United States
Environmental Protection
Agency

Office of Air Quality
Planning and Standards
Research Triangle Park, NC 27711

EPA-454/R-93-052
December 1993

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COMPARISON OF DESIGN CONCENTRATIONS BASED ON HOURLY MIXING HEIGHTS ESTIMATED BY RAMMET AND METPRO

Office of Air Quality
Clean Air
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Planning and Standards

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U. S. ENVIRONMENTAL PROTECTION AGENCY
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U.S. Environmental Protection Agency
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ACKNOWLEDGEMENTS

This report was prepared by Mr. James O. Paumier and Mr. Roger W. Brode of Pacific Environmental Services, Inc., Research Triangle Park, North Carolina. This effort has been funded by the U.S. Environmental Protection Agency under Contract No. 68D00124, with Mr. C. Thomas Coulter as the Work Assignment Manager. Special thanks go to Mr. John S. Irwin for helpful suggestions and Mr. Gerald Moss for assisting in retrieving the upper air sounding data used in this study.

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 the effects of utilizing two different mixing height algorithms, RAMMET and METPRO, in regulatory applications of Gaussian dispersion models. The comparisons are for rural environments only; a future effort is planned to compare these algorithms to treat urban effects.

The Environmental Protection Agency must conduct a formal and public review before the Agency can recommend replacement of the RAMMET mixing height algorithm with the METPRO mixing height algorithm. This report is being released to establish a basis for review of the consequences resulting from use of METPRO-derived rural mixing height estimates in routine dispersion modeling of air pollution impacts. As implied above, this report is one of two that must be considered before any formal changes can be considered.

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1. INTRODUCTION

One of the input values required by many of the Gaussian dispersion models currently recommended by the *Guideline on Air Quality Models (Revised)*[1] (EPA, 1986) is the hourly mixing height, the vertical section of the lower atmosphere with intense vertical mixing. Historically, these values have been provided by a meteorological preprocessor (such as RAMMET (EPA, 1977), PCRAMMET or MPRM[2] (Irwin et al., 1990)) which linearly interpolates twice-daily values to each hour of the day. The twice-daily values are obtained from rawinsonde observations at National Weather Service (NWS) stations that routinely collect such data. The soundings, in combination with NWS surface observations of dry bulb temperature, are processed according to the development by Holzworth (1972) to obtain the twice-daily mixing heights.

With these twice-daily estimates, RAMMET occasionally computes unrealistically low mixing heights for rural sites. When the preprocessor encounters stable conditions for the hour just before sunrise, it sets the mixing height to zero at sunrise. Hourly mixing heights then are computed by interpolating from the surface up to the maximum afternoon mixing height. This sometimes results in hourly mixing heights of a meter or less just after sunrise. If these mixing heights are input to a dispersion model to estimate concentrations from a ground-based source (e.g., area sources), the dispersion model may yield unrealistically high concentrations because the emissions are trapped in a very shallow layer.

In METPRO, the meteorological preprocessor for the Complex Terrain Dispersion Model (CTDMPLUS), hourly estimates of heat (daytime only) and momentum (both day and night) flux are utilized to compute the hourly mixing heights. During the daytime METPRO uses an energy budget approach to estimate the hourly surface heat flux. Net or total incoming radiation, either measured directly

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[1]Hereinafter referred to as the "Guideline".

[2]Mixing height estimation in RAMMET, PCRAMMET and MPRM are functionally equivalent. The term RAMMET will be applied as a generic term to include all three preprocessors.

or estimated from other parameters, is used to obtain the sensible heat flux at the surface for the hour. The surface friction velocity is determined through an iterative procedure that requires only one level of wind speed. The mixing height algorithm, originally developed by Carson (1973) and modified by Weil and Brower (1983) (hereafter referred to as the CWB model), uses the morning sounding and hourly integrated values of the surface heat flux to estimate a mixing height due to convective processes. The sounding and integrated values of the friction velocity are used to produce a mixing height estimate due to mechanical (shear) processes. The larger of the two estimates is chosen for the hour's mixing height. For near-neutral conditions during the daytime, a third estimate of the mixing height is computed. In this case, the largest of the three estimates is selected as the hour's mixing height. Paumier and Irwin (1991) noted, however, that the near-neutral estimate often exceeded the convective and mechanical estimates by an order of magnitude or more, particularly during the morning transition period (the hours shortly after sunrise). They found that the near-neutral estimate was selected about 15% of the time (i.e., of all daytime hours). When selected, this estimate frequently caused abrupt and large increases and decreases from the gradual rise of the mixing height.

At night, the friction velocity is estimated from cloud cover and wind speed by a method developed by Venkatram (1980). This, with an estimate of the Monin-Obukhov length, is used to estimate the mixing height from a scheme developed by Zilitinkevich (1972) and extended by Nieuwstadt (1981).

The performance of the CWB model versus the interpolation approach was investigated by Paumier and Irwin (1991). Mixing heights from the two methods were compared to observed mixing heights. Both models performed comparably in the late afternoon, but the CWB model (without the near neutral estimate) performed better in the early morning.

The purpose of this study is to use the mixing heights estimated by both RAMMET and METPRO in a Guideline dispersion model and compare the resulting pollutant concentrations across a

range of source characteristics and meteorological data bases. The results of this comparison will provide an indication of the effect the CWB mixing height algorithm would have on design concentrations for regulatory modeling applications. The data bases used in this comparison and the preprocessor procedures are discussed in the next section. The modeling options are discussed in Section 3, performance measures used in the analysis are explained in Section 4, the results and discussion are presented in Section 5, with concluding remarks in Section 6. References are provided in Section 7.

2. METEOROLOGICAL DATA BASES AND PREPROCESSOR OPTIONS

RAMMET requires two input data files - NWS hourly surface observations and twice-daily mixing heights processed by the National Climatic Data Center. METPRO requires the NWS surface observations and 1200 GMT[3] upper air sounding. Additionally METPRO requires a profile of winds and temperature from the site for which the data are being processed.

Two years of data for three sites were retrieved and processed. The three sites selected for this study are Pittsburgh, PA (WBAN station #94823), representative of an urban east coast site; Oklahoma City, OK (WBAN station #13967), representative of a southern plains site; and Brownsville, TX (WBAN station #12919), representative of a coastal environment. Data for 1984 and 1985 were used at Pittsburgh and Oklahoma City; for Brownsville, 1985 and 1986 data were used. The twice-daily mixing heights and NWS surface observations were retrieved from EPA's Office of Air Quality Planning and Standards Technology Transfer Network electronic bulletin board. Prior to being made available on the bulletin board, the data are checked for blank fields (missing data) and filled by accepted procedures. No additional modifications to the data were made after retrieving them from the bulletin board.

