ADDENDUM TO ISC3 USER'S GUIDE

THE PRIME PLUME RISE AND BUILDING DOWNWASH MODEL

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1. Overview of PRIME

The Electric Power Research Institute (EPRI) sponsored a study to develop and evaluate new, improved plume rise and building downwash algorithms suitable for integration into regulatory air quality models. The **P**lume **Ri**se **M**odel **E**nhancements (PRIME) model was designed to incorporate the two fundamental features associated with building downwash: enhanced plume dispersion coefficients due to the turbulent wake, and reduced plume rise caused by a combination of the descending streamlines in the lee of the building and the increased entrainment in the wake. The PRIME algorithms have been integrated into the ISCST model, and can be installed in other analytical, Gaussian-based models. A full description of PRIME, including the key model equations, is provided by Schulman et al. (1998).

Wind-tunnel and field studies have made it clear that incorporating estimates of wind speed, streamline deflection, and turbulence intensities in the wake, as well as the location of the source, are crucial to improving modeling simulations of the influence of buildings on ground-level concentrations. This is the central approach used in PRIME; to explicitly treat the trajectory of the plume near the building, and to use the position of the plume relative to the building to calculate interactions with the building wake. PRIME calculates fields of turbulence intensity, wind speed, and the slopes of the mean streamlines as a function of the projected building dimensions. These fields gradually decay to ambient values downwind of the building. Coupled with a numerical plume rise model and these local values, PRIME determines the change in plume centerline location with downwind distance and the rate of plume dispersion. Plume rise incorporates the descent of the air containing the plume material, and rise of the plume relative to the streamlines due to buoyancy or momentum effects.

PRIME addresses the entire structure of the wake, from the cavity immediately downwind of the building, to the far wake (see Figure 1). The building cavity can be defined as the region bounded above by the separation streamline originating at the upwind edge of the roof, and bounded downwind of the building by the reattachment streamline. The cavity is bounded laterally by the streamlines emanating from the corners of the building. Depending on the building geometry, there can be a separate roof-top and downwind cavity, or a single recirculation cavity. The cavity downwind of the building is often called the near-wake. The wake beyond the reattachment streamline is called the far wake. The entire wake envelope bounds the building recirculating cavities and the far wake.

<u>Mean Streamline Slope</u>

The formulation for the slope of the mean streamlines is based on the location and maximum height of the roof-top recirculation cavity, the length of the downwind recirculation cavity and the building length scale. It simulates wind-tunnel data which show a region of marked ascent upwind of and over the building extending to the point of maximum height of the roof-top cavity, a region of streamline descent that follows the shape of the upper boundary of near wake, and a region of more gradual streamline descent in the far wake. The slope decreases with height above the building. For example, for a very wide building the descent of the mean streamlines is not as steep as for a narrow building of the same height and length. For two buildings of the same height and width, the descent of the mean streamlines is steeper for the building with the shorter length. The magnitude of the descent changes with wind direction as the projected building width and length change.

