Processing Meteorological Data From an On-Site Tower for Regulatory Air Modeling - A Study in Stability Class Determination Methods

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Bruce Tripp

IBM, Inc., Building 325, Route 52, Hopewell Junction, NY 12533

Karen C. Takacs and John F. Takacs

HighPoint Software Services, Inc., P.O. Box 874, Westminster, MA 01473

ABSTRACT

The IBM facility in East Fishkill, NY has operated for a number of years an on-site meteorological tower instrumented at the 10-meter and 40-meter levels. The tower is used to collect on-site meteorological data for air quality modeling purposes. Besides being instrumented for measuring wind speed and direction at both levels, the tower also collects sigma theta at each level, delta temperature and measures solar radiation.

Current EPA guidelines allow for the calculation of stability class by different methods. One of the accepted methods uses the measured sigma theta and another method uses the measured delta temperature and solar radiation. In this study IBM has preprocessed the on-site meteorological data using EPA's Meteorological Processor for Regulatory Models (MPRM). Two separate runs were made using different methods for calculating stability class:

- Sigma Theta Method
- Solar Radiation / Delta Temperature Method

The two methods give varying stability class distributions. Since both methods are accepted as valid methodologies by EPA, IBM has used each version of the preprocessed meteorological datasets to show how dispersion modeling results can vary with differing stability class distributions.

INTRODUCTION

The IBM Plant, located in East Fishkill New York, manufactures semiconductor devices (chips) and substrate packaging. The substrate packaging is used to mount the "chips" for installation into the computers. The semiconductor and substrate packaging manufacturing processes consists of hundreds of chemical steps. In order to manage the air quality issues related to the manufacturing of semiconductor and substrate packaging, IBM conducts its own regulatory air quality modeling. The meteorological data used in the air quality modeling studies is from an on-site tower.

The IBM facility on-site meteorological tower is instrumented at the 10-meter and 40-meter levels. Besides being instrumented for measuring wind speed and direction at both levels, the tower also collects sigma theta at each level, delta temperature and measures solar radiation.

Current EPA guidelines allow for the calculation of stability class by different methods[1]. The EPA preferred method is Turner's method for stability class determination, but with on-site data cloud cover and ceiling height data are not readily available. In lieu of using Turner's method, the meteorological parameters were collected on-site to be able to use the Solar Radiation –Delta Temperature method (SRDT) or the Sigma Theta method. An overview of the methods and the required input data is as follows:

- **Turner's method:** Requires information on solar altitude or zenith angle, cloud cover, cloud ceiling height and wind speed.

- **Solar Radiation /Delta Temperature method:** Retains the basic structure and rationale of Turner's method but eliminates the need for observations of cloud cover and ceiling height. The method uses the surface-layer wind speed (measured at 10 m) in combination with measurements of total solar radiation during the day and a vertical temperature gradient and surface wind speed at night.

- **Sigma Theta method:** A turbulence based method that involves the standard deviation of the wind direction and the surface wind speed (daytime and nighttime).

In this paper IBM has preprocessed the on-site meteorological data using EPA's Meteorological Processor for Regulatory Models (MPRM). Since the IBM on-site tower contains the parameters to determine stability class using different methods, two separate MPRM runs were made calculating stability class via the Sigma Theta method and the Solar Radiation / Delta Temperature method

The two methods give varying stability class distributions for the East Fishkill site. Since both methods are accepted as valid methodologies by EPA, IBM has used each version of the preprocessed meteorological datasets to show how dispersion modeling results can vary with these differing stability class distributions.

ON-SITE TOWER

On-site meteorological data for 1998 was collected for the IBM East Fishkill facility in Hopewell Junction, NY[2]. A multi-level tower measured data at ground level, 2-meters, 10-meters, and 40-meters. Measurements were taken of wind speed, wind direction, and temperature at the 40-meter level; wind speed, wind direction, sigma theta, delta temperature, and dew point at the 10-meter level; solar radiation at the 2-meter level; and precipitation and barometric pressure at ground level.

In Appendix W to 40 CFR Part 51, the USEPA Meteorological Preprocessor for Regulatory Models (MPRM) model[3] is the recommended meteorological preprocessor to use with on-site data. MPRM, therefore, was used to process the one year, 1998, of on-site data.