For METPRO to work properly, there must be a 1200 GMT sounding each day. The upper air data obtained for this study did not always meet this condition, so METPRO was modified to skip the daytime mixing height estimation whenever there was no 1200 GMT sounding for an individual day. The sounding files were modified by inserting one record at the point of a missing sounding to indicate to METPRO that there were no data to process. Table 2.1 summarizes the number of missing soundings by site and by year.

METPRO also requires hourly profiles of wind and temperature from the site being modeled. There were no on-site data, so a 1-level profile was constructed from the NWS surface wind and temperature observations, with the height of the observations

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[3]Greenwich Mean Time

Table 2.1 Missing soundings and calm wind conditions by site and year.

Site	Year	Hours/year	Missing Soundings		Calm wind conditions
			0000 GMT	1200 GMT	
Pittsburgh	1984	8784	0	0	858
Pittsburgh	1985	8760	2	2	1027
Oklahoma City	1984	8784	0	0	181
Oklahoma City	1985	8760	0	1	245
Brownsville	1985	8760	0	0	381
Brownsville	1986	8760	0	6	566

(i.e., anemometer height) set to 10m. At night, METPRO will not compute a mixing height for a wind speed of 0 ms^{-1} (calm wind). By using NWS data to construct the profile, there were several hundred hours of calm wind conditions for all the sites combined. The number of hours of calm wind conditions detected in the file of profile data is shown in Table 2.1.

METPRO requires two additional files. The first is a file of locally observed solar and net radiation and mixing heights. None of the parameters in this file are required for METPRO to make its computations, but they would be used if they were available. With no locally observed data, a file indicating that there was no available data was created for METPRO to read. The second file is much more important and contains information defining the physical characteristics of the site, e.g., the surface roughness length, albedo (a measure of the reflectivity at the surface), and Bowen ratio (a measure of the surface moisture). These parameters are specified by categories or sectors of wind direction (as defined by the wind direction in the file of profile data) and by month. METPRO allows up to eight nonoverlapping sectors covering all possible directions. Without detailed information about each site, the parameters for this study are defined for only one sector (1° - 360°) and are the same for all months at all three sites. The values used for this analysis are: 0.25m for the surface roughness length, 0.40 for the albedo, and 0.75 for the Bowen ratio.

One additional modification was made to METPRO in accordance with the objectives of this study. As discussed earlier, the daytime near-neutral estimate may cause abrupt changes in the rise of the daytime mixing height. Therefore, the daytime near-neutral estimate of the mixing height was ignored in this study. Thus only the convective and mechanical estimates from the CWB model were candidate mixing heights for each hour.

With all the raw data processed and modifications made to METPRO, both preprocessors were run on the six sets (3 sites X 2 yrs/site) of data. The output file from RAMMET, a binary file, was converted to ASCII and the METPRO mixing heights merged into the RAMMET files as a separate field (column). Thus, there were three mixing heights per hour in each ASCII file - the rural and urban estimates from RAMMET and the METPRO estimate. If any one of the three mixing heights was missing for the hour, then all three were set to missing when the files were merged.

3. MODEL OPTIONS

The dispersion model used in this study was the Industrial Source Complex Short Term (ISCST2) model. This version of the model adds the capability to indicate which fields to read (in an ASCII file) for a particular run, allowing both RAMMET and METPRO mixing heights to reside in the same file as described above. A new (draft) area source algorithm capable of computing concentration estimates at receptor locations inside the perimeter of an area source was used in this study. This differs from the version currently available to the general modeling community, which sets concentration estimates to 0.0 for receptors inside the perimeter.

ISCST2 requires an input file that defines the modeling options, the source (emissions) information, receptor configuration and file input/output. These options are described next.

3.1 Modeling options

The options of most interest here control which dispersion option (rural or urban) to use, the averaging periods, and how to handle missing input data. For this analysis, only the rural dispersion option (corresponding to the rural mixing heights from RAMMET) was used. METPRO only produces one set of mixing heights, and it is assumed that these are representative of rural sites.

The averaging periods included in this study were the 1-hr, 3-hr and 24-hr short term averages, plus the period (in this case, the annual) average.

Another option employed in this comparison was for processing missing data necessitated by missing METPRO mixing heights due to missing upper air soundings. This processing option provides a means for computing the 3-hr, 24-hr and period (annual) concentrations that are consistent with the regulatory treatment of calm winds.

3.2 Source characteristics

Four sources were processed for this study: three point sources and one area source. For the point sources, constant emissions of 100 gs^{-1} were assumed. The characteristics for each of these sources is presented in Table 3.1.

Table 3.1 Source characteristics.

Point sources					
Stack height (m)	X,Y location & base elevation (m)	Emission rate (gs^{-1})	Exit velocity (ms^{-1})	Stack diameter (m)	Temperature (K)
35	0, 0, 0	100	11.7	2.4	432
100	0, 0, 0	100	18.8	4.6	416
200*	0, 0, 243.84	100	26.5	5.6	425
Ground-level area source					
Area (m^2)	Length of side (m)	Emission rate ($gs^{-1}m^{-2}$)			
250,000	500	0.0004			

*All model runs with the 200m stack were made with elevated terrain.

3.3 Receptor configuration

A gridded polar array of receptors was used in this analysis. There were 36 radials (beginning at 10 degrees from north and spaced every 10 degrees). The number and distance of the concentric rings varied according to the source being modeled. For the 35m and 100m stacks, distances of 400m, 800m, 1200m, 2000m, 4000m, 7000m, and 15000m were used. For the 200m stack, which is located in elevated terrain, distances of 800m, 2000m , 4000m, 7000m and 15000m were used. For the area source, receptor distances were 125m (halfway between the origin and the perimeter), 250m (touching the perimeter at the midpoint of each side), 350m (approximately at the perimeter corners), 800m, 1200m, 2000m and 4000m.

As indicated, the 200m stack was modeled with elevated terrain. The terrain elevations are given in Table 3.2 by radial and distance.

Table 3.2. Terrain elevation used in the modeling for the 200m stack. All elevations are in feet.

