Comparative Use of ISCST3, ISC-PRIME and AERMOD in Air Toxics Risk Assessment

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ABSTRACT

The new AERMOD and ISC-PRIME models have been proposed by U.S. Environmental Protection Agency (U.S. EPA) as the preferred regulatory models for most applications over the widely used ISCST3 model. This paper describes the methodologies and results of a model sensitivity study that apply all three models in air toxics risk assessment. The dispersion models have been applied to realistic test cases, i.e. actual facilities with real emissions and meteorological data. Health risks are predicted by two state of the art multipathway risk assessment models (ACE2588 and ACEHWCF) and compared. Modeling results show that both cancer and noncancer risks are much higher with ISC-PRIME than with ISCST3, due to the new PRIME building downwash algorithms. The AERMOD results show lower cancer risk and acute hazard index but slightly higher chronic hazard index than the ISCST3 predictions. It is recommended that, at a minimum, ISC-PRIME and AERMOD be upgraded to incorporate all the capabilities of the latest version of the ISCST3 model, and a single model that combines all the best features of these three models be developed for regulatory applications.

INTRODUCTION

U.S. Environmental Protection Agency (U.S. EPA) has proposed ISC-PRIME and AERMOD as the new guideline models that are preferred for most applications over the ISCST3 model. This paper describes the methodologies and results of a model sensitivity study that apply all three models in air toxics risk assessment and compare the differences in potential health risks. The dispersion models have been applied to realistic test cases, i.e. actual facilities with real emissions and meteorological data, and health risks predicted by two state of the art multipathway risk assessment models developed by Applied Modeling Inc. (AMI): ACE2588 for the California's Air Toxics Hot Spots program, and ACEHWCF for RCRA hazardous waste combustion facilities. The following paragraphs summarize the salient features of the dispersion models and the risk assessment models used in this modeling study, describe the modeled facilities and discuss the modeling results.

MODEL DESCRIPTION

Dispersion modeling is an important step in a health risk assessment (HRA) since it provides pollutant concentrations and deposition rates in ambient air. The ISCST3 model is the most widely used model due its ability to handle both flat and complex terrain, both point and non-point sources and its acceptance by regulatory agencies. Salient features of the proposed dispersion models ISC-PRIME and AERMOD, and the multipathway risk assessment models are summarized below.

The ISC-PRIME Model

ISC-PRIME (dated 99020) is based on a version of ISCST3 (dated 96113) that incorporates the PRIME (Plume Rise Model Enhancement) algorithms for improved treatment of building downwash. The PRIME submodel handles the stack/building geometry better than the ISCST3 algorithm since it internally accounts for the plume rise and trajectory around building obstacles. The building dimensions preprocessor program, BPIP, has been modified to provide additional values for ISC-PRIME. The modified program, called BPIPPRM, readily accepts a BPIP input file and outputs additional values needed as input to ISC-PRIME.

The AERMOD Model

The AERMOD model (dated 99351) has been developed by AERMIC (American Meteorological Society/Environmental Protection Agency Regulatory Model Improvement Committee). It is based on an older version of the ISCST2 model (version 93109). Special features of AERMOD include its ability to treat the vertical inhomogeneity of the planetary boundary layer, special treatment of surface releases, irregularly-shaped area sources, a three plume model for the convective boundary layer, limitation of vertical mixing in the stable boundary layer, and fixing the reflecting surface at the stack base. AERMOD also includes an improved treatment of dispersion in the presence of intermediate and complex terrain, yet without the complexity of the Complex Terrain Dispersion Model-Plus (CTDMPLUS). To the extent practicable, the structure of the input or the control file for AERMOD is the same as that for ISCST3. At this time, AERMOD contains the same algorithms for building downwash as those found in the ISCST3 model.

The AERMOD model is actually a modeling system with three separate components: AERMOD (AERMIC Dispersion Model), AERMAP (AERMOD Terrain Preprocessor), and AERMET (AERMOD Meteorological Preprocessor). AERMET is the meteorological preprocessor for the AERMOD. Input data can come from hourly cloud cover observations, surface meteorological observations and twice-a-day upper air soundings. Output includes surface meteorological observations and parameters and vertical profiles of several atmospheric parameters.