SURFACE DATA

The on-site meteorological data set contained the data needed to form one year of on-site data for air quality modeling. The wind speed and wind direction measured at 10 meters were used in the MPRM processing. Calm winds were set to a speed of less than or equal to 1.1 mph, the threshold velocity of the wind sensor. The Temperature at 10 meters was calculated from the delta temperature measurement and temperature measurement at 40 meters.

The MPRM program was used to check for missing data and preprocess the on-site meteorological data. Missing values of the required parameters were identified by Stage 1of the MPRM model. Stage 1 also performed a quality assurance of the data, determining if any of the measured values exceeded specified bounds.

From the MRPM Stage 1 processing, missing values were identified. For the surface data, if only a single hour was missing, then the objective method, per Atkinson and Lee[4], was used. The objective method allows for missing wind speed and direction values, to use the two hours before and after the missing hour and create an averaged value that is used in the database for the missing hour. For missing temperature values the objective method uses the preceding and following temperature to interpolate the missing temperature record.

If the objective method could not be used, then backup data sources were used to substitute for the missing values. Temperature and wind data from the National Weather Service's Poughkeepsie station (COOP 306820) was used to fill in missing values if data from both tower levels was missing.

UPPER AIR DATA

Morning and afternoon mixing heights were obtained from NCDC for 1998 based on Albany, NY upper air data, the closest representative upper air station. Of the 730 mixing heights, 188 were missing. According to Atkinson and Lee[4], there are two methods to substitute for the missing values, by either the objective or subjective procedure. The objective procedure uses an interpolated value from the preceding and successive mixing heights. Eighteen missing mixing heights were replaced using the objective procedure.

The remaining missing mixing heights were substituted by the subjective procedure using the Holzworth Method[5], implemented using algorithms from the EPA's MIXHT model, available on EPA's SCRAM website. By this method, the morning mixing height is "calculated as the height above ground at which the dry adiabatic extension of the morning minimum surface temperature plus 5 degrees centigrade intersects the vertical temperature profile observed at 1200 GMT". The minimum surface temperature is the minimum temperature observed between the hours of 0200 and 0600 LST. The afternoon mixing height is calculated the same way, except the maximum observed temperature from 1200 through 1600 LST is used. The Albany 12Z soundings and Albany surface temperature and pressure were available for 152 of the mixing heights needed. The last 18 mixing heights were replaced using soundings and surface temperatures from Upton, NY, located on Long Island, NY. This station is approximately the same distance from East Fishkill as Albany.

MPRM PROCESSING

There are three stages to MPRM processing. Stage 1, that identifies missing data values was explained above. Stage 2 merges the surface and upper air datasets. Finally, Stage 3 produces the final meteorological data set and accompanying summary statistics. The goal of MPRM is to produce a year of preprocessed meteorological data for use in EPA air quality models. In this study, two meteorological data sets were created based on the IBM on-site data for 1998: one using the Sigma Theta method for determining stability class and another year based on the Solar Radiation / Delta Temperature (SRDT) stability class method.

MPRM internally used the Sigma Theta method if the data for the SRDT method was missing, and vice-versa. If data required for both methods were missing for an hour, cloud cover, ceiling height, and wind speed from the Poughkeepsie station was used to calculate stability class by applying the Turner method[3].

Table 1 shows the stability class distribution of the 8,760 hours for the two methods.

Table 1. Stability class distributions for the two methods.

Stability Class Method	**A**	**B**	**C**	**D**	**E**	**F**
Sigma Theta	920	900	1324	2697	1198	1721
SRDT	153	797	1310	3414	1346	1740
Difference	767	103	14	717	148	19

The third row in the Table 1 gives the difference in the number of occurrences of each stability class. An analysis shows that for the East Fishkill site the determination of stability classes C and F are almost identical but there are larger differences in stability classes A and D as well as significant variation in classes B and E.

The most notable difference is that the SRDT method has less unstable occurrences and more neutral conditions (D), while the Sigma Theta method shows greater occurrences of unstable categories (A and B).

What would cause these stability class distribution differences between the two methods? For the Sigma Theta method to obtain stability classes of A and B for an hour, it must be during the daytime, since it is not possible to obtain these classes at night. So what is the difference in the corresponding SRDT method that does not give as many unstable occurrences? Remember that the Sigma Theta method is determined by the variation of the horizontal wind direction and wind speed. So light winds with a large horizontal wind variation will give unstable conditions.

The SRDT method in the daytime is based on the incoming solar radiation. So if the incoming solar radiation is not great enough during the same hour that the sigma theta method measures light winds and a large horizontal wind fluctuation, the two method would give varying results.