Radial (°)	Distance				
	800m	2000m	4000m	7000m	15000m
10.00	940.00	1100.00	640.00	1000.00	1000.00
20.00	1040.00	1100.00	720.00	900.00	720.00
30.00	960.00	1060.00	1040.00	1160.00	1120.00
40.00	1020.00	1040.00	1120.00	1160.00	1200.00
50.00	1160.00	1040.00	1040.00	1280.00	1280.00
60.00	1200.00	1160.00	1140.00	1080.00	1220.00
70.00	1180.00	1200.00	1280.00	1320.00	1280.00
80.00	1100.00	1140.00	1220.00	1300.00	1300.00
90.00	1040.00	1020.00	1180.00	1180.00	1140.00
100.00	960.00	860.00	1280.00	900.00	1360.00
110.00	780.00	1040.00	1280.00	1240.00	1240.00
120.00	680.00	900.00	1160.00	1100.00	1180.00
130.00	700.00	780.00	880.00	940.00	1040.00
140.00	740.00	760.00	1040.00	1260.00	1320.00
150.00	740.00	660.00	1060.00	1300.00	1260.00
160.00	740.00	800.00	860.00	1120.00	1120.00
170.00	700.00	800.00	1200.00	1140.00	1200.00
180.00	660.00	660.00	1200.00	1260.00	1280.00
190.00	620.00	620.00	620.00	880.00	1200.00
200.00	610.00	630.00	700.00	640.00	1140.00
210.00	610.00	1020.00	900.00	1200.00	840.00
220.00	660.00	1100.00	980.00	1220.00	1240.00
230.00	860.00	1120.00	1040.00	1300.00	1300.00
240.00	900.00	1160.00	1200.00	1240.00	1220.00
250.00	1020.00	1240.00	1240.00	1260.00	1280.00
260.00	1000.00	1260.00	1240.00	1280.00	1280.00
270.00	940.00	1100.00	1100.00	1280.00	1220.00
280.00	920.00	1180.00	1180.00	1280.00	1300.00
290.00	740.00	1100.00	1220.00	1360.00	1260.00
300.00	610.00	760.00	1280.00	1320.00	1200.00
310.00	610.00	840.00	1260.00	1220.00	1180.00
320.00	640.00	640.00	1220.00	1300.00	1000.00
330.00	640.00	640.00	1200.00	1100.00	780.00
340.00	640.00	640.00	1160.00	660.00	1060.00
350.00	680.00	680.00	1060.00	760.00	1020.00
360.00	780.00	840.00	700.00	680.00	900.00

4. PERFORMANCE MEASURES

To compare the effects of mixing heights on concentration, the high-first-high (H1H) and high-second-high (H2H) are reported by site, by year, by source and by averaging time. The H2H was chosen because it is the design concentration on which judgement is based as to whether an existing or proposed pollutant source will violate a National Ambient Air Quality Standard. The Guideline recommends that five years of NWS meteorological data be used for such an analysis. If less than five years of data are available, then the Guideline recommends using the H1H concentration.

To compare the concentration estimates, the ratio of the concentration using METPRO-generated mixing heights (χ_M) to the concentration using RAMMET-generated mixing heights (χ_R), χ_M/χ_R, is computed. With this ratio, the concentrations using RAMMET mixing heights are regarded as the "observed" concentrations because they are the standard input values to ISCST2.

5. MODELING RESULTS AND DISCUSSION

The H1H and H2H are tabulated by site, by year, by source, by averaging time, and by mixing height method in Tables 5.1 - 5.3. The ratio χ_M/χ_R is also shown, and is averaged for the H1H and H2H across all sources.

There are several overall impressions from looking at the tables. First, the concentration estimates from the area source are orders of magnitude larger than the point source estimates. Second, there are numerous cases where the concentration estimate using the two different mixing heights are equal, i.e., the ratio is identically equal to 1.00. Third, for all but the area source, the concentration estimates using the METPRO-generated mixing heights are generally larger than the estimates using the RAMMET mixing heights.

The first point is not too surprising with a ground-level release area source and a portion of the receptor array within the perimeter of the source. The H1H and H2H concentrations occurred at the 250m arc for Pittsburgh and Brownsville. At Oklahoma City, most of the H1H and H2H estimates were at the 250m arc, with a few at the 125m and 350m arcs. The maximum period (annual) averages all occurred at the 125m arc at all the sites for both years. The most interesting point regarding the area source is the difference between the 1-hr H1H concentrations using RAMMET and METPRO mixing heights and, also, the difference between the H1H and H2H for RAMMET alone, most notably for Pittsburgh 1984, Oklahoma City 1985, and Brownsville 1986. The unusually large H1H concentration for the RAMMET estimates is due to an extremely small mixing height at or just after sunrise. In each of the three cases, the mixing height was less than 1m (only 0.1m for the Brownsville case). The large 3-h H1H for Oklahoma City 1985 and Brownsville 1986 are due to the dominance of the 1-h H1H in the 3-h average. As stated in the introduction, it is this type of behavior that is of concern with the RAMMET procedure. When small mixing heights such as these are used in ISCST2, pollutants are trapped in an extremely shallow layer, causing an extremely large concentration.

Table 5.1 The estimated H1H and H2H by year, source and averaging time for Pittsburgh, PA. χ_R is the concentration estimate using the rural mixing height estimates from RAMMET; χ_M is the concentration estimate using mixing heights from METPRO.

