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ANALYSES OF THE CALMET/CALPUFF MODELING SYSTEM IN A SCREENING MODE

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PREFACE

CALPUFF is a multi-layer, gridded non-steady-state puff dispersion model that can simulate the effects of temporally and spatially varying meteorological conditions on pollutant transport, remove pollutants through dry and wet deposition processes, and transform pollutant species through chemical reactions. This complexity requires a significant effort in creating the meteorological data file for CALPUFF. An option within CALPUFF is to use an ISCST3 meteorological data file generated with a preprocessor such as PCRAMMET. This greatly simplifies the input at the expense of temporal resolution in the modeling domain. In this report, five years of ISCST3-type meteorological data are used in a 'screening' version of CALPUFF, and the results are compared to those obtained using a fully developed wind field for one year of data. The modeling domain was a 600 kilometer by 600 kilometer region in the central United States where the influences of terrain are considered minimal.

ACKNOWLEDGMENTS

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1.0 INTRODUCTION

A simple method for estimating pollutant concentration without a complete application of a refined model is a useful element in the air quality permitting process. An effective screening procedure should be easy to implement, yet provide reasonable overestimates of that which would be obtained from a more refined dispersion model. For example, SCREEN3 (U.S. EPA, 1995a) is a screening model for the Industrial Source Complex Short-Term (ISCST3) model (U.S. EPA, 1995b). SCREEN3 is a single-source plume dispersion model that applies a matrix of meteorological conditions that are likely to yield the highest 1-hour surface-level concentration values. The useful domain of application for the ISCST3 model involves transport distances where one may assume the meteorological conditions are reasonably steady-state.

To overcome some of the limitations of ISCST3, the CALPUFF dispersion model (U.S. EPA, 1995c) is currently being investigated by the U.S. Environmental Protection Agency (EPA). CALPUFF is especially envisioned to be useful for characterization of long-range transport, say beyond 50 km, or where the meteorological conditions are highly variable either in time or space. CALPUFF is a multi-layer, gridded non-steady-state puff dispersion model that can simulate the effects of temporally and spatially varying meteorological conditions on pollutant transport. In addition, CALPUFF can remove pollutants through dry and wet deposition processes and transform pollutant species through chemical reactions. The input data requirements for CALPUFF include a meteorological data file prepared by the CALMET preprocessor (U.S. EPA, 1995d), and a control file that defines the modeling domain, the modeling options, and source information. If variable-rate emissions are used, CALPUFF also requires a file defining the hourly emission rates.

Preparing the input for a CALPUFF run requires more effort than running a simple plume dispersion model. Developing the time-varying three-dimensional wind field and other meteorological parameters, with all the data input and processing decisions, requires advanced expertise and knowledge of micrometeorology. The purpose of this study was to test a screening mode by which a simpler set of input data can be applied to the CALPUFF dispersion model and provide concentration estimates that are reasonably conservative when compared to a CALPUFF modeling effort with a fully-developed (hereafter referred to as ‘refined’) wind field. In place of developing a full characterization of the meteorology, the CALPUFF model is run using the meteorological input as would be used to drive the ISCST3 model.

Section 2 briefly describes the input for a refined CALPUFF run, particularly the input to CALMET. The specific methodology and assumptions for obtaining screening estimates are discussed in Section 3. Section 4 describes the testing that was performed. Section 5 presents the comparison of screening versus refined modeling results. Results in a tabular form appear in Appendix A, and problems encountered in developing the meteorological fields for a refined CALPUFF model run are discussed in Appendix B. Appendix C offers some background information concerning the modeling domain, meteorological data, and modeling options.

2.0 DEVELOPING CALPUFF INPUT

To run the CALPUFF dispersion model, there are two required input files and several optional input files. The simplest mode of running CALPUFF requires the control file and a file of hourly, gridded meteorological data. The optional files include time-varying emissions, complex terrain hill data, turbulence data, chemical transformation rates, deposition velocities (for deposition only), and hourly ozone data.

Preparing the gridded meteorological data with CALMET is a multi-step process, with the following inputs required at a minimum:

1) Hourly surface observations in the National Climatic Data Center's (NCDC) TD-1440 format or from the Solar and Meteorological Surface Observation Network (SAMSON) compact disc; data for one or more stations are required.

2) Upper air data - at a minimum, the twice-daily soundings released at 00 Greenwich Mean Time (GMT) and 12 GMT; data for one or more stations are required.

3) Geophysical parameters (land use, terrain heights, surface roughness length, albedo, Bowen ratio, soil and anthropogenic heat fluxes, and leaf area index) for each cell in the lowest layer of the meteorological grid.

4) CALMET input control file.

Other files that may be required, depending on the application, are:

5) Hourly precipitation data in NCDC's TD-3240 format for modeling wet processes; data for one or more stations are required if wet processes are modeled.

6) Over water data files.

7) Gridded wind field data, such as output from the MM4 prognostic model, used as the initial guess wind fields, a "step 1" field, or as "observations."

8) Terrain weighting factor for MM4-derived wind field data if the MM4 data are used as "step 1" field or as "observations."

CALMET requires data from one or more hourly surface stations and one or more upper air sounding stations. These data may be from National Weather Service (NWS) sites, but any data that are in the proper format are acceptable. For applications over a large domain (several hundred kilometers), 10-20 NWS surface and 10 NWS upper air stations may be used in a modeling study. For smaller applications, the number of stations may be reduced. Whether the number of surface and upper air stations to be processed is small or large, considerable effort is required to format these data.

In addition to the meteorological data, a file of gridded land use and gridded terrain heights is required to estimate the geophysical parameters such as surface roughness length and mixing height. The land use and terrain heights may be derived from programs and data provided with the CALPUFF Modeling System compact disc (EPA, 1996) or may be generated with the user's own software and data. Whatever method is chosen, several steps are required to obtain the final file of geophysical parameters (the file referred to as 'GEO.DAT' in the CALMET user's guide (U.S. EPA, 1995a)).

CALMET also requires its own input control file that contains station information, processing options, and information about the meteorological grid including the origin, size, resolution, and the vertical levels. This information varies according to the individual application of the CALPUFF modeling system.

Much effort can be expended creating the meteorological file and determining which options to use. Defining the wind fields is especially important in areas of complex terrain. If items 5-8 are included in the data preparation, then the effort is even greater. Another consideration in running CALPUFF is the size of the meteorological input file. Depending on the size of the meteorological domain, the grid resolution, and the number of levels, the size of the meteorological file can tax a personal-computer-based system's storage capacity. For example, one year of meteorological data on a 42-by-40 horizontal grid with six vertical layers would require about 1.7 **gigabytes** of hard disk space to store the meteorological input to CALPUFF.

3.0 SCREENING METHODOLOGY

In a screening procedure, the effort to create the input should be minimized. CALPUFF has a built-in mode whereby it can use the meteorological data file generated by PCRAMMET (U.S. EPA, 1995e) for the ISCST3 model, thus bypassing the need to run CALMET.

The CALPUFF system also includes a program (ISC2PUF) that translates an ISCST3 control file to a CALPUFF control file. The converted control file should be reviewed prior to running CALPUFF and can be generated in one of two ways: using a text editor to modify the control file directly, or using the CALPUFF graphical user interface (GUI) to guide the user through the options.

The following approach for running CALPUFF in a screening mode to estimate ground-level concentrations over a large area was used in this effort:

1) generate ISCST3 input meteorology using PCRAMMET,

2) generate an ISCST3 control file and use the ISC2PUF conversion program to create the CALPUFF control file,

3) use the GUI to finalize the CALPUFF control file before running the CALPUFF model,

4) run CALPUFF with the ISCMET.DAT data option, and

5) pick the maximum concentration for each distance modeled (see section 3.2 for the discussion on receptors).

3.1 ISCST3 Control Files and Meteorology

Using this proposed methodology, the control file and meteorology input can be created as if preparing for an application of the ISCST3 dispersion model. This approach has the advantage that many dispersion modelers are familiar with both the meteorological data and control file structures.

3.1.1 ISCST3 Control File Options

The rural dispersion coefficients were used with the regulatory default settings, which include use of stack-tip downwash, buoyancy induced dispersion, final plume rise, default wind speed profile exponents, and default vertical potential temperature gradient. Averaging times for the model runs were 1-hr, 3-hr, 24-hr, and annual averages.

3.1.2 Meteorology

PCRAMMET was used to generate the meteorological data files for CALPUFF. Utilizing hourly surface observations and twice-daily mixing heights, PCRAMMET computes atmospheric stability in the form of Pasquill-Gifford (PG) categories and rural and urban mixing heights. These data, along with the wind direction, wind speed, and temperature, are read directly by CALPUFF without any modification to the data file. Although the meteorology does not vary spatially as in a refined CALMET/CALPUFF modeling effort, the use of PCRAMMET-generated meteorology provides a complete range of time-varying meteorological conditions for a single location.

To perform dry deposition calculations, the surface roughness, friction velocity, and Monin-Obukhov length are required. These parameters can be computed by PCRAMMET and written to the output file as well. In order to estimate these additional parameters, several additional input values are required by PCRAMMET, including: surface roughness at the site where the wind measurements are taken (usually an airport), surface roughness at the site where the model is to be applied, noon-time albedo, Bowen ratio, and fraction of the net radiation absorbed by the ground. For this application, a surface roughness length at the measurement site (Oklahoma City airport) of 0.10 meters was assumed. To obtain the roughness length at the application site, which is the entire modeling domain, the roughness lengths for all grid cells generated for the 'GEO.DAT' file were averaged. The result was 0.34 meters. A similar analysis was performed for the albedo and Bowen ratio, resulting in a noon-time albedo of 0.15 and a Bowen ratio of 1.00. A value of 0.15 was assumed for the fraction of net radiation absorbed by the ground.

3.2 Receptor grid

A polar grid was used to define the receptor locations. However, CALPUFF does not accept a polar grid directly. Receptors must be a subset of the computational domain (which is a subset of the meteorological domain), i.e., a Cartesian grid, or they must be discrete receptors. The ISC2PUF program can convert a polar grid and associated terrain to discrete receptors with terrain. However, the ISC2PUF has a limitation on the number of receptors that can be processed. The number is not known exactly, but is thought to be about 1200. Since the source code is not available, large applications may require two or more runs of this program followed by merging the results into a single CALPUFF control file.

For this initial phase, the following polar networks were used:

Distance (km)	Receptor Spacing Along Each Ring	# Receptors	Distance Along Ring Between Receptors
1, 2, 3, 5, 10, 15, 20, 30, 50	every 10°	324	0.2 - 8.7 km
75, 100, 150, 200, 250, 300	every 5°	432	6.5 - 26.2 km

These two networks result in 756 receptors, well below the limit of about 1200. Thus, CALPUFF was run once per source and option configuration.

3.3 Terrain

The modeling in this approach is for a region in the central part of the United States with relatively flat terrain. The transport distances are large and terrain effects would likely be minimal. For this initial screening effort, CALPUFF was run in a flat terrain mode, i.e., all source and receptor elevations were set to 0. This assumption allows assessing the screening procedure and results without the confounding effects of terrain. Any conclusions reached without considering terrain would not necessarily be applicable to the screening procedures applied in areas of significant terrain.

4.0 MODEL RUNS AND ANALYSES

Five years of meteorological data were processed through PCRAMMET to create the necessary input meteorology for the CALPUFF screening. Oklahoma City was used for the hourly surface observations and Oklahoma City/Norman for the upper air data. Data from the Solar and Meteorological Surface Observation Network (SAMSON) compact disc were used to obtain the hourly surface data. The twice-daily mixing heights were retrieved from EPA's Support Center for Regulatory Air Models (SCRAM) system. The mixing height data on SCRAM restricted the period of choice from 1984 through 1991. The upper air station changed from Oklahoma City to Norman in 1989. Due to this change, there were no 1989 mixing height data on SCRAM. Data from Oklahoma City for 1986-1988 and data from Norman for 1990-1991 were used for this modeling effort, since Norman is only 25-30 kilometers from Oklahoma City. There were no periods of missing data for Oklahoma City that required filling. However, there were five 2-hour periods of unfilled mixing heights for the two years of data at Norman. The mixing heights were filled by linearly interpolating between the hours before and after the missing mixing height periods.

A screening procedure must be tested against the results of a refined modeling analysis to determine if the screening method provides a reasonably conservative estimate. The CALPUFF screening results for the Oklahoma 600-kilometer study were compared to results from ISCST3 for the period 1985-1988, 1990-1991, and using a refined wind field and spatial variations of the geophysical parameters in CALPUFF for 1990 only. To test the screening procedure, the 600-kilometer Oklahoma field experiment was used since the meteorological domain is large enough to accommodate the proposed polar grid without modifying the geophysical parameter file developed for a tracer study analysis (U.S. EPA, 1998). The sources were located near the center of the meteorological domain for the modeling. This location allowed for modeling out to 300 kilometers from the sources. For additional background information on the Great Plains field experiment (which originated near Oklahoma City, OK), see Appendix C.

The size of one year of PCRAMMET-generated meteorological data, without parameters for deposition estimates, is about 700 Kb. As noted earlier, the size of one year of CALMET-generated meteorological data for a 42-by-40-by-6 domain with a 20-kilometer grid resolution requires about 1.7 gigabytes of hard disk space. For the refined modeling, meteorological data for 1990 from 19 hourly surface stations and nine upper air stations were used.

4.1 Source Characterization

The initial focus was on buoyant point sources only. The following source characterizations were used in this analysis:

Stack ht. (m)	Stack diameter (m)	Exit velocity ($m\ s^{-1}$)	Exit temp. (K)	Bldg. ht. (m)	Bldg. width (m)	Emission rate ($g\ s^{-1}$)
2.0	0.5	10.0	300	NA	NA	100.0
35.0	2.4	11.7	432	NA	NA	100.0
200.0	5.6	26.5	425	NA	NA	100.0

4.2 Other Considerations for CALPUFF

In CALPUFF, there are several options that the user must specify through the GUI or by editing the control file directly (independent of the ISC2PUF conversion program). These options include the use of puffs or slugs and the type of dispersion - Pasquill-Gifford or internally-computed σ's. Also to be considered are the pollutants of interest, modeling of chemical transformations, and modeling dry deposition processes.

4.2.1 Pollutants

The transformation pathways for five active pollutants are treated by the MESOPUFF II scheme in CALPUFF: SO_2, SO_4, NO_x, HNO_3, and NO_3. Since haze and visibility are of concern in areas such as national parks, CALPUFF is most likely to be applied to sulfates. Therefore, for this modeling effort, the focus was on SO_2 and SO_4.

4.2.2 Slug model vs puff model

The slug model with the set of default options for slugs was used for the initial screening and refined modeling. The primary advantage of using the slug model vs the puff model is to prevent underestimation of concentration at receptors between puffs. At nearby receptors, there is a tendency for the puff model to either underestimate concentrations between receptors or to overestimate concentration at receptors at the puff centers. Also, slugs are free to evolve independently in response to local effects such as dispersion, chemical transformation, and removal.

4.2.3 Dispersion coefficients

Pasquill-Gifford dispersion coefficients for both the screening and refined CALPUFF modeling were used.

4.2.4 Concentration estimates

CALPUFF was run initially for both the refined (one year) and screening modes (five years) without any chemistry treatment or deposition. This provides ‘baseline’ concentration estimates without the effects of chemistry and deposition.

4.2.5 Chemical transformations

There are two transformation options in CALPUFF: 1) MESOPUFF II mechanisms and 2) a file with a diurnal cycle of transformation rates. The MESOPUFF II option requires relative humidity as one of the input variables for chemical transformations. However, this variable is not present in the ISCST3 meteorological data file and limits the application to SO_2 and NO_x transformations since the $HNO_3 \rightarrow NO_3$ transformation is a function of relative humidity. The second mode requires a file of diurnal transformation rates specified by the user. In this mode, transformation rates are spatially uniform but provides for some temporal variability. The second method, with the file of transformation rates, was used in this modeling effort.

For this study, John Vimont of the U.S. National Park Service recommended a 3.0 %/hr transformation rate for daylight hours and 0.2 %/hr at night for the SO_2 to SO_4 transformation, with these rates skewed toward the length of a summer day. These rates were used for both CALPUFF refined and screening modes, with the daytime period defined as 0700 to 2000 local standard time.

4.2.6 Dry deposition

In CALPUFF, deposition can be modeled as either particle or gas, depending on the pollutant. Since the primary pollutant is SO_4, the deposition was modeled for particles (per communication with John Vimont). The current version of ISCST3 can compute the deposition of particles.

To estimate deposition, the surface roughness length, surface friction velocity, and Monin-Obukhov length are estimated by CALMET and vary temporally and spatially when CALPUFF is run in a refined mode. In the screening mode, though, these variables are specified for each hour on an ‘extended’ data record in the meteorological file. PCRAMMET was run to generate these extended data records for the CALPUFF screening mode.

To compute dry deposition of particles, CALPUFF requires one of the following: 1) a file of the diurnal variation of deposition velocities for each pollutant modeled, or 2) specification of the mass mean diameter, geometric standard deviation, and number of particle size intervals to evaluate the effective particle deposition velocity. CALPUFF has default parameters for several pollutants, including SO_4, for the latter option. For this modeling effort, the latter option was chosen.

4.2.7 Model run summary

To summarize, the following model runs were performed:

	Concentration without deposition or chemistry treatment (for SO_2)	Dry deposition and chemistry treatment (for SO_2 and SO_4)
CALPUFF refined (with slugs and PG dispersion)	1 year	1 year
CALPUFF screening (with slugs and PG dispersion)	5 years	5 years
ISCST3	5 years	not applicable

4.3 Results

CALPUFF screening mode and ISCST3 were run for SO_2 concentration estimates without deposition or chemistry treatment for a five year period (as noted above). CALPUFF refined mode was run only for 1990 for SO_2 concentration estimates due to limitations of computer resources.

Figures 1-3 show the results for 1990 for each of the three sources for the 1-hr, 24-hr , and period averages for SO_2 concentration without deposition or chemistry treatment. There is no clear tendency for the concentration estimates from any one model to be greater or less than the others. The 1-hr average CALPUFF refined estimates are just as likely to be as great or greater than the screening estimates, whereas for 24-hr averages, the refined estimates are greater than the screening estimates for nearly all sources and downwind distances, with the only exception being the 200-meter source at 10 kilometers. For the annual average SO_2 concentration, the CALPUFF screening mode produced greater values than the refined mode for all sources and at all distances, except close in for the 200-meter source.

The year to year variation between CALPUFF screening mode and ISCST3 are shown in Figures 4-6 as a ratio formed by dividing the CALPUFF screen result by the ISCST3 result. As averaging time increased, there was less variation between years. There are some generals trends in the 1-hr averages. For the 2-meter source, CALPUFF screen concentration estimates were less than ISCST3 estimates at all distances (except for a spike at 20 kilometers), with the ratio ranging from about 0.75 near the source to 0.1 at 300 kilometers. This trend was apparent in the 24-hr and period average also, although the ratio was a little larger for the 24-hr and period averages.

For the 35-meter source, there was a lot of variation for the 1-hr averages, with the ratio decreasing from about 0.95 near the source to about 0.60 at 300 kilometers. For the 24-hr and period averages, there was good agreement between CALPUFF screen and ISCST3 out to about 10 kilometers. At distances greater than 10 kilometers, the 24-hr averages display much scatter with a tendency for CALPUFF screen to produce larger results, and the period averages first show a slight tendency for larger values from CALPUFF screen out to about 50 kilometers, at which point the CALPUFF screen estimates are less than the ISCST3 estimates.

