-10m (8187 valid hours; 94% of the period).

STABILITY	Turner (%)	SRDT (%)	$\|\Delta\|$ (%)	Mean (%)
A	81 (1.0)	175 (2.1)	(1.2)	
B	880 (10.7)	993 (12.1)	(1.4)	
C	829 (10.1)	776 (9.5)	(0.6)	
D_{day}	2153 (26.3)	1999 (24.4)	(1.9)	
			→	(1.3)
D_{night}	1682 (20.6)	1268 (15.5)	(5.0)	
E	478 (5.8)	714 (8.7)	(2.9)	
F	2084 (25.4)	2262 (27.6)	(2.2)	
			→	(3.4)
				(2.2)

Hourly coincidence of stability categories: 58.0%
Hourly categories ± one class: 85.0%

Table 4-7. Stability classification results for Bloomington, IN data using key described in Table 4-1 and ΔT values from 2-10m (8437 valid hours; 89% of the period).

STABILITY	Turner (%)	SRDT (%)	$\|\Delta\|$ (%)	Mean (%)
A	119 (1.4)	56 (0.7)	(0.7)	
B	807 (9.6)	699 (8.3)	(1.3)	
C	1077 (12.8)	1218 (14.4)	(1.6)	
D_{day}	2266 (26.9)	2296 (27.2)	(0.3)	
			→	(1.0)
D_{night}	1632 (19.3)	1762 (20.9)	(1.6)	
E	495 (5.9)	600 (7.1)	(1.2)	
F	2041 (24.2)	1806 (21.4)	(2.8)	
			→	(1.9)
				(1.4)

Hourly coincidence of stability categories: 66.9%
Hourly categories ± one class: 93.5%

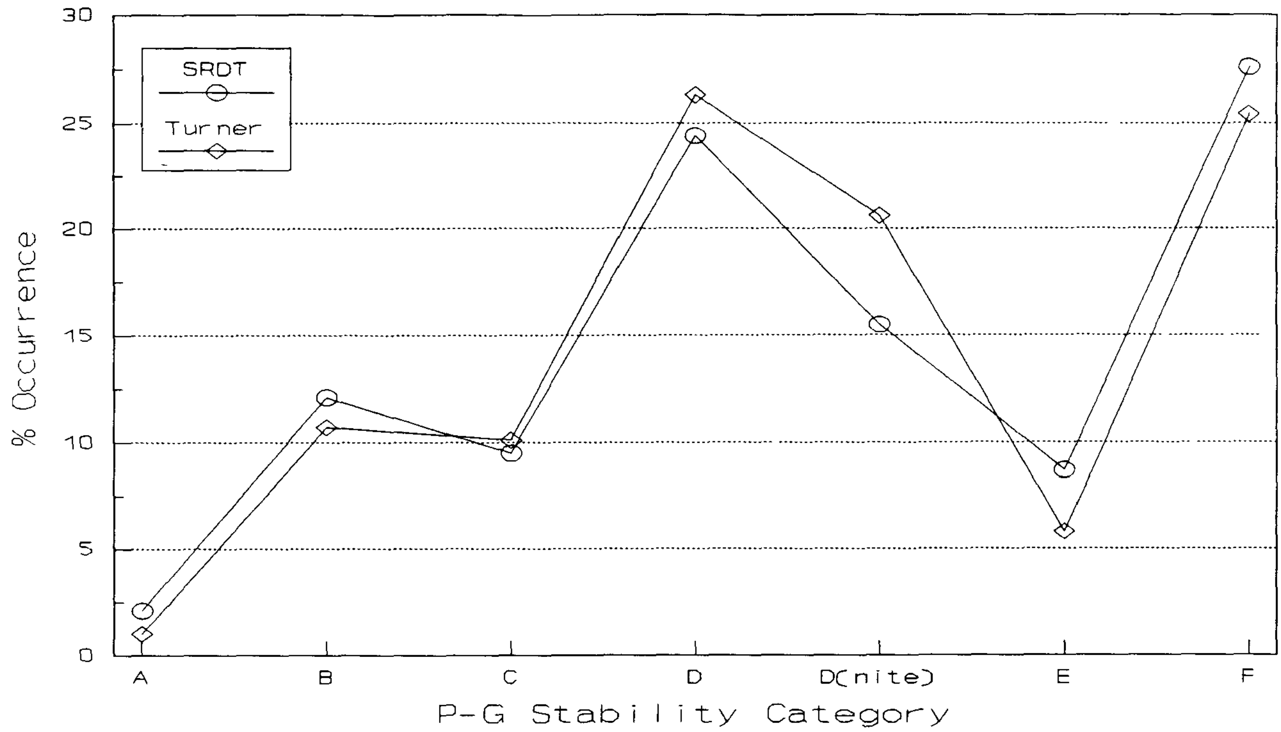

Figure 4-3. **Stability classification plot for Longview, WA data using key described in Table 4-1; 2-10m ΔT values (8187 valid hours; 94% of the period).**

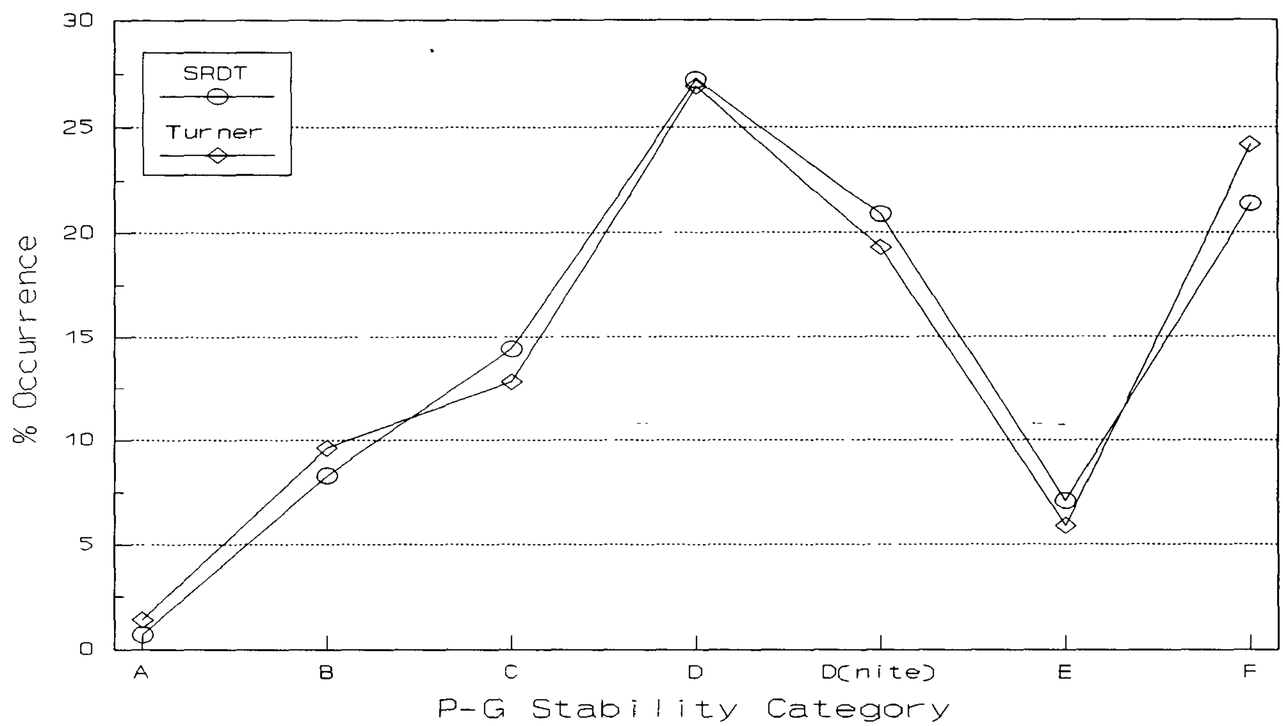

Figure 4-4. **Stability classification plot for Bloomington, IN data using key described in Table 4-1; 2-10m ΔT values (8437 valid hours; 89% of the period).**

-0.02) would have shown greater skill for the 10-50m ΔT's. Iteratively, it was found that a value of -0.01 $°Cm^{-1}$ seemed to produce only marginally better results than those using 0.0 $°Cm^{-1}$. For Kincaid, the nighttime mean absolute residual ($|\bar{\Delta}|$) was 6.9% for ΔT_L = -0.01 and -0.02 (versus 7.9% for ΔT_L = 0.0). For Longview, $|\Delta|$ was 3.9% for ΔT_L = -0.01 and -0.02 (versus 4.3% for ΔT_L = 0.0). Temperature difference offers only a minor refinement to the determination of stability category. Therefore, it was decided to employ a 0.0 $°Cm^{-1}$ cutpoint, regardless of measurement height interval.

The results for Kincaid (Table 4-8; Fig. 4-5) were similar to those using the 2-10m ΔT's; the mean residual for nighttime stability categories was about 7 percent. For the Longview site (Table 4-9; Fig. 4-6), the mean residual for nighttime stability categories was about 4 percent, slightly greater (4.3%) than that using the 2-10m ΔT's (3.4%). The analyses for both sites serve to show that stability categories can be as reasonably determined using ΔT values measured above 10m using the same ΔT criteria as for 2-10m. Indeed, analyses with more data bases may better support the notion that use of a ΔT cutpoint somewhat less that 0.0 $°Cm^{-1}$ affords better classification skill for intervals above 10m. However, for practicality in implementing the SRDT method it was considered that 0.0 $°Cm^{-1}$ was reasonable, particularly given site-to-site variability seen among the data bases used here.

4.6 Discussion

Of interest in illustrating how the mechanics of the SRDT method work, it may be noted that the D stability category at night occurred for about 12 to 15 percent fewer hours at the Longview site than those examined at the Bloomington and Kincaid site, respectively. This difference is primarily explainable by the nighttime wind regime. At the Longview site, nighttime winds ≤2 ms^{-1} (a requirement for stable classification for any lapse rate) occurred 11 to 25 percent more frequently than did those at Bloomington and Kincaid, respectively. It is thought that such a regime at the Longview site is due to micrometeorological effects (see Section 4.3).