The AERMAP preprocessor is a terrain preprocessor designed to simplify and standardize the input of terrain data for AERMOD. Input data include receptor terrain elevation data. The terrain data may be in the form of digital terrain data that is available from the U.S. Geological Survey. Output includes, for each receptor, location and height scale, which are elevations used for the computation of airflow around hills.

The ACE2588 Risk Assessment Model

Since its development in 1991 by Applied Modeling Inc. (AMI), ACE2588 (Assessment of Chemical Exposure for AB 2588) has become the most widely used risk assessment model in California[1]. It has been applied to hundreds of facilities under the California's Air Toxics Hot Spots program (AB 2588) and other regulatory programs, such as New Source Review and PSD permit applications. It fully implements the guidelines of the California regulatory agencies (CAPCOA, OEHHA and CARB). The model calculates cancer risk from both inhalation and non-inhalation exposure, and hazard indices for noncancer acute and chronic health effects. Pollutant concentrations in ambient air are calculated by an appropriate dispersion model and a constant deposition velocity (0.02 m/s for controlled or 0.05 m/s for uncontrolled sources) is used to simulate pollutant deposition. The ACE2588 model is designed to handle large facilities (e.g., oil refineries) with hundreds of emission sources, pollutants and receptors. In its latest version (dated 00256), the model can handle different short-term averaging times (1-hour, 4-hour, 6-hour and 7-hour) for noncancer acute exposure. The ACE2588 user's guide is available from our Web site[2].

In the dispersion modeling run, unit emission rates (1 g/s) are used for all sources and a AMI-modified version of the dispersion model (e.g. ISCST3, ISC-PRIME or AERMOD) is used to compute, for each emitted pollutant, short-term peak and annual-averaged concentrations at each receptor from actual input emission rates. The model also computes partial contributions from each source to these short-term peak and annual concentrations. Short-term peak concentrations are used in quantifying non-cancer acute health effects, and annual-averaged concentrations in carcinogenic and non-cancer chronic health effects. This approach does not require a big partial concentration file and allows an accurate analysis of the contributions from each individual emission source.

The ACEHWCF Risk Assessment Model

The ACEHWCF (Assessment of Chemical Exposure for Hazardous Waste Combustion Facilities) model has recently been developed by AMI[3]. It fully meets the U.S. EPA risk assessment guidelines for hazardous waste combustors[4]. The model calculates cancer risk from both inhalation and non-inhalation exposure, and hazard indices for noncancer acute and chronic health effects. Dispersion modeling requirements by ACEHWCF are more extensive than those by ACE2588 and, generally, three modeling runs are required to accommodate the different phases of pollutant emissions: vapor, particle and particle-bound. In general, most metals and organics with very low volatility occur only in the particle phase. Organics can occur as either only vapor phase or with a portion of the vapor condensed onto the surface of particulate (e.g. particle-bound). Pollutants released only as particulate are modeled with different mass fractions allocated to each particle size than the mass fractions for the organics released in both the vapor and particle-bound phases. Normally, five years of appropriate meteorological data are used in the modeling.

Pollutant concentrations in ambient air are calculated by an appropriate dispersion model and a constant deposition velocity (0.03 m/s) is used to simulate pollutant dry deposition for vapor. The ACEHWCF multipathway exposure algorithms also require dry deposition rates from particle phase, and wet deposition rates from vapor and particle phases. In the dispersion modeling runs, unit emission rates (1 g/s) are used for all sources and a AMI-modified version of the dispersion model (e.g., ISCST3, ISC-PRIME or AERMOD) is used to compute, for each emitted pollutant, short-term (1-hour only) peak and annual-averaged concentrations and deposition rates at each receptor from actual input emission rates. The same approach used in ACE2588 has also been implemented in the ACEHWCF model.

MODELED TESTS AND RESULTS

ACE2588 Test and Modeling Results

The facility in the ACE2588 test is a chrome plating shop with 15 emission sources and 17 pollutants. Modeling was conducted for 809 receptors. The 1990 meteorological data sets, with surface data from Shreveport, LA and upper-air data from Longview, Texas, were obtained from a recent risk assessment by US EPA Region 6 (see the ACEHWCF test below). The same data set is used for both ISCST3 and ISC-PRIME modeling. The only differences in the ISCST3 and ISC-PRIME input files are the additional projected building length and distances generated by the BPIPPRM preprocessor. Raw 1990 data sets were obtained for Shreveport (surface data in SAMSON format) and Longview (upper-air data in TD 6201 format) and processed by the AERMET preprocessor for use in AERMOD modeling.