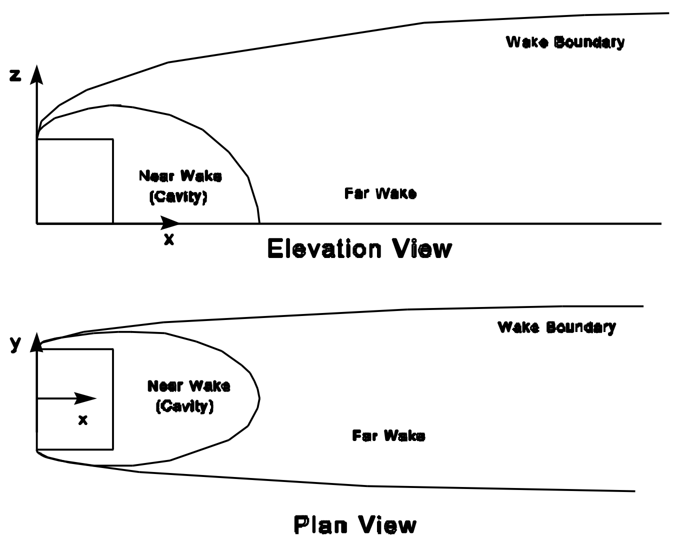

Figure 1. Illustration of wake structure behind a building

Plume Rise

The PRIME plume rise is computed using a numerical solution of the mass, energy and momentum conservation laws. The model allows arbitrary ambient temperature stratification, arbitrary uni-directional wind shear, and arbitrary initial plume size. It includes radiative heat losses and can be run optionally in a non-Boussinesq mode. The implementation of the plume rise model in PRIME allows for streamline ascent/descent effects to be considered, as well as the enhanced dilution due to building induced turbulence. A key feature of the model is its ability to include vertical wind shear effects, which are important for many buoyant releases from short stacks. Additionally, the wind speed deficit induced by the building is modified as a function of downwind distance from the building. The deficit also leads to increased plume rise from short stacks.

Dispersion Coefficients

Enhanced turbulence intensity and velocity deficit values are calculated within the wake region. These values are a maximum at the lee wall of the building and decay with the two-thirds power downwind. A plume released upwind of the wake initially grows at the ambient rate. At the point that the plume intercepts the wake, a probability density function (p. d. f.) model is used for plume dispersion over a distance equal to the length of the near wake, and an eddy diffusivity model for plume growth is used beyond. When the turbulence intensity within the wake has decayed to the ambient rate, a virtual source technique is used to transition to the ISC3 dispersion curves. In the convective boundary layer, or if the plume is intercepted by the wake several building heights downwind, the building effects on plume dispersion may be small and short-lived. Nearer to the building or with neutral and stable approach flows, the building effects will be larger. Both the horizontal and vertical dispersion coefficients are enhanced within the building wake.

Near/Far Wake Concentrations

The near wake concentration is uniform in the x-z plane, with a Gaussian distribution across the flow. The mass for this concentration results from the capture and recirculation by the near wake of some fraction of the elevated primary plume. Using the equations for the height and width of the near wake boundary, the fractions of the vertical plume distribution, f_Z, and the horizontal plume distribution, f_Y, are calculated at many distances along the near wake length. The fraction captured is then estimated as the maximum of the product $f_Z f_Y$. The value of f_Z is capped at the fraction of the plume that lies below the height of the building at the end of the near wake to allow low plumes with momentum or buoyancy to partially or fully escape capture.

Plume mass captured by the near wake is re-emitted to the far wake as a ground-level volume source. The volume source is located at the base of the lee wall of the building, but is only evaluated near the end of the near wake and beyond. Its initial σ_y is proportional to the projected building width, and the initial σ_z is calculated by matching the peak concentration in the near wake, and conserving mass flux. The portion of the primary elevated plume that is not captured by the near wake is modeled with the reduced (complementary) mass flux.

2. Instructions for Running ISC3-PRIME

ISC3-PRIME uses the standard ISCST3 input files with few modifications. These modifications allow the specification of three new inputs used to describe the building/stack configuration. Therefore, only the source pathway (SO) has changed. Note that building downwash using the PRIME algorithms is applied within the existing framework of ISCST3, and so nearly all of the familiar restrictions remain (e.g. downwash algorithms do not apply to volume, area or open pit sources). The notable exception is that concentrations are now computed in the cavity region.

The new variables are entered using the keywords:

BUILDLEN	projected length of the building along the flow
XBADJ	along-flow distance from the stack to the center of the upwind face of the projected building
YBADJ	across-flow distance from the stack to the center of the upwind face of the projected building

These are defined in Figure 2. Values for each 10-degree flow sector must be provided.