The 200-meter source displays some year to year coherence within 10 kilometers of the source (excluding 1990). Beyond 10 kilometers, there is much scatter, with CALPUFF screen estimates exceeding ISCST3 estimates by as much as a factor of 3.0 or more. The 24-hr averages for the 200-meter source show a curious, unexplainable "U" shape in the ratios. The overall tendency is for CALPUFF screen estimates to be larger than the ISCST3 estimates. The CALPUFF screen period averages display a factor of 2-3 greater than the ISCST3 estimates near the source, but settle down to about a 25% difference beyond that point.

Estimates of sulfate (SO_4) concentrations and dry deposition from CALPUFF screening and refined modes for 1990 were compared. An SO_2 release was simulated with dry deposition and chemistry "turned on" in CALPUFF to generate sulfate. Since ISCST3 does not have any chemistry mechanisms, there were no model runs made with ISCST3. However, the Interagency Workgroup on Air Quality Modeling (EPA, 1993) recommends the following for a level 1 analysis for evaluating the effects of long range transport and regional visibility:

> "... it should be assumed that all SO_2 has been converted to SO_4^- ... in the analysis."
>
> "Multiply the hourly concentrations of SO_2 and NO_x by the ratios of the molecular weights of the secondary species to the primary species."

Thus, for SO_2 to sulfate, the SO_2 results should be multiplied by 1.5 (96 and 64 for SO_4 and SO_2, respectively).

Figures 7-9 show the resulting SO_4 concentration estimates. The solid line in each figure represents the SO_2 concentrations estimated by ISCST3; the ISCST3 estimates have not been multiplied by 1.5. There is no clear trend for concentration estimates from CALPUFF screening mode to be greater or less than the estimates from CALPUFF refined mode. One thing is clear though: the ISCST3 results are much greater than the CALPUFF results even without using the multiplicative factor. Note that in Figure 9, the ISCST3 estimates extend above 0.10 µg m-3 in the middle section (from two to 100 kilometers), but the plotting software dropped all data outside the axis limit and connected the lines.

Figures 10-12 show the SO_2 dry deposition estimates from CALPUFF screening and refined modes. There are no dry deposition estimates from ISCST3. The overall tendency here is that the CALPUFF refined estimates are greater than the CALPUFF screening estimates, except possibly for the period averages for the 2-meter source, where the estimates are nearly equal, and the period averages for the 35-meter source beyond about 5 kilometers. If the screening estimates were multiplied by a factor of two, then the screening estimates would be greater than the refined estimates about 90-95% of the time, with the exceptions being the 1-hr and 24-hr averages for the 200-meter source closer than about five kilometers.

Figures 13 and 14 show the SO_4 dry deposition estimates from CALPUFF screening and refined modes for the 24-hr and period averages. There are no dry deposition estimates from ISCST3. Generally, the reverse trend is seen here, with the CALPUFF screening estimates greater than the refined estimates except for the 24-hr average for the 200-meter source.

Tabulations of these results, that include 3-hr averages, can be found in Appendix A.

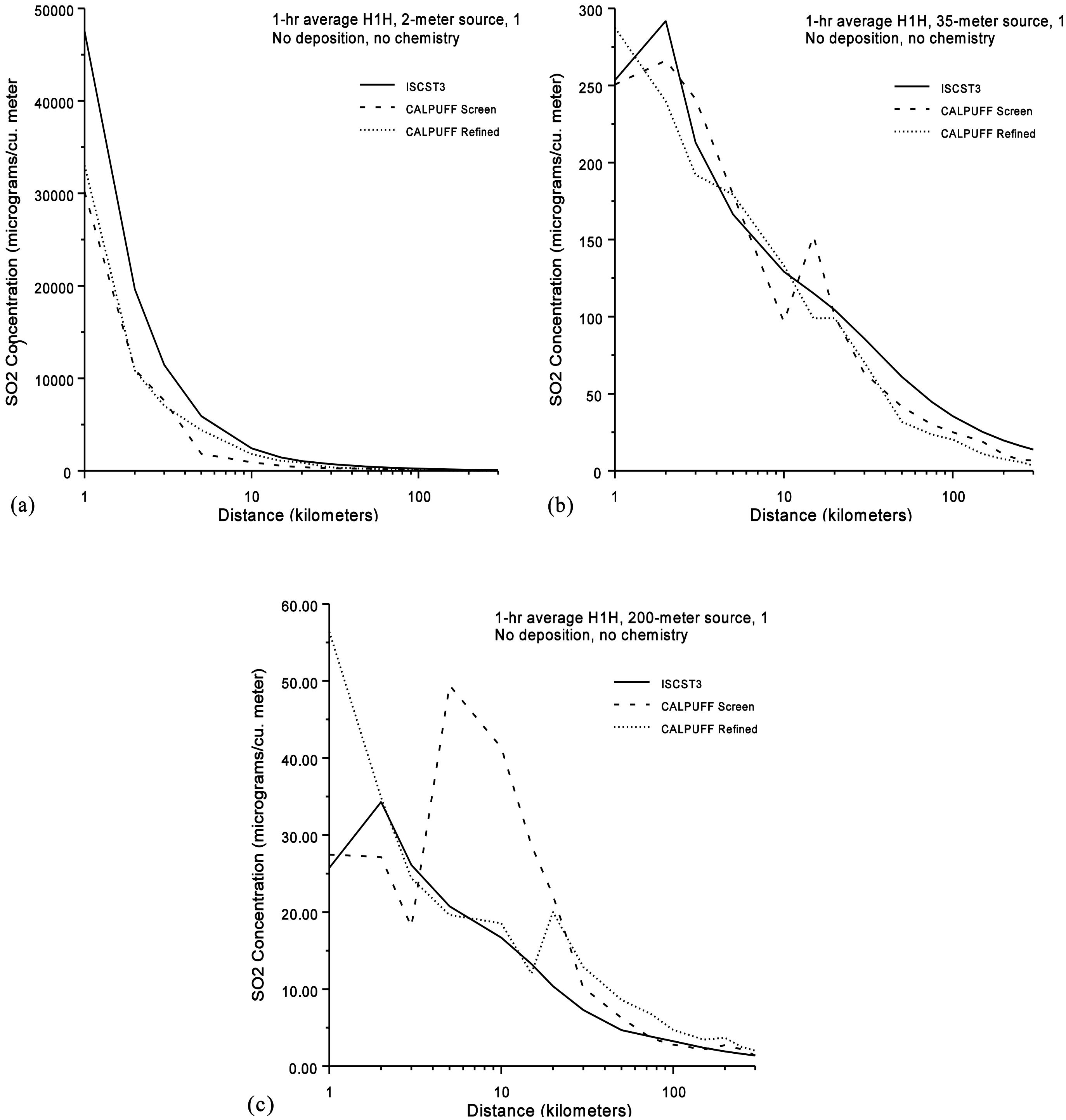

Figure 1. Highest (H1H) 1-hour average SO2 concentration estimates without deposition and chemistry for 1990 for the a) 2-meter source, b) 35-meter source, and c) 200-meter source.

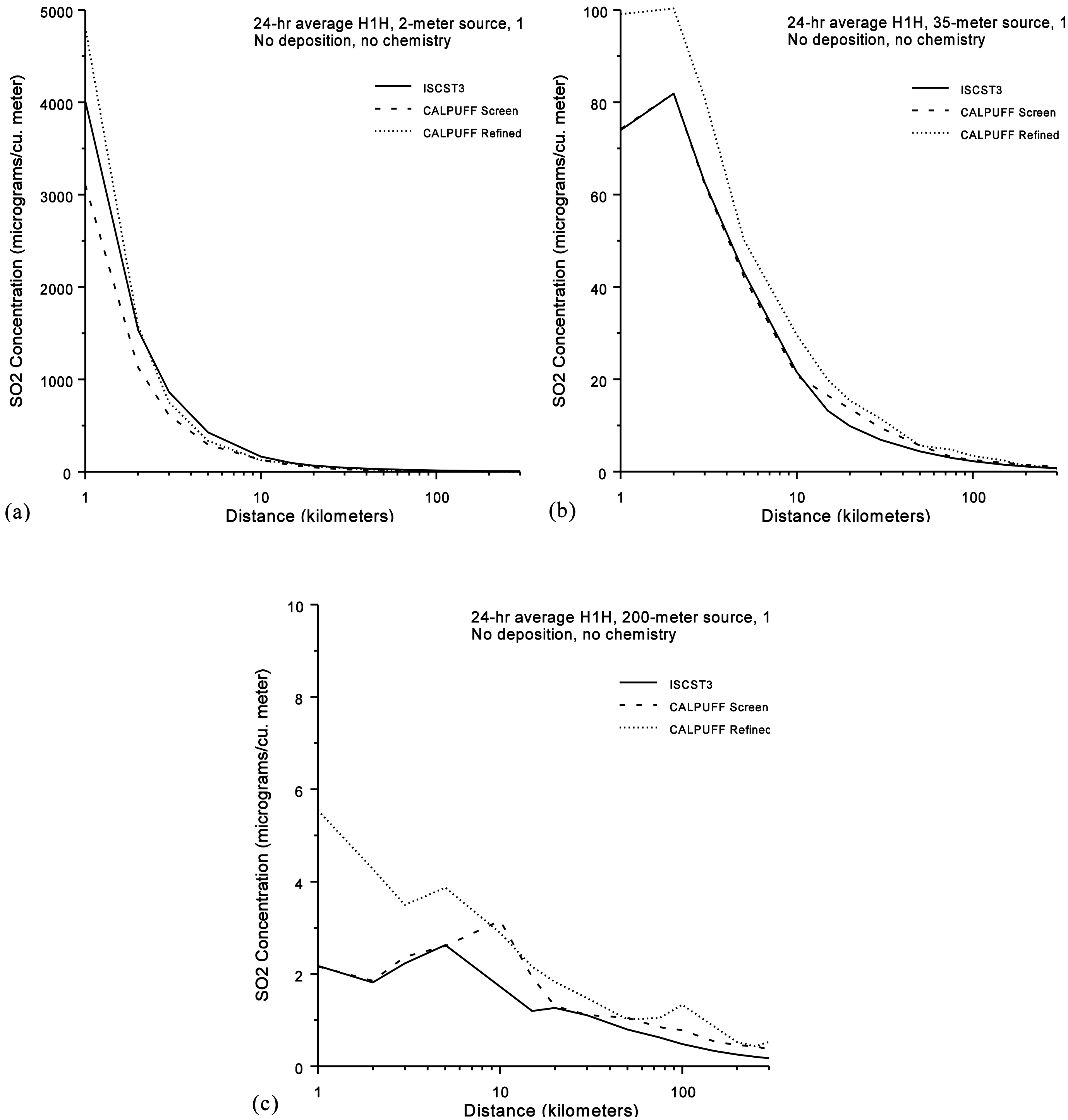

Figure 2. Highest (H1H) 24-hour average SO2 concentration estimates without deposition and chemistry for 1990 for the a) the 2-meter source, b) 35-meter source, and c) the 200-meter source.

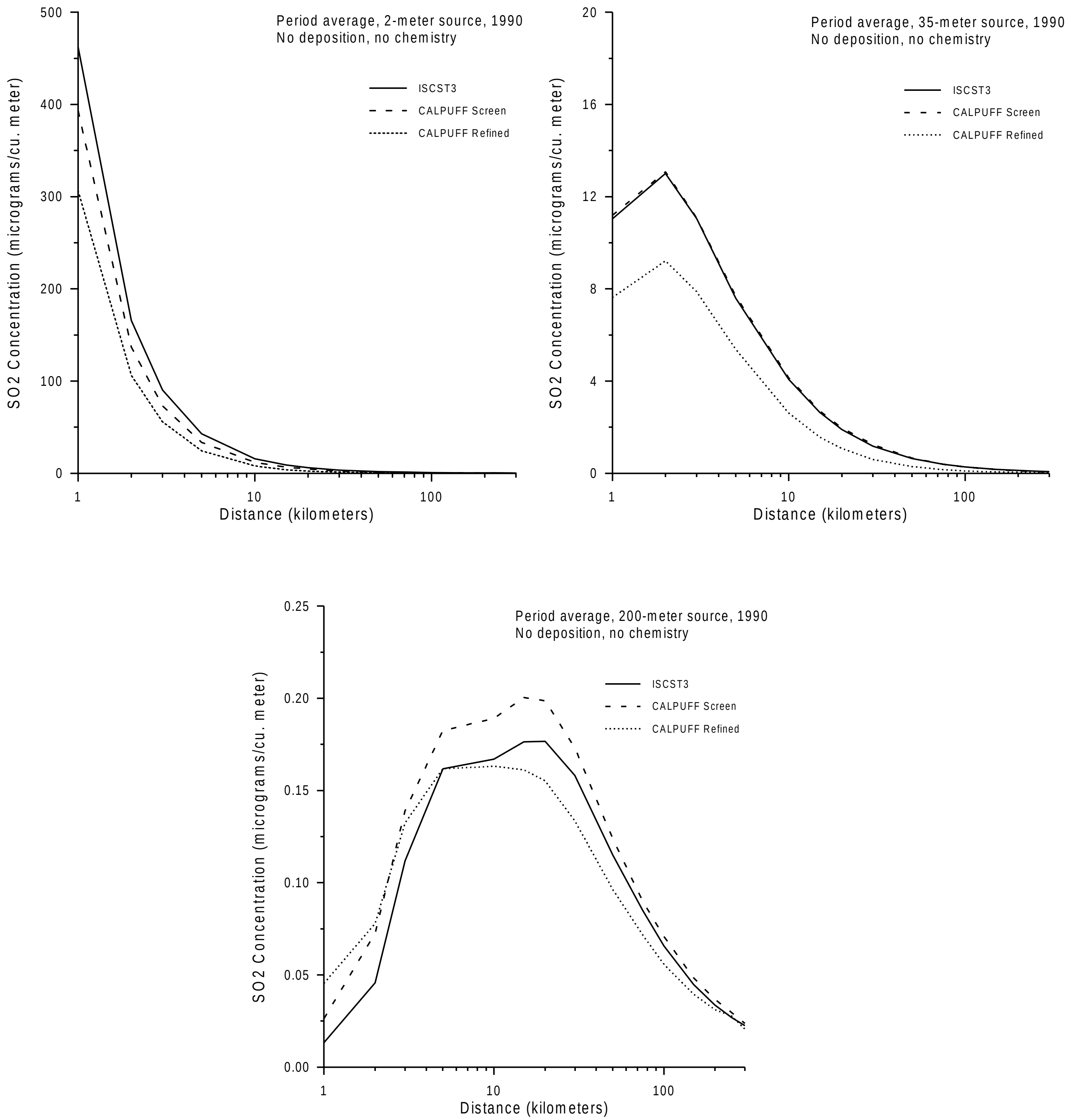

Figure 3. Period average SO2 concentration estimates without deposition and chemistry for 1990 for the a) 2-meter source, b) 35-meter source, and c) 200-meter source.

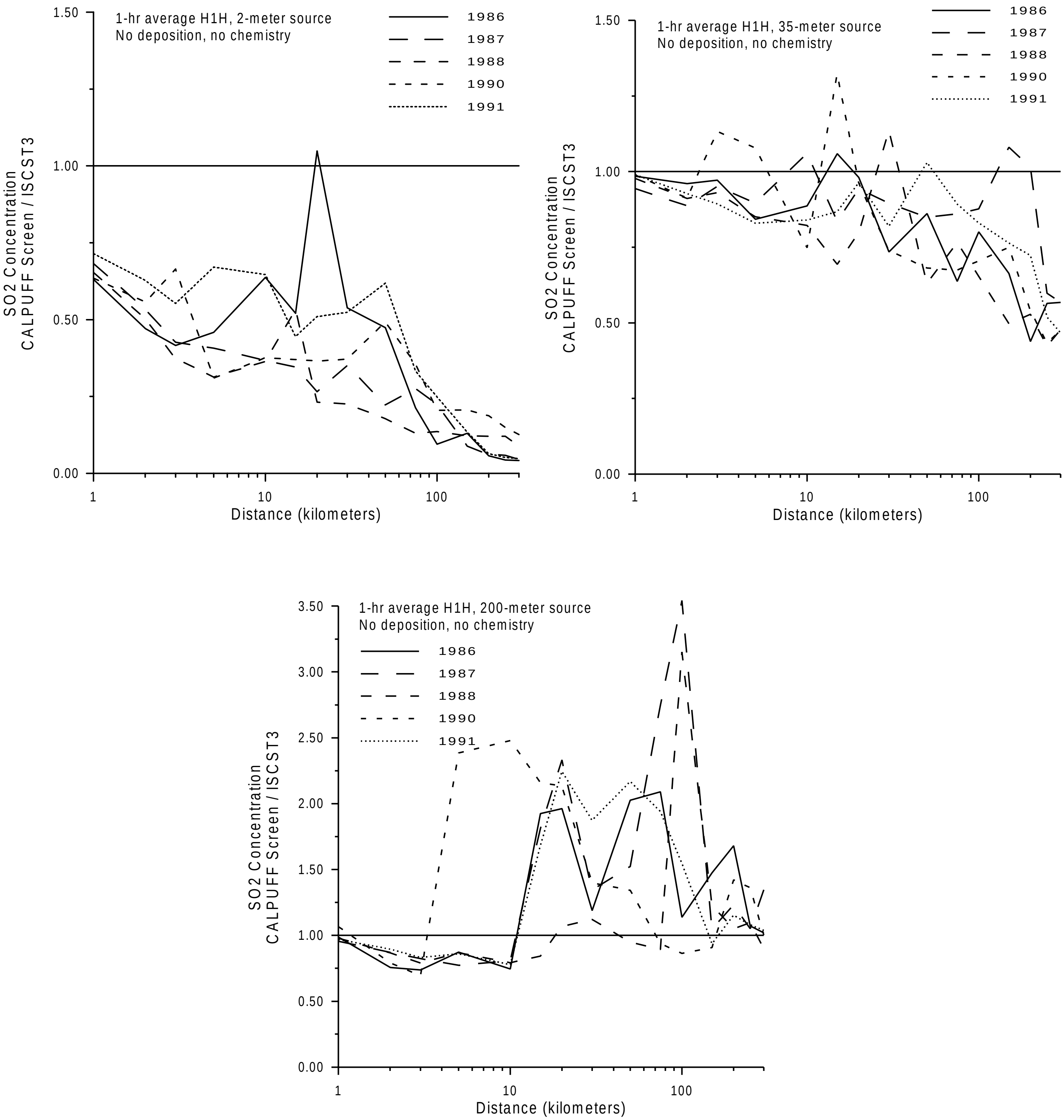

Figure 4. Year to year variation of the ratio of the CALPUFF screen concentration estimates to the ISCST3 estimates for the highest (H1H) 1-hour average SO2 concentration estimates without deposition and chemistry for the a) 2-meter source, b) 35-meter source, and c) 200-meter source.