Table 1 presents the predicted maximum cancer risk, acute and chronic hazard indices. For ISC-PRIME and AERMOD, the table also shows the ratios of their predictions over the ISCST3 values. All health risks predicted with ISC-PRIME are higher than those with ISCST3, up to a factor of 3 for maximum cancer risk. Results of AERMOD show lower cancer risk (by 54%) and acute hazard index (by 33%) and slightly higher chronic hazard index (by 11%) than the ISCST3 predictions. For all risk measures, AERMOD predictions are lower than those by ISC-PRIME.

Table 1. Predicted Maximum Health Risks

Predicted	ISCST3	ISC-PRIME/Ratio	AERMOD/Ratio
Cancer Risk	1.44E-5	4.33E-5 (3.01)	6.56E-6 (0.46)
Acute Hazard Index	4.47E-2	6.27E-2 (1.40)	3.01E-2 (0.67)
Chronic Hazard Index	3.89E-1	7.08E-1 (1.82)	4.32E-1 (1.11)

Source contributions to the predicted maximum cancer risks are shown in Table 2. Large increases in ISC-PRIME cancer risk over the ISCST3 risk are due to the effects of the new PRIME building downwash algorithms. For all sources, AERMOD predictions are lower than those of ISCST3.

Maps of risk contours (1.0E-6, 5.0E-6 and 1.0E-5) are presented in Figures 1 and 2 and 3. Compared to the ISCST3 predictions in Figure 1, cancer risks predicted by ISC-PRIME are not only higher but the risk contours also cover larger areas as can be seen in Figure 2. The maximum cancer risk of ISC-PRIME is located close to the ISCST3 maximum (only 6 meters south of this maximum). Figure 3 shows that AERMOD predicts lower cancer risks and narrower impact zones than the other two models. The AERMOD maximum is also located further away from the ISCST3 maximum (about 80 meters northwest of this maximum).

Table 2. Source Contributions to Predicted Maximum Cancer Risk

Source	Building Downwash	ISCST3	ISC-PRIME	AERMOD
1,5,7,8,9	No	1.87E-6	1.84E-6	9.58E-7
2,3,4,6,10,11,12,13,14	Yes	1.25E-5	4.14E-5	5.59E-6
15	No (Fugitive)	3.36E-8	3.67E-8	1.42E-8
Total		1.44E-5	4.33E-5	6.56E-6