		1984				1985			
		χ_R (μgm^{-3})	χ_M (μgm^{-3})	χ_M/χ_R	Avg. by Source	χ_R (μgm^{-3})	χ_M (μgm^{-3})	χ_M/χ_R	Avg. by Source
35m stack									
1-h	H1H	247.20	315.89	1.28		255.56	378.06	1.48	
	H2H	238.28	305.51	1.28		242.33	302.63	1.25	
3-h	H1H	194.70	194.70	1.00		199.53	199.53	1.00	
	H2H	187.72	187.72	1.00		171.25	171.25	1.00	
24-h	H1H	58.03	58.03	1.00		63.42	63.42	1.00	
	H2H	53.64	52.70	0.98		56.87	57.01	1.00	
Annual		5.00	4.98	1.00		6.42	6.43	1.00	
				H1H:	**1.07**			H1H:	**1.12**
				H2H:	**1.09**			H2H:	**1.08**
100m stack									
1-h	H1H	81.06	94.02	1.16		72.90	85.03	1.17	
	H2H	50.98	61.29	1.20		54.95	58.45	1.06	
3-h	H1H	30.85	39.41	1.28		28.81	34.15	1.19	
	H2H	25.51	27.97	1.10		23.12	24.33	1.05	
24-h	H1H	7.65	7.88	1.03		6.59	6.75	1.03	
	H2H	5.96	7.04	1.18		5.83	5.52	0.95	
Annual		0.396	0.380	0.96		0.454	0.436	0.96	
				H1H:	**1.11**			H1H:	**1.09**
				H2H:	**1.16**			H2H:	**1.02**
200m stack with terrain									
1-h	H1H	34.86	38.38	1.10		38.56	36.34	0.94	
	H2H	26.59	30.99	1.17		31.06	30.63	0.99	
3-h	H1H	18.43	18.82	1.02		15.69	13.42	0.86	
	H2H	17.65	17.65	1.00		13.06	11.98	0.92	
24-h	H1H	4.57	4.57	1.00		4.17	4.17	1.00	
	H2H	3.63	3.28	0.90		4.14	3.90	0.94	
Annual		0.317	0.282	0.89		0.397	0.352	0.89	
				H1H:	**1.00**			H1H:	**0.92**
				H2H:	**1.02**			H2H:	**0.95**
500m X 500m area source									
1-h	H1H	133769.88	46544.85	0.35		69466.44	69466.44	1.00	
	H2H	46544.84	46544.84	1.00		68483.44	68483.44	1.00	
3-h	H1H	50539.97	44961.72	0.89		45150.68	45150.68	1.00	
	H2H	41696.00	41535.11	1.00		41454.49	41454.49	1.00	
24-h	H1H	24299.63	24299.63	1.00		25947.32	25947.32	1.00	
	H2H	22485.08	22482.52	1.00		21757.81	21757.82	1.00	
Annual		10638.29	10631.30	1.00		10266.72	10225.05	1.00	
				H1H:	**0.81**			H1H:	**1.00**
				H2H:	**1.00**			H2H:	**1.00**
Average				H1H:	**1.00**			H1H:	**1.03**
				H2H:	**1.07**			H2H:	**1.01**

Table 5.2 Same as Table 5.1, except results are for Oklahoma City, OK.

		1984				1985			
		χ_R (μgm^{-3})	χ_M (μgm^{-3})	χ_M/χ_R	Avg. by Source	χ_R (μgm^{-3})	χ_M (μgm^{-3})	χ_M/χ_R	Avg. by Source
35m stack									
1-h	H1H	265.13	371.21	1.40		276.13	324.69	1.18	
	H2H	255.05	342.16	1.34		263.74	300.76	1.14	
3-h	H1H	200.19	200.19	1.00		208.77	208.77	1.00	
	H2H	180.68	180.68	1.00		175.34	175.34	1.00	
24-h	H1H	87.84	87.84	1.00		87.78	87.78	1.00	
	H2H	68.71	68.71	1.00		80.69	80.69	1.00	
Annual		8.12	8.05	0.99		8.61	8.67	1.01	
				H1H:	**1.10**			H1H:	**1.05**
				H2H:	**1.11**			H2H:	**1.05**
100m stack									
1-h	H1H	85.79	95.71	1.12		69.17	97.67	1.41	
	H2H	53.91	69.42	1.29		65.80	70.66	1.07	
3-h	H1H	38.19	43.95	1.15		35.08	35.08	1.00	
	H2H	27.91	29.46	1.06		25.69	27.14	1.06	
24-h	H1H	6.27	6.35	1.01		6.30	6.29	1.00	
	H2H	5.58	5.25	0.95		5.82	5.82	1.00	
Annual		0.632	0.559	0.88		0.612	0.592	0.97	
				H1H:	**1.04**			H1H:	**1.10**
				H2H:	**1.10**			H2H:	**1.04**
200m stack with terrain									
1-h	H1H	34.41	39.38	1.14		29.43	34.44	1.17	
	H2H	22.26	28.55	1.28		21.52	25.22	1.17	
3-h	H1H	17.23	17.23	1.00		15.32	17.71	1.16	
	H2H	14.46	13.90	0.96		13.29	16.02	1.21	
24-h	H1H	5.96	5.96	1.00		5.62	5.62	1.00	
	H2H	3.80	3.80	1.00		5.06	5.22	1.03	
Annual		0.514	0.477	0.93		0.438	0.395	0.90	
				H1H:	**1.02**			H1H:	**1.06**
				H2H:	**1.08**			H2H:	**1.14**
500m X 500m area source									
1-h	H1H	77739.06	46544.84	0.60		499111.81	46524.45	0.09	
	H2H	46521.00	46521.00	1.00		56094.27	46370.65	0.83	
3-h	H1H	45041.38	45041.38	1.00		166370.61	40946.88	0.25	
	H2H	41791.86	41791.86	1.00		40946.88	38395.19	0.94	
24-h	H1H	21741.98	21742.17	1.00		23747.79	20367.43	0.86	
	H2H	19813.41	19909.74	1.00		20331.11	18883.18	0.93	
Annual		8592.98	8588.95	1.00		8414.03	8383.18	1.00	
				H1H:	**0.90**			H1H:	**0.55**
				H2H:	**1.00**			H2H:	**0.90**
Average				H1H:	**1.02**			H1H:	**0.94**
				H2H:	**1.07**			H2H:	**1.03**

Table 5.3 Same as Table 5.1, except the results are for Brownsville, TX.