Also, as indicated by data from the Kincaid and Longview sites, prevalence of nighttime D categories increased for the 10-50m ΔT data compared to their

Table 4-8. **Stability classification results for Kincaid, IL data using key described in Table 4-1 except ΔT values are from 10-50m (2917 valid hours; 83% of the period).**

STABILITY	Turner (%)	SRDT (%)	$\lvert\Delta\rvert$ (%)	Mean (%)
A	61 (2.1)	42 (1.4)	(0.7)	
B	376 (12.9)	301 (10.3)	(2.6)	
C	497 (17.0)	432 (14.8)	(2.2)	
D_{day}	618 (21.2)	777 (26.6)	(5.4)	
			→	(2.7)
D_{night}	323 (11.1)	631 (21.6)	(10.5)	
E	237 (8.1)	277 (9.5)	(1.4)	
F	805 (27.6)	457 (15.7)	(11.9)	
			→	(7.9)
				(5.0)

Hourly coincidence of stability categories: 56.1%
Hourly categories ± one class: 90.5%

Table 4-9. **Stability classification results for Longview, WA data using key described in Table 4-1 except ΔT values are from 10-50m (8187 valid hours; 94% of the period).**

STABILITY	Turner (%)	SRDT (%)	$\lvert\Delta\rvert$ (%)	Mean (%)
A	81 (1.0)	175 (2.1)	(1.2)	
B	880 (10.7)	993 (12.1)	(1.4)	
C	829 (10.1)	776 (9.5)	(0.6)	
D_{day}	2153 (26.3)	1999 (24.4)	(1.9)	
			→	(1.3)
D_{night}	1682 (20.5)	1553 (19.0)	(1.5)	
E	478 (5.8)	1011 (12.3)	(6.5)	
F	2084 (25.4)	1680 (20.5)	(4.9)	
			→	(4.3)
				(2.6)

Hourly coincidence of stability categories: 56.6%
Hourly categories ± one class: 88.8%

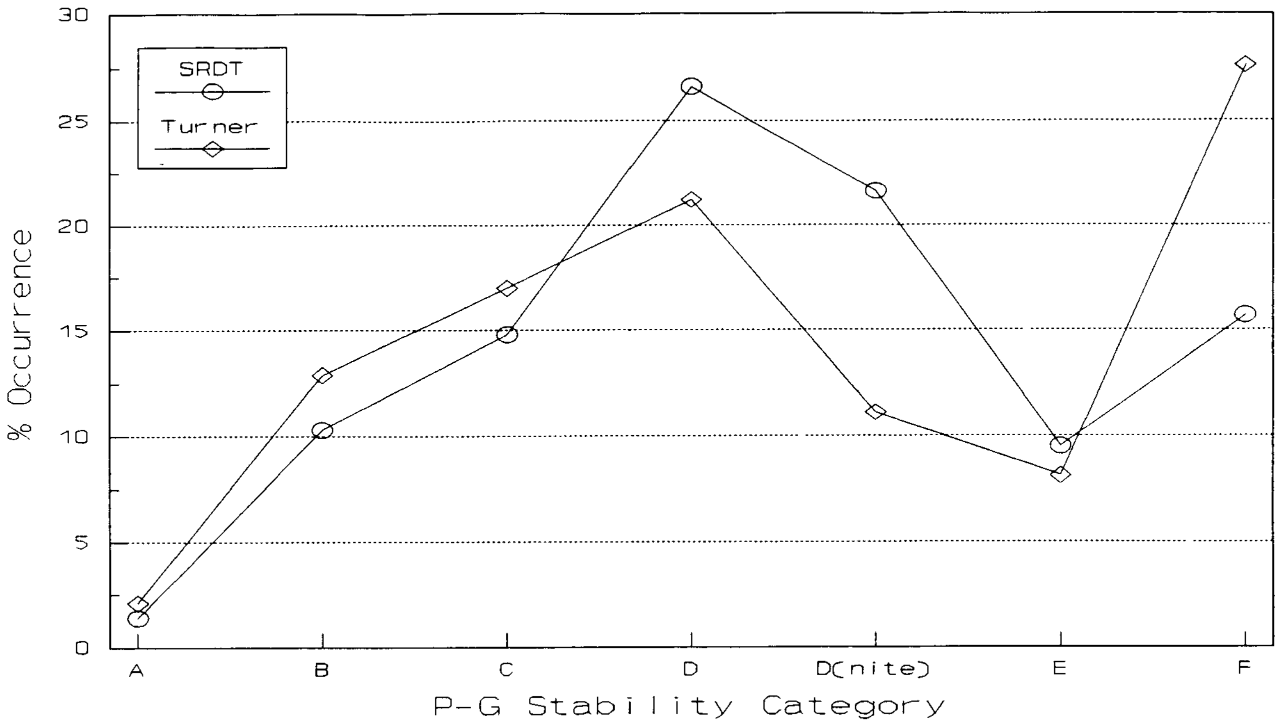

Figure 4-5. **Stability classification plot for Kincaid, IL data using key described in Table 4-1 except ΔT values are from 10-50m (2917 valid hours; 83% of the period).**

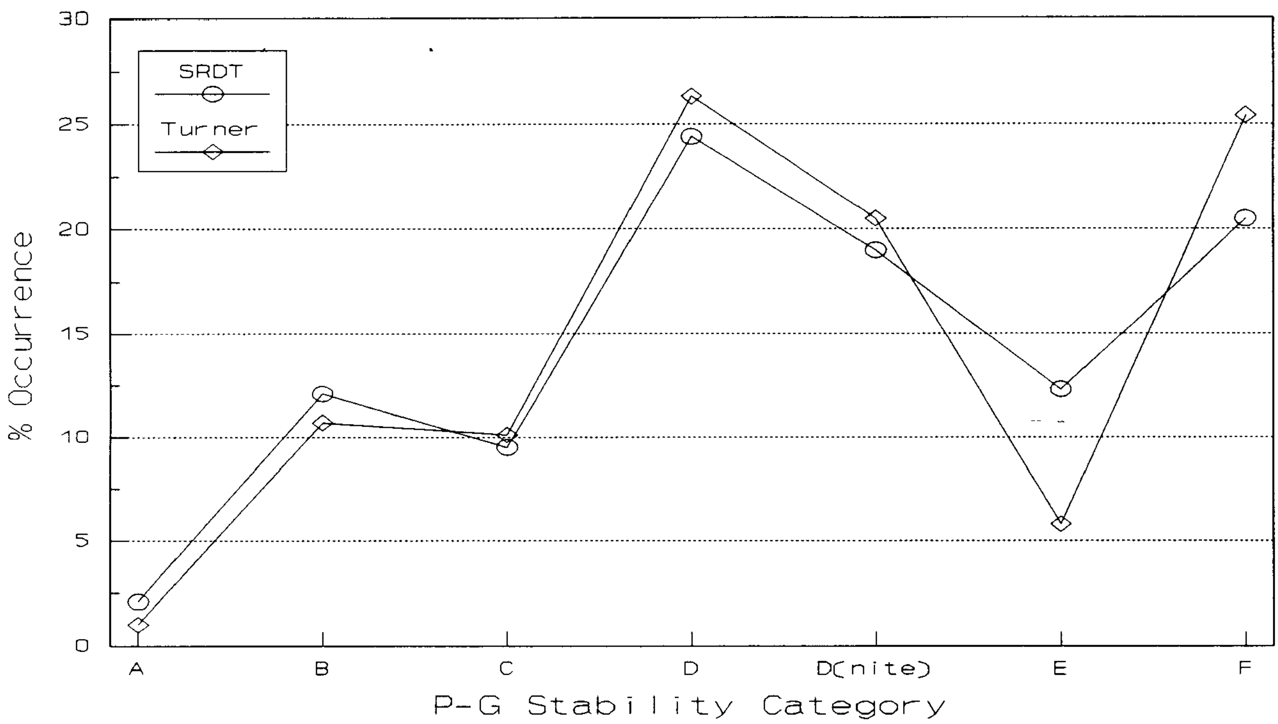

Figure 4-6. **Stability classification plot for Longview, WA data using key described in Table 4-1 except ΔT values are from 10-50m (8187 valid hours; 94% of the period).**

2-10m ΔT counterparts at both sites. The increase is due to the less frequent occurrence of isothermal/positive lapse rates seen in the upper boundary layer (Section 4.5), and the increase seen is roughly proportional to the decrease in occurrence of such lapse rates.

For the analysis of stability comparisons, Tables 4-4 through 4-9 emphasize the overall comparability of the frequency of occurrence of stability categories **in the aggregate**, i.e., without regard to hourly correspondence. As explained in Section 3.2, a systematic effort was employed to evenly allocate residuals on an hourly basis across all stability categories. Detailed hourly correspondence of stability categories was analyzed for all comparisons but reported (in matrix format) only in Table 4-2 for the pooled data. For 2-10m ΔT measurements, hourly correspondence of stability categories ranged from 56 to 58 percent for three data bases analyzed; categories were within one class for 85 to 94 percent of the hours examined. For 10-50m ΔT measurements, hourly correspondence of stability categories ranged from 56 to 57 percent for two data bases analyzed; categories were within one class for 89 to 91 percent of the hours examined. As indicated in the matrix for the pooled data (Table 4-2), infrequently the corresponding categories differed by two classes or more. An important point to remember in viewing these results is that having a stability category that differs by no more than one class most of the time on an hourly basis can still result in quite different design concentrations as different wind speeds, directions and mixing heights are being linked with those stability categories.

These results suggest use of a nighttime ΔT cutpoint value of 0.0 $°Cm^{-1}$ is robust enough to accommodate a range of height intervals, provided attention is given to proper siting of temperature sensors so as to effectively characterize the boundary layer. Consistent with probe placement guidance (EPA, 1987a), the lower temperature sensor should be least in the range of order of $20z_0$ - $100z_0$, but never less than 1m, above the ground surface (Irwin et al., 1985). The upper sensor should be of the order 5 times the lower sensor height. These criteria ensure that the lower instrument level is within the surface layer and that a reasonable separation is maintained between the two measurement levels. Stronger temperature gradients are expected in the lower atmosphere. Hence, as the distance above ground increases for the lower measurement level, the separation distance accordingly should increase.

5. RESULTS FROM DISPERSION MODELING

To ascertain the possible effect of the new SRDT stability classification method on design concentrations, a sensitivity analysis was performed on the ratios of design concentrations ($\chi_{SRDT}/\chi_{Turner}$). The Industrial Source Complex (ISC2) model was used to compute concentration values for averaging times of 1-hour, 3-hour, 24-hour, and the entire period modeled. ISC2 provides both the high first high (H1H) and the high second high (H2H) concentrations. Three stationary point sources[a] of heights 35m, 100m, and 200m, respectively, were used in these analyses. These same sources have been used in past modeling evaluations to assess the impact of revisions to regulatory air quality models (Lee et al., 1979). Receptors were arranged in a polar grid network with 36 radials and 180 sites on 5 concentric rings at 800m, 2000m, 4000m, 7000m, and 15000m, respectively; the sources were placed at the origin. Flat terrain was assumed and the model was run in the RURAL mode. Hours with on-site wind speed less than 0.5 ms^{-1} were treated as calms, and the option 'MSGPRO', which allows processing of missing hours,[b] was set 'ON'. For analyses of 24-hour concentrations, days with more than 6 missing hours were omitted. The daytime morning mixing height is determined daily within the meteorological processor based on the stability category just before sunrise. The maximum afternoon mixing height ($z_{i\text{-}max}$) was preset to 2500m. This configuration conferred a measure of consistency between the ISC2 runs. The tabulated results for all ISC2 runs are presented in Appendix B.