The major difference between the two methods is on cloudy/overcast days. The SRDT method includes this effect of solar insolation that was part of the Turner method but the Sigma Theta method depends only on horizontal wind fluctuations and wind speed, a turbulence indicator.

AIR QUALTIY MODELING

Two MPRM preprocessed meteorological datasets were prepared using the SRDT method and the Sigma Theta method for stability class determination. What are the effects on air quality modeling impacts using the two preprocessed datasets that only vary in stability class distribution ?   To answer that question IBM conducted air quality modeling with the 1998 meteorological datasets that were prepared for each stability class determination method. The ISC-PRIME model was used to determine 24-hour impacts of a pollutant for each meteorological dataset.

A modeling scenario was setup for a fictitious stack placed at the center of the facility. Table 2 gives the physical parameters for the stack used in the modeling exercise.

Table 2.   Stack parameters used in the ISC-PRIME model.

Stack Parameters	**Model Input Values**
Source ID	1
UTM X (Meters)	598126
UTM Y (Meters)	4599410
Stack Height (ft)	60
Stack Diameter (in)	12
Stack Exit Temperature (F)	350
Flow Rate (ft^3/min)	2827.5
Exit Velocity	60
Ground Elevation (ft)	252
Pollutant Emission Rate (lbs/hr)	10

Figure 1 shows the impacts from the meteorological dataset using the Sigma Theta method to determine stability class. The figure shows the location of the stack as a blue dot and the results of the modeling are contoured in 10 microgram / cubic meter intervals. The maximum 24-hour impact on the contour plot is 34.31 micrograms / cubic meter at the location 597832.37 Easting and 4600123.5 Northing just to the north of the facility. Table 3 gives a listing of the 13 highest impacts from the model run and their location.

Figure 1. ISC-Prime Impacts Using the Sigma Theta Stability Method.