Figure 1. Cancer Risk Predicted by ISCST3/ACE2588

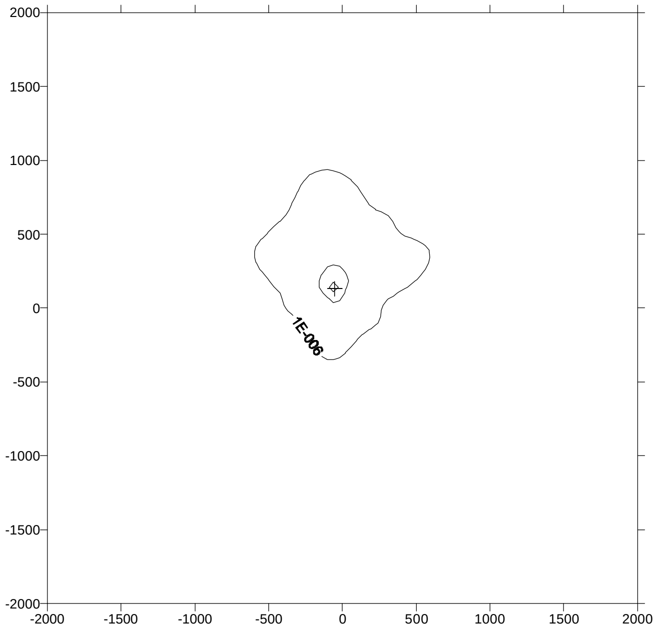


Figure 2. Cancer Risks Predicted by ISC-PRIME/ACE2588

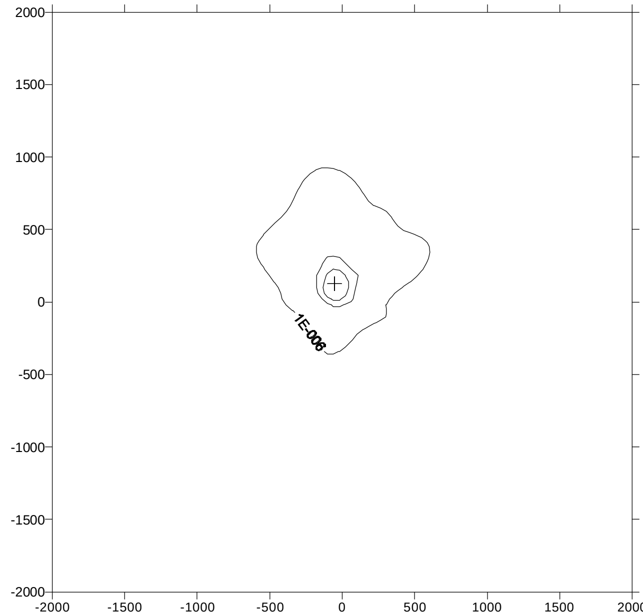
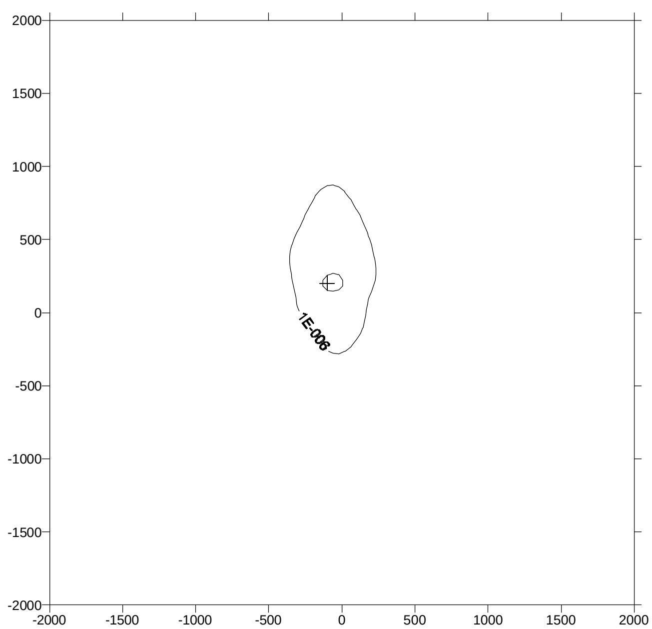


Figure 3. Cancer Risks Predicted by AERMOD/ACE2588



ACEHWCF Test and Modeling Results

The facility in the ACEHWCF test is a hazardous waste combustion facility proposed in Sterlington, Louisiana. Potential health risks from this facility have recently been evaluated by U.S. EPA[5]. The risk assessment involved the use of the ISCST3 and ISC-PRIME models and one year (1990) sequential meteorological data set. The AERMOD model was not used in this test because of its current lack of treatment for particle dispersion and deposition. Stack emissions from the boiler are modeled as a point source and fugitive emissions are represented by three volume sources. The facility emits a total of 223 pollutants. Three separate ISCST3 and ISC-PRIME modeling runs were performed (vapor phase for all four sources, particle and particle-bound phases for the boiler only) for over 5200 gridded receptors. The only differences in the ISCST3 and ISC-PRIME input files are the additional projected building length and distances generated by the BPIPPRM preprocessor.

Table 3 shows the health risks predicted at the maximum exposed individual (MEI)-adult farmer with an exposure duration of 40 years. Similar to the ACE2588 results above, cancer risk and chronic hazard index predicted with ISC-PRIME are higher than those with ISCST3. Cancer risk and chronic hazard index are predicted to increase by 31% and 21%, respectively. Table 4 shows that these increases by ISC-PRIME are due to the effects of the new PRIME building downwash algorithms. Compared to the ISCST3 risk contours in Figure 4, ISC-PRIME predicts higher cancer risk and larger impact zones as shown in Figure 5. It is also noted that ISC-PRIME requires substantially more computer time than ISCST3, up to an order of magnitude more for the particle run.