5.1 Results for the Bloomington Site

At the Bloomington, IN site, where the ΔT interval was 2-10m, the composite mean ratio (across 4 averaging times, 3 source heights, and both concentration types; 24 values) was 1.06 (median was also 1.06), with a range (R) of 0.85 - 1.24 (Table B-1); the geometric mean ratio was 1.05. For the H1H concentrations (12 values), the mean ratio was 1.07 (R = 0.97 - 1.16), with a median of 1.05; the geometric mean was 1.07. For the H2H concentrations (12 values),

[a]For the 35m stack, parameters were: Q_s = 100 gs^{-1}, T_s = 432K, v_s = 11.7 ms^{-1}, d_s = 2.4m
For the 100m stack, parameters were: Q_s = 100 gs^{-1}, T_s = 416K, v_s = 18.8 ms^{-1}, d_s = 4.6m
For the 200m stack, parameters were: Q_s = 100 gs^{-1}, T_s = 425K, v_s = 26.5 ms^{-1}, d_s = 5.6m

[b]Such hours are also processed as calms.

the mean ratio was 1.05 (R = 0.85 - 1.24), with a median of 1.07; the geometric mean was 1.04.

5.2 Results for the Kincaid Site

For analyses done with 2-10m ΔT data, the composite mean ratio was 1.06 (median was 1.08), with a range of 0.75 - 1.62 (Table B-2); the geometric mean ratio was 1.05. For the H1H concentrations, the mean ratio was 1.09 (R = 0.77 - 1.62), with a median of 1.12; the geometric mean was 1.08. For the H2H concentrations, the mean ratio was 1.04 (R = 0.75 - 1.41), with a median of 1.05; the geometric mean was 1.01.

5.3 Results for the Longview Site

For analyses done with 2-10m ΔT data, the composite mean ratio was 1.24 (median was 1.20), with a range of 1.00 - 1.70 (Table B-4); the geometric mean ratio was 1.22. For the H1H concentrations, the mean ratio was 1.25 (R = 1.00 - 1.70), with a median of 1.20; the geometric mean was 1.23. For the H2H concentrations, the mean ratio was 1.24 (R = 1.00 - 1.62), with a median of 1.19; the geometric mean was 1.22.

5.4 Discussion

As noted in the above results (as well as in the footnotes for Tables B-1 to B-5), for each site and ΔT interval a composite mean ratio was computed based on 24 values. Mean ratios were also computed for the H1H and H2H concentrations based on 12 values for each. Likewise, the geometric mean and standard deviation were also computed and reported. Because the design concentration ratios are considered to be approximately log-normally distributed, the latter statistics probably better characterize the ratio distribution. Formal hypothesis testing is impractical as strict independence among the ratios cannot be assumed. For example, a concentration value that figures into a ratio for one averaging time may also figure into a ratio for a longer averaging time at the same site.

The ratios at both the Kincaid and Bloomington sites do not appear to be significantly different than 1.0. Nor is there sufficient evidence to warrant the conclusion that design concentrations predicted via SRDT-derived stabilities are from a different population than those predicted via Turner-derived stabilities. While the same relationship does not appear to be the case with the Longview data, neither can meaningful confidence bounds be established. As explained in Section 4.6, there may be some site-specific features at the Longview site that result in some unusual influences. Taken on the whole, the range of concentration differences seen among the three sites is of the order expected for site to site differences and professional judgement should be used in viewing the modeling results presented.

5.5 Analysis of Computed Mixing Heights

For ratios ≥1.15, special attention was given to the influence of computed mixing height values for the averaging times involved. Such values are themselves determined by the occurrence of stability category, and can be highly influential in the model predicted concentrations. Thus, values for estimated mixing heights in the short term, as well as their long term distribution pattern, was of interest in assessing the consequence of the SRDT method on concentration values; one must interpret such concentrations in the context of the associated mixing heights. The behavior of the computed mixing heights was investigated using simple statistics, and the diurnal patterns are depicted in Figures B-1 to B-5. In these Figures, the mean ($\overline{z}_i$) (Figs. B-1a to B-5a) and median (Figs. B-1b to B-5b) mixing height was determined by hour of the day. For convenience, only daytime hours were analyzed.

At the Bloomington site, on three occasions the ratio was ≥1.15. The associated mixing heights were not seen to have been influential in the prediction of the higher ambient concentration via SRDT-derived stability categories. While the period averages were consistently higher via SRDT, the period averaged daytime mixing heights via Turner (2150m; median = 2500m) were lower than those computed via SRDT (2170m; median = 2500m). Therefore, mean mixing height does not adequately explain the high concentrations for the period.

At the Kincaid site, on 8 occasions the ratio was ≥1.15. The associated mixing heights were seen to be increasing the ratio in half of these instances, though the pattern appeared to be random. The period averages were higher via SRDT only for the 35m stack. As with the Bloomington site, the period averaged daytime mixing heights via Turner (2040m; median = 2500m) were lower than those computed via SRDT (2130m; median = 2500m). When stability category was estimated using the 10-50m ΔT data, the results were virtually identical to those found with the 2-10m ΔT data (compare Tables B-2 and B-3).

At the Longview site, on 14 occasions the ratio was ≥1.15. In some of these cases, differences in early morning daytime mixing heights seemed to account for the differences seen in concentration values. This was especially true for the 200m source. As with the Kincaid site, period averages were consistently higher via SRDT. However, the period averaged daytime mixing heights via Turner (2150m; median = 2500m) were greater than those computed via SRDT (2130m; median = 2500m). When stability category was estimated using the 10-50m ΔT data, the results were virtually identical to those found with the 2-10m ΔT data (compare Tables B-4 and B-5). The period averaged daytime mixing heights via Turner using the 10-50m ΔT data (2470m; median = 2500m) were also greater than those computed via SRDT (2150m; median = 2500m). For this site, the mean mixing height may at least partially explain the high concentrations for the period.

In general, at all sites and for both ΔT intervals, the mean mixing height at or just after sunrise computed by MPRM is greater with SRDT-derived stabilities ($\overline{z}_{i\text{-}SRDT}$) than with those derived via Turner ($\overline{z}_{i\text{-}Turner}$) stabilities (Figs. B-1a to B-5a). Whereas, except for at Kincaid, mean afternoon[a] $\overline{z}_{i\text{-}SRDT}$ seems to be lower than $\overline{z}_{i\text{-}Turner}$.

This disparate behavior in the time series of computed mixing heights is an inherent trait of the mixing height algorithm as implemented in MPRM and can, in part, be traced directly to how mixing heights are determined for daytime hours having neutral stability. In these cases, the algorithm interpolates in time by one of two different algorithms, depending on the estimated stability just before sunrise. This may result in spurious increases and decreases in the time series of early morning daytime mixing height values.

At the Bloomington site, the early morning $\overline{z}_{i\text{-}SRDT}$ is considerably higher than $\overline{z}_{i\text{-}Turner}$. This is mainly due to the greater number of nighttime hours with D stability via SRDT. In mid-morning this pattern reverses, followed by convergence at about 1400 hours. At the Kincaid site, the early morning $\overline{z}_{i\text{-}SRDT}$ is also higher than $\overline{z}_{i\text{-}Turner}$, again due to a greater number of nighttime hours having D stability via SRDT. After a mid-morning convergence, $\overline{z}_{i\text{-}SRDT}$ again exceeds $\overline{z}_{i\text{-}Turner}$, followed by convergence at about 1400 hours. Note that $\overline{z}_{i\text{-}SRDT}$ is

[a]I.e., from about 0900 - 1400 hours.

never lower than $\bar{z}_{i\text{-}Turner}$. At Longview, the pattern is not quite so predictable/ explainable as that for the other sites. For the 2-10m ΔT data, the early morning $\bar{z}_{i\text{-}Turner}$ is initially higher than $\bar{z}_{i\text{-}SRDT}$, due to a greater number of nighttime hours having D stability via Turner. By 0600 hours, though, the pattern reverses. Following a mid-morning convergence, there is another reversal, with $\bar{z}_{i\text{-}Turner}$ again higher than $\bar{z}_{i\text{-}SRDT}$; by 1400 hours the $\bar{z}_i$'s converge. For the 10-50m ΔT data, the pattern is the same as that for the 2-10m ΔT data except that the early morning $\bar{z}_{i\text{-}SRDT}$ is higher than $\bar{z}_{i\text{-}Turner}$, even though there were still 8 percent more nighttime hours with D stability via Turner! Perhaps some of the aforementioned micrometeorological influences (Section 4.6) were operating in some more complex way for the computation of mixing heights at this site.

The occurrence of a larger early morning mixing height is largely related to the prevalence of nighttime D stability category (specifically, its occurrence the hour before sunrise). This relationship was borne out in all mixing height analyses except for that using the 10-50m ΔT data at the Longview site (Figure B-5a), where the relationship was reversed. The mixing height analyses serve to illustrate how the prediction of ambient concentrations is affected by mixing heights, which themselves exhibit complex patterns due to the influence of stability categories and their occurrence relative to the time of sunrise. Because of the nonlinear linkage between the occurrence of stability category and predicted concentration via factors such as mixing height, care should be exercised in interpreting the stability comparison results and those from the dispersion modeling (see discussion at end of Section 4.6).

Thus, in the comparisons made in this evaluation, apparent disparities in mixing heights, which may indeed result in the prediction of significant concentration values, are as likely as not an artifact of the computational system. Though it was possible, it was not deemed prudent to "factor" the mixing height influence out because it would not have emulated the complete computational system as it is employed for making model predictions in regulatory applications.

6. SUMMARY AND CONCLUSIONS

Turner's method for estimating the P-G stability categories provides a practical procedure for the routine implementation of Gaussian dispersion models if representative cloud observations are available. The proposed SRDT method uses on-site meteorological data without the need for such cloud observations, while retaining the basic structure and rationale of Turner's method.

A comparative analysis was performed using on-site data from three sites: Kincaid, IL (7 April - 31 August 1980), Longview, WA (January - December 1991), and Bloomington, IN (July 1991 - July 1992). Meteorological data included 10m wind speed, total solar radiation, and temperature difference (ΔT). All three sites had ΔT data from 2-10m; 10-50m ΔT data were available from Kincaid and Longview. Valid observations from all three sites were pooled to yield a composite data base of 19,540 hours. The SRDT method was developed empirically to emulate the results obtained using the Turner stability estimation scheme. Through iterations, optimum "cutpoints" (meteorological parameter limits) were determined, initially using only the 2-10m ΔT data. For the pooled data, stability categories estimated by both methods coincided for 62 percent of the hours, and were within one class for 89 percent. Using the same cutpoints for each site gave comparable results. In an effort to evaluate the system for ΔT intervals other than 2-10m, the 10-50m ΔT data were evaluated for two sites. Using the same optimum cutpoints determined for the 2-10m ΔT data produced virtually the same distribution of stability categories.