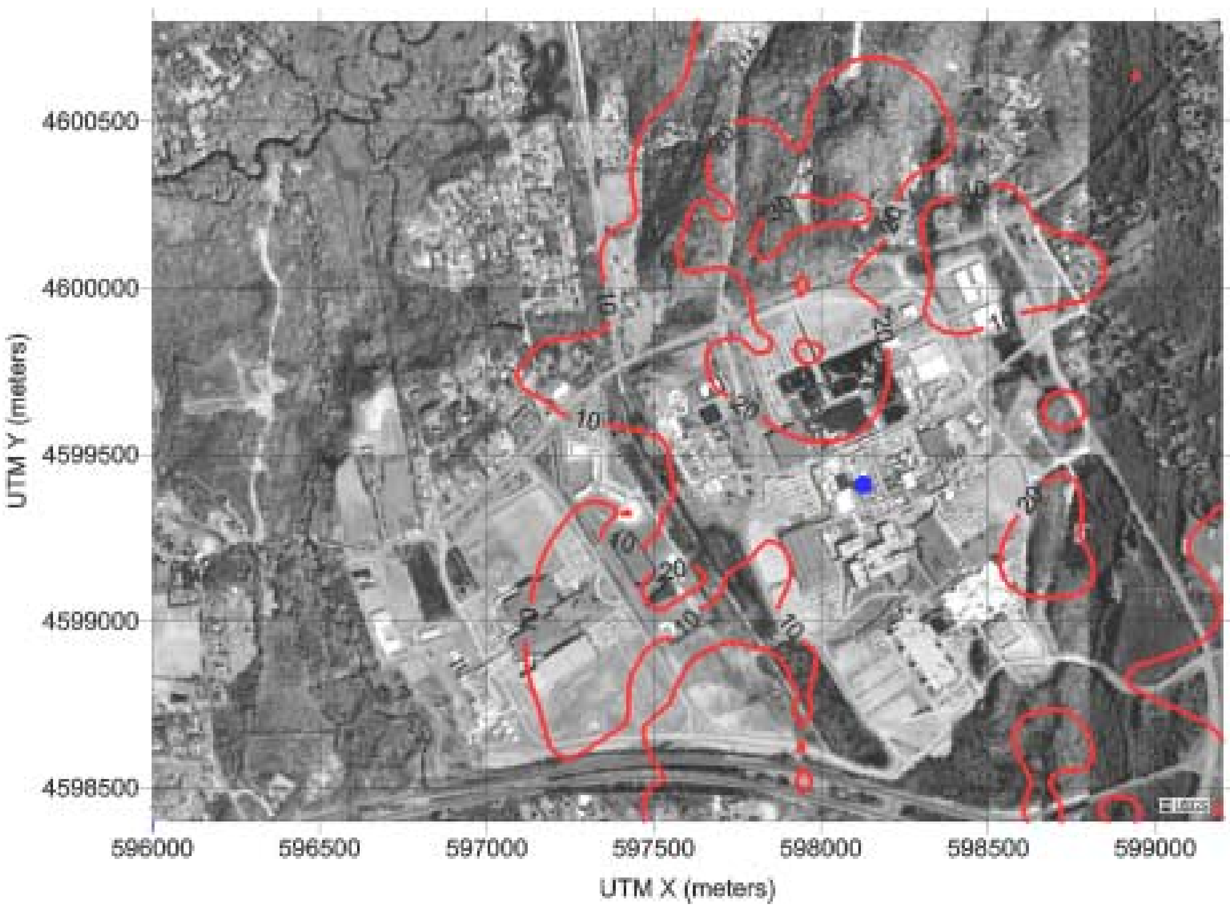

Table 3. ISC-Prime Tabular Impacts Using the Sigma Theta Stability Method.

HIGH FIRST HIGH IMPACTS

Model: ISC-PRIME Averaging Time: 24 Hours

Pollutant: AWMA Pollutant

Title: AWMA

UTM X (m)	UTM Y (m)	Concentration (µg/m**3)
597,832.38	4,600,123.50	34.31159
597,932.38	4,600,223.50	33.52163
597,932.38	4,600,223.50	32.75098
598,132.38	4,600,223.50	32.74537
597,932.38	4,599,823.50	32.00728
598,132.38	4,600,223.50	31.53529
597,832.38	4,600,223.50	30.60878
598,032.38	4,600,223.50	29.97741
598,032.38	4,599,823.50	29.32839
598,032.38	4,600,123.50	28.40888
598,732.38	4,599,123.50	26.58390
597,832.38	4,599,723.50	25.93463
597,832.38	4,600,023.50	25.85562

Figure 2 shows the impacts from the meteorological dataset using the Solar Radiation / Delta Temperature method to determine stability class. The figure shows the location of the stack as a blue dot and the results of the modeling are contoured in 10 microgram / cubic meter intervals. The maximum 24-hour impact on the contour plot is 51.11 micrograms / cubic meter at the location 597832.37 Easting and 4600023.5 Northing just to the north of the facility. Table 4 gives a listing of the 13 highest impacts from the model run and their location.

Figure 2. ISC-Prime Impacts Using the Solar Radiation / Delta Temperature Method.