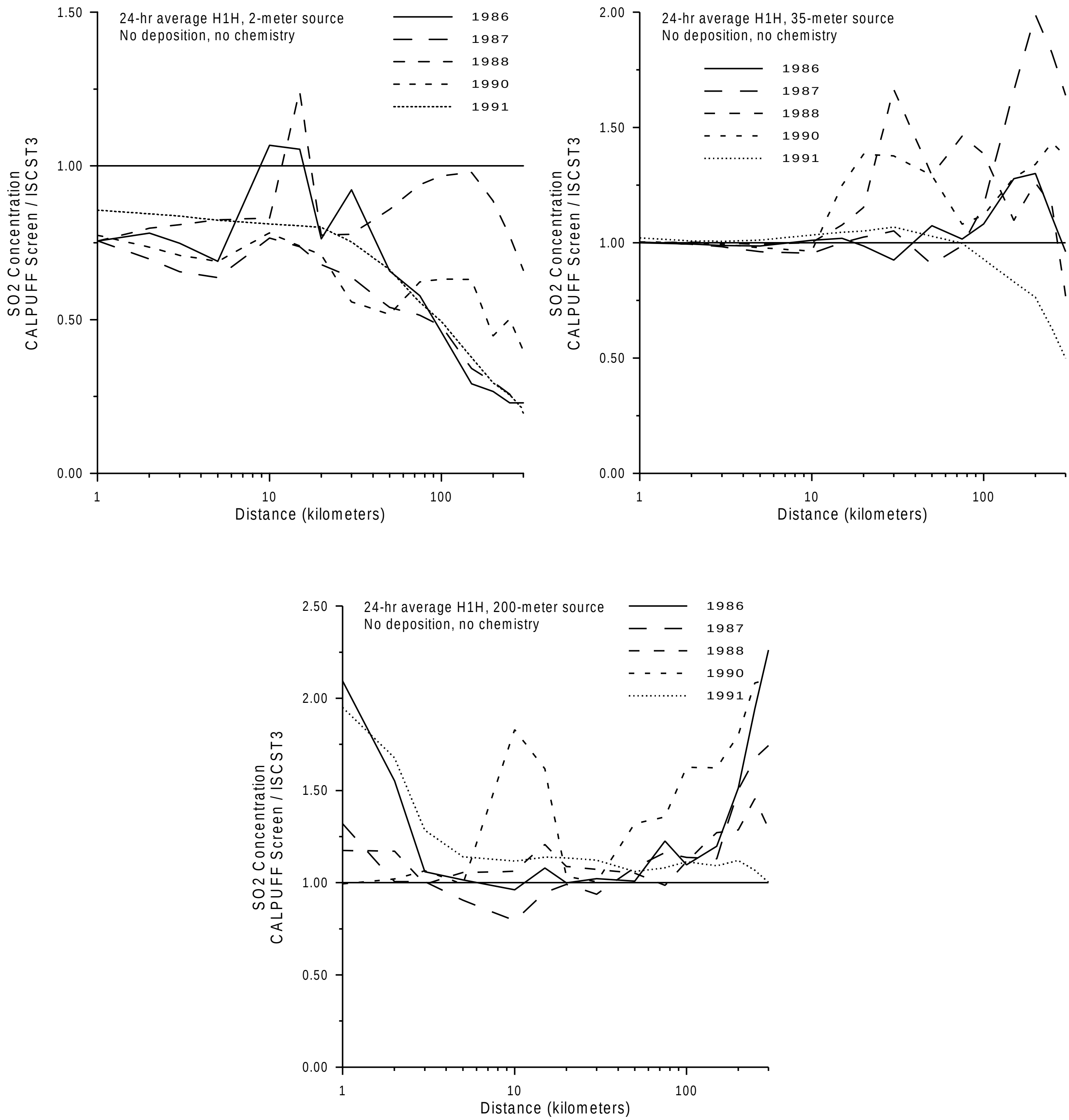

Figure 5. Year to year variation of the ratio of the CALPUFF screen concentration estimates to the ISCST3 estimates for the highest (H1H) 24-hour average SO2 concentration estimates without deposition and chemistry for the a) 2-meter source, b) 35-meter source, and c) 200-meter source.

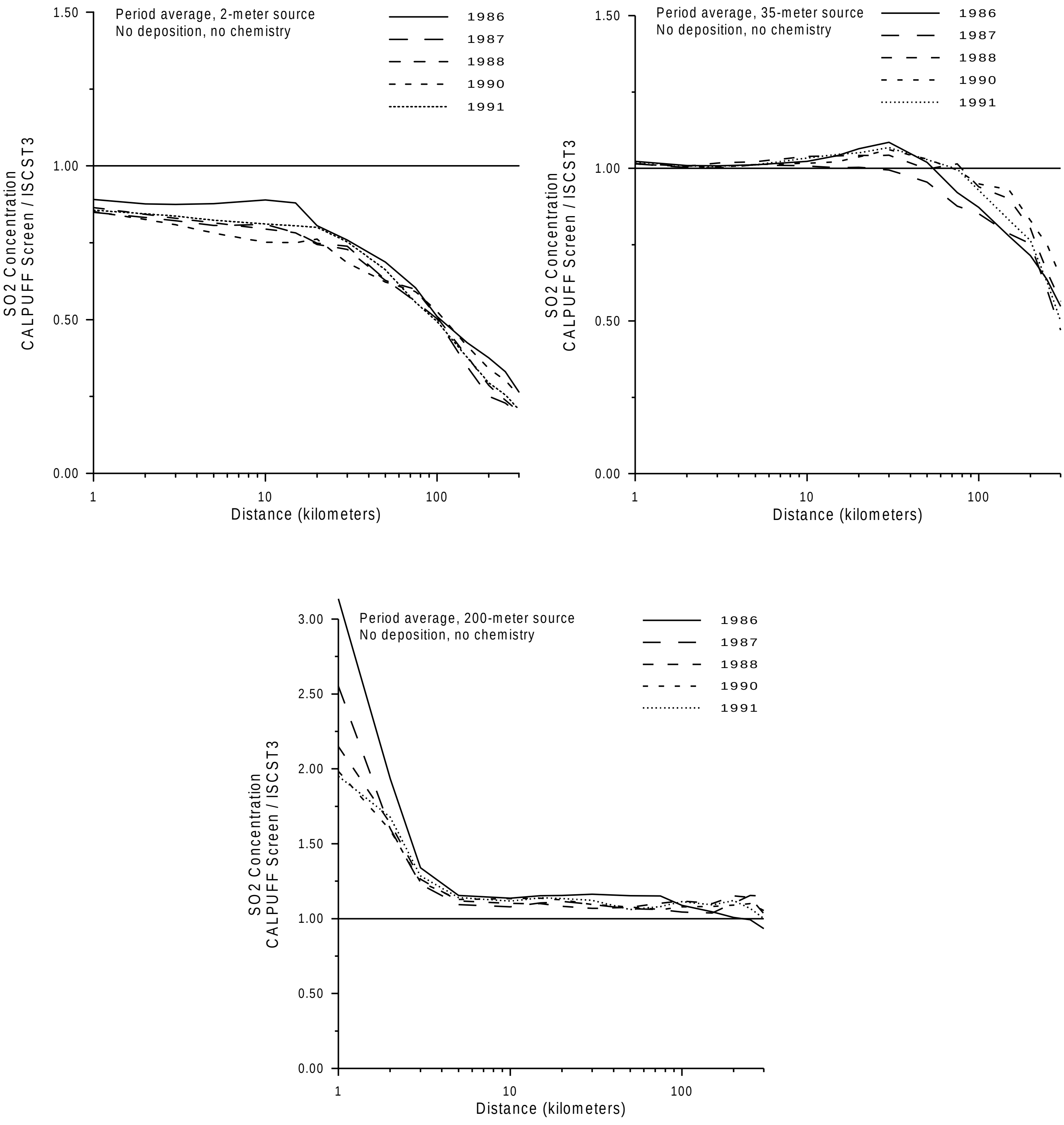

Figure 6. Year to year variation of the ratio of the CALPUFF screen concentration estimates to the ISCST3 estimates for the period average SO2 concentration estimates without deposition and chemistry for the a) 2-meter source, b) 35-meter source, and c) 200-meter source.

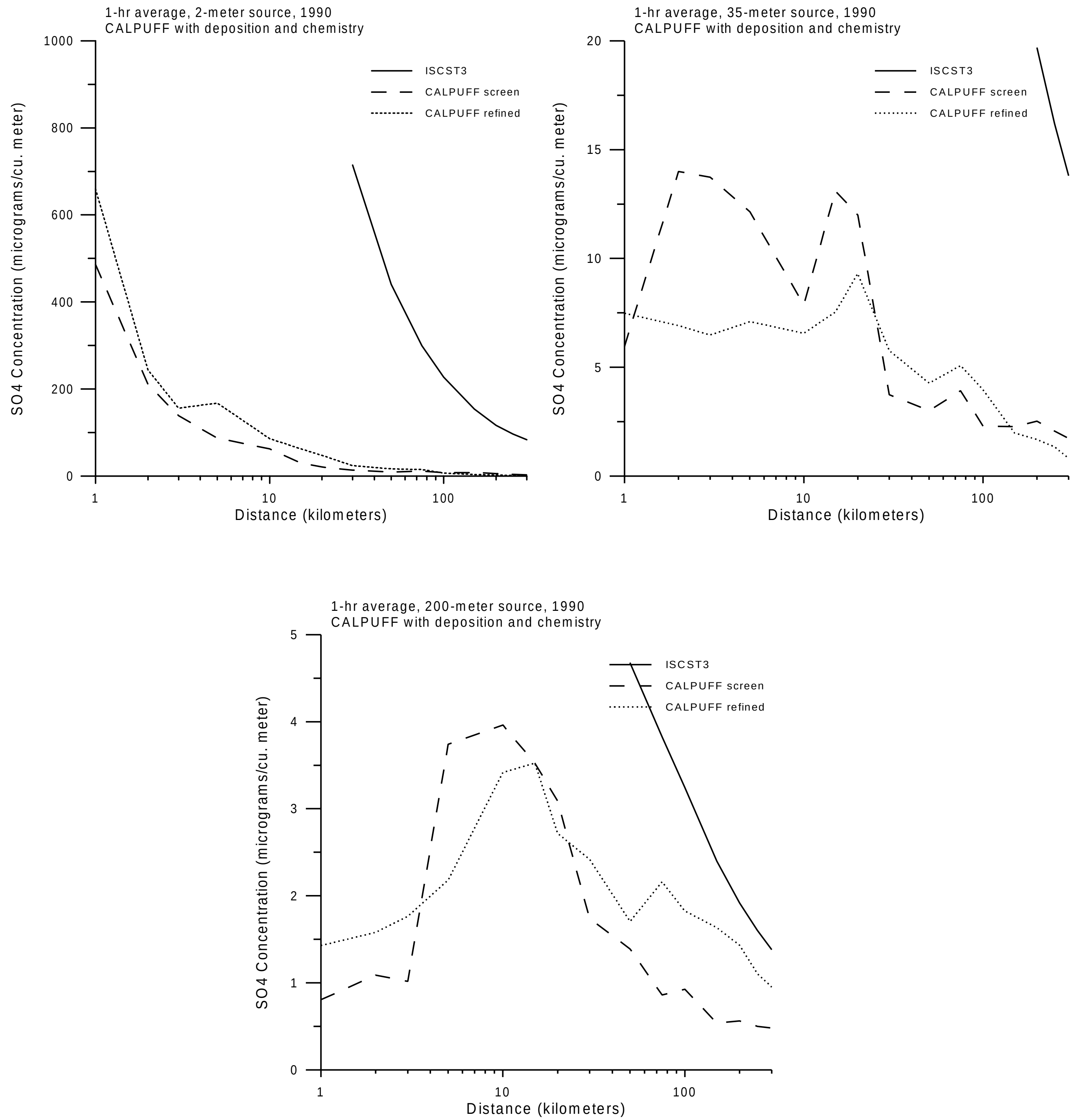

Figure 7. Highest (H1H) 1-hr average SO4 concentration estimates with deposition and chemistry for 1990 for the a) 2-meter source, b) 35-meter source, and c) 200-meter source.

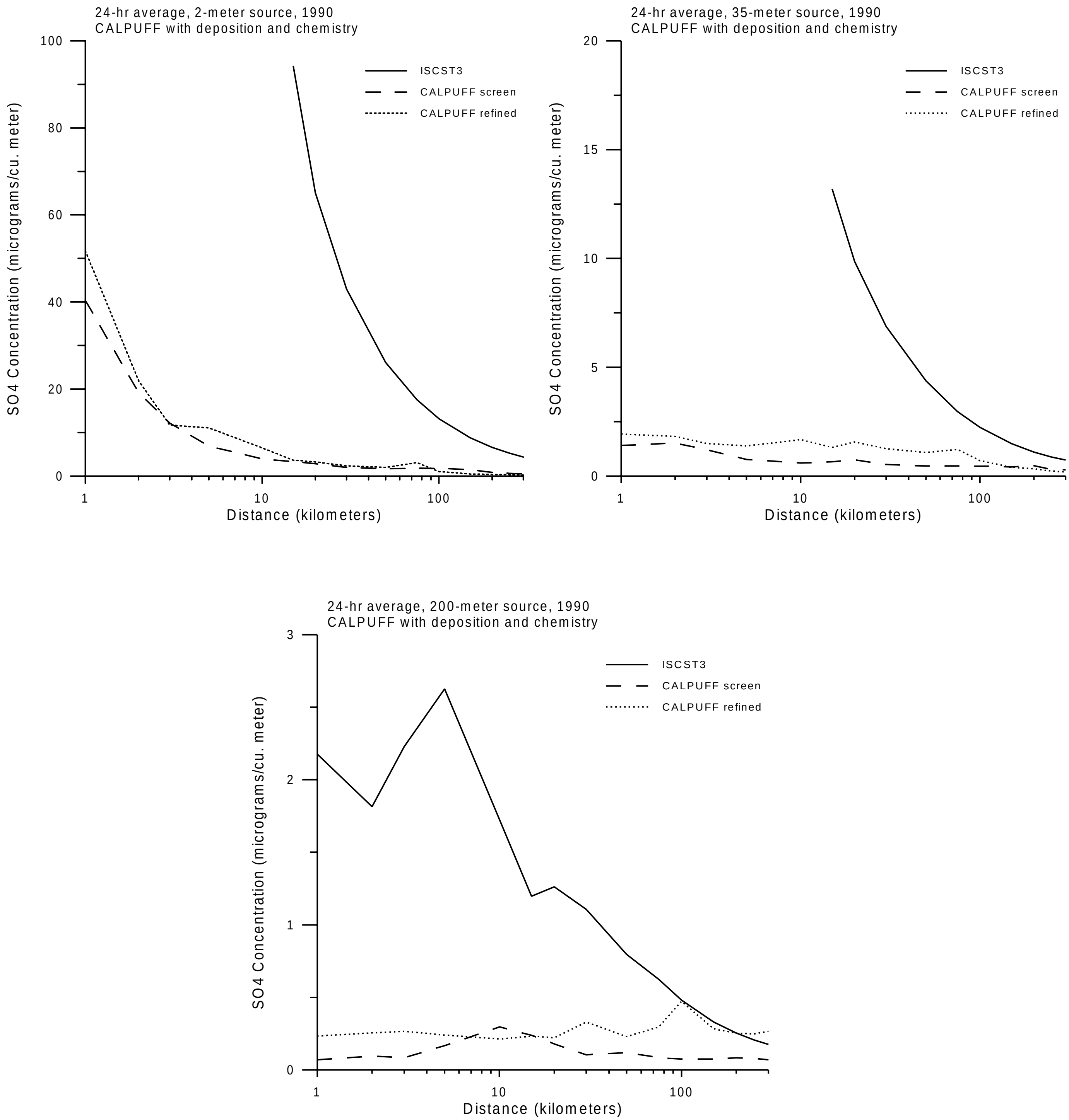

Figure 8. Highest (H1H) 24-hr average SO4 concentration estimates with deposition and chemistry for 1990 for the a) 2-meter source, b) 35-meter source, and c) 200-meter source.

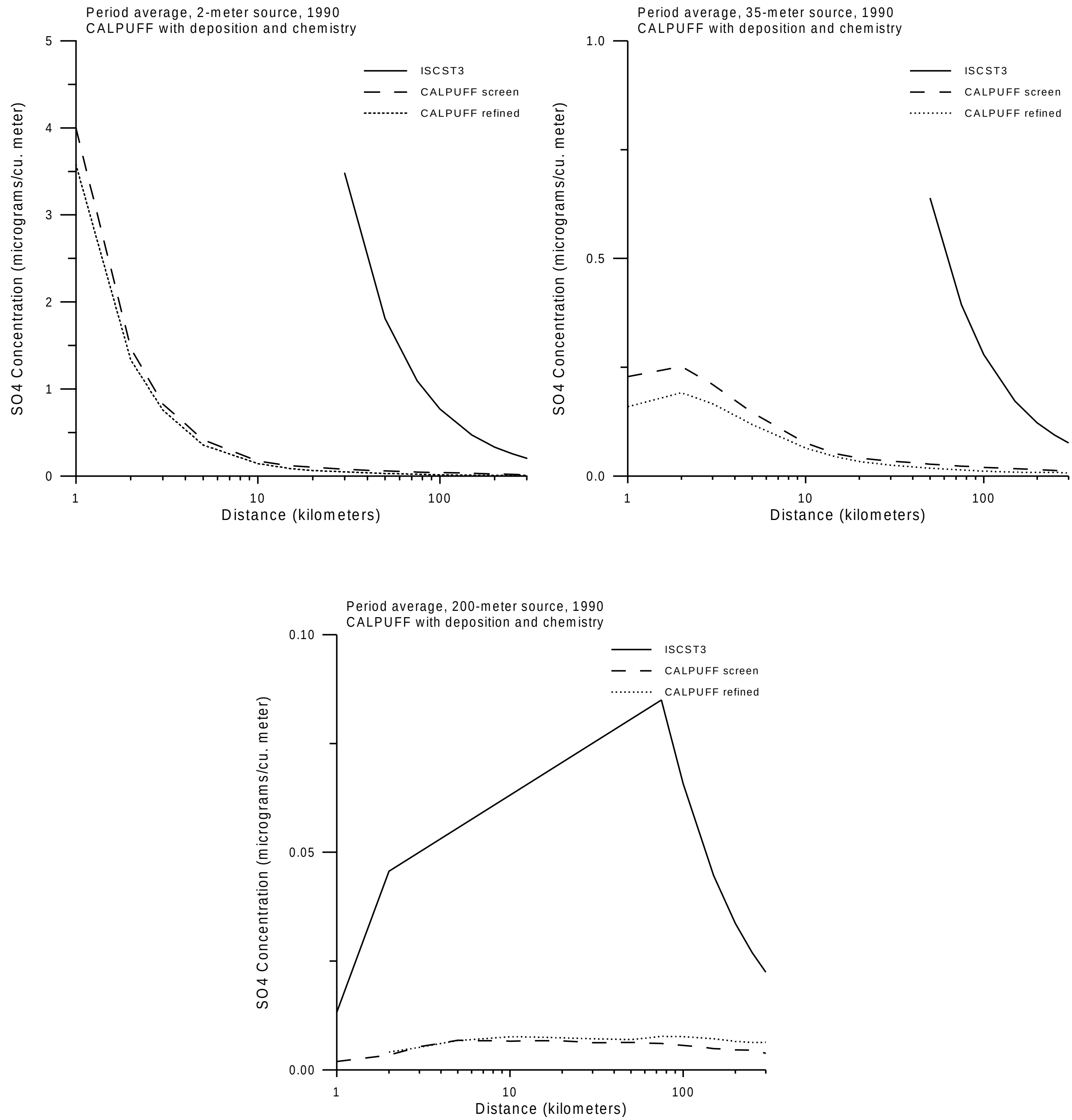

Figure 9. Period average SO4 concentration estimates with deposition and chemistry for 1990 for the a) 2-meter source, b) 35-meter source, and c) 200-meter source.