		1984				1985			
		χ_R (μgm^{-3})	χ_M (μgm^{-3})	χ_M/χ_R	Avg. by Source	χ_R (μgm^{-3})	χ_M (μgm^{-3})	χ_M/χ_R	Avg. by Source
35m stack									
1-h	H1H	271.29	362.31	1.34		296.51	364.30	1.23	
	H2H	269.54	323.96	1.20		270.14	270.14	1.00	
3-h	H1H	226.60	226.60	1.00		200.46	200.46	1.00	
	H2H	210.33	210.33	1.00		188.18	188.18	1.00	
24-h	H1H	111.56	111.56	1.00		85.04	85.04	1.00	
	H2H	78.90	78.90	1.00		82.35	82.97	1.01	
Annual		14.58	14.63	1.00		13.40	13.40	1.00	
				H1H:	**1.09**			H1H:	**1.06**
				H2H:	**1.07**			H2H:	**1.00**
100m stack									
1-h	H1H	59.69	77.16	1.29		79.49	77.15	0.97	
	H2H	49.05	58.18	1.19		51.36	52.61	1.02	
3-h	H1H	35.34	35.38	1.00		26.50	32.83	1.24	
	H2H	23.16	23.16	1.00		23.46	23.38	1.00	
24-h	H1H	8.23	8.23	1.00		6.63	6.25	0.94	
	H2H	5.73	5.73	1.00		5.67	6.12	1.08	
Annual		1.04	1.04	1.00		0.973	0.957	0.98	
				H1H:	**1.07**			H1H:	**1.03**
				H2H:	**1.06**			H2H:	**1.03**
200m stack with terrain									
1-h	H1H	34.71	38.55	1.11		33.34	39.06	1.17	
	H2H	28.29	36.80	1.30		25.31	29.62	1.17	
3-h	H1H	17.78	17.06	0.96		17.12	17.12	1.00	
	H2H	14.99	14.99	1.00		15.43	15.46	1.00	
24-h	H1H	6.49	6.33	0.98		5.66	5.66	1.00	
	H2H	6.29	6.29	1.00		5.33	5.33	1.00	
Annual		0.950	0.915	0.96		0.851	0.836	0.98	
				H1H:	**1.00**			H1H:	**1.04**
				H2H:	**1.10**			H2H:	**1.06**
500m X 500m area source									
1-h	H1H	69466.44	69466.44	1.00		486653.59	69815.01	0.14	
	H2H	68942.10	68942.10	1.00		69815.01	66808.31	0.96	
3-h	H1H	59532.11	59532.11	1.00		166256.86	45567.40	0.27	
	H2H	55198.79	55198.79	1.00		44901.20	44703.58	1.00	
24-h	H1H	24867.44	24867.44	1.00		23801.00	23801.00	1.00	
	H2H	22010.57	22010.58	1.00		22065.44	22065.44	1.00	
Annual		9490.38	9489.02	1.00		10051.20	10012.65	1.00	
				H1H:	**1.00**			H1H:	**0.60**
				H2H:	**1.00**			H2H:	**0.99**
Average				H1H:	**1.04**			H1H:	**0.93**
				H2H:	**1.06**			H2H:	**1.02**

Very near the surface, small increases in mixing height can result in much smaller concentration estimates. For example, increasing the mixing height from 0.1m to 2.1m in the Brownsville 1986 case decreased the maximum concentration for that hour from 486,653 μgm^{-3} to about 25,000 μgm^{-3}, still quite large but significantly less. There were no mixing heights less than 3.0m from METPRO, therefore the concentrations for the ground-level area source did not show the extreme variations exhibited with the RAMMET mixing heights.

The second point, that the ratios are identically 1.00 (i.e., $\chi_R \equiv \chi_M$) in many instances, is due in part to the meteorology. Only the mixing heights differ between ISCST2 runs using RAMMET output and METPRO output. For the hour, all other meteorology is identical. Why a particular mix of meteorological conditions produces the H1H or H2H concentration from an entire year of data is beyond the scope of this comparison. Rather, the focus is on the differences between the input data bases, i.e., the mixing heights and (to some extent) atmospheric stability.

In examining the cases[4] where $\chi_M \equiv \chi_R$, the estimates occurred for the same hour or group of hours. In many cases the stability class was either 5, 6 or 7 (stable atmosphere). ISCST2 assumes unlimited vertical mixing in stable conditions. Computationally, the terms for reflections at the mixing height are omitted from the vertical term of the Gaussian plume equation. Consequently, mixing heights from both RAMMET and METPRO, no matter how different, will produce the same concentration. For a more detailed discussion of the vertical dispersion term in ISCST2, see Section 1.1.6 in the User's Guide for the Industrial Source Complex (ISC2) Dispersion Models, Volume II (EPA, 1992).

Another consideration on this point is the effective plume height (h_e) relative to the mixing height in unstable atmospheric conditions. A general rule of thumb (R. W. Brode, Pacific Environmental Services, Inc., personal communication) is that the mixing height has little or no affect on the maximum concentration

[4]Cases where the ratio differs from 1.00 in the fourth or fifth digit to the right of the decimal were not considered.

estimate if the mixing height is greater than twice the effective plume height. This was particularly evident for the 35m stack where the effective plume height is only 100m - 200m and the mixing height from both preprocessors is 400m or more. This "rule" becomes less clear for the 200m stack, but may be explained in terms of the effect of elevated terrain on h_e and the mixing height. Assume that the terrain is monotonically rising in the direction of plume transport. With the plume remaining at its stabilization height, the effective plume height decreases downwind. However, the mixing height is terrain-following. The net effect is to increase the difference between h_e and the mixing height, possibly to the point where the mixing height has little or no effect on ground level concentrations. For example, if the effective plume height in flat terrain is 350m and the mixing height is 600m above local ground level, there may be significant reflections from the mixed layer top that enhance the ground level concentrations. However, for a receptor that is 140m above stack base, the mixing height is still 600m above local ground level but the effective plume height is now only 210m and, according to the "rule of thumb", there are no contributions to ground-level concentrations by reflections from the mixed layer top. With the elevated terrain in this study, particularly at the more remote arcs, the effective plume height can be reduced by 100m or more. This apparently makes a sufficient adjustment such that the H1H and H2H 24-hr average concentrations are identical for both RAMMET- and METPRO-generated mixing heights. Section 1.1.6.2 in the User's Guide for the Industrial Source Complex (ISC2) Dispersion Models, Volume II (EPA, 1992) provides a more complete discussion on the vertical dispersion term in elevated terrain.

The final point is the primary purpose of this study - to determine what effect, if any, mixing heights estimated by METPRO have on concentration estimates. The primary focus here is on the H2H (design) concentrations. Table 5.4 summarizes the ratios of the H2H estimates listed in Tables 5.1 - 5.3. The design concentrations using mixing heights from METPRO are generally greater by 15-30% than those using RAMMET mixing heights. The

Table 5.4 Ratios of the H2H concentrations for all sites, years, sources and averaging times (concentration values are neither paired in time nor space).