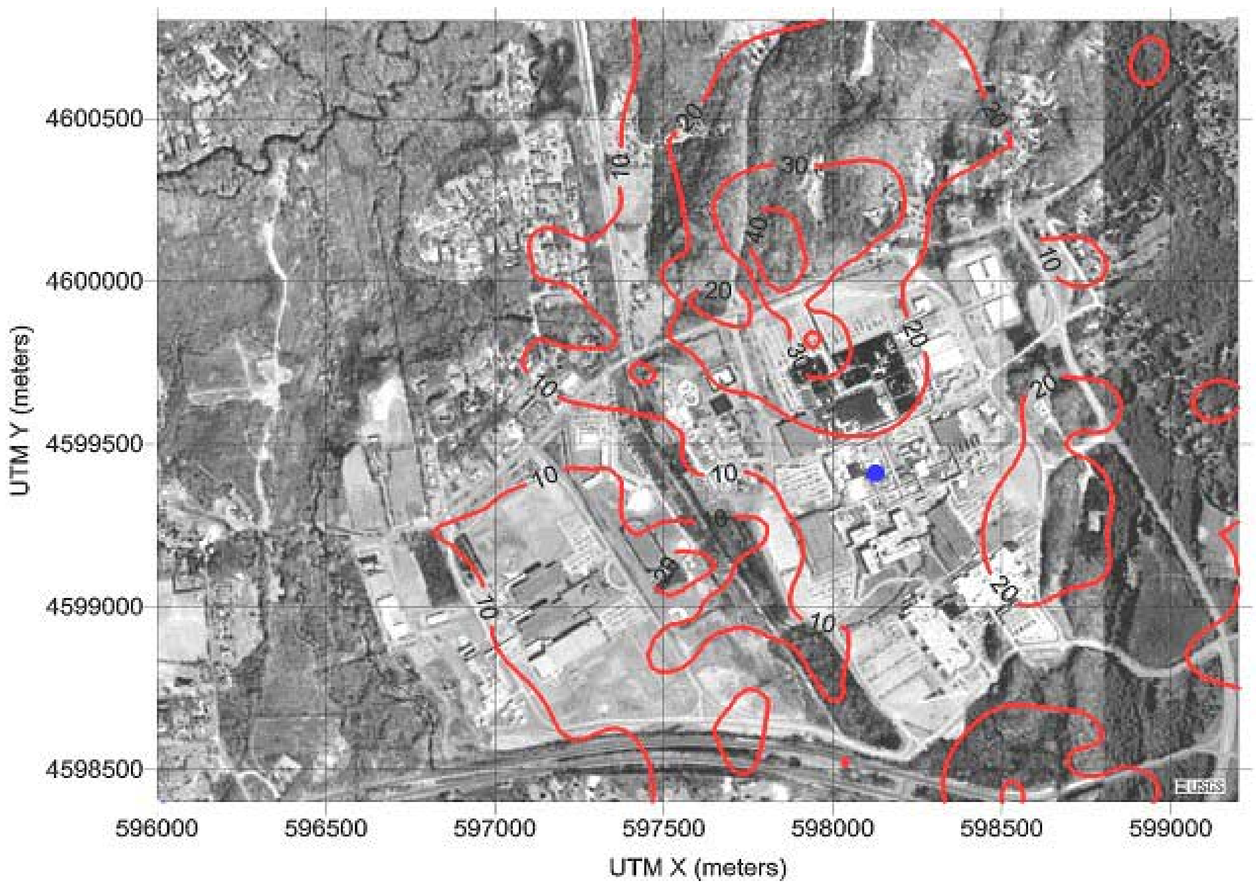

Table 4. ISC-Prime Tabular Impacts Using the Solar Radiation / Delta Temperature Method.

HIGH FIRST HIGH IMPACTS

Model: ISC-PRIME Averaging Time: 24 Hours

Pollutant: AWMA Pollutant

Title: AWMA - SRDT

UTM X (m)	UTM Y (m)	Concentration (µg/m**
597,832.38	4,600,023.50	51.10806
597,832.38	4,600,123.50	47.23558
597,932.38	4,599,823.50	45.38565
597,732.38	4,600,123.50	40.57346
598,032.38	4,600,123.50	40.00854
597,832.38	4,600,223.50	39.93724
598,132.38	4,600,223.50	39.39217
597,732.38	4,600,223.50	39.13226
598,132.38	4,600,223.50	38.81863
597,732.38	4,600,223.50	37.36068
597,932.38	4,600,223.50	37.15845
597,932.38	4,600,023.50	36.96595
597,932.38	4,600,223.50	36.54881

The plots of the modeled impacts show a difference in the 24-hour maximum concentrations. The SRDT method produces higher impacts over a wide range of receptors than the Sigma Theta method for the modeled stack. The percent difference between the maximum 24-hour concentrations between the two methods is approximately 49 %.

CONCLUSION

Current EPA guidelines allow for the calculation of stability class by different methods. One of the accepted methods uses the measured Sigma Theta and another method uses the measured Delta Temperature and Solar Radiation. In this study IBM preprocessed on-site meteorological data using EPA's Meteorological Processor for Regulatory Models (MPRM). Two separate runs were made using different methods for calculating stability class using the Sigma Theta Method and the Solar Radiation / Delta Temperature Method.

The results of the two methods give varying stability class distributions that can be explained by the SRDT method being based on the amount of solar insolation and the Sigma Theta method only depending on horizontal wind fluctuations and wind speed. Since both methods are accepted as valid methodologies by EPA, IBM used each version of the preprocessed meteorological datasets to show how regulatory modeling results can vary with differing stability class distributions. In this study, for the East Fishkill site, 24-hour maximum impacts can vary by as much as 49% between the two stability class distributions.

Typically due to cost or availability of data, on-site meteorological data is preprocessed with the method that best fits the parameters that are available. In this study we had the luxury of having additional measured parameters to allow stability class calculation using more than one method. The results show that different stability class methods for this site give varying results and when used in an air modeling study give differing impacts that can be critical in certain regulatory situations.

KEY WORDS

Meteorological Data, Air Quality Modeling

REFERENCES

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