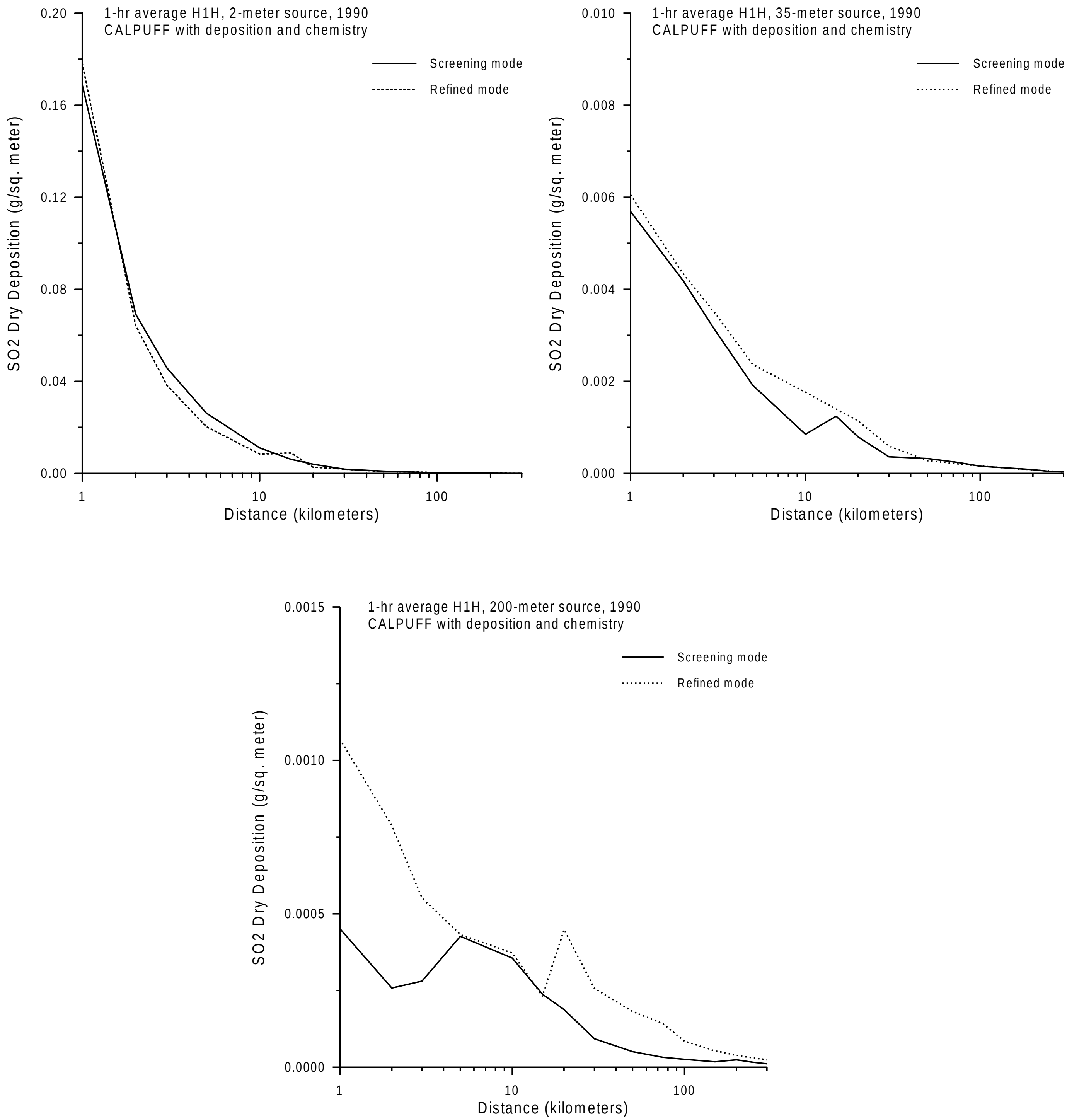

Figure 10. Highest (H1H) 1-hr average SO2 dry deposition estimates with deposition and chemistry for 1990 for the a) 2-meter source, b) 35-meter source, and c) 200-meter source.

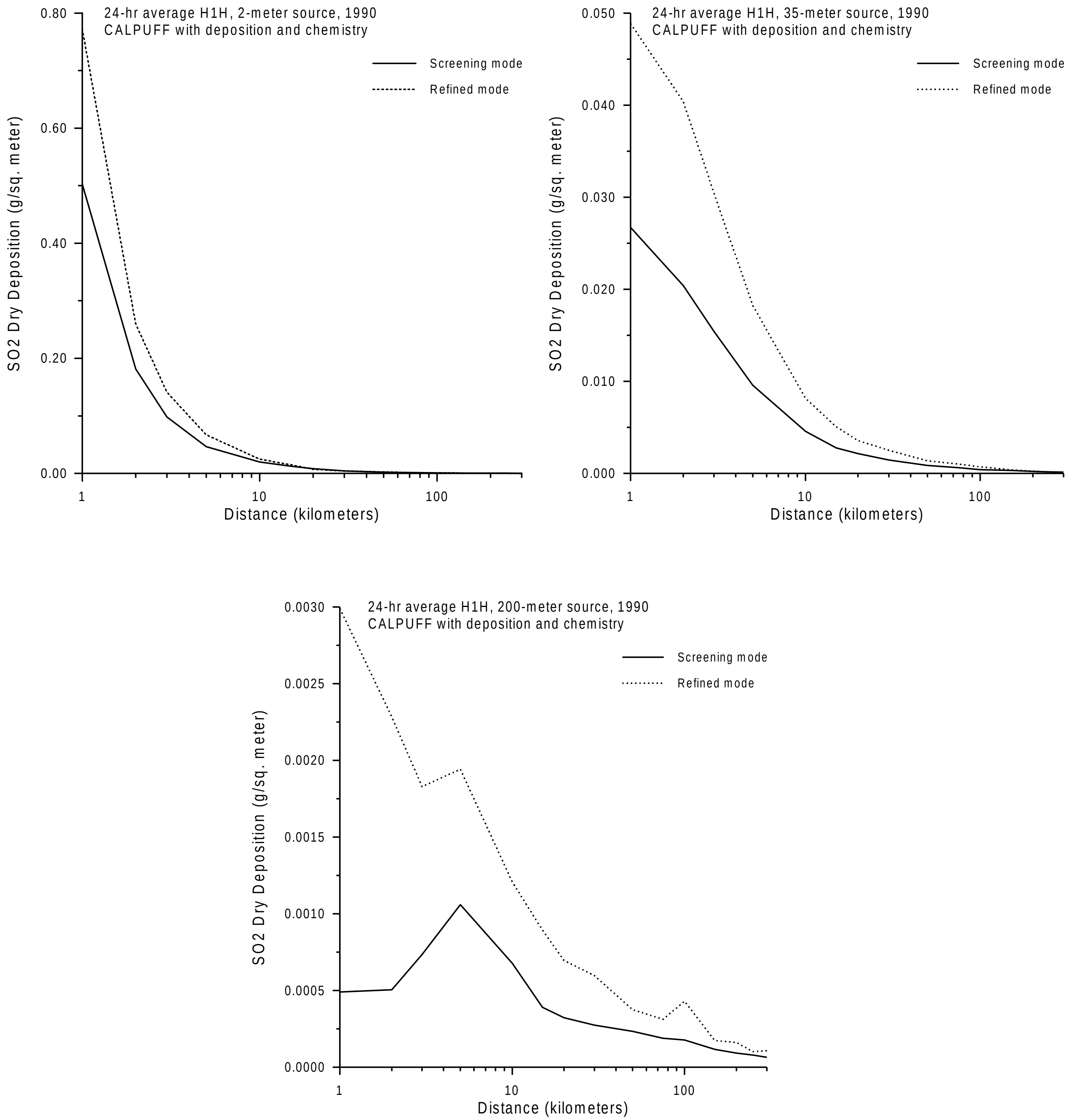

Figure 11. Highest (H1H) 24-hr average SO2 dry deposition estimates with deposition and chemistry for 1990 for the a) 2-meter source, b) 35-meter source, and c) 200-meter source.

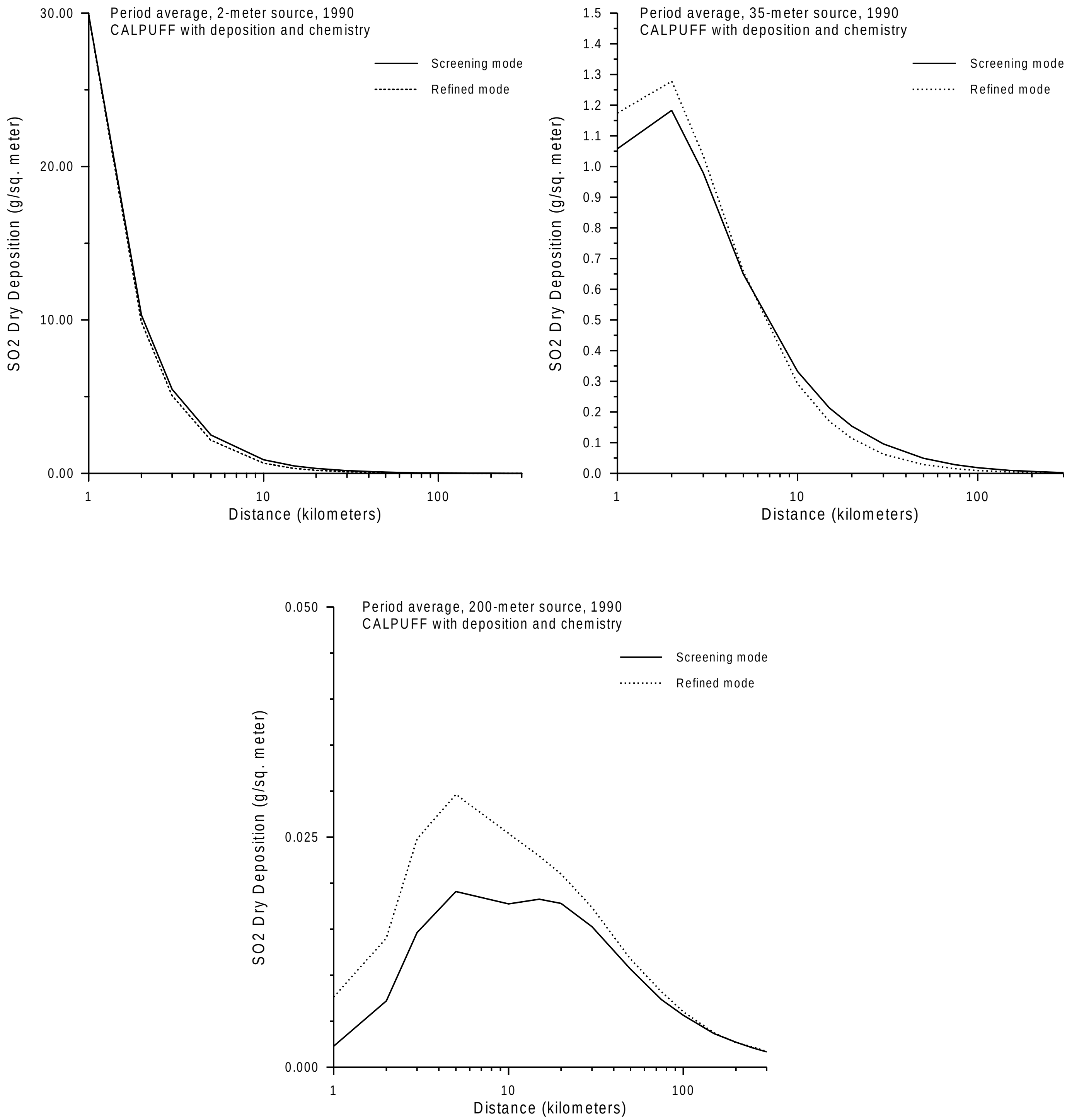

Figure 12. Period average SO2 dry deposition estimates with deposition and chemistry for 1990 for the a) 2-meter source, b) 35-meter source, and c) 200-meter source.

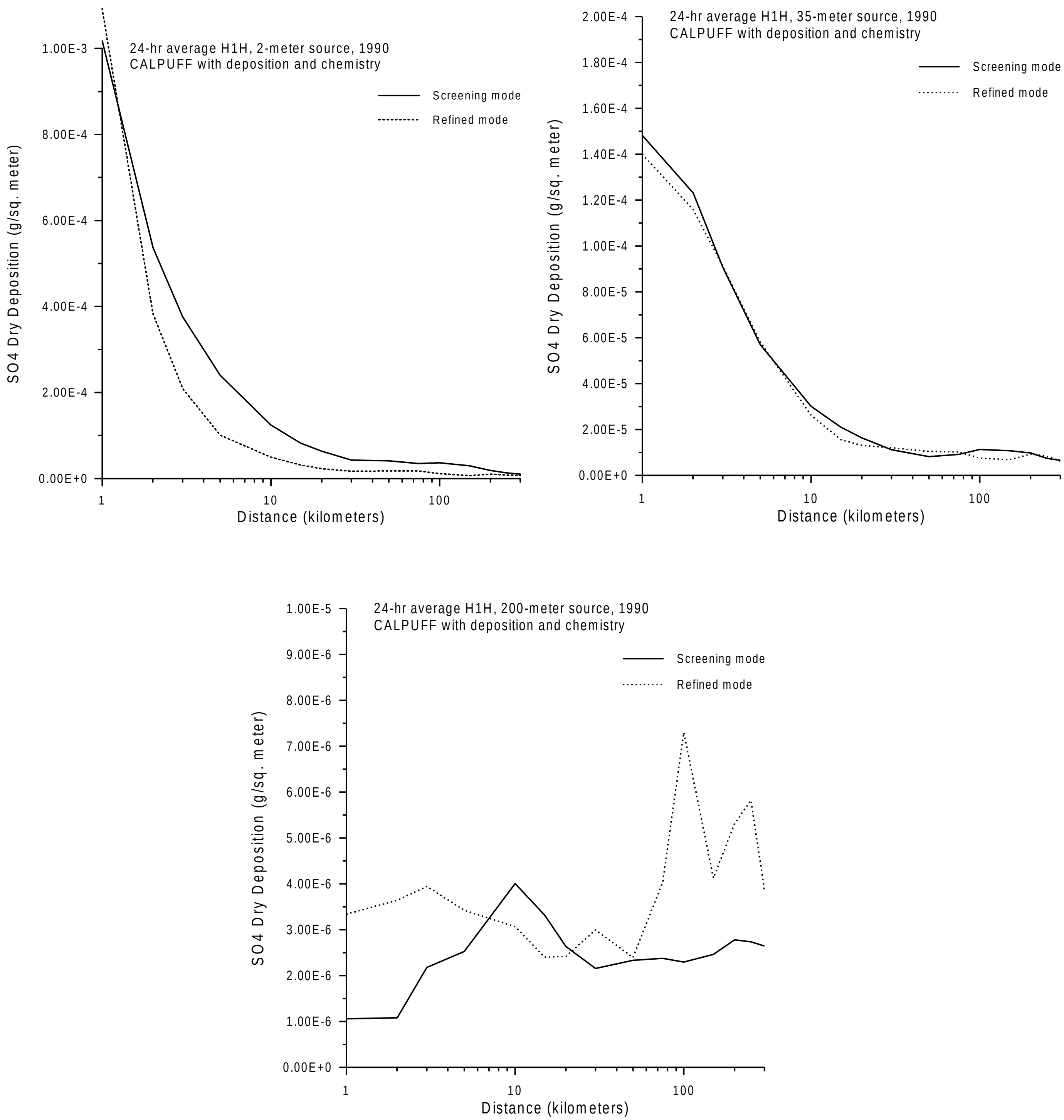

Figure 13. Highest (H1H) 24-hr average SO4 dry deposition estimates with deposition and chemistry for 1990 for the a) 2-meter source, b) 35-meter source, and c) 200-meter source.

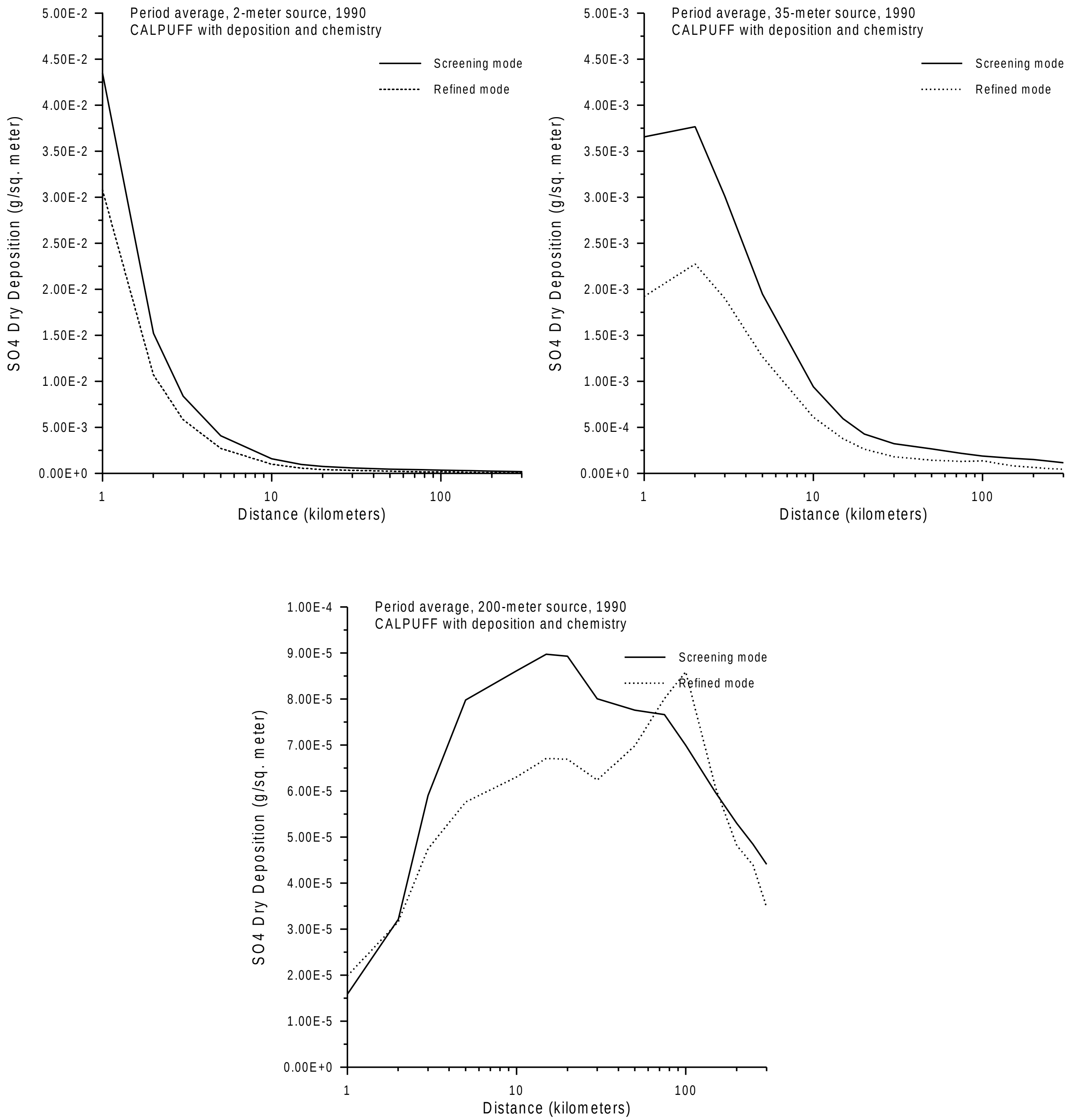

Figure 14. Period average SO4 dry deposition estimates with deposition and chemistry for 1990 for the a) 2-meter source, b) 35-meter source, and c) 200-meter source.

5.0 CONCLUDING REMARKS

5.1 Summary and Conclusions

The CALPUFF dispersion model was run for a five year period (1986-88, 1990-91) in a "screening mode" in which the input meteorology was meteorological data prepared for the ISCST3 dispersion model. In addition, a 3-dimensional wind field was developed to run CALPUFF in a "refined" mode for a single year (1990). The ISCST3 model was also run for the same five year period. Rings of receptors, ranging from 0.5 to 300 kilometers, were placed around three idealized point sources centered in the middle of a 600 by 600 kilometer modeling domain. Flat terrain was assumed for all modeling. Concentrations of SO_2 without deposition or chemical transformation were estimated by ISCST3 and the two CALPUFF modes. In addition, chemical transformations and dry deposition of SO_2 were assumed to occur (for 1990 only) to estimate sulfate deposition and concentration from the two CALPUFF modeling modes.