Averaging Time	Source	1984 PA	1984 OK	1984 TX	1984 Avg.	1985 PA	1985 OK	1985 TX	1985 Avg.	2-year Average
1-hr	35m	1.28	1.34	1.20	1.27	1.25	1.14	1.00	1.13	**1.20**
	100m	1.20	1.29	1.19	1.23	1.06	1.07	1.02	1.05	**1.14**
	200m	1.17	1.28	1.30	1.25	0.99	1.17	1.17	1.11	**1.18**
	Area	1.00	1.00	1.00	1.00	1.00	0.83	0.96	0.93	**0.97**
3-hr	35m	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	**1.00**
	100m	1.10	1.06	1.00	1.05	1.05	1.06	1.00	1.04	**1.05**
	200m	1.00	0.96	1.00	0.99	0.92	1.21	1.00	1.04	**1.02**
	Area	1.00	1.00	1.00	1.00	1.00	0.94	1.00	0.98	**0.99**
24-hr	35m	0.98	1.00	1.00	0.99	1.00	1.00	1.01	1.00	**1.00**
	100m	1.18	0.95	1.00	1.04	0.95	1.00	1.08	1.01	**1.03**
	200m	0.90	1.00	1.00	0.97	0.94	1.03	1.00	0.99	**0.98**
	Area	1.00	1.00	1.00	1.00	1.00	0.93	1.00	0.98	**0.99**
Annual	35m	1.00	0.99	1.00	1.00	1.00	1.01	1.00	1.00	**1.00**
	100m	0.96	0.88	1.00	0.95	0.96	0.97	0.98	0.97	**0.96**
	200m	0.89	0.93	0.96	0.93	0.89	0.90	0.98	0.92	**0.93**
	Area	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	**1.00**
									Average:	**1.03**

difference is particularly notable for point source simulations with 1-hr averaging times. The differences between the two sets of estimates decrease with averaging period, but are essentially identical for averaging times greater than 1-hr. When all sites, years, sources and averaging times are pooled, χ_M/χ_R = 1.03.

To gain some insight into why the concentration estimates using METPRO mixing heights are higher than those using RAMMET mixing heights, ISCST2 was rerun for hours producing the H2H values in the initial analyses. For the hours that produced a H2H 1-hr concentration using a RAMMET mixing height (Tables 5.1 - 5.3), the same hours were rerun using the METPRO mixing heights, pairing in time and space. The results of this combination are shown in Table 5.5. Similarly, for the hours that produced a H2H concentration using a METPRO mixing height (Tables 5.1 - 5.3), the

Table 5.5 H2H concentration using RAMMET mixing heights and the analogous concentration using METPRO mixing heights (concentrations are paired in time and space for the indicated hours). Note that h_e is the effective plume height and z_i is the mixing height.

Site & year	Source	Julian day /hour	h_e (m)	RAMMET z_i (m)	RAMMET χ_R (μgm^{-3})	METPRO z_i (m)	METPRO χ_M (μgm^{-3})	Ratio (χ_M/χ_R)
Pittsburgh,	200m	167/14	860	1052	26.6	830	0.0	0.00
1984	100m	211/12	476	1649	51.0	1183	51.0	1.00
	35m	163/12	115	1195	238.3	1312	238.3	1.00
Pittsburgh,	200m	161/12	745	970	31.1	829	36.3	1.17
1985	100m	211/12	715	1160	54.9	1460	49.8	0.91
	35m	169/11	78	1445	242.3	1472	242.3	1.00
Oklahoma City,	200m	203/12	269	1833	22.3	844	22.3	1.00
1984	100m	210/13	465	1981	53.9	1512	53.9	1.00
	35m	250/13	68	1709	255.0	1198	255.0	1.00
Oklahoma City,	200m	209/13	250	1063	21.5	724	21.5	1.00
1985	100m	123/12	483	718	65.8	672	70.7	1.07
	35m	221/14	75	1341	263.7	1041	263.7	1.00
Brownsville,	200m	163/13	961	1097	28.3	913	34.0	1.20
1985	100m	237/12	548	1321	49.1	942	58.2	1.19
	35m	247/11	71	929	269.5	1138	269.5	1.00
Brownsville,	200m	242/11	741	1197	25.3	776	39.1	1.55
1986	100m	164/11	461	834	51.4	939	51.3	1.00
	35m	182/14	68	1629	270.1	1459	270.1	1.00
							Average:	1.01

same hours were rerun using the RAMMET mixing heights, pairing in time and space. The results are shown in Table 5.6.

As in the ranked comparisons listed in tables 5.1 - 5.3 (in which concentration estimates are **unpaired** in time and space), Tables 5.5 and 5.6 illustrate that the METPRO mixing heights tended to produce higher concentrations overall by 20%. For the 36 cases in the two tables, METPRO and RAMMET produced identical concentrations for 12 of the cases. Seven of the 12 cases were for the 35m stack where the mixing height was often much higher

Table 5.6 H2H concentration using METPRO mixing heights and the analogous concentration using RAMMET mixing heights (concentrations are paired in time and space for the indicated hours). Note that the columns for RAMMET and METPRO are reversed from those in Table 5.5; the ratios remain χ_M/χ_R.

Site & year	Source	Julian day /hour	h_e (m)	METPRO z_i (m)	METPRO χ_M (μgm^{-3})	RAMMET z_i (m)	RAMMET χ_R (μgm^{-3})	Ratio (χ_M/χ_R)
Pittsburgh,	200m	212/13	780	1153	31.0	1591	22.5	**1.38**
1984	100m	164/12	467	759	61.3	1328	44.3	**1.38**
	35m	252/09	157	158	305.5	505	155.0	**1.97**
Pittsburgh,	200m	211/12	1032	1460	30.6	1160	38.6	**0.79**
1985	100m	161/12	477	829	58.5	970	51.1	**1.14**
	35m	246/07	126	136	302.6	601	184.1	**1.64**
Oklahoma City,	200m	187/14	640	1059	28.6	1943	15.7	**1.82**
1984	100m	175/13	541	735	69.4	1033	49.5	**1.40**
	35m	115/08	117	124	342.2	1119	195.8	**1.75**
Oklahoma City,	200m	144/13	694	1183	25.2	2180	14.0	**1.80**
1985	100m	123/11	483	672	70.7	718	65.8	**1.07**
	35m	299/09	116	124	300.8	1244	174.5	**1.72**
Brownsville,	200m	237/12	875	942	36.8	1321	26.2	**1.40**
1985	100m	237/12	548	942	58.2	1321	49.1	**1.19**
	35m	198/08	122	132	324.0	349	197.7	**1.64**
Brownsville,	200m	164/11	741	939	29.6	834	33.3	**0.89**
1986	100m	131/11	552	708	52.6	689	54.0	**0.97**
	35m	182/14	68	1459	270.1	1629	270.1	**1.00**
							Average:	**1.39**

than the effective plume height, h_e (recall the discussion earlier on the relation of h_e to the mixing height). In four of the 36 cases, the RAMMET mixing height produced a higher concentration. In one of the cases, the METPRO mixing height was below h_e, yielding a concentration of 0.0. In the remaining 19 cases, the concentration using a METPRO mixing height was greater than the concentration using the RAMMET mixing height. For the hours from 7 to 9 (the morning transition period), the concentration

difference was as much as a factor of 2 for the 35m stack. For those morning hours, the METPRO mixing height was about 150m and the RAMMET mixing height was 3-10 times higher. This behavior is not necessarily unique to these few cases.