Using ISC2, an analysis of the effects on design concentration ratios, $\chi_{SRDT}/\chi_{Turner}$, was completed for three hypothetical sources. For three sites, the ratios averaged 1.06 to 1.24 across four averaging times, three source heights, and two concentration types. Computed mixing heights were examined to help understand their influence in the model-predicted concentrations.

7. REFERENCES

Bowen, B.M., J.M. Dewart and A.I. Chen, 1983. Stability class determination: a comparison for one site. Proceedings, Sixth Symposium on Turbulence and Diffusion, American Meteorological Society, Boston, MA; pp. 211-214.

Bowen, B.M. and S.E. Pamp, 1994. Comparison and Evaluation of Turbulence Estimation Schemes at the Rocky Flats Plant. Proceedings, Eighth Joint Conference on Air Pollution Meteorology, American Meteorological Society/ Air & Waste Management Association, 24-28 January 1994, Nashville, TN; pp. 54-60.

Chandler, T.J., 1965. <u>The Climate of London</u>. Hutchinson and Co., Ltd.; 292 pp.

EPA, 1986. Guideline on Air Quality Models (Revised), Supplement A (1987) and Supplement B (1993). EPA-450/2-78-027R. Codified as Appendix W of 40 CFR Part 51. U.S. Environmental Protection Agency, Research Triangle Park, NC.

EPA, 1987a. On-site Meteorological Program Guidance for Regulatory Modeling Applications. EPA-450/4-87-013. U.S. Environmental Protection Agency, Research Triangle Park, NC.

EPA, 1987b. Ambient Monitoring Guidelines for Prevention of Significant Deterioration (PSD). EPA-450/4-87-007. U.S. Environmental Protection Agency, Research Triangle Park, NC.

EPA, 1990. Summary of Public Comments and EPA Responses on the Fourth Conference on Air Quality Modeling - October 1988. EPA Docket A-88-04, Item No. II-0-1. U.S. Environmental Protection Agency, Research Triangle Park, NC.

EPA, 1993. Summary of Public Comments and EPA Responses on the Fifth Conference on Air Quality Modeling: March 1993. EPA Docket A-88-04, Item No. V-C-1. U.S. Environmental Protection Agency, Research Triangle Park, NC.

EPRI, 1983. A Catalog of Data for the Plume Model Validation and Development Data Base--Plains Site. EPRI Report No. EA-3080, Electric Power Research Institute, Palo Alto, CA.

Gifford, F.A. Jr., 1961. Use of routine meteorological observations for estimating atmospheric dispersion. *Nuclear Safety* 2(4): 47-57.

Irwin, J.S., S.E. Gryning, A.A.M. Holtslag and B. Sivertsen, 1985. Atmospheric Dispersion Modeling Based on Boundary Layer Parameterization. EPA-600/ 3-85-056. U.S. Environmental Protection Agency, Research Triangle Park, NC.

Irwin, J.S., J.O. Paumier and R.W. Brode, 1988. Meteorological Processor for Regulatory Models (MPRM 1.2) User's Guide. EPA-600/3-88-043R. U.S. Environmental Protection Agency, Research Triangle Park, NC.

Lee, R.F., J.A. Tikvart, J.L. Dicke and R.W. Fisher, 1979. The effect of revised dispersion parameters on concentration estimates. Proceedings, Fourth Symposium on Turbulence, Diffusion, and Air Pollution, American Meteorological Society, Boston, MA; pp. 70-74.

Ludwig, F.L. and W.F. Dabberdt, 1972. Evaluation of the APRAC-1A urban diffusion model for carbon monoxide. Final report, Coordinating Research Council and EPA Contract CAPA-3-68 (1-69), Stanford Research Institute, Menlo Park, CA; 147 pp. (NTIS No. PB 210819)

Ludwig, F.L. and W.F. Dabberdt, 1976. Comparison of two practical stability classification schemes in an urban application. *Journal of Applied Meteorology*, 15: 1172-1176.

Miller, D.H., 1981. Energy at the Surface of the Earth, Volume 27. International Geophysics Series. Academic Press; 516pp.

Pasquill, F., 1961. The estimation of the dispersion of windborne material. *Meteorological Magazine*, 90: 33-49.

Smith, F.B., 1972. A scheme for estimating the vertical dispersion of plumes from a source near ground level. Proc. Third Meeting Expert Panel on Air Pollution Modeling. NATO Committee on Challenges of Modern Society, XVII-1 to XVII-14.

Turner, D.B., 1964. A diffusion model for an urban area. *Journal of Applied Meteorology*, 3: 83-91.

Appendix A

Results of Randomization Analysis

As discussed in the Section 3.2, the composite data were randomly split into two complementary subsets and the same stability classification and comparison applied to each. Results of the stability calculations for the two methods are presented in Table A-1. The results shown are representative of what was seen throughout all analyses performed. Different seed values[a] would result in different cases being selected for the two bins (i.e., Bin 0 and Bin 1). The results shown indicate only minor differences in the comparison statistics between the two stability estimation methods.

For Bin 0, valid data for use in joint stability calculations were available for 9834 out of 10970 hours (89.6 percent) randomly selected of the 909-day period. For Bin 1, valid data were available for 9706 out of 10846 hours (89.4 percent) so selected. For Bin 0, the stability classifications for the two methods coincided for 62 percent of the hours and were within one category for 89 percent of the hours. The unstable category was the same, while the neutral category decreased slightly and the stable category increased slightly. The mean absolute residual (see Section 4.1) was 0.88% over all categories; for daytime categories it was 0.40%, while for nighttime categories it was 1.5%. For Bin 1, the stability classifications for the two methods also coincided for 62 percent of the hours and were within one category for 89 percent of the hours. Stable and unstable categories decreased slightly, while the neutral category increased slightly. The mean absolute residual was 0.82% over all categories; for daytime categories it was 0.45%, while for nighttime categories it was 1.3%. The frequency distributions of stability categories for the two methods (both bins) are displayed in Table A-1.

[a]Randomization was accomplished using a random number generator. The unique assignment of a subset to one bin versus that assigned to the other is controlled by the seed value.

Table A-1. Comparison of hourly stability categories via Turner versus SRDT for random subsets of the composite data (see page A-4 for notes).[a]

TEST0PL[b]

		Turner							
		A	B	C	D_{day}	D_{night}	E	F&G	TOTAL
SRDT	A	45	72	1	1	0	0	0	119
	B	62	627	202	127	0	0	0	1018
	C	18	235	489	517	0	0	0	1259
	D_{day}	2	128	488	1875	0	0	1	2493
	D_{night}	0	0	0	0	1079	427	324	1830
	E	0	0	0	0	359	134	325	818
	F	0	0	0	0	446	29	1822	2297
	TOTAL	127	1062	1180	2520	1884	590	2471	9834

	FREQUENCY (%)[d]	
STABILITY CLASS	Turner	SRDT
A	1.3	1.2
B	10.8	10.4
C	12.0	12.8
D	44.8	44.0
E	6.0	8.3
F	25.1	23.4
UNSTABLE	24.1	24.4
NEUTRAL	44.9	44.0
STABLE	31.1	31.7

TEST1PL[c]

		Turner							
		A	B	C	D_{day}	D_{night}	E	F&G	TOTAL
SRDT	A	63	88	2	1	0	0	0	154
	B	56	603	191	125	0	0	0	975
	C	13	194	481	479	0	0	0	1167
	D_{day}	2	116	549	1912	0	0	0	2579
	D_{night}	0	0	0	0	1006	478	327	1811
	E	0	0	0	0	300	116	337	753
	F	0	0	0	0	446	26	1795	2267
	TOTAL	134	1001	1223	2517	1752	620	2459	9706

	FREQUENCY (%)[e]	
STABILITY CLASS	Turner	SRDT
A	1.4	1.6
B	10.3	10.0
C	12.6	12.0
D	44.0	45.2
E	6.4	7.8
F	25.3	23.4
UNSTABLE	24.3	23.7
NEUTRAL	44.0	45.2
STABLE	31.7	31.1

Notes for Table A-1

a) On-site data are pooled from all three sites (see Section 3.2).

b) This analysis was done using *TEST0PL*, which selects records randomly assigned an index of 0 from pooled data sets. Of 21816 records read from the 3 raw meteorological input files, 10846 were ignored while 10970 were randomly selected for processing. Of those selected, 1136 were rejected for missing data. These included 649 with flags for invalid P-G stabilities and 1106 with flags for missing on-site data, including:

706 with flags for 10m wind speed;
682 with flags for total solar radiation; and
265 with flags for 2-10m $\Delta T/\Delta Z$ measurements.

Thus, the Turner/SRDT comparison matrix is based on 9834 valid records (hours), or 89.6% of the records randomly selected with initial seed value: 1500. Randomly selected were 5679 daytime hours and 5291 nighttime hours; processed were 4889 daytime hours and 4945 nighttime hours.

c) This analysis was done using *TEST1PL*, which selects records randomly assigned an index of 1 from pooled data sets. Of 21816 records read from the 3 raw meteorological input files, 10970 were ignored while 10846 were randomly selected for processing. Of those selected, 1140 were rejected for missing data. These included 646 with flags for invalid P-G stabilities and 1122 with flags for missing on-site data, including:

715 with flags for 10m wind speed;
699 with flags for total solar radiation; and
264 with flags for 2-10m $\Delta T/\Delta Z$ measurements.

Thus, the Turner/SRDT comparison matrix is based on 9706 valid records (hours), or 89.5% of the records randomly selected with initial seed value: 1500. Randomly selected were 5686 daytime hours and 5160 nighttime hours; processed were 4875 daytime hours and 4831 nighttime hours.

d) Using *TEST0PL*, the stability classifications for the two methods coincided for 61.7% of the hours, and were within one category for 89.4% of the hours (with P-G categories F and G via Turner combined).

e) Using *TEST1PL*, the stability classifications for the two methods coincided for 61.6% of the hours, and were within one category for 89.4% of the hours (with P-G categories F and G via Turner combined).

Appendix B

Results of Gaussian Dispersion Modeling:

A Consequence Analysis

Table B-1. Design concentration ratios derived from ISC2ST for Bloomington, IN site; 2-10m ΔT (see Section 5.1).