When all the data are compared, there is no clear tendency for one model or mode to dominate the others. Clearly, though, from the figures showing the year to year variability (Figures 4-6), ISCST3 is not conservative relative to the CALPUFF screening mode and ISCST3 is overly conservative in estimating SO_4 concentration (Figures 7-9). In comparing the two CALPUFF modes, there is no clear tendency for one mode to be greater or less than the other mode, although a multiplicative factor of two applied to the screening mode estimates for SO_2 dry deposition (Figures 10-12) appears to provide a very good screening method for the refined mode. The CALPUFF screening mode generally appears to be a good screen for the refined mode for SO_4 dry deposition (Figures 13-14) without any multiplicative factor.

5.2 Additional Analyses

Since only one year (1990) of refined modeling was performed, making a multi-year model run would demonstrate if similar results are obtained for other years.

As a possible follow-on to this effort, one could include the effects of terrain in the analysis. Since the terrain is relatively flat in the central United States, studying an area of the country where there is complex terrain, such as in the Pacific Northwest, the Rocky Mountain states or the Appalachian region, could be advantageous.

For cases with terrain, the user must specify the terrain height for each receptor. The elevations could be taken directly from a U.S. Geological Survey (USGS) topographic map but the number of receptors does not make this option feasible. Alternatively, the elevations could be obtained from Digital Elevation Model (DEM) (USGS, 1998a) data by using software developed to extract the terrain height at user-defined locations. One-degree DEM data are available free through the USGS' world wide web site (USGS, 1998b) and 7.5-minute data can be purchased from USGS. A third option would be to use the terrain data provided on the CALPUFF Modeling System compact disc (CD) (EPA, 1996) and modify the software provided on the CD to extract the required data.

6.0 REFERENCES

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APPENDIX A

TABULATIONS OF MODEL RESULTS

Table	Title
Table A-1	Five years of CALPUFF screening and ISCST3 highest 1-hour SO2 concentration (ug/m3) estimates without deposition and chemistry treatment
Table A-2	Five years of CALPUFF screening and ISCST3 highest 24-hour average SO2 concentration (ug/m3) estimates without deposition and chemistry treatment
Table A-3	Five years of CALPUFF screening and ISCST3 highest annual average concentration (ug/m3) estimates without deposition and chemistry treatment
Table A-4	1990 CALPUFF screening (S), refined (R), and ISCST3 highest (H1H) average SO2 concentration (ug/m3) estimates without deposition or chemistry treatment
Table A-5	1990 CALPUFF screening (S)/refined (R) for highest (H1H) & 2nd highest (H2H) SO2 dry fluxes (ug/m2/s) with deposition and chemistry for SO2
Table A-6	1990 CALPUFF screening (S)/refined (R) for highest (H1H) & 2nd highest (H2H) SO4 dry fluxes (ug/m2/s) with deposition and chemistry for SO2
Table A-7	1990 CALPUFF screening (S)/refined (R) for highest (H1H) and 2nd highest (H2H) SO4 concentrations (ug/m3) with deposition and chemistry for SO2

Table A-1. Five years of CALPUFF screening and ISCST3 highest 1-hour SO2 concentration (ug/m3) estimates without deposition and chemistry

	1986			1987			1988			1990			1991		
Distance	CALPUFF	ISCST3	CAL/ISC	CALPUFF	ISCST3	CAL/ISC	CALPUFF	ISCST3	CAL/ISC	CALPUFF	ISCST3	CAL/ISC	CALPUFF	ISCST3	CAL/ISC
2-meter	H1H			H1H			H1H			H1H			H1H		
1	27103.00	42964.00	0.63	23548.00	34534.00	0.68	31054.00	47533.00	0.65	30175.00	47541.00	0.63	24674.00	34535.00	0.71
2	8505.40	18089.00	0.47	7701.30	14429.00	0.53	9851.60	19627.00	0.50	10926.00	19625.00	0.56	8512.90	13576.00	0.63
3	4510.60	10844.00	0.42	4257.60	9999.40	0.43	4270.90	11435.00	0.37	7594.60	11435.00	0.66	4312.60	7807.80	0.55
5	2608.70	5688.20	0.46	2570.60	6312.80	0.41	1841.20	5880.50	0.31	1827.50	5903.20	0.31	2668.20	3979.40	0.67
10	1495.90	2347.30	0.64	1246.20	3396.40	0.37	1141.50	3136.50	0.36	911.83	2426.50	0.38	1208.20	1869.00	0.65
15	729.84	1402.50	0.52	818.81	2369.50	0.35	1161.30	2177.40	0.53	535.53	1447.90	0.37	577.34	1297.50	0.44
20	1051.30	1002.50	1.05	487.07	1837.60	0.27	389.05	1682.10	0.23	381.76	1045.80	0.37	510.79	1002.30	0.51
30	368.36	684.66	0.54	451.27	1286.80	0.35	263.93	1170.70	0.23	265.08	714.24	0.37	365.30	697.52	0.52
50	200.18	422.59	0.47	183.41	824.32	0.22	131.77	742.95	0.18	217.05	440.78	0.49	273.75	442.70	0.62
75	118.34	556.86	0.21	160.09	580.70	0.28	67.22	518.78	0.13	106.52	299.71	0.36	151.99	457.36	0.33
100	41.20	435.13	0.09	101.88	453.77	0.22	54.69	402.44	0.14	46.54	227.50	0.20	88.20	354.80	0.25
150	40.06	308.27	0.13	28.30	321.47	0.09	34.25	281.74	0.12	31.63	153.68	0.21	33.29	248.39	0.13
200	13.74	241.95	0.06	15.27	252.31	0.06	26.35	218.96	0.12	21.81	116.58	0.19	12.28	193.03	0.06
250	8.60	200.80	0.04	12.29	209.40	0.06	21.64	180.15	0.12	14.40	96.75	0.15	8.17	158.82	0.05
300	7.12	172.60	0.04	8.04	180.00	0.04	13.45	153.64	0.09	10.47	83.17	0.13	6.42	135.45	0.05
35-meter															
1	256.49	260.42	0.98	287.94	305.21	0.94	251.97	257.85	0.98	250.62	253.41	0.99	251.97	254.59	0.99
2	253.70	264.27	0.96	283.55	319.77	0.89	276.62	303.61	0.91	266.26	291.94	0.91	243.17	262.36	0.93
3	213.06	219.28	0.97	216.73	228.00	0.95	212.90	228.87	0.93	241.33	213.01	1.13	230.68	258.25	0.89
5	154.45	183.33	0.84	139.63	155.84	0.90	155.10	182.36	0.85	179.33	166.39	1.08	155.71	187.75	0.83
10	113.56	128.10	0.89	136.12	128.34	1.06	104.43	127.02	0.82	96.69	129.18	0.75	97.75	116.37	0.84
15	120.27	113.55	1.06	83.43	99.83	0.84	79.37	114.43	0.69	152.36	115.16	1.32	83.34	96.08	0.87
20	100.75	102.71	0.98	78.77	83.54	0.94	82.49	103.40	0.80	100.43	104.36	0.96	81.05	84.13	0.96
30	61.82	84.18	0.73	58.97	65.86	0.90	96.18	84.64	1.14	63.37	85.73	0.74	54.28	66.23	0.82
50	51.45	59.73	0.86	38.32	45.15	0.85	37.84	59.98	0.63	41.51	60.96	0.68	46.72	45.35	1.03
75	27.85	43.75	0.64	27.88	32.41	0.86	33.61	43.91	0.77	30.15	44.71	0.67	39.11	43.85	0.89
100	27.73	34.62	0.80	22.23	25.36	0.88	22.68	34.74	0.65	24.96	35.41	0.70	28.90	34.80	0.83
150	16.33	24.63	0.66	19.23	17.79	1.08	12.28	24.70	0.50	18.90	25.22	0.75	18.97	24.84	0.76
200	8.42	19.23	0.44	13.97	13.77	1.01	10.18	19.27	0.53	10.65	19.69	0.54	14.04	19.43	0.72
250	8.92	15.82	0.56	6.73	11.26	0.60	6.69	15.85	0.42	7.01	16.21	0.43	8.30	16.01	0.52
300	7.64	13.46	0.57	5.42	9.54	0.57	6.45	13.49	0.48	6.56	13.80	0.48	6.36	13.65	0.47
200-meter															
1	25.27	25.61	0.99	29.54	30.90	0.96	32.79	33.54	0.98	27.46	25.74	1.07	44.63	46.10	0.97
2	28.14	37.20	0.76	27.90	32.04	0.87	32.81	37.85	0.87	27.13	34.29	0.79	34.49	38.52	0.90
3	20.89	28.33	0.74	19.75	23.98	0.82	22.06	27.93	0.79	18.08	26.11	0.69	23.46	28.19	0.83
5	18.34	21.03	0.87	16.43	21.27	0.77	17.15	19.76	0.87	49.45	20.75	2.38	19.27	22.41	0.86
10	11.48	15.41	0.74	12.34	15.26	0.81	12.12	15.30	0.79	41.32	16.67	2.48	11.89	15.28	0.78
15	21.58	11.22	1.92	21.56	11.89	1.81	9.46	11.22	0.84	28.65	13.26	2.16	19.71	11.73	1.68
20	19.93	10.16	1.96	21.85	9.37	2.33	10.32	9.66	1.07	22.16	10.39	2.13	21.22	9.45	2.24
30	8.90	7.49	1.19	8.90	6.62	1.34	8.09	7.22	1.12	10.20	7.29	1.40	12.35	6.59	1.87
50	9.77	4.82	2.03	6.52	4.28	1.52	4.41	4.65	0.95	6.28	4.68	1.34	9.39	4.33	2.17
75	7.78	3.73	2.09	9.92	3.61	2.75	3.15	3.53	0.89	3.59	3.83	0.94	6.73	3.47	1.94
100	3.42	3.01	1.14	10.96	3.09	3.54	9.59	3.04	3.15	2.80	3.24	0.86	4.68	3.02	1.55
150	3.33	2.25	1.48	2.42	2.31	1.05	2.80	2.28	1.23	2.18	2.40	0.91	2.23	2.38	0.94
200	3.08	1.83	1.68	2.26	1.83	1.23	1.90	1.81	1.05	2.72	1.92	1.42	2.31	2.00	1.15
250	1.65	1.54	1.07	1.60	1.52	1.05	1.65	1.51	1.10	2.18	1.60	1.36	1.96	1.81	1.08
300	1.35	1.32	1.02	1.79	1.33	1.35	1.16	1.30	0.90	1.38	1.38	1.00	1.71	1.65	1.04

Table A-2. Five years of CALPUFF screening and ISCST3 highest 24-hour average SO2 concentration (ug/m3) estimates without deposition and chemistry

	1986			1987			1988			1990			1991		
Distance	CALPUFF	ISCST3	CAL/ISC	CALPUFF	ISCST3	CAL/ISC	CALPUFF	ISCST3	CAL/ISC	CALPUFF	ISCST3	CAL/ISC	CALPUFF	ISCST3	CAL/ISC
2-meter	H1H			H1H			H1H			H1H			H1H		
1	3093.00	4094.80	0.76	3685.00	4871.60	0.76	2695.90	3570.10	0.76	3112.00	4018.40	0.77	3259.30	4523.90	0.72
2	1218.00	1559.30	0.78	1264.90	1814.90	0.70	1122.60	1407.70	0.80	1127.10	1532.70	0.74	1146.90	1685.90	0.68
3	656.40	877.77	0.75	668.65	1020.40	0.66	651.16	804.95	0.81	610.96	861.89	0.71	618.66	941.01	0.66
5	298.83	433.66	0.69	322.86	507.06	0.64	332.37	403.04	0.82	293.12	425.36	0.69	286.08	460.31	0.62
10	179.21	167.89	1.07	154.30	201.63	0.77	148.91	179.32	0.83	127.98	163.66	0.78	138.74	175.26	0.79
15	102.65	97.40	1.05	90.02	122.19	0.74	150.29	120.73	1.24	69.59	94.12	0.74	70.88	100.23	0.71
20	54.07	70.93	0.76	59.27	87.30	0.68	70.75	91.26	0.78	46.25	65.07	0.71	44.50	69.15	0.64
30	42.21	45.77	0.92	34.87	54.65	0.64	47.90	61.58	0.78	23.97	42.98	0.56	36.34	41.31	0.88
50	17.69	26.88	0.66	18.52	34.35	0.54	32.24	37.55	0.86	13.50	26.11	0.52	24.21	22.17	1.09
75	14.18	24.57	0.58	12.44	24.20	0.51	23.81	25.36	0.94	10.92	17.55	0.62	16.59	19.75	0.84
100	8.81	19.17	0.46	9.06	18.91	0.48	18.58	19.20	0.97	8.34	13.21	0.63	10.92	15.23	0.72
150	3.94	13.55	0.29	4.56	13.40	0.34	12.71	12.98	0.98	5.56	8.82	0.63	5.75	10.59	0.54
200	2.83	10.62	0.27	3.12	10.51	0.30	8.72	9.84	0.89	2.95	6.61	0.45	2.86	8.20	0.35
250	2.02	8.80	0.23	2.24	8.72	0.26	6.12	7.93	0.77	2.65	5.27	0.50	2.24	6.73	0.33
300	1.73	7.56	0.23	1.47	7.50	0.20	4.41	6.67	0.66	1.74	4.37	0.40	1.79	5.73	0.31
35-meter															
1	98.81	98.83	1.00	72.23	72.02	1.00	85.56	85.52	1.00	74.20	73.93	1.00	62.85	62.81	1.00
2	92.44	92.95	0.99	93.04	93.71	0.99	80.39	80.22	1.00	81.92	81.90	1.00	89.59	89.35	1.00
3	66.77	67.57	0.99	76.12	77.48	0.98	63.49	63.47	1.00	62.24	62.60	0.99	74.96	75.19	1.00
5	37.93	38.48	0.99	46.95	48.87	0.96	38.96	39.26	0.99	42.26	43.21	0.98	46.70	47.43	0.98
10	22.17	21.93	1.01	20.11	21.09	0.95	19.66	19.63	1.00	20.76	21.55	0.96	19.48	20.25	0.96
15	15.47	15.18	1.02	15.79	15.79	1.00	16.21	15.05	1.08	16.48	13.20	1.25	14.43	15.00	0.96
20	11.85	12.03	0.99	13.20	12.88	1.02	14.07	12.21	1.15	13.64	9.86	1.38	11.51	12.07	0.95
30	7.97	8.62	0.92	9.83	9.36	1.05	14.57	8.74	1.67	9.46	6.87	1.38	8.48	8.54	0.99
50	5.83	5.43	1.07	5.40	5.96	0.91	7.07	5.47	1.29	5.65	4.37	1.29	4.81	5.23	0.92
75	3.78	3.72	1.02	4.02	4.08	0.99	5.41	3.70	1.46	3.21	2.97	1.08	3.51	3.46	1.02
100	3.07	2.84	1.08	3.59	3.09	1.16	3.87	2.79	1.39	2.51	2.24	1.12	4.04	2.55	1.58
150	2.47	1.93	1.28	3.45	2.08	1.66	2.04	1.86	1.10	1.90	1.49	1.28	2.08	1.65	1.27
200	1.91	1.47	1.30	3.10	1.56	1.99	1.76	1.39	1.26	1.48	1.10	1.34	1.96	1.21	1.63
250	1.32	1.18	1.11	2.27	1.25	1.82	1.29	1.11	1.16	1.25	0.87	1.43	1.94	0.98	1.98
300	0.95	0.99	0.96	1.70	1.04	1.64	0.71	0.92	0.77	1.02	0.74	1.38	1.59	0.83	1.91
200-meter															
1	2.82	1.35	2.09	2.57	1.95	1.32	2.53	2.16	1.17	2.16	2.18	0.99	2.63	3.02	0.87
2	3.21	2.07	1.55	2.31	2.29	1.01	2.26	1.93	1.17	1.85	1.81	1.02	2.77	3.16	0.88
3	2.47	2.33	1.06	2.33	2.32	1.01	2.37	2.39	0.99	2.37	2.23	1.06	2.53	3.02	0.84
5	2.54	2.50	1.02	2.63	2.90	0.91	2.27	2.15	1.05	2.61	2.63	0.99	2.39	2.43	0.98
10	1.68	1.74	0.96	1.74	2.19	0.79	1.53	1.44	1.06	3.16	1.72	1.83	1.75	1.56	1.12
15	1.55	1.44	1.08	1.39	1.46	0.95	1.40	1.16	1.21	1.94	1.20	1.62	1.77	1.54	1.15
20	1.44	1.44	1.00	1.46	1.47	0.99	1.36	1.25	1.09	1.30	1.26	1.03	2.10	1.88	1.12
30	1.23	1.20	1.02	1.28	1.36	0.94	1.23	1.15	1.07	1.11	1.11	1.01	2.11	1.95	1.08
50	1.07	1.06	1.01	1.04	0.96	1.08	0.88	0.83	1.05	1.05	0.80	1.32	1.65	1.52	1.09
75	1.01	0.83	1.23	0.91	0.78	1.16	0.81	0.82	0.99	0.85	0.62	1.36	1.24	1.09	1.13
100	0.72	0.66	1.10	0.70	0.61	1.14	0.70	0.63	1.11	0.78	0.48	1.62	1.04	0.84	1.24
150	0.55	0.46	1.20	0.48	0.42	1.13	0.54	0.43	1.27	0.54	0.33	1.62	0.83	0.57	1.46
200	0.53	0.35	1.51	0.49	0.32	1.50	0.42	0.33	1.29	0.46	0.25	1.80	0.70	0.43	1.63
250	0.55	0.28	1.94	0.44	0.26	1.67	0.38	0.26	1.46	0.43	0.21	2.08	0.63	0.35	1.81
300	0.54	0.24	2.26	0.38	0.22	1.74	0.29	0.22	1.29	0.37	0.17	2.10	0.53	0.29	1.84

Table A-3. Five years of CALPUFF screening and ISCST3 highest annual average concentration (ug/m3) estimates without deposition and chemistry