The influence of mixing height estimates on the occurrence of particularly high concentration ratios, and the long term distribution pattern of such estimates, was of interest in assessing the consequence of using the CWB model. Figures 5.1 - 5.3 show the annual average mixing height by hour of day for 1985 from each of the three sites. Each data point represents an average of 365 values. The mixing heights from RAMMET were, on average, about 250m - 350m higher than the annual average METPRO mixing heights for the hours corresponding to the H2H values in Tables 5.5 and 5.6. By late afternoon (hour 16 and later), the differences are much less. This tendency was observed and reported by Paumier and Irwin (1991). In their analysis they noticed that, until the maximum mixing height was observed, the mixing heights estimated by RAMMET significantly overpredicted the observed values, while those estimated by METPRO showed a modest underprediction. After the maximum mixing height was observed, estimates from either method showed little bias.

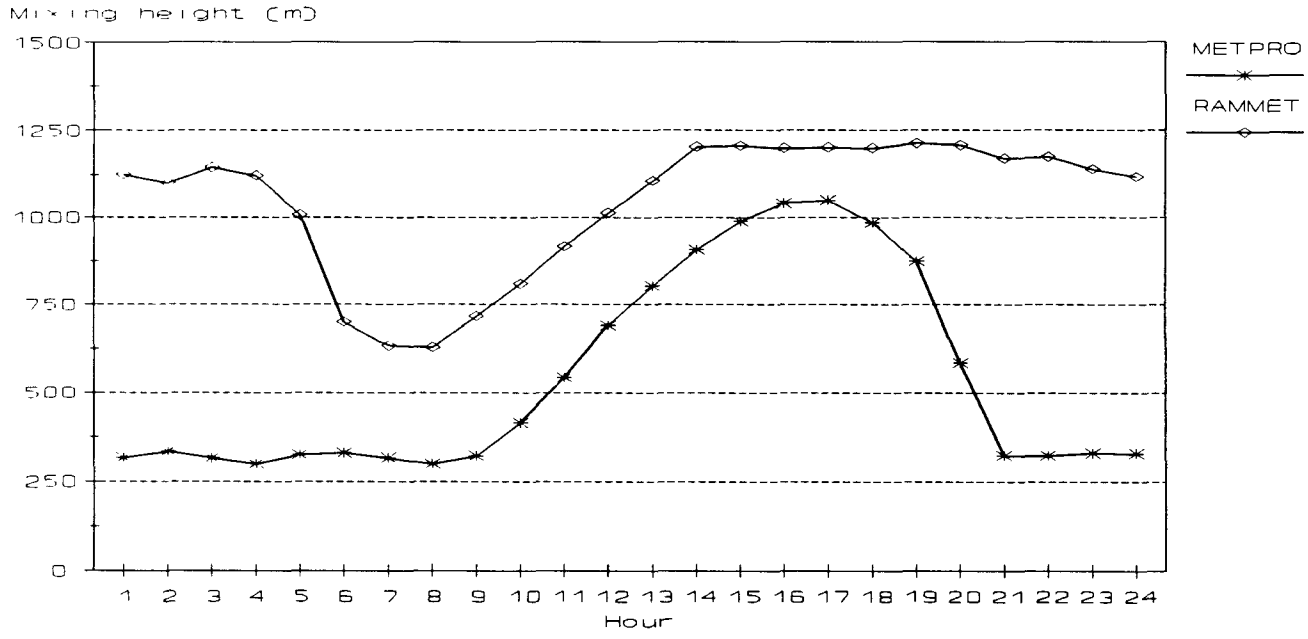

Figure 5.1. Annual average mixing height by hour of day for Pittsburgh, 1985.

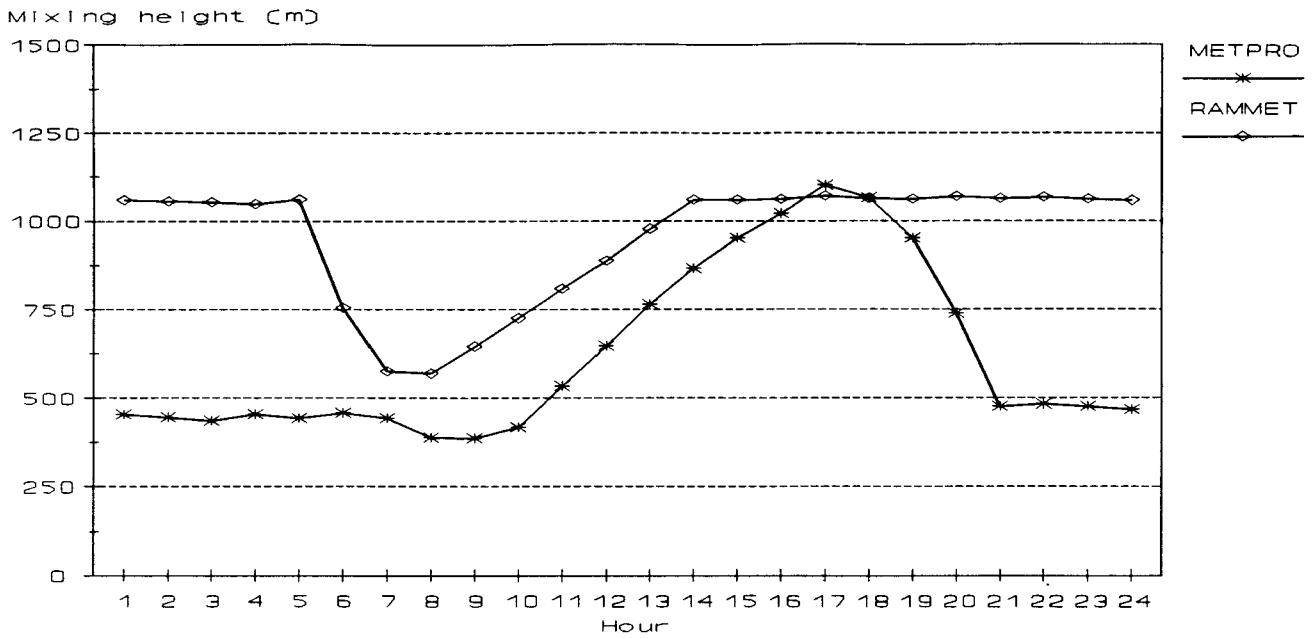

Figure 5.2. Same as Figure 5.1, except results are for Oklahoma City, 1985.