Source[b]	Avg. Time	Ambient Concentration[a] via ISC2ST (μgm^{-3}) Turner[c]	SRDT[d]	Ratio[e] ($\chi_{SRDT}/\chi_{Turner}$)
Single 35m Stack	1-hour	245.7	238.1	0.97
		232.9	233.7	1.00
	3-hour	217.3	225.3	1.04
		198.4	214.2	1.08
	24-hour	76.1	75.7	1.00
		67.9	67.9	1.00
	Period (8437 hours)	4.38	4.90	1.12
		4.12	4.64	1.13
Single 100m Stack	1-hour	55.9	56.8	1.02
		55.3	47.3	0.85
	3-hour	34.2	35.5	1.04
		31.1	33.7	1.08
	24-hour	7.98	9.26	1.16
		6.49	8.02	1.24
	Period (8437 hours)	0.349	0.391	1.12
		0.348	0.376	1.08
Single 200m Stack	1-hour	30.2	30.7	1.02
		24.3	25.9	1.06
	3-hour	15.4	17.7	1.15
		12.0	11.2	0.94
	24-hour	2.93	3.24	1.10
		2.60	2.65	1.02
	Period (8437 hours)	0.104	0.110	1.06
		0.097	0.105	1.08

[a]For each averaging time, high 1st high (H1H) concentration appears above dotted line; high 2nd high (H2H) concentration appears below dotted line.

[b]See text, Section 5.0, for description of all source and receptor parameters used in the dispersion model runs.

[c]Hourly mixing heights are computed based on Turner-derived stabilities.

[d]Hourly mixing heights are computed based on SRDT-derived stabilities.

[e]Statistical analysis (see Section 5.1):

	median	$\bar{X}$	s	$\bar{X}_g$	s_g
For all 24 values:	1.06	1.06	0.08	1.05	1.08
For 12 H1H concentration ratios only:	1.05	1.07	0.06	1.07	1.06
For 12 H2H concentration ratios only:	1.07	1.05	0.10	1.04	1.10

Table B-2. Design concentration ratios derived from ISC2ST for Kincaid, IL site; 2-10m ΔT (see Section 5.2).

Source[b]	Ambient Concentration[a] via ISC2ST (μgm^{-3})			
	Avg. Time	Turner[c]	SRDT[d]	Ratio[e] ($\chi_{SRDT}/\chi_{Turner}$)
Single 35m Stack	1-hour	254.4	236.7	0.93
		233.5	236.1	1.01
	3-hour	201.9	234.5	1.16
		186.4	194.4	1.04
	24-hour	60.8[f]	69.8	1.15
		53.5	56.5	1.06
	Period	5.86	6.43	1.10
	(2842 hours)	5.25	5.96	1.13
Single 100m Stack	1-hour	61.8	61.8	1.00
		54.7	37.0	0.68
	3-hour	37.2	36.6	0.99
		27.8	30.6	1.10
	24-hour	9.21	10.6	1.15
		7.43	7.48	1.01
	Period	0.649	0.567	0.87
	(2842 hours)	0.649	0.563	0.87
Single 200m Stack	1-hour	26.3	32.2	1.22
		24.6	30.1	1.22
	3-hour	12.3	19.9	1.62
		11.1	15.7	1.41
	24-hour	3.00	3.65	1.22
		2.44	2.70	1.11
	Period	0.225	0.172	0.77
	(2842 hours)	0.221	0.166	0.75

[a]For each averaging time, high 1st high (H1H) concentration appears above dotted line; high 2nd high (H2H) concentration appears below dotted line.

[b]See text, Section 5.0, for description of all source and receptor parameters used in the dispersion model runs.

[c]Hourly mixing heights are computed based on Turner-derived stabilities.

[d]Hourly mixing heights are computed based on SRDT-derived stabilities.

[e]Statistical analysis (see Section 5.2):

	median	$\overline{X}$	s	$\overline{X}_g$	s_g
For all 24 values:	1.08	1.07	0.21	1.05	1.22
For 12 H1H concentration ratios only:	1.12	1.10	0.22	1.08	1.21
For 12 H2H concentration ratios only:	1.05	1.03	0.20	1.01	1.22

[f]One hour was missing in the computation of this concentration.

Table B-3. Design concentration ratios derived from ISC2ST for Kincaid, IL site; 10-50m ΔT (see Section 5.2).

Source[b]	Ambient Concentration[a] via ISC2ST (μgm^{-3})			
	Avg. Time	Turner[c]	SRDT[d]	Ratio[e] ($\chi_{SRDT}/\chi_{Turner}$)
Single 35m Stack	1-hour	254.4	236.7	0.93
		233.5	236.1	1.01
	3-hour	201.9	234.5	1.16
		186.4	194.4	1.04
	24-hour	60.8[f]	69.8	1.15
		53.5	56.5	1.06
	Period (2842 hours)	5.86	6.43	1.10
		5.25	5.96	1.14
Single 100m Stack	1-hour	61.8	61.8	1.00
		54.7	37.0	0.68
	3-hour	37.2	36.6	0.99
		27.8	30.6	1.10
	24-hour	9.21	10.6	1.15
		7.43	7.48	1.01
	Period (2842 hours)	0.649	0.567	0.87
		0.649	0.563	0.87
Single 200m Stack	1-hour	26.3	32.2	1.22
		24.6	30.1	1.22
	3-hour	12.3	19.9	1.62
		11.1	15.7	1.41
	24-hour	3.00	3.65	1.22
		2.44	2.70	1.11
	Period (2842 hours)	0.225	0.172	0.77
		0.221	0.166	0.75

[a]For each averaging time, high 1st high (H1H) concentration appears above dotted line; high 2nd high (H2H) concentration appears below dotted line.

[b]See text, Section 5.0, for description of all source and receptor parameters used in the dispersion model runs.

[c]Hourly mixing heights are computed based on Turner-derived stabilities.

[d]Hourly mixing heights are computed based on SRDT-derived stabilities.

[e]Statistical analysis (see Section 5.2):

	median	$\bar{X}$	s	$\bar{X}_g$	s_g
For all 24 values:	1.08	1.07	0.21	1.05	1.22
For 12 H1H concentration ratios only:	1.12	1.10	0.22	1.08	1.21
For 12 H2H concentration ratios only:	1.05	1.03	0.20	1.01	1.22

[f]One hour was missing in the computation of this concentration.

Table B-4. Design concentration ratios derived from ISC2ST for Longview, WA site; 2-10m ΔT (see Section 5.3).

Source[b]	Ambient Concentration[a] via ISC2ST (μgm^{-3})			
	Avg. Time	Turner[c]	SRDT[d]	Ratio[e] ($\chi_{SRDT}/\chi_{Turner}$)
Single 35m Stack	1-hour	234.4	236.3	1.01
		228.8	235.5	1.03
	3-hour	196.8	217.7	1.11
		189.6	211.5	1.12
	24-hour	82.7	82.7	1.00
		58.5	58.5	1.00
	Period (8187 hours)	7.24	9.31	1.29
		6.14	7.34	1.18
Single 100m Stack	1-hour	55.9	55.9	1.00
		55.8	55.8	1.00
	3-hour	34.3	34.3	1.00
		29.6	33.1	1.12
	24-hour	7.01	8.58	1.22
		6.11	7.76	1.27
	Period (8187 hours)	0.613	0.962	1.57
		0.575	0.835	1.45
Single 200m Stack	1-hour	30.2	36.0	1.19
		26.3	32.5	1.24
	3-hour	17.8	23.7	1.33
		10.6	17.1	1.62
	24-hour	2.56	4.34	1.70
		2.39	2.88	1.21
	Period (8187 hours)	0.195	0.306	1.57
		0.187	0.301	1.61

[a]For each averaging time, high 1st high (H1H) concentration appears above dotted line; high 2nd high (H2H) concentration appears below dotted line.

[b]See text, Section 5.0, for description of all source and receptor parameters used in the dispersion model runs.

[c]Hourly mixing heights are computed based on Turner-derived stabilities.

[d]Hourly mixing heights are computed based on SRDT-derived stabilities.

[e]Statistical analysis (see Section 5.3):

	median	$\bar{X}$	s	$\bar{X}_g$	s_g
For all 24 values:	1.20	1.24	0.23	1.22	1.19
For 12 H1H concentration ratios only:	1.20	1.25	0.25	1.23	1.21
For 12 H2H concentration ratios only:	1.19	1.24	0.22	1.22	1.18

Table B-5. Design concentration ratios derived from ISC2ST for Longview, WA site; 10-50m ΔT (see Section 5.3).

Source[b]	Ambient Concentration[a] via ISC2ST (μgm^{-3})			
	Avg. Time	Turner[c]	SRDT[d]	Ratio[e] ($\chi_{SRDT}/\chi_{Turner}$)
Single 35m Stack	1-hour	234.4	236.3	1.01
		228.8	235.5	1.03
	3-hour	196.8	217.7	1.11
		189.6	211.5	1.12
	24-hour	82.7	82.7	1.00
		58.5	58.5	1.00
	Period (8187 hours)	7.24	9.32	1.29
		6.14	7.35	1.20
Single 100m Stack	1-hour	55.9	55.9	1.00
		55.8	55.8	1.00
	3-hour	34.3	34.3	1.00
		29.6	33.1	1.12
	24-hour	7.01	8.58	1.22
		6.11	7.78	1.27
	Period (8187 hours)	0.613	0.963	1.57
		0.575	0.835	1.45
Single 200m Stack	1-hour	30.2	36.0	1.19
		26.3	32.5	1.24
	3-hour	17.8	23.7	1.33
		10.6	17.1	1.62
	24-hour	2.56	4.34	1.70
		2.39	2.88	1.21
	Period (8187 hours)	0.195	0.306	1.57
		0.187	0.301	1.61

[a]For each averaging time, high 1st high (H1H) concentration appears above dotted line; high 2nd high (H2H) concentration appears below dotted line.

[b]See text, Section 5.0, for description of all source and receptor parameters used in the dispersion model runs.

[c]Hourly mixing heights are computed based on Turner-derived stabilities.

[d]Hourly mixing heights are computed based on SRDT-derived stabilities.