Table 3. Predicted Health Risks at the MEI - Farmer

Predicted	**ISCST3**	**ISC-PRIME/Ratio**
Cancer Risk	5.16E-5	6.75E-5 (1.31)
Acute Hazard Index	2.38E-5	0.0
Chronic Hazard Index	9.52E-2	1.15E-1 (1.21)

Table 4. Source Contributions to MEI-Farmer Cancer Risk

Source	**Building Downwash**	**ISCST3**	**ISC-PRIME**
Boiler	Yes	5.11E-5	6.70E-5
Fugitive	No	5.00E-7	5.00E-7
Total		5.16E-5	6.75E-5

Figure 4. Cancer Risks Predicted by ISCST3/ACEHWCF

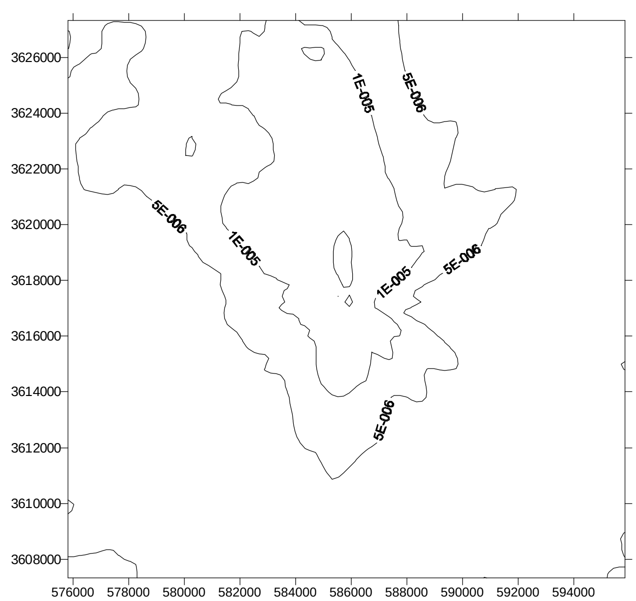
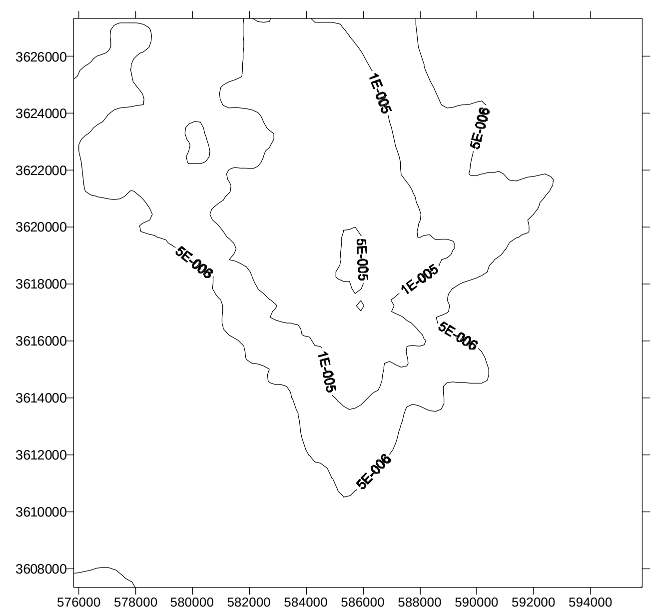


Figure 5. Cancer Risks Predicted by ISC-PRIME/ACEHWCF



SUMMARY

The dispersion models ISCST3, ISC-PRIME and AERMOD, along with the multipathway risk assessment models ACE2588 and ACEHWCF, have been applied to predict health risks at two actual facilities: a chrome plating shop and a hazardous waste combustor. Using actual emission and meteorological data, modeling results show that ISC-PRIME predictions are much higher than those of ISCST3 due to the improved PRIME building downwash algorithms. AERMOD predictions are comparable to or lower than those of ISCST3 as a result of refined treatment of turbulent dispersion. It is recommended that, at a minimum, ISC-PRIME and AERMOD be upgraded to incorporate all the capabilities of the latest version of the ISCST3 model, and a single model that combines all the best features of these three models be developed for regulatory applications.

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KEYWORDS

Dispersion modeling
Health risk assessment
US EPA guideline models