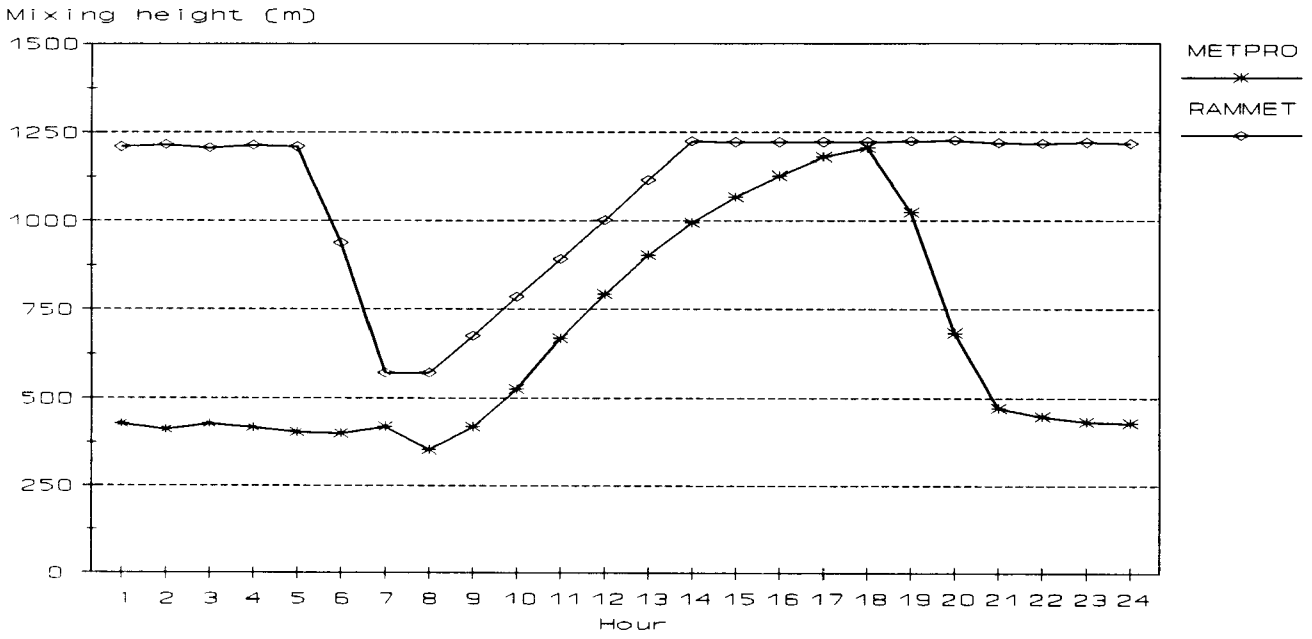

Figure 5.3. Same as Figure 5.1, except results are for Brownsville, 1985.

The increase in the 1-hr concentration estimates using METPRO mixing heights can be attributed to the mixing height being much closer to the effective plume height. As simulated by ISCST2, all plume material is below the mixing height when h_c is less than z_i.

Conversely, no plume material is below the mixing height when h_c is greater than z_i. Such phenomena are exemplified in Table 5.5.

6. CONCLUDING REMARKS

This comparison has shown that the 1-hr H2H design concentrations estimated using mixing height estimates from METPRO are generally larger than the design concentrations using RAMMET mixing heights for the point sources by an average of 15-20%. For other averaging periods, the point source results appear to be independent of mixing height algorithm. Similar conclusions are reached when the concentrations are paired in time and space. A notable difference is the H1H 1-hr concentration for an area source. The potential for unusually large concentration estimates resulting from extremely small mixing heights for a ground-level area source is far greater when using RAMMET-generated mixing heights. In this comparison, three of the six site-years exhibited such an occurrence.

These results should be viewed with the reminder that the NWS surface observations were used to create an on-site profile of winds and temperature for METPRO. When METPRO was developed, the intent was that the profile data would come from a multi-level, instrumented tower (and in future years from remote sensing capabilities) located at the site where the data are required. The concentration estimates on an hour-by-hour basis would certainly change if on-site data were employed, but the effect on conclusions reached in this study would not be expected to change significantly.

It should be emphasized that this comparison was for mixing height estimation in rural areas only. As mentioned above, METPRO does not estimate mixing heights for urban ares, as does RAMMET. However, a modification to allow METPRO to emulate the urban "switch" in RAMMET is being contemplated and will await future testing and evaluation.

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TECHNICAL REPORT DATA

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1. REPORT NO. EPA-454/R-93-052	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Comparison of Design Concentrations Based on Hourly Mixing Heights Estimated by RAMMET and METPRO		5. REPORT DATE December 1993
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) James O. Paumier		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Technical Support Division, Research Triangle Park, NC 27711		10. PROGRAM ELEMENT NO.
		11. CONTRACT/GRANT NO. 68D00124
12. SPONSORING AGENCY NAME AND ADDRESS		13. TYPE OF REPORT AND PERIOD COVERED
		14. SPONSORING AGENCY CODE
15. SUPPLEMENTARY NOTES		

16. ABSTRACT

A consequence analysis was conducted to investigate the effect on design concentration values resulting from using two different methods for estimating mixing height. Two years of meteorological data from Pittsburgh, PA, Oklahoma City, OK and Brownsville, TX were processed through RAMMET and METPRO meteorological preprocessors. The mixing heights from METPRO were merged with the RAMMET output and separate ISCST2 model runs were made using the two sets of mixing heights from each site and year. The effects of the two mixing height algorithms on predicted high second-high pollutant concentrations (design concentrations) were compared. The 1-hr design concentrations using mixing height estimates from METPRO were generally larger than those using RAMMET mixing heights for the three point sources by about 20%. Similar results were obtained when the data were paired in time and space. This tendency was not as apparent for other averaging times. For the ground-level area source, the potential for unusually large concentrations from extremely small mixing heights is far greater when using RAMMET mixing heights.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Air Pollution Atmospheric Dispersion Modeling Meteorological Preprocessors Mixing Height Estimation		

18. DISTRIBUTION STATEMENT Release Unlimited	19. SECURITY CLASS *(Report)* Unclassified	21. NO. OF PAGES 24
	20. SECURITY CLASS *(Page)* Unclassified	22. PRICE

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