[e]Statistical analysis (see Section 5.3):

	median	$\bar{X}$	s	$\bar{X}_g$	s_g
For all 24 values:	1.20	1.24	0.23	1.23	1.19
For 12 H1H concentration ratios only:	1.20	1.25	0.25	1.23	1.21
For 12 H2H concentration ratios only:	1.19	1.24	0.22	1.22	1.18

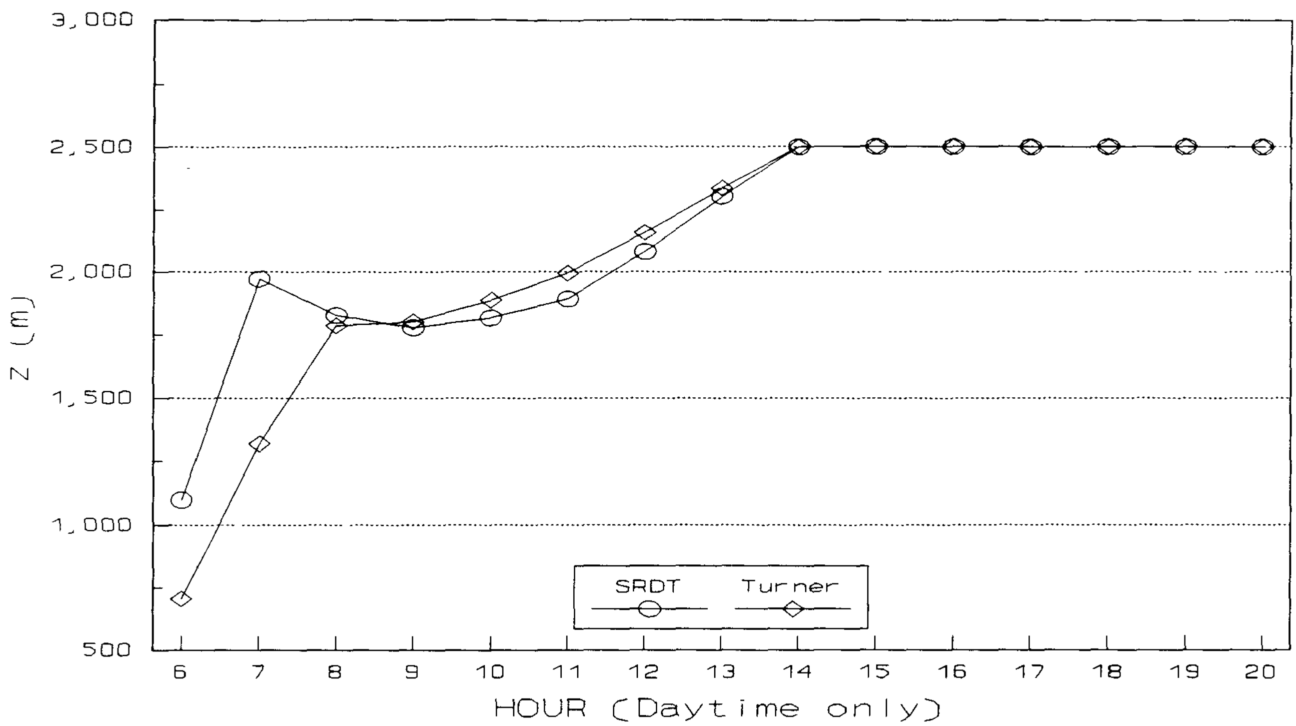

Figure B-1a. Mean mixing height by hour of the day for Bloomington, IN site; 2-10m ΔT (see Table B-1).

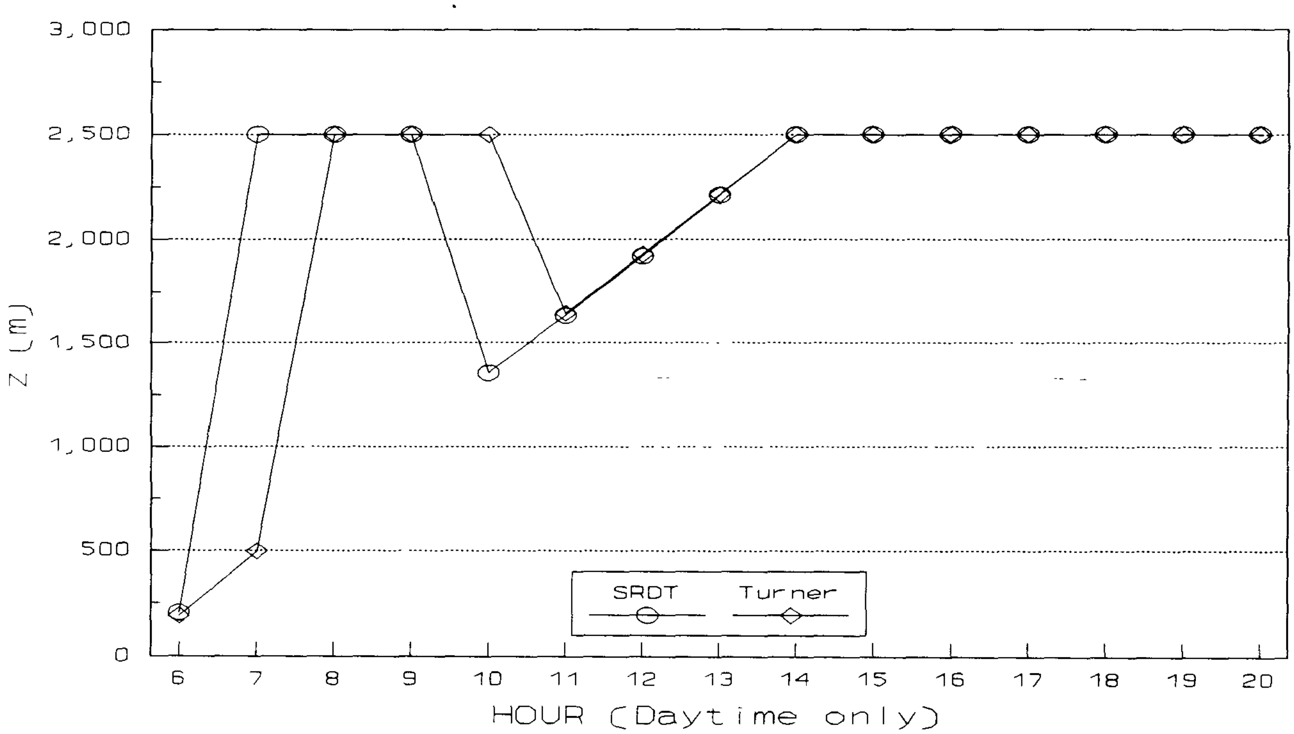

Figure B-1b. Median mixing height by hour of the day for Bloomington, IN site; 2-10m ΔT (see Table B-1).

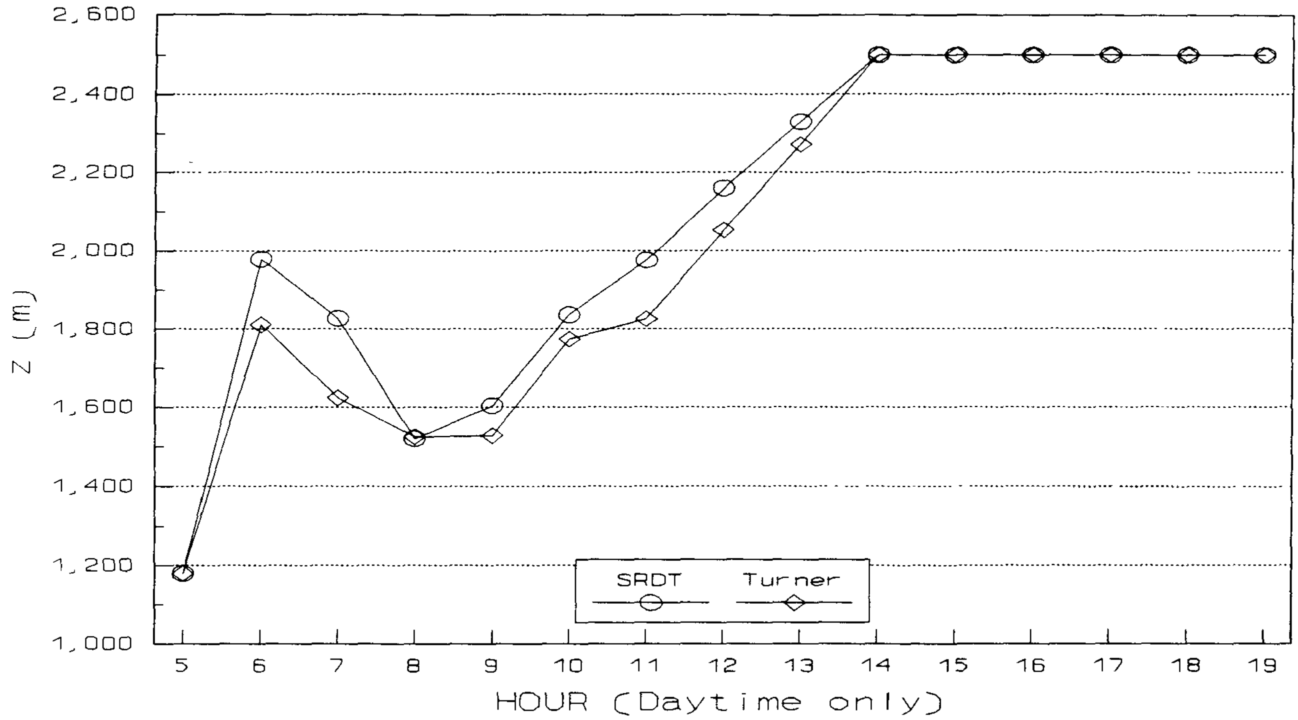

Figure B-2a. Mean mixing height by hour of the day for Kincaid, IL site; 2-10m ΔT (see Table B-2).

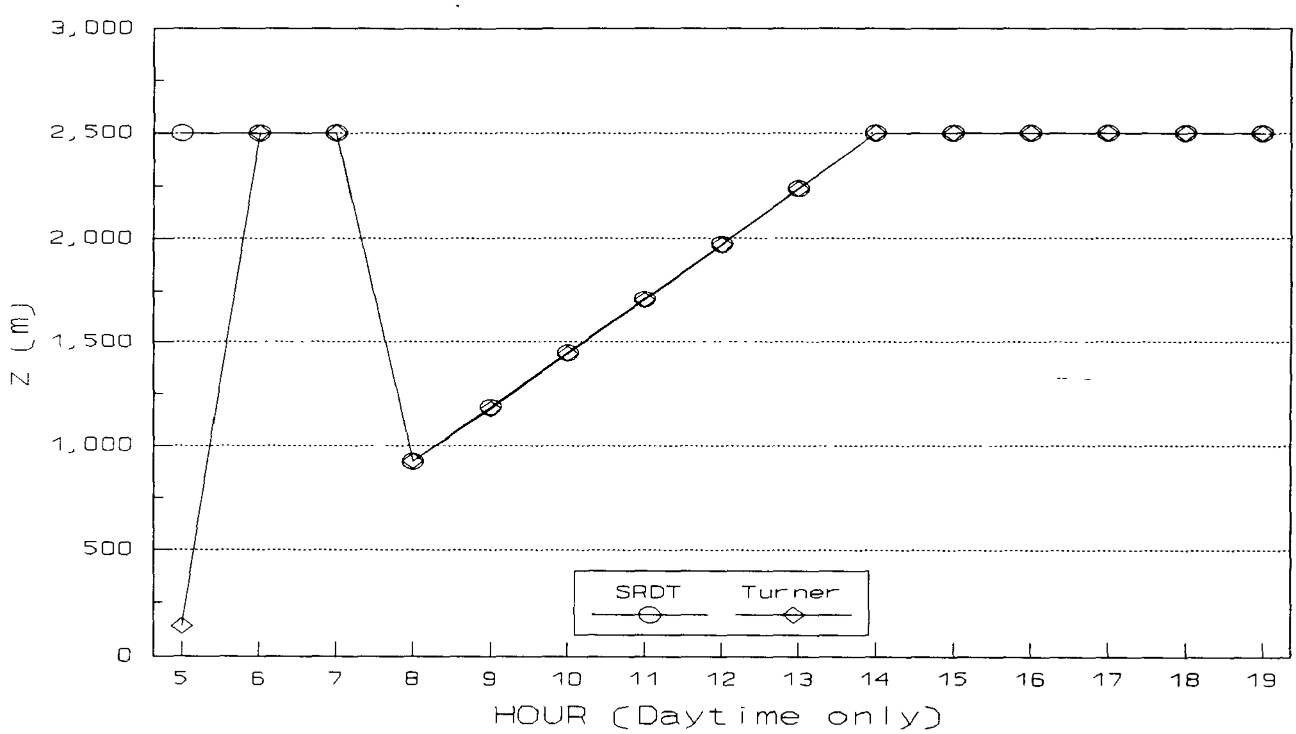

Figure B-2b. Median mixing height by hour of the day for Kincaid, IL site; 2-10m ΔT (see Table B-2).