	1986			1987			1988			1990			1991		
Distance	CALPUFF	ISCST3	CAL/ISC	CALPUFF	ISCST3	CAL/ISC	CALPUFF	ISCST3	CAL/ISC	CALPUFF	ISCST3	CAL/ISC	CALPUFF	ISCST3	CAL/ISC
2-meter	H1H			H1H			H1H			H1H			H1H		
1	353.05	396.13	0.89	341.29	402.09	0.85	323.15	373.99	0.86	393.53	462.17	0.85	365.51	427.06	0.86
2	121.33	138.52	0.88	120.75	145.17	0.83	112.23	133.27	0.84	136.81	165.75	0.83	129.25	153.16	0.84
3	65.20	74.56	0.87	65.12	79.27	0.82	60.08	72.43	0.83	73.04	90.32	0.81	69.75	83.36	0.84
5	30.41	34.69	0.88	30.28	37.55	0.81	27.78	34.10	0.81	33.35	42.67	0.78	32.37	39.33	0.82
10	11.08	12.47	0.89	11.15	13.78	0.81	9.89	12.46	0.79	11.76	15.66	0.75	11.65	14.37	0.81
15	6.13	6.97	0.88	6.09	7.78	0.78	5.50	7.02	0.78	6.63	8.84	0.75	6.51	8.09	0.81
20	3.76	4.67	0.81	3.94	5.26	0.75	3.52	4.73	0.74	4.55	5.97	0.76	4.36	5.45	0.80
30	2.05	2.70	0.76	2.27	3.07	0.74	2.01	2.76	0.73	2.38	3.48	0.68	2.38	3.16	0.75
50	0.96	1.40	0.69	1.01	1.60	0.63	0.90	1.44	0.63	1.13	1.81	0.62	1.09	1.64	0.66
75	0.51	0.84	0.60	0.54	0.97	0.56	0.52	0.87	0.60	0.65	1.09	0.59	0.55	0.99	0.56
100	0.30	0.59	0.51	0.34	0.69	0.50	0.31	0.61	0.51	0.41	0.77	0.53	0.34	0.69	0.49
150	0.15	0.36	0.42	0.15	0.42	0.35	0.14	0.38	0.38	0.19	0.47	0.41	0.16	0.42	0.38
200	0.10	0.26	0.38	0.08	0.30	0.25	0.08	0.27	0.29	0.11	0.33	0.34	0.09	0.30	0.29
250	0.07	0.20	0.33	0.05	0.23	0.23	0.05	0.20	0.24	0.08	0.25	0.30	0.06	0.23	0.25
300	0.04	0.16	0.26	0.04	0.19	0.19	0.03	0.17	0.20	0.05	0.20	0.25	0.04	0.18	0.21
35-meter															
1	10.06	9.84	1.02	9.78	9.64	1.01	9.808	9.659	1.02	11.19	11.03	1.01	9.66	9.47	1.02
2	12.40	12.29	1.01	10.60	10.57	1.00	10.59	10.52	1.01	13.08	13.01	1.01	11.23	11.15	1.01
3	10.91	10.82	1.01	8.82	8.81	1.00	9.02	8.86	1.02	11.09	11.05	1.00	9.54	9.48	1.01
5	7.80	7.71	1.01	6.11	6.04	1.01	6.49	6.35	1.02	7.69	7.59	1.01	6.59	6.52	1.01
10	4.07	3.98	1.02	3.36	3.33	1.01	3.49	3.36	1.04	4.14	4.07	1.02	3.69	3.57	1.03
15	2.65	2.54	1.04	2.22	2.21	1.00	2.27	2.18	1.04	2.70	2.64	1.02	2.46	2.35	1.05
20	1.92	1.81	1.06	1.62	1.62	1.00	1.63	1.56	1.04	1.97	1.90	1.04	1.79	1.70	1.05
30	1.21	1.11	1.09	1.02	1.03	0.99	1.01	0.97	1.04	1.25	1.17	1.06	1.14	1.07	1.07
50	0.61	0.60	1.02	0.55	0.57	0.95	0.53	0.53	1.00	0.66	0.64	1.03	0.60	0.59	1.03
75	0.34	0.37	0.92	0.32	0.36	0.88	0.33	0.33	1.01	0.39	0.39	0.99	0.36	0.36	1.00
100	0.23	0.26	0.87	0.22	0.26	0.85	0.22	0.23	0.94	0.26	0.28	0.95	0.24	0.26	0.93
150	0.13	0.16	0.78	0.13	0.16	0.79	0.13	0.14	0.90	0.16	0.17	0.93	0.13	0.16	0.83
200	0.08	0.12	0.71	0.09	0.12	0.75	0.08	0.10	0.80	0.10	0.12	0.83	0.09	0.12	0.76
250	0.06	0.09	0.64	0.06	0.09	0.60	0.05	0.08	0.66	0.07	0.09	0.75	0.06	0.09	0.63
300	0.04	0.07	0.55	0.04	0.08	0.47	0.04	0.06	0.56	0.05	0.08	0.64	0.04	0.07	0.50
200-meter															
1	0.03	0.01	3.14	0.03	0.01	2.55	0.03	0.02	2.15	0.03	0.01	1.98	0.04	0.02	1.95
2	0.07	0.03	1.93	0.08	0.05	1.60	0.07	0.05	1.64	0.07	0.05	1.59	0.08	0.05	1.68
3	0.12	0.09	1.34	0.16	0.13	1.23	0.13	0.11	1.26	0.14	0.11	1.24	0.14	0.11	1.28
5	0.17	0.15	1.15	0.21	0.19	1.09	0.17	0.16	1.12	0.18	0.16	1.13	0.19	0.16	1.14
10	0.19	0.16	1.14	0.19	0.18	1.08	0.17	0.16	1.10	0.19	0.17	1.13	0.18	0.16	1.12
15	0.20	0.17	1.15	0.18	0.16	1.10	0.17	0.15	1.10	0.20	0.18	1.14	0.18	0.16	1.14
20	0.20	0.17	1.15	0.17	0.15	1.11	0.16	0.15	1.08	0.20	0.18	1.12	0.18	0.16	1.13
30	0.18	0.15	1.16	0.15	0.13	1.09	0.14	0.13	1.07	0.17	0.16	1.09	0.16	0.14	1.12
50	0.13	0.12	1.15	0.10	0.10	1.07	0.10	0.10	1.08	0.12	0.12	1.08	0.11	0.10	1.06
75	0.10	0.08	1.15	0.07	0.07	1.06	0.08	0.07	1.10	0.09	0.09	1.06	0.08	0.07	1.08
100	0.07	0.06	1.09	0.05	0.05	1.04	0.06	0.05	1.12	0.07	0.07	1.08	0.06	0.06	1.11
150	0.05	0.04	1.04	0.04	0.04	1.04	0.04	0.04	1.10	0.05	0.04	1.08	0.04	0.04	1.09
200	0.03	0.03	1.01	0.03	0.03	1.10	0.03	0.03	1.15	0.04	0.03	1.09	0.03	0.03	1.12
250	0.03	0.03	0.99	0.02	0.02	1.15	0.03	0.02	1.14	0.03	0.03	1.10	0.02	0.02	1.07
300	0.02	0.02	0.93	0.02	0.02	1.15	0.02	0.02	1.03	0.02	0.02	1.05	0.02	0.02	1.00

Table A-4. 1990 CALPUFF screening (S), refined (R), and ISCST3 highest (H1H) average SO2 concentration (ug/m3) estimates without deposition or chemistry

Distance	ISCST3	CALPUFF-S	CALPUFF-R	scrn/ISC3	scrn/ref	ISCST3	CALPUFF-S	CALPUFF-R	scrn/ISC3	scrn/ref	ISCST3	CALPUFF-S	CALPUFF-R	scrn/ISC3	scrn/ref	ISCST3	CALPUFF-S
2-meter	SO2 1-hour average					SO2 3-hour average					SO2 24-hour average					SO2 period avera	
1	47541.00	30175.00	33042.00	0.63	0.91	16865.00	13281.00	17074.00	0.79	0.78	4018.40	3112.00	4817.60	0.77	0.65	4.62E+02	3.94E+02
2	19625.00	10926.00	10835.00	0.56	1.01	6709.80	6606.10	6342.60	0.98	1.04	1532.70	1127.10	1578.20	0.74	0.71	1.66E+02	1.37E+02
3	11435.00	7594.60	7024.60	0.66	1.08	3893.30	3687.30	3168.10	0.95	1.16	861.89	610.96	749.83	0.71	0.81	9.03E+01	7.30E+01
5	5903.20	1827.50	4393.20	0.31	0.42	1992.70	1465.80	1838.10	0.74	0.8	425.36	293.12	333.77	0.69	0.88	4.27E+01	3.33E+01
10	2426.50	911.83	1798.30	0.38	0.51	808.84	728.62	910.28	0.9	0.8	163.66	127.98	124.70	0.78	1.03	1.57E+01	1.18E+01
15	1447.90	535.53	1081.40	0.37	0.50	482.62	409.20	555.95	0.85	0.74	94.12	69.59	89.14	0.74	0.78	8.84E+00	6.63E+00
20	1045.80	381.76	882.93	0.37	0.43	348.59	252.12	414.13	0.72	0.61	65.07	46.25	56.93	0.71	0.81	5.97E+00	4.55E+00
30	714.24	265.08	356.22	0.37	0.74	238.08	121.99	181.12	0.51	0.67	42.98	23.97	39.43	0.56	0.61	3.48E+00	2.38E+00
50	440.78	217.05	202.84	0.49	1.07	146.93	92.72	79.13	0.63	1.17	26.11	13.50	16.06	0.52	0.84	1.81E+00	1.13E+00
75	299.71	106.52	96.56	0.36	1.10	99.90	52.13	71.39	0.52	0.73	17.55	10.92	17.07	0.62	0.64	1.09E+00	6.46E-01
100	227.50	46.54	53.88	0.20	0.86	75.83	34.66	32.31	0.46	1.07	13.21	8.34	6.58	0.63	1.27	7.69E-01	4.05E-01
150	153.68	31.63	21.28	0.21	1.49	51.23	20.46	16.16	0.4	1.27	8.82	5.56	2.92	0.63	1.9	4.70E-01	1.95E-01
200	116.58	21.81	11.20	0.19	1.95	39.00	14.99	5.49	0.38	2.73	6.61	2.95	1.57	0.45	1.88	3.33E-01	1.13E-01
250	96.75	14.40	5.09	0.15	2.83	32.34	10.67	4.03	0.33	2.65	5.27	2.65	0.80	0.5	3.29	2.55E-01	7.70E-02
300	83.17	10.47	5.01	0.13	2.09	27.79	7.05	3.13	0.25	2.25	4.37	1.74	0.67	0.4	2.59	2.05E-01	5.20E-02
35-meter																	
1	253.41	250.62	287.58	0.99	0.87	219.63	216.18	219.63	0.98	0.98	73.93	74.20	99.11	1	0.75	1.10E+01	1.12E+01
2	291.94	266.26	239.74	0.91	1.11	162.74	158.78	170.34	0.98	0.93	81.90	81.92	100.33	1	0.82	1.30E+01	1.31E+01
3	213.01	241.33	192.09	1.13	1.26	133.20	127.88	136.93	0.96	0.93	62.60	62.24	80.96	0.99	0.77	1.10E+01	1.11E+01
5	166.39	179.33	179.17	1.08	1.00	103.06	102.42	133.70	0.99	0.77	43.21	42.26	50.27	0.98	0.84	7.60E+00	7.69E+00
10	129.18	96.69	133.21	0.75	0.73	69.94	62.13	85.92	0.89	0.72	21.55	20.76	29.59	0.96	0.7	4.07E+00	4.14E+00
15	115.16	152.36	98.91	1.32	1.54	57.42	58.19	62.16	1.01	0.94	13.20	16.48	19.90	1.25	0.83	2.64E+00	2.70E+00
20	104.36	100.43	99.05	0.96	1.01	46.86	53.70	57.38	1.15	0.94	9.86	13.64	15.39	1.38	0.89	1.90E+00	1.97E+00
30	85.73	63.37	70.41	0.74	0.90	33.69	38.76	45.96	1.15	0.84	6.87	9.46	11.42	1.38	0.83	1.18E+00	1.25E+00
50	60.96	41.51	31.79	0.68	1.31	21.24	29.21	20.50	1.38	1.43	4.37	5.65	5.62	1.29	1	6.39E-01	6.58E-01
75	44.71	30.15	23.53	0.67	1.28	15.40	16.13	15.05	1.05	1.07	2.97	3.21	4.75	1.08	0.67	3.93E-01	3.91E-01
100	35.41	24.96	20.26	0.70	1.23	11.80	13.21	12.65	1.12	1.04	2.24	2.51	3.36	1.12	0.75	2.79E-01	2.65E-01
150	25.22	18.90	10.94	0.75	1.73	8.41	10.81	8.05	1.29	1.34	1.49	1.90	2.41	1.28	0.79	1.72E-01	1.60E-01
200	19.69	10.65	7.50	0.54	1.42	6.56	6.44	4.88	0.98	1.32	1.10	1.48	1.25	1.34	1.18	1.22E-01	1.02E-01
250	16.21	7.01	5.66	0.43	1.24	5.40	5.68	4.23	1.05	1.34	0.88	1.25	1.04	1.43	1.2	9.40E-02	7.10E-02
300	13.80	6.56	3.44	0.48	1.90	4.60	5.09	2.98	1.11	1.71	0.74	1.02	0.65	1.38	1.57	7.60E-02	4.90E-02
200-meter																	
1	25.74	27.46	56.40	1.07	0.49	16.09	15.72	26.36	0.98	0.6	2.18	2.16	5.54	0.99	0.39	1.30E-02	2.60E-02
2	34.29	27.13	34.86	0.79	0.78	11.43	12.78	19.30	1.12	0.66	1.81	1.85	4.27	1.02	0.43	4.60E-02	7.30E-02
3	26.11	18.08	24.39	0.69	0.74	10.93	10.89	14.74	1	0.74	2.23	2.37	3.49	1.06	0.68	1.12E-01	1.39E-01
5	20.75	49.45	19.62	2.38	2.52	10.99	17.12	12.48	1.56	1.37	2.63	2.61	3.87	0.99	0.67	1.62E-01	1.82E-01
10	16.67	41.32	18.54	2.48	2.23	8.62	23.65	11.59	2.74	2.04	1.72	3.16	2.89	1.83	1.09	1.67E-01	1.89E-01
15	13.26	28.65	12.03	2.16	2.38	6.34	9.84	8.78	1.55	1.12	1.20	1.94	2.16	1.62	0.9	1.76E-01	2.00E-01
20	10.39	22.16	20.03	2.13	1.11	4.86	8.71	7.97	1.79	1.09	1.26	1.31	1.83	1.03	0.71	1.77E-01	1.99E-01
30	7.29	10.20	12.89	1.40	0.79	3.32	4.71	5.44	1.42	0.87	1.11	1.11	1.48	1.01	0.75	1.58E-01	1.73E-01
50	4.68	6.28	8.61	1.34	0.73	2.48	2.39	4.72	0.96	0.51	0.80	1.05	1.02	1.32	1.03	1.15E-01	1.24E-01
75	3.83	3.59	6.73	0.94	0.53	2.01	2.18	3.56	1.09	0.61	0.62	0.85	1.05	1.36	0.81	8.50E-02	9.00E-02
100	3.24	2.80	4.70	0.86	0.59	1.63	1.95	3.87	1.19	0.5	0.48	0.78	1.33	1.62	0.59	6.60E-02	7.10E-02
150	2.40	2.18	3.46	0.91	0.63	1.17	1.69	2.48	1.44	0.68	0.33	0.54	0.86	1.62	0.63	4.50E-02	4.80E-02
200	1.92	2.72	3.68	1.42	0.74	0.92	1.15	2.69	1.26	0.43	0.25	0.46	0.53	1.8	0.87	3.40E-02	3.70E-02
250	1.60	2.18	2.49	1.36	0.88	0.76	1.07	1.96	1.42	0.55	0.21	0.43	0.43	2.08	1	2.70E-02	3.00E-02
300	1.38	1.38	1.99	1.00	0.69	0.65	1.09	1.47	1.69	0.75	0.18	0.37	0.53	2.1	0.69	2.20E-02	2.40E-02