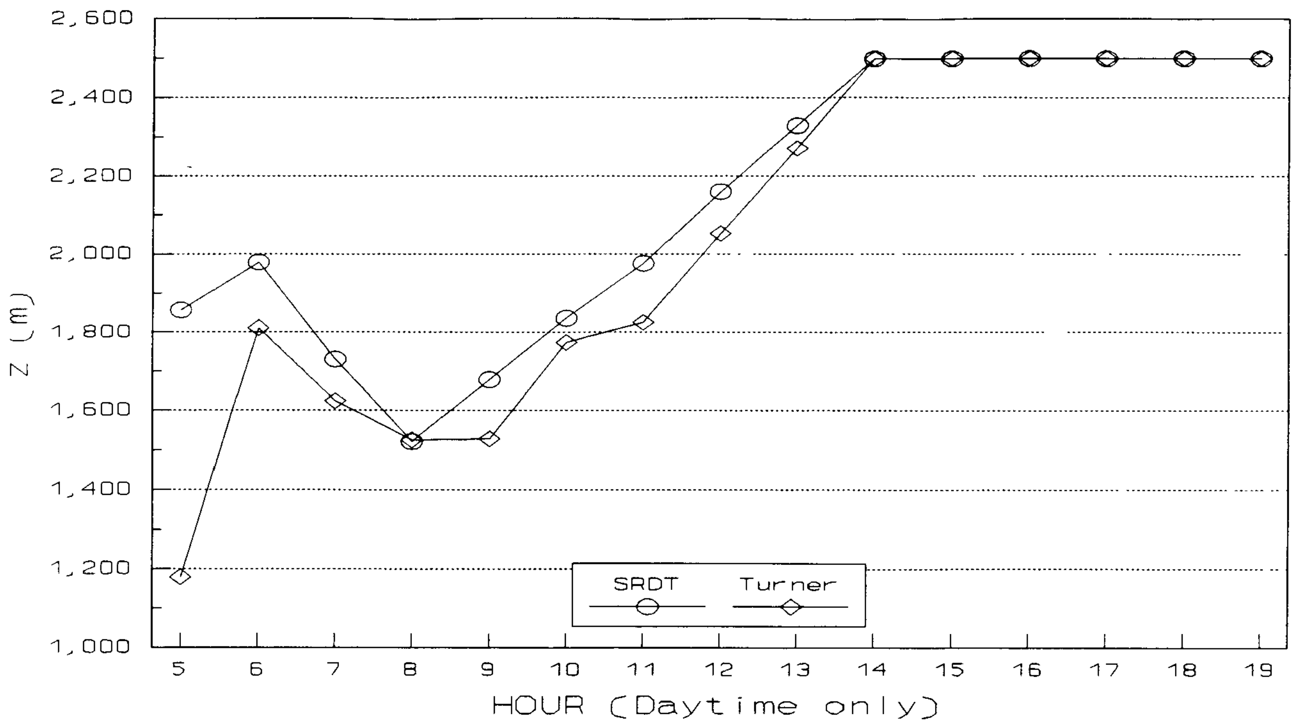

Figure B-3a. Mean mixing height by hour of the day for Kincaid, IL site; 10-50m ΔT (see Table B-3).

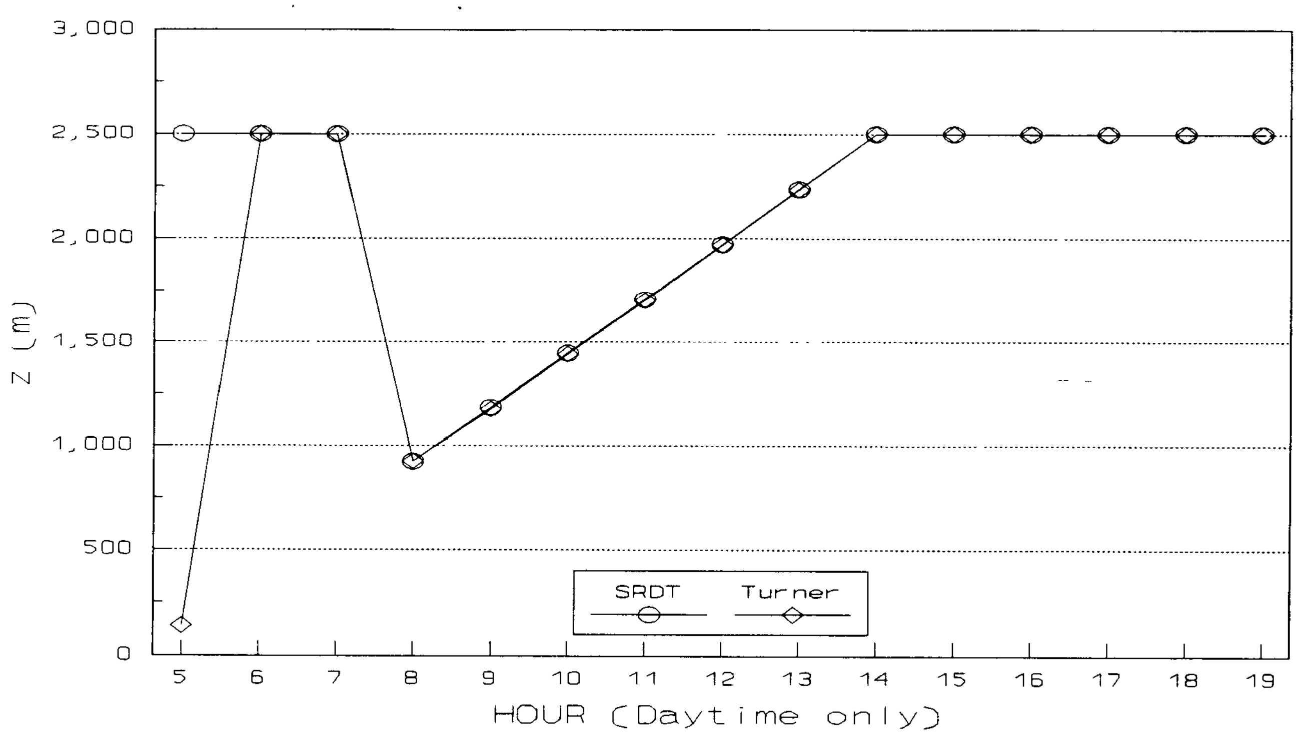

Figure B-3b. Median mixing height by hour of the day for Kincaid, IL site; 10-50m ΔT (see Table B-3).

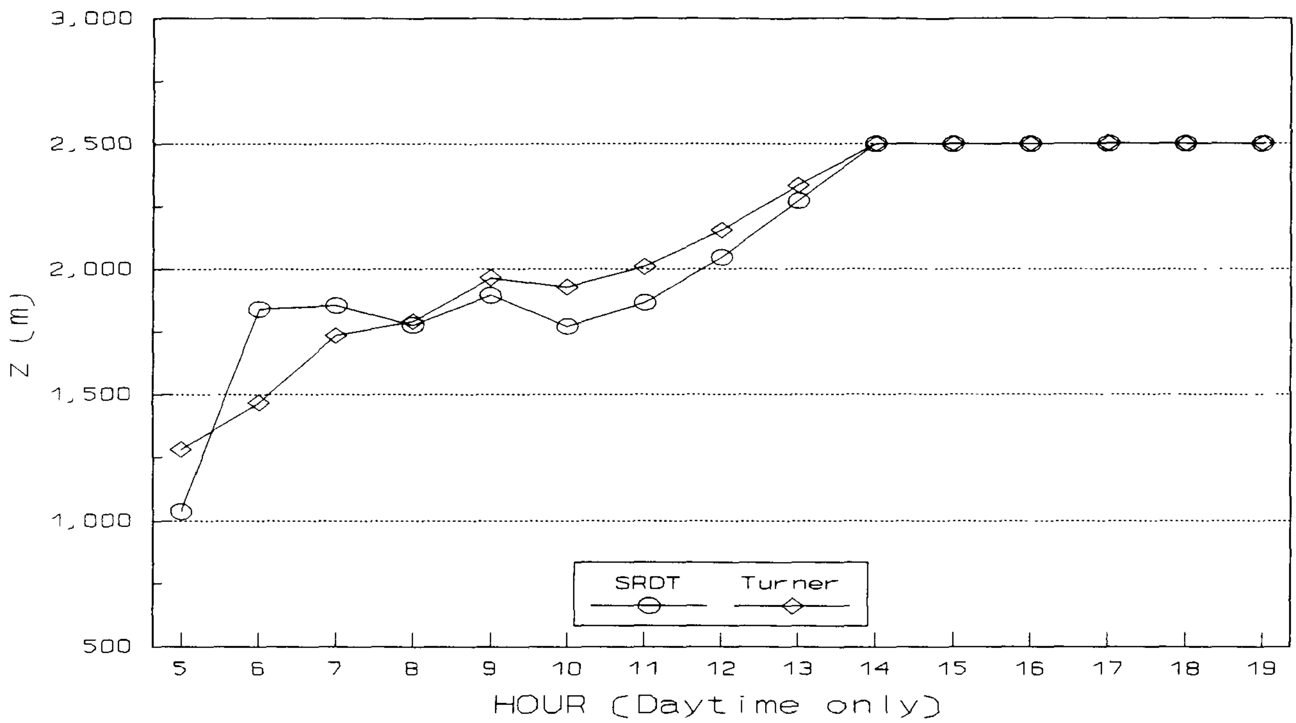

Figure B-4a. Mean mixing height by hour of the day for Longview, WA site; 2-10m ΔT (see Table B-4).