Table A-5. 1990 CALPUFF screening (S)/refined (R) for highest (H1H) & 2nd highest (H2H) SO2 dry fluxes (ug/m2/s) w/dep. and chemistry for SO2															
	SO2 1-hour average				SO2 3-hour average				SO2 24-hour average				SO2 period average		
	H1H		H2H		H1H		H2H		H1H		H2H		Highest		
2-meter	S	R	S	R	S	R	S	R	S	R	S	R	S	R	S/R
1	4.69E+01	4.95E+01	3.54E+01	4.61E+01	2.41E+01	2.98E+01	1.85E+01	2.79E+01	5.82E+00	8.94E+00	4.55E+00	7.73E+00	9.476E-01	9.470E-01	1.00
2	1.92E+01	1.78E+01	1.21E+01	1.69E+01	9.18E+00	1.25E+01	8.20E+00	1.02E+01	2.10E+00	3.01E+00	1.63E+00	2.94E+00	3.270E-01	3.129E-01	1.05
3	1.27E+01	1.06E+01	6.61E+00	1.03E+01	5.17E+00	6.78E+00	4.71E+00	5.25E+00	1.14E+00	1.63E+00	9.28E-01	1.56E+00	1.740E-01	1.604E-01	1.08
5	7.28E+00	5.63E+00	3.50E+00	4.69E+00	2.65E+00	3.41E+00	2.29E+00	2.67E+00	5.37E-01	7.73E-01	4.96E-01	7.37E-01	7.932E-02	6.819E-02	1.16
10	3.07E+00	2.32E+00	1.57E+00	2.02E+00	1.30E+00	1.34E+00	8.62E-01	9.82E-01	2.28E-01	2.84E-01	2.11E-01	2.41E-01	2.778E-02	2.098E-02	1.32
15	1.70E+00	2.46E+00	8.97E-01	1.10E+00	6.94E-01	1.34E+00	5.34E-01	7.49E-01	1.44E-01	1.72E-01	1.17E-01	1.02E-01	1.551E-02	1.013E-02	1.53
20	1.09E+00	7.44E-01	5.77E-01	6.85E-01	4.14E-01	3.89E-01	3.61E-01	3.63E-01	9.14E-02	8.03E-02	7.88E-02	7.65E-02	1.035E-02	6.091E-03	1.70
30	4.97E-01	5.02E-01	3.41E-01	4.11E-01	2.43E-01	2.29E-01	1.96E-01	1.85E-01	5.00E-02	4.53E-02	3.49E-02	3.13E-02	5.281E-03	3.321E-03	1.59
50	2.71E-01	1.98E-01	1.83E-01	1.93E-01	1.19E-01	1.24E-01	8.55E-02	8.38E-02	2.49E-02	2.63E-02	1.84E-02	1.81E-02	2.315E-03	1.318E-03	1.76
75	1.34E-01	1.83E-01	1.12E-01	8.16E-02	7.17E-02	7.02E-02	5.81E-02	4.32E-02	1.63E-02	1.37E-02	1.35E-02	9.00E-03	1.199E-03	5.751E-04	2.09
100	6.31E-02	6.91E-02	4.73E-02	5.30E-02	3.83E-02	5.51E-02	3.68E-02	2.50E-02	1.09E-02	8.78E-03	7.01E-03	4.83E-03	7.364E-04	2.901E-04	2.54
150	2.77E-02	2.34E-02	2.44E-02	2.21E-02	1.95E-02	1.86E-02	1.62E-02	1.19E-02	5.01E-03	4.13E-03	3.97E-03	3.32E-03	3.381E-04	1.404E-04	2.41
200	1.24E-02	1.76E-02	1.05E-02	1.08E-02	8.67E-03	9.65E-03	8.22E-03	6.26E-03	2.29E-03	2.20E-03	2.05E-03	1.53E-03	1.878E-04	9.307E-05	2.02
250	6.98E-03	8.34E-03	6.38E-03	6.63E-03	5.73E-03	5.79E-03	5.04E-03	4.74E-03	1.60E-03	1.46E-03	1.30E-03	8.87E-04	1.235E-04	7.853E-05	1.57
300	5.56E-03	6.72E-03	3.67E-03	4.32E-03	2.96E-03	3.45E-03	2.35E-03	2.93E-03	1.42E-03	1.16E-03	1.11E-03	6.84E-04	7.962E-05	5.296E-05	1.50
35-meter															
1	1.58E+00	1.68E+00	1.54E+00	1.66E+00	1.17E+00	1.51E+00	1.17E+00	1.41E+00	3.09E-01	5.66E-01	2.58E-01	4.16E-01	3.355E-02	3.725E-02	0.90
2	1.16E+00	1.20E+00	1.15E+00	1.18E+00	8.12E-01	1.11E+00	6.51E-01	9.33E-01	2.36E-01	4.68E-01	1.89E-01	4.43E-01	3.751E-02	4.053E-02	0.93
3	8.73E-01	9.76E-01	8.55E-01	9.70E-01	6.60E-01	8.60E-01	4.83E-01	7.66E-01	1.79E-01	3.52E-01	1.48E-01	3.38E-01	3.105E-02	3.280E-02	0.95
5	5.32E-01	6.57E-01	5.18E-01	6.00E-01	3.96E-01	5.19E-01	2.93E-01	4.71E-01	1.11E-01	2.11E-01	9.02E-02	2.11E-01	2.058E-02	2.083E-02	0.99
10	2.36E-01	4.89E-01	2.05E-01	2.60E-01	1.56E-01	2.62E-01	1.49E-01	1.89E-01	5.28E-02	9.45E-02	4.64E-02	9.21E-02	1.054E-02	9.257E-03	1.14
15	3.45E-01	3.89E-01	1.46E-01	2.13E-01	1.26E-01	1.92E-01	1.05E-01	1.12E-01	3.19E-02	5.85E-02	3.08E-02	5.28E-02	6.770E-03	5.390E-03	1.26
20	2.21E-01	3.17E-01	1.26E-01	1.91E-01	9.82E-02	1.26E-01	8.49E-02	9.49E-02	2.50E-02	4.12E-02	2.33E-02	3.42E-02	4.883E-03	3.610E-03	1.35
30	1.00E-01	1.65E-01	9.57E-02	1.07E-01	6.96E-02	8.88E-02	6.23E-02	6.27E-02	1.69E-02	2.90E-02	1.60E-02	2.13E-02	3.033E-03	1.967E-03	1.54
50	8.89E-02	7.65E-02	6.03E-02	5.96E-02	4.63E-02	5.09E-02	3.44E-02	4.04E-02	9.94E-03	1.57E-02	8.96E-03	1.09E-02	1.547E-03	9.069E-04	1.71
75	6.60E-02	5.74E-02	4.38E-02	4.34E-02	2.92E-02	3.52E-02	2.79E-02	3.27E-02	7.03E-03	1.16E-02	6.05E-03	6.55E-03	8.826E-04	4.777E-04	1.85
100	4.36E-02	4.45E-02	3.72E-02	4.30E-02	2.39E-02	3.35E-02	1.96E-02	2.18E-02	4.75E-03	8.14E-03	4.40E-03	4.39E-03	5.726E-04	2.785E-04	2.06
150	3.15E-02	2.95E-02	2.22E-02	2.47E-02	1.98E-02	2.00E-02	1.39E-02	1.15E-02	3.59E-03	4.36E-03	3.06E-03	2.99E-03	3.146E-04	1.479E-04	2.13
200	2.21E-02	2.15E-02	1.41E-02	1.30E-02	9.54E-03	1.10E-02	8.84E-03	7.59E-03	2.54E-03	2.86E-03	1.83E-03	1.81E-03	1.924E-04	1.036E-04	1.86
250	1.16E-02	1.36E-02	1.05E-02	9.66E-03	9.15E-03	8.72E-03	6.21E-03	5.61E-03	1.87E-03	1.68E-03	1.45E-03	1.21E-03	1.304E-04	8.016E-05	1.63
300	9.59E-03	7.58E-03	8.51E-03	5.99E-03	7.74E-03	5.27E-03	4.72E-03	3.60E-03	1.45E-03	1.38E-03	1.14E-03	8.73E-04	8.720E-05	5.886E-05	1.48
200-meter															
1	1.26E-01	2.97E-01	6.49E-02	2.01E-01	4.45E-02	1.65E-01	2.41E-02	1.12E-01	5.68E-03	3.46E-02	3.73E-03	1.44E-02	7.251E-05	2.417E-04	0.30
2	7.17E-02	2.19E-01	5.87E-02	1.72E-01	3.14E-02	1.20E-01	2.44E-02	9.10E-02	5.84E-03	2.64E-02	4.55E-03	1.58E-02	2.285E-04	4.445E-04	0.51
3	7.78E-02	1.53E-01	7.68E-02	1.18E-01	4.67E-02	9.07E-02	3.12E-02	8.14E-02	8.50E-03	2.12E-02	6.27E-03	1.99E-02	4.640E-04	7.863E-04	0.59
5	1.18E-01	1.20E-01	5.92E-02	9.77E-02	4.63E-02	7.75E-02	3.57E-02	6.65E-02	1.23E-02	2.25E-02	8.79E-03	1.66E-02	6.054E-04	9.394E-04	0.64
10	9.87E-02	1.03E-01	6.87E-02	6.42E-02	5.58E-02	6.43E-02	2.05E-02	3.82E-02	7.84E-03	1.40E-02	5.67E-03	1.22E-02	5.627E-04	8.050E-04	0.70
15	6.61E-02	6.43E-02	3.46E-02	4.79E-02	2.27E-02	3.53E-02	1.34E-02	2.71E-02	4.52E-03	1.03E-02	3.34E-03	8.68E-03	5.784E-04	7.273E-04	0.80
20	5.21E-02	1.25E-01	1.85E-02	5.26E-02	2.05E-02	4.92E-02	1.13E-02	2.20E-02	3.73E-03	8.05E-03	3.01E-03	6.96E-03	5.642E-04	6.652E-04	0.85
30	2.56E-02	7.14E-02	1.43E-02	3.98E-02	1.11E-02	2.99E-02	8.75E-03	1.95E-02	3.18E-03	6.91E-03	2.67E-03	5.49E-03	4.841E-04	5.507E-04	0.88
50	1.41E-02	5.04E-02	9.61E-03	2.81E-02	6.92E-03	2.56E-02	6.20E-03	1.47E-02	2.70E-03	4.34E-03	2.15E-03	3.70E-03	3.375E-04	3.717E-04	0.91
75	8.86E-03	3.93E-02	7.89E-03	2.94E-02	7.00E-03	1.48E-02	4.87E-03	1.19E-02	2.18E-03	3.61E-03	1.55E-03	3.14E-03	2.325E-04	2.598E-04	0.89
100	7.14E-03	2.36E-02	5.97E-03	2.33E-02	5.05E-03	1.87E-02	3.86E-03	1.00E-02	2.05E-03	4.97E-03	1.25E-03	2.49E-03	1.785E-04	1.908E-04	0.94
150	4.91E-03	1.49E-02	4.16E-03	1.24E-02	3.65E-03	1.06E-02	3.44E-03	8.31E-03	1.33E-03	2.01E-03	9.34E-04	1.89E-03	1.160E-04	1.183E-04	0.98
200	6.60E-03	1.07E-02	3.00E-03	8.37E-03	2.94E-03	6.90E-03	2.18E-03	4.56E-03	1.07E-03	1.86E-03	8.21E-04	1.20E-03	8.637E-05	8.481E-05	1.02
250	4.55E-03	8.44E-03	3.15E-03	6.99E-03	2.39E-03	5.21E-03	1.74E-03	4.63E-03	9.05E-04	1.17E-03	5.82E-04	9.48E-04	6.611E-05	6.934E-05	0.95
300	3.00E-03	6.71E-03	2.27E-03	6.17E-03	1.55E-03	4.31E-03	1.44E-03	3.02E-03	7.44E-04	1.24E-03	5.24E-04	7.08E-04	5.283E-05	5.427E-05	0.97

Table A-6. 1990 CALPUFF screening (S)/refined (R) for highest (H1H) & 2nd highest (H2H) SO4 dry fluxes (ug/m2/s) w/dep. and chemistry for SO2

	SO4 1-hour average				SO4 3-hour average				SO4 24-hour average				SO4 period average		
Distance	H1H		H2H		H1H		H2H		H1H		H2H		H1H		
2-meter	S	R	S	R	S	R	S	R	S	R	S	R	S	R	S/R
1	2.16E-01	5.43E-02	1.00E-01	4.17E-02	7.31E-02	3.56E-02	4.83E-02	2.92E-02	1.18E-02	1.27E-02	1.04E-02	1.05E-02	1.38E-03	9.77E-04	1.41
2	1.16E-01	1.98E-02	3.39E-02	1.72E-02	3.94E-02	1.29E-02	1.68E-02	1.04E-02	6.21E-03	4.43E-03	3.76E-03	3.66E-03	4.82E-04	3.39E-04	1.42
3	8.07E-02	1.19E-02	1.99E-02	9.89E-03	2.77E-02	7.52E-03	9.13E-03	6.23E-03	4.35E-03	2.42E-03	2.06E-03	1.96E-03	2.66E-04	1.85E-04	1.44
5	5.07E-02	1.41E-02	1.06E-02	8.26E-03	1.77E-02	6.11E-03	5.37E-03	3.30E-03	2.78E-03	1.17E-03	9.99E-04	9.13E-04	1.30E-04	8.59E-05	1.51
10	2.49E-02	7.16E-03	5.56E-03	5.53E-03	9.11E-03	2.42E-03	3.25E-03	2.17E-03	1.44E-03	5.73E-04	3.83E-04	3.16E-04	5.02E-05	3.12E-05	1.61
15	1.37E-02	3.52E-03	3.54E-03	3.40E-03	5.36E-03	2.87E-03	2.44E-03	1.03E-03	9.57E-04	3.63E-04	2.19E-04	2.16E-04	3.06E-05	1.79E-05	1.71
20	6.31E-03	2.52E-03	2.33E-03	1.40E-03	2.85E-03	1.31E-03	1.94E-03	7.06E-04	7.36E-04	2.64E-04	1.74E-04	1.70E-04	2.35E-05	1.29E-05	1.83
30	3.18E-03	1.84E-03	1.80E-03	1.22E-03	1.50E-03	9.16E-04	1.06E-03	5.19E-04	4.99E-04	1.93E-04	1.39E-04	1.14E-04	1.87E-05	1.01E-05	1.85
50	2.45E-03	1.76E-03	1.88E-03	1.17E-03	1.45E-03	6.62E-04	9.98E-04	5.56E-04	4.76E-04	2.05E-04	1.04E-04	7.27E-05	1.47E-05	7.18E-06	2.05
75	3.41E-03	2.22E-03	1.60E-03	1.03E-03	1.31E-03	7.81E-04	1.07E-03	6.13E-04	4.01E-04	2.03E-04	1.14E-04	9.30E-05	1.24E-05	5.41E-06	2.29
100	3.47E-03	1.38E-03	1.85E-03	9.93E-04	1.28E-03	6.08E-04	9.40E-04	5.28E-04	4.19E-04	1.31E-04	1.23E-04	1.07E-04	1.12E-05	5.63E-06	1.98
150	2.49E-03	9.02E-04	1.41E-03	5.56E-04	1.38E-03	3.99E-04	7.04E-04	1.82E-04	3.44E-04	7.63E-05	1.21E-04	5.27E-05	9.43E-06	2.94E-06	3.20
200	1.45E-03	9.13E-04	1.03E-03	5.49E-04	9.00E-04	5.11E-04	7.21E-04	3.47E-04	2.16E-04	1.18E-04	1.10E-04	5.36E-05	7.73E-06	2.22E-06	3.48
250	1.08E-03	8.14E-04	8.12E-04	6.62E-04	6.86E-04	5.67E-04	4.92E-04	1.70E-04	1.52E-04	9.44E-05	9.22E-05	3.35E-05	6.99E-06	1.78E-06	3.92
300	1.23E-03	6.59E-04	7.61E-04	4.59E-04	6.24E-04	4.43E-04	3.62E-04	2.50E-04	1.18E-04	7.85E-05	7.83E-05	5.23E-05	5.65E-06	1.39E-06	4.07
35-meter															
1	2.62E-02	6.39E-03	1.66E-02	6.30E-03	9.28E-03	4.70E-03	8.76E-03	4.40E-03	1.71E-03	1.62E-03	1.09E-03	1.21E-03	1.16E-04	6.09E-05	1.90
2	1.73E-02	5.25E-03	1.29E-02	4.98E-03	7.47E-03	4.48E-03	5.82E-03	3.95E-03	1.42E-03	1.34E-03	1.07E-03	1.32E-03	1.19E-04	7.21E-05	1.66
3	1.12E-02	3.82E-03	8.88E-03	3.72E-03	5.17E-03	3.27E-03	3.78E-03	3.07E-03	1.05E-03	1.06E-03	7.94E-04	9.82E-04	9.55E-05	6.03E-05	1.58
5	6.06E-03	2.27E-03	5.03E-03	2.23E-03	2.93E-03	1.90E-03	2.03E-03	1.88E-03	6.60E-04	6.72E-04	4.73E-04	5.88E-04	6.18E-05	4.02E-05	1.54
10	3.38E-03	9.84E-04	2.15E-03	9.67E-04	1.23E-03	8.18E-04	8.31E-04	8.01E-04	3.48E-04	3.04E-04	2.10E-04	2.54E-04	2.98E-05	1.93E-05	1.54
15	2.39E-03	9.16E-04	1.35E-03	7.66E-04	8.26E-04	4.81E-04	5.12E-04	4.69E-04	2.43E-04	1.80E-04	1.30E-04	1.51E-04	1.88E-05	1.19E-05	1.57
20	1.84E-03	1.28E-03	1.01E-03	7.76E-04	6.41E-04	4.41E-04	3.90E-04	3.61E-04	1.89E-04	1.51E-04	9.18E-05	1.03E-04	1.36E-05	8.33E-06	1.63
30	1.33E-03	6.56E-04	7.47E-04	5.95E-04	4.76E-04	4.98E-04	2.80E-04	2.66E-04	1.29E-04	1.39E-04	6.87E-05	6.79E-05	1.02E-05	5.71E-06	1.78
50	1.22E-03	1.00E-03	7.54E-04	4.68E-04	4.32E-04	4.22E-04	3.41E-04	3.31E-04	9.42E-05	1.20E-04	5.62E-05	4.95E-05	8.43E-06	4.51E-06	1.87
75	1.34E-03	9.82E-04	7.27E-04	5.45E-04	4.62E-04	4.17E-04	3.41E-04	3.26E-04	1.06E-04	1.18E-04	6.18E-05	4.44E-05	6.90E-06	4.11E-06	1.68
100	1.33E-03	1.12E-03	9.19E-04	7.31E-04	5.54E-04	5.60E-04	4.52E-04	3.59E-04	1.30E-04	8.66E-05	5.70E-05	7.06E-05	5.93E-06	4.29E-06	1.38
150	1.40E-03	5.34E-04	9.51E-04	3.92E-04	5.88E-04	2.60E-04	3.27E-04	1.77E-04	1.24E-04	7.90E-05	6.38E-05	5.74E-05	5.16E-06	2.58E-06	2.00
200	1.49E-03	7.99E-04	9.15E-04	7.80E-04	5.38E-04	5.62E-04	3.98E-04	4.49E-04	1.13E-04	1.08E-04	7.25E-05	9.36E-05	4.79E-06	2.04E-06	2.34
250	7.95E-04	8.45E-04	6.88E-04	5.81E-04	4.05E-04	4.85E-04	3.96E-04	2.56E-04	8.60E-05	9.57E-05	7.15E-05	5.81E-05	4.15E-06	1.60E-06	2.59
300	7.66E-04	4.74E-04	4.46E-04	3.25E-04	3.96E-04	2.72E-04	2.63E-04	2.00E-04	7.57E-05	7.13E-05	5.30E-05	4.97E-05	3.62E-06	1.38E-06	2.63
200-meter															
1	2.81E-04	2.08E-04	1.26E-04	1.88E-04	9.79E-05	1.48E-04	6.41E-05	1.39E-04	1.22E-05	3.86E-05	9.34E-06	2.92E-05	5.04E-07	6.29E-07	0.80
2	2.88E-04	2.40E-04	1.83E-04	2.11E-04	9.98E-05	1.70E-04	6.44E-05	1.33E-04	1.25E-05	4.21E-05	1.12E-05	3.18E-05	1.02E-06	1.00E-06	1.02
3	4.08E-04	2.65E-04	2.87E-04	2.22E-04	1.63E-04	1.83E-04	1.05E-04	1.37E-04	2.52E-05	4.56E-05	1.73E-05	3.25E-05	1.87E-06	1.50E-06	1.24
5	6.30E-04	2.87E-04	3.01E-04	2.23E-04	2.22E-04	1.69E-04	1.24E-04	1.49E-04	2.92E-05	3.96E-05	2.23E-05	3.27E-05	2.53E-06	1.83E-06	1.39
10	6.61E-04	3.95E-04	5.23E-04	2.69E-04	3.57E-04	1.74E-04	1.09E-04	1.13E-04	4.64E-05	3.55E-05	1.87E-05	1.94E-05	2.73E-06	2.00E-06	1.37
15	5.31E-04	4.07E-04	3.50E-04	2.87E-04	2.06E-04	2.06E-04	1.26E-04	1.18E-04	3.84E-05	2.78E-05	2.02E-05	2.47E-05	2.85E-06	2.13E-06	1.34
20	5.29E-04	5.21E-04	3.63E-04	2.63E-04	2.15E-04	2.24E-04	1.24E-04	1.12E-04	3.05E-05	2.80E-05	2.06E-05	2.36E-05	2.83E-06	2.12E-06	1.34
30	4.16E-04	3.47E-04	3.33E-04	2.24E-04	1.95E-04	1.50E-04	1.27E-04	1.27E-04	2.49E-05	3.46E-05	1.86E-05	2.59E-05	2.54E-06	1.98E-06	1.28
50	4.34E-04	2.81E-04	2.54E-04	2.32E-04	1.79E-04	1.47E-04	1.13E-04	1.15E-04	2.70E-05	2.77E-05	1.89E-05	2.16E-05	2.46E-06	2.21E-06	1.11
75	5.03E-04	5.64E-04	2.75E-04	3.27E-04	1.93E-04	3.13E-04	1.05E-04	1.30E-04	2.75E-05	4.67E-05	2.02E-05	3.39E-05	2.43E-06	2.54E-06	0.96
100	4.40E-04	5.94E-04	3.15E-04	4.98E-04	1.52E-04	2.78E-04	1.30E-04	2.07E-04	2.65E-05	8.45E-05	1.90E-05	3.82E-05	2.22E-06	2.72E-06	0.81
150	5.65E-04	5.99E-04	2.21E-04	2.83E-04	1.91E-04	3.25E-04	1.25E-04	1.27E-04	2.85E-05	4.77E-05	2.12E-05	3.10E-05	1.89E-06	1.93E-06	0.98
200	5.66E-04	5.47E-04	1.96E-04	5.05E-04	1.90E-04	3.74E-04	8.97E-05	1.95E-04	3.22E-05	6.15E-05	2.00E-05	3.03E-05	1.68E-06	1.53E-06	1.10
250	2.91E-04	6.40E-04	1.74E-04	4.87E-04	1.38E-04	4.07E-04	8.94E-05	2.11E-04	3.17E-05	6.74E-05	2.28E-05	5.11E-05	1.54E-06	1.39E-06	1.10
300	3.08E-04	3.61E-04	1.47E-04	3.24E-04	1.34E-04	2.90E-04	8.39E-05	1.12E-04	3.06E-05	4.48E-05	1.88E-05	2.68E-05	1.40E-06	1.10E-06	1.27

Table A-7. 1990 CALPUFF screening (S)/refined (R) for highest (H1H) & 2nd highest (H2H) SO4 concentrations (ug/m3) w/dry dep. and chemistry for SO2