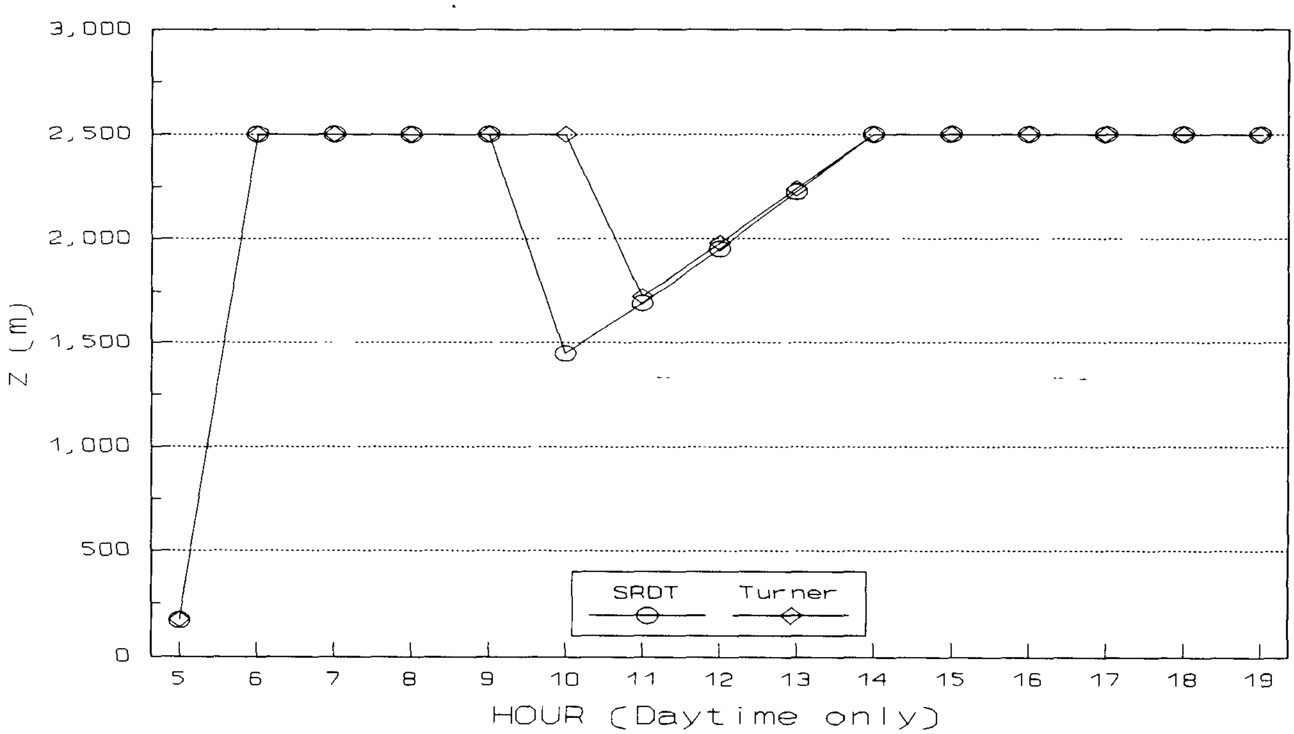

Figure B-4b. Median mixing height by hour of the day for Longview, WA site; 2-10m ΔT (see Table B-4).

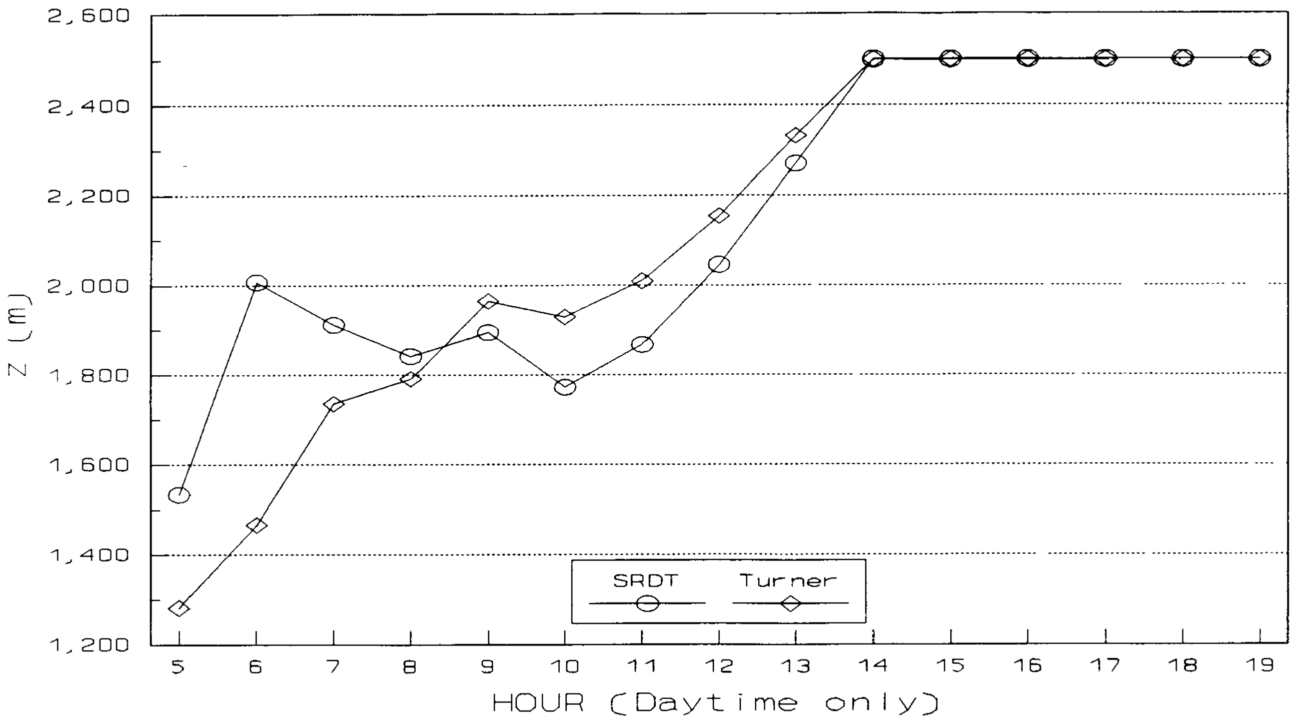

Figure B-5a. Mean mixing height by hour of the day for Longview, WA site; 10-50m ΔT (see Table B-5).

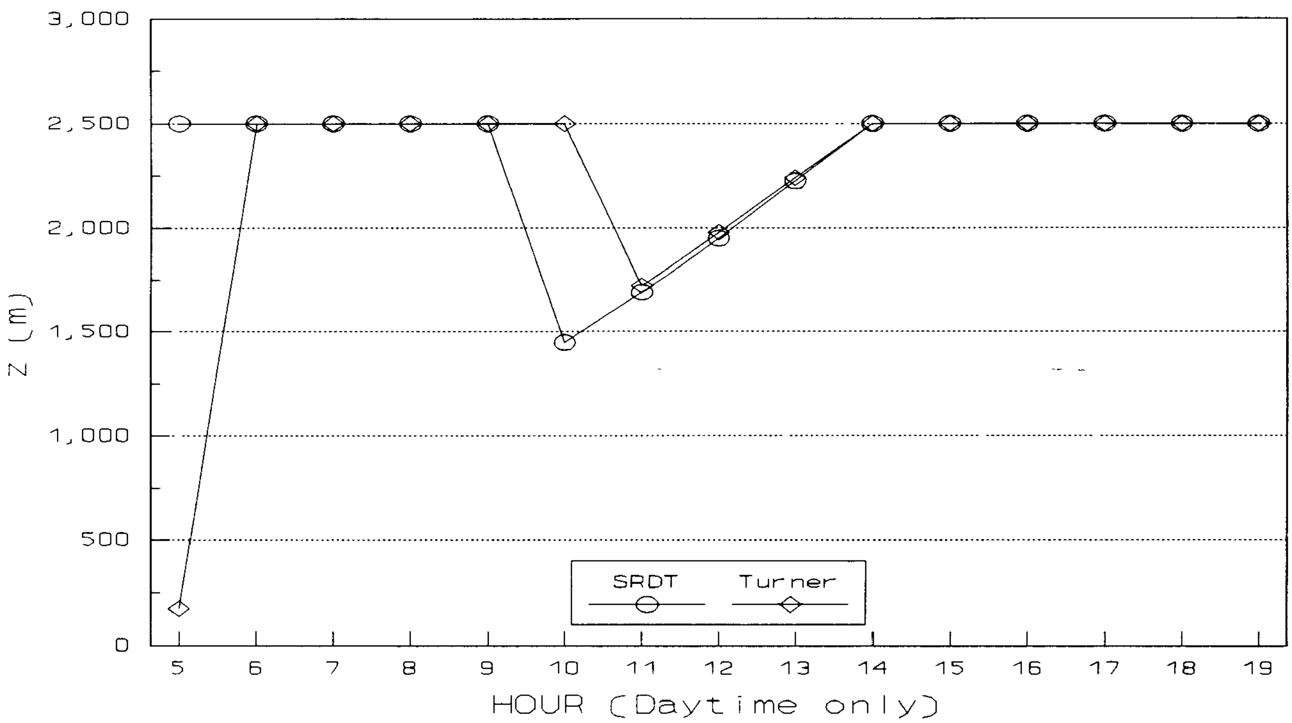

Figure B-5b. Median mixing height by hour of the day for Longview, WA site; 10-50m ΔT (see Table B-5).

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16. ABSTRACT

This publication documents the effort made to develop and evaluate a new methodology for estimating stability category using on-site meteorological data that can be automatically collected and logged, e.g., wind speed and solar radiation during daytime and temperature difference (ΔT) at night. The new method (Solar Radiation/Delta-T, SRDT) uses 5 wind speed classes and 4 insolation classes during daytime, and 3 wind speed classes and 2 ΔT classes during nighttime. To fulfill the objectives of the evaluation three on-site meteorological data bases were obtained: Kincaid, IL (4/80 - 8/80), Longview, WA (1/91 - 12/91), and Bloomington, IN (7/91 - 7/92). The data were pooled to yield 19,540 valid hours. Using the composite data, stability classification criteria were determined iteratively for the SRDT method. Stability categories via both methods were rigorously compared for all valid hours. Overall, stability categories coincided for 62% of the hours examined, and were ±1 class for 89% of the hours. The same criteria were then applied to each of the three sites individually to assess site to site variability. This variability was seen to be of the order of that seen within an individual site. For two sites, the SRDT method was evaluated for ΔT values measured from an interval other than 2-10m (i.e., 10-50m). The same methodology produced vurtually identical results. Finally, a dispersion model (ISC2) was run to demonstrate the effect of the SRDT method on design concentration ratios using meteorological data from all sites and for both ΔT measurement heights.

17. KEY WORDS AND DOCUMENT ANALYSIS

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