	SO4 1-hr average				SO4 3-hr average				SO4 24-hr average				SO4 period average		
Distance	H1H		H2H		H1H		H2H		H1H		H2H				
2-meter	S	R	S	R	S	R	S	R	S	R	S	R	S	R	S/R
1	485.89	659.89	347.82	548.87	207.72	392.62	133.88	249.74	40.33	51.71	27.69	43.34	4.00E+00	3.58E+00	1.12
2	211.11	243.79	136.82	229.15	100.63	158.10	62.69	108.50	19.14	21.88	11.51	18.31	1.47E+00	1.34E+00	1.10
3	138.63	156.10	77.22	110.65	59.30	77.58	36.36	61.50	12.15	11.71	6.82	10.31	8.30E-01	7.58E-01	1.10
5	87.12	167.77	41.18	80.28	34.43	82.42	17.52	29.38	6.87	11.06	3.63	4.43	4.16E-01	3.56E-01	1.17
10	62.45	85.87	27.25	57.29	24.22	33.70	9.88	21.97	3.93	6.45	2.04	3.63	1.71E-01	1.43E-01	1.20
15	30.78	62.96	21.98	38.81	15.10	23.44	8.04	15.65	3.31	3.65	1.46	2.60	1.19E-01	8.58E-02	1.38
20	20.93	47.45	18.45	21.53	10.84	18.18	7.06	14.07	2.86	3.24	1.13	2.51	1.02E-01	6.32E-02	1.61
30	13.39	23.96	12.45	17.97	7.70	13.55	6.12	7.80	1.97	2.33	1.04	1.80	7.71E-02	4.81E-02	1.60
50	9.41	16.41	7.68	11.84	4.86	9.65	3.99	5.94	1.67	1.99	0.64	0.73	5.91E-02	2.93E-02	2.02
75	11.39	14.93	5.12	12.80	6.20	11.05	3.59	9.48	1.79	3.09	0.53	0.57	4.62E-02	2.12E-02	2.18
100	7.97	6.85	5.30	5.88	4.42	4.17	4.33	4.11	1.76	1.03	0.73	0.86	4.04E-02	1.35E-02	2.99
150	7.88	3.43	5.36	2.55	5.23	1.61	3.17	1.09	1.45	0.47	0.52	0.39	3.11E-02	9.70E-03	3.20
200	5.59	2.17	3.16	1.84	3.91	1.63	2.51	0.79	0.86	0.37	0.45	0.27	2.44E-02	9.31E-03	2.62
250	3.70	1.57	2.71	1.28	2.78	1.16	2.16	0.92	0.64	0.28	0.34	0.17	1.96E-02	9.83E-03	2.00
300	2.58	1.73	1.71	1.08	1.78	0.98	1.47	0.57	0.50	0.22	0.24	0.19	1.50E-02	7.37E-03	2.04
35-meter															
1	5.96	7.48	5.84	5.82	5.29	5.17	4.73	4.62	1.40	1.93	1.31	1.67	2.28E-01	1.60E-01	1.43
2	13.99	6.91	9.45	5.91	5.03	5.54	3.86	3.84	1.51	1.82	1.14	1.65	2.52E-01	1.91E-01	1.32
3	13.73	6.48	6.82	5.70	4.82	4.88	3.05	3.74	1.21	1.50	1.01	1.27	2.10E-01	1.66E-01	1.27
5	12.14	7.10	4.25	5.71	4.66	4.82	2.24	3.64	0.76	1.38	0.67	1.06	1.45E-01	1.18E-01	1.23
10	7.87	6.56	3.71	6.41	3.41	5.77	1.68	3.62	0.60	1.67	0.35	1.20	7.57E-02	6.41E-02	1.18
15	13.11	7.54	3.65	6.07	4.76	4.13	1.52	3.48	0.66	1.32	0.33	1.15	5.07E-02	4.36E-02	1.16
20	11.99	9.30	5.09	5.05	4.00	4.43	1.71	3.12	0.74	1.57	0.33	0.82	4.09E-02	3.32E-02	1.23
30	3.74	5.77	3.37	4.39	2.01	4.21	1.69	3.26	0.53	1.26	0.28	0.89	3.45E-02	2.51E-02	1.38
50	3.01	4.27	2.32	3.82	1.40	3.70	1.25	2.42	0.46	1.08	0.27	0.40	2.74E-02	1.80E-02	1.52
75	3.92	5.08	2.42	4.11	1.89	3.26	1.18	2.84	0.46	1.22	0.31	0.32	2.28E-02	1.40E-02	1.63
100	2.29	3.96	1.64	3.84	1.45	2.71	1.03	2.44	0.45	0.71	0.21	0.56	2.01E-02	1.13E-02	1.78
150	2.27	1.98	1.89	1.36	1.46	1.31	1.03	0.96	0.42	0.40	0.20	0.31	1.67E-02	8.87E-03	1.88
200	2.53	1.68	2.16	1.12	1.40	1.03	1.18	0.76	0.48	0.33	0.18	0.24	1.50E-02	8.29E-03	1.81
250	2.06	1.34	1.99	0.96	1.71	0.89	1.24	0.76	0.31	0.23	0.30	0.18	1.28E-02	8.54E-03	1.50
300	1.72	0.82	1.59	0.75	1.31	0.61	1.15	0.56	0.29	0.19	0.21	0.11	1.04E-02	6.77E-03	1.54
200-meter															
1	0.81	1.43	0.61	1.37	0.42	0.92	0.26	0.75	0.07	0.23	0.06	0.20	1.90E-03	4.08E-03	0.47
2	1.09	1.58	0.64	1.44	0.61	1.06	0.32	0.84	0.10	0.26	0.06	0.20	3.39E-03	5.19E-03	0.65
3	1.02	1.76	0.71	1.51	0.48	1.13	0.31	0.89	0.08	0.27	0.07	0.21	5.35E-03	6.75E-03	0.79
5	3.74	2.18	0.79	1.34	1.32	1.04	0.37	0.87	0.17	0.24	0.09	0.20	6.80E-03	7.62E-03	0.89
10	3.96	3.42	3.17	1.33	2.28	1.47	0.55	0.83	0.30	0.21	0.09	0.18	6.61E-03	7.51E-03	0.88
15	3.52	3.52	1.98	1.40	1.20	1.74	0.71	0.72	0.24	0.23	0.09	0.15	6.69E-03	7.36E-03	0.91
20	3.09	2.72	1.07	2.25	1.23	1.65	0.63	0.94	0.18	0.22	0.10	0.14	6.67E-03	7.14E-03	0.93
30	1.74	2.42	0.78	1.64	0.78	1.21	0.32	1.03	0.10	0.33	0.06	0.17	6.28E-03	6.96E-03	0.90
50	1.39	1.71	0.65	1.34	0.61	0.83	0.28	0.80	0.12	0.23	0.06	0.16	6.32E-03	7.71E-03	0.82
75	0.86	2.16	0.53	1.25	0.45	1.20	0.30	1.18	0.08	0.30	0.08	0.18	6.06E-03	7.62E-03	0.80
100	0.93	1.83	0.52	1.38	0.56	1.13	0.23	1.04	0.07	0.47	0.06	0.21	5.64E-03	7.16E-03	0.79
150	0.54	1.63	0.41	0.90	0.31	0.94	0.25	0.50	0.08	0.28	0.06	0.17	4.91E-03	6.56E-03	0.75
200	0.56	1.43	0.40	1.22	0.28	1.13	0.22	0.49	0.08	0.25	0.06	0.13	4.60E-03	6.29E-03	0.73
250	0.50	1.11	0.41	0.97	0.35	0.86	0.23	0.67	0.08	0.25	0.08	0.18	4.50E-03	6.36E-03	0.71
300	0.48	0.95	0.39	0.94	0.30	0.65	0.22	0.54	0.07	0.27	0.06	0.09	3.82E-03	5.58E-03	0.68

APPENDIX B

PROBLEMS ENCOUNTERED RUNNING THE CALPUFF MODELING SYSTEM

As noted in the introduction, developing the meteorological data file with the CALMET processor requires much effort. CALMET requires several different data type, which include:

- hourly surface weather observations,
- upper air soundings,
- gridded land use, and
- gridded terrain data.

Each of these data types required special attention in order to successfully create the final meteorological data file for input to CALPUFF. This appendix describes several of the special processing steps or problems encountered during the meteorological data preparation.

HOURLY SURFACE WEATHER OBSERVATIONS

CALMET requires that the hourly surface observations be in a special format. A preprocessor program, SMERGE, is provided for this purpose. SMERGE accepts hourly surface observations in one of two formats: 1) the 80-column CD-144 format in which the hourly weather observations are compactly reported in one record, and 2) the data retrieved from the Solar and Meteorological Surface Observation Network (SAMSON) compact discs. SMERGE formats selected variables from these files by combining the data from each station hour-by-hour. In other words, each hour contains the weather variables from each station.

Two problems have been identified with the SMERGE program provided on the CALPUFF modeling system compact disc. First, the program does not appear to process the CD-144 formatted data. When CD-144 data are used, the output file consists of missing value indicators for all variables for all hours. Second, when data from the SAMSON compact discs are used, the data in the output file appears to be shifted by one hour (e.g., data from SAMSON hour 2 is written as hour 3). Several attempts to "trick" SMERGE into writing the correct hour met with failure, and the output file for this modeling effort had to be postprocessed to adjust all the hours in the file.

UPPER AIR SOUNDINGS

Processing upper air data through CALMET has its own set of unique problems. CALMET requires that:

1) the time difference between soundings be no greater than 12 hours;

2) the height above local ground of each sounding extend above the top of the modeling domain;

3) the height of the top level be no greater than 9999.0 meters (a formatting limitation).

If either of the first two (error) conditions occur, the CALMET stops processing the data and reports the error. Without any restart capability, once the problem is corrected, CALMET must be started from the first day to be processed. Such an iterative procedure could result in several dozen attempts to completely process the data until all the errors are corrected. This is a very inefficient way to process the data through CALMET and suggests that a processor be developed that can check each sounding for various problems and report (but not necessarily correct) the problem.

Extended periods of missing soundings are particularly difficult to correct. An interpolation routine between stations is a possible solution, but this solution would require yet another processor to perform the interpolation. A quicker approach would be to substitute from a nearby upper air station, although it is likely that the station is already included in the analysis.

GRIDDED LAND USE DATA

The gridded land use that accompanies the CALMET/CALPUFF Modeling System CD provides sufficient data to develop the file of geophysical parameters (GEO.DAT) required by CALMET. However, the resolution of the data in the file is very coarse. The data are defined on a 4-cell (east-west) by 6-cell (north-south) grid per degree, which is equivalent to about 27 kilometers east-west and 18 kilometers north-south. If data on a finer resolution are needed or desired, the user must locate the data and develop the necessary software to prepare the data for the GEO.DAT file.

APPENDIX C

BACKGROUND INFORMATION FOR SCREENING ANALYSIS

In the EPA (1998) tracer report, concentration estimates from the CALPUFF dispersion model were compared to observed tracer concentrations from two short term field experiments. The first experiment was at the Savannah River Laboratory (SRL) in South Carolina in December 1975 (DOE, 1978) and the second was the Great Plains experiment near Norman, Oklahoma (Ferber et al., 1981) in July 1980. Both experiments examined long-range transport of inert tracer materials to demonstrate the feasibility of using other tracers as alternatives to the more commonly used sulfur hexafluoride (SF_6). Several tracers were released for a short duration (3-4 hours) and the resulting plume concentrations were recorded at an array of monitors downwind from the source. For the SRL field experiment, monitors were located about 100 kilometers from the source. For the Great Plains experiment, arcs of monitors were located 100 and 600 kilometers from the source.

This appendix summarizes the processing of the meteorology for the Great Plains experiment as these data were extended and employed in the screening analyses discussed in this report.

MODELING DOMAIN

The CALPUFF modeling system uses a grid system consisting of an array of horizontal grid cells and multiple vertical layers. Two grids must be defined in the CALPUFF model -- meteorological and computational. The meteorological grid defines the extent over which land use, winds, and other meteorological variables are defined. The computational grid defines the extent of the concentration calculations, and is required to be identical to or a subset of the meteorological grid. For the Great Plains simulations, the computational grid is defined to be identical to the meteorological grid.

To properly characterize the meteorology for the CALPUFF modeling system, a grid that spans, at a minimum, the distance between source and receptor is required. However, to allow for possible recirculation of puffs that may be transported beyond the receptors and to allow for upstream influences on the wind field, the meteorological and computational domains should be larger than this minimum.

The Great Plains site is shown in Figure 1. Two arcs of monitors were deployed during the field experiment -- 100 and 600 kilometers. For this analysis, two separate grids were defined. For the 100-kilometer arc, a grid extending approximately from 35° N to 36.5°N latitude and from 96° W to 98.5° W longitude was defined. A 42-by-40 horizontal grid with a 10-kilometer resolution was used for this arc. For the 600-kilometer arc, the grid extended from approximately 35° N to 42°N latitude and from 89° W to 100° W longitude. A 44-by-40 horizontal grid with a 20-kilometer resolution was used for this arc.

To adequately characterize the vertical structure of the atmosphere, six layers were defined: surface-20, 20-50, 50-100, 100-500, 500-2000, and 2000-3300 meters. This vertical resolution is consistent with the analysis by Irwin (1997) of the 1977 Idaho Falls field study.

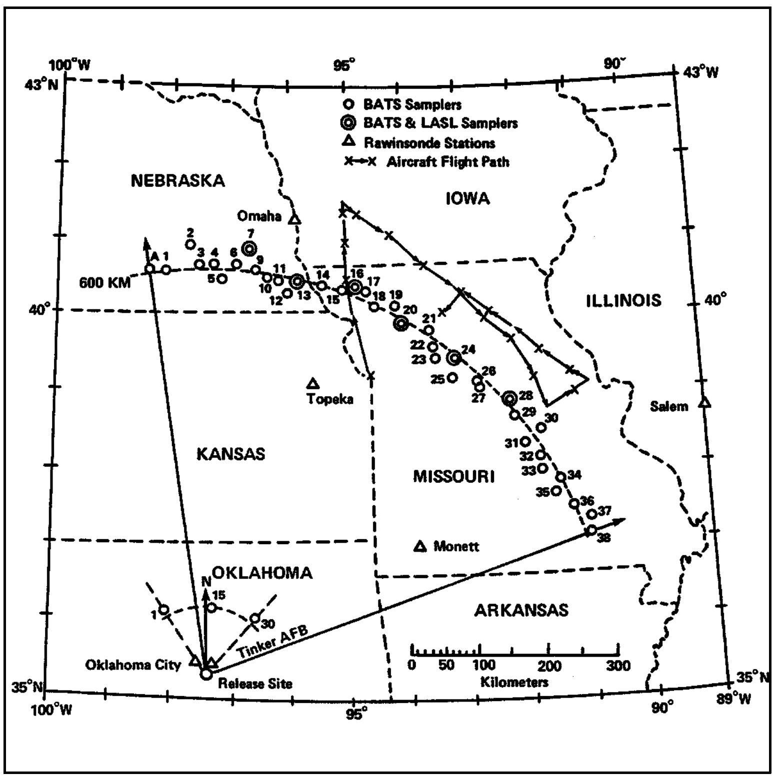

Figure 1. Great Plains field experiment site.

METEOROLOGICAL DATA

The CALMET preprocessor utilizes NWS meteorological data and on-site data to produce temporally and spatially varying three dimensional wind fields for CALPUFF. Only NWS data were used for this effort and came from two compact disc (CD) data sets (information on where to obtain these discs is in Appendix B). The first was the *Solar and Meteorological Surface Observation Network* (SAMSON) compact discs, which were used to obtain the hourly surface observations. The following surface stations were used for each of the field experiments:

Arkansas:	Fort Smith
Iowa:	Des Moines
Illinois:	Springfield
Kansas:	Dodge City, Topeka, Wichita
Missouri:	Columbia, Kansas City, Springfield, St. Louis
Nebraska:	Grand Island, Omaha, North Platte
Oklahoma:	Oklahoma City, Tulsa
Texas:	Amarillo, Dallas-Fort Worth, Lubbock, Wichita Falls

Twice daily soundings came from the second set of compact discs, the *Radiosonde Data for North America*. The following stations were used for each of the field experiments:

Arkansas:	Little Rock	Nebraska:	North Platte, Omaha
Illinois:	Peoria	Oklahoma:	Oklahoma City
Kansas:	Dodge City, Topeka	Texas:	Amarillo
Missouri:	Monett		

MODELING OPTIONS

In the CALPUFF modeling system, each of the three programs (CALMET, CALPUFF, and CALPOST) uses a control file of user-selectable options to control the data processing. There are numerous options in each and several that can result in significant differences. The following model controls for CALMET and CALPUFF were employed for the analyses with the tracer data.

CALMET Options

The following CALMET control parameters and options are chosen to be consistent with the 1977 INEL study by Irwin (1997). The most important options relate to the development of the wind field and were set as follows:

IWFCOD	= 1	Use diagnostic wind model to develop the 3-D wind fields
IFRADJ	= 1	Compute Froude number adjustment effects (thermodynamic blocking effects of terrain)
IKINE	= 1	Compute kinematic effects of terrain
IOBR	= 0	Do NOT use O'Brien procedure for adjusting vertical velocity
IEXTRP	= 4	Use similarity theory to extrapolate surface winds to upper layers
IPROG	= 0	Do NOT use prognostic wind field model output as input to diagnostic wind field model

Mixing heights are important in the estimating ground level concentrations. The options that affect mixing heights were set as follows:

IAVEZI	= 1	Conduct spatial averaging
MNDAV	= 3	Maximum search radius (in grid cells) in averaging process
HAFANG	= 30.	Half-angle of upwind looking cone for averaging
ILEVZI	= 1	Layer of winds to use in upwind averaging
DPTMIN	= .001	Minimum potential temperature lapse rate (K/m) in stable layer above convective mixing height
DZZI	= 200	Depth of layer (meters) over which the lapse rate is computed
ZIMIN	= 20	Minimum mixing height (meters) over land
ZIMAX	= 3300	Maximum mixing height (meters) over land, defined to be the top of the modeling domain

CALPUFF Options

The following CALPUFF control parameters, which are a subset of the control parameters, were used. As with CALMET, these parameters and options were chosen to be consistent with the 1977 INEL study.

Technical options (group 2):

MCTADJ	= 0	No terrain adjustment
MCTSG	= 0	No subgrid scale complex terrain is modeled
MSLUG	= 1	Near field puffs modeled as elongated (i.e., slugs)
MTRANS	= 1	Transitional plume rise is modeled
MTIP	= 1	Stack tip downwash is modeled
MSHEAR	= 0	Vertical wind shear is NOT modeled above stack top
MCHEM	= 0	No chemical transformations
MWET	= 0	No wet removal processes
MDRY	= 0	No dry removal processes
MPARTL	= 0	No partial plume penetration
MREG	= 0	No check made to see if options conform to regulatory options

Two different values were used for the option MDISP:

	= 2	Dispersion coefficients from internally calculated sigmas
	= 3	PG dispersion coefficients for RURAL areas

Several miscellaneous dispersion and computational parameters (group 12) were set as follows:

SYTDEP	= 550.	Horizontal puff size beyond which Heffter equations are used for sigma-y and sigma-z
MHFTSZ	= 0	Do NOT use Heffter equation for sigma-z
XMXLEN	= 0.1	Maximum length of slug (in grid cells)
XSAMLEN	= 0.1	Maximum travel distance of puff/slug (in grid cells) during one sampling step
MXNEW	= 199	Maximum number of slugs/puffs released during one time step
SL2PF	= 5.0	Slug-to-puff transition criterion factor (= sigma-y/slug length)

For the screening analyses in this document, a full 5-year period of meteorological data was used to compare CALPUFF screening to the ISCST3 refined model. The 5-year period of 1986-1991 was used. Tables A-1 through A-3 (in Appendix A) illustrate the comparison of the CALPUFF screening vs. ISCST3 analyses.

Meteorological processing discussed in the EPA (1998) tracer studies was limited to a single year. A refined analysis run was made during 1990. Tables A-5 through A-7 (in Appendix A) illustrate the comparison of the CALPUFF screening vs. refined analyses. Table A-4 compares CALPUFF screening, CALPUFF refined, and ISCST3 analyses.

TECHNICAL REPORT DATA

(Please read Instructions on reverse before completing)

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EPA-454/R-98-010		

4. TITLE AND SUBTITLE	5. REPORT DATE
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16. ABSTRACT

The CALPUFF model is a multi-layer, gridded non-steady-state puff dispersion model that can simlulate the effects of temperally and spatially varying meteorological conditions on pollutant transport, remove pollutants through dry and wet deposition proceses, and transform pollutant species through chemical reactions. Meteorological processing through the Calmet processor is a complex task. In order to provide a screening version of CALPUFF, an ISCST3-type of meteorological file is used as input. Documentation herein compares the screening and refined CALPUFF results.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
CALPUFF Regional Modeling Air Dispersion Models	Model Performance Long-Range Transport	

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