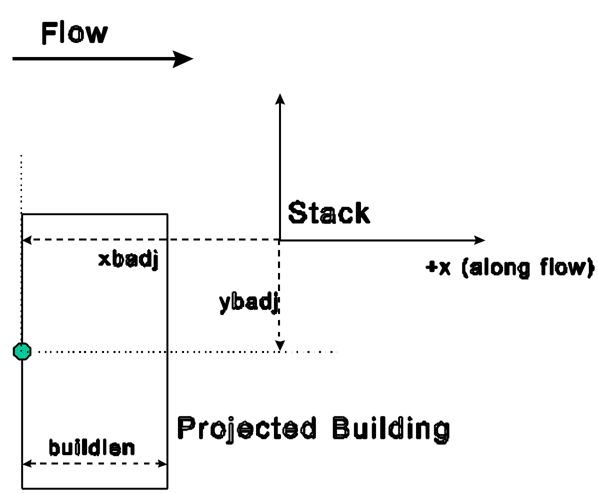

Figure 2. Schematic identifying new building data for PRIME.

Procedures for obtaining projected building data remain the same, and for convenience, the BPIP processor has been modified to output the new variables (see the example in Section 3). The syntax, type and order for all of the direction-specific building data are the same, as illustrated for the BUILDLEN keyword, used to input direction specific building lengths:

Syntax:	SO BUILDLEN Srcid (or Srcrng) Dsbl (i), i=1, 36 (16 for LT)
Type:	Optional, Repeatable
Order:	Must follow the LOCATION card for each source input

The following notes are reproduced from the ISC3 Users Guide. Note that the discussion refers to entering building heights rather building lengths, but the process is identical.

The Srcid parameter is the same source ID that was entered on the LOCATION card for a particular source. The user also has the option of specifying a range of sources (the Srcrng parameter) for which the building heights apply, instead of identifying a single source. This is accomplished by two source ID character strings separated by a dash, e.g., STACK1-STACK10. Since the model reads the source range as a single input field there must not be any spaces between the source IDs. The model then places the building heights that follow (the Dsbh(i) parameter) into the appropriate arrays for all Srcid's that fall within that range, including STACK1 and STACK10.

When comparing a source ID to the range limits for a Srcrng parameter, the model separates the source IDs into three parts: an initial alphabetical part, a numerical part, and then the remainder of the string. Each part is then compared to the corresponding parts of the source range, and all three parts must satisfy the respective ranges in order for the source ID to be included. If there is no numeric part, then the ID consists of only one alphabetical part. If the ID begins with a numeric character, then the initial alphabetical part defaults to a single blank. If there is no trailing alphabetical part, then the third part also defaults to a single blank part. If the trailing part consists of more than one alphabetical or numeric field, it is all lumped into one character field. For example, the source ID 'STACK2' consists of the parts 'STACK' plus '2' plus a single trailing blank, ' '. By comparing the separate parts of the source IDs, it can be seen that STACK2 falls between the range 'STACK1-STACK10.' For a three-part example, it can also be seen that VENT1B falls within the range of VENT1A-VENT1C. However, VENT2 does not fall within the range of VENT1A to VENT3B, since the third part of VENT2 is a single blank, which does not fall within the range of A to C. This is because a blank character will precede a normal alphabetical character. Normally, the source ranges will work as one would intuitively expect for simple source names. Most importantly, for names that are made up entirely of numeric characters, such as for old input files converted using STOLDNEW (see Appendix C), the source ranges will be based simply on the relative numerical values. The user is strongly encouraged to check the summary of model inputs to ensure that the source ranges were interpreted as expected, and also to avoid using complex source names in ranges, such as AA1B2C-AB3A3C. Since the order of keywords within the SO pathway is quite flexible, it is also important to note that the building heights will only be applied to those sources that have been defined previously in the input file.

Following the Srcid or the Srcrng parameter, the user inputs 36 direction-specific building heights (Dsbh parameter) in meters for the Short Term model, beginning with the 10 degree flow vector (wind blowing toward 10 degrees from north), and incrementing by 10 degrees in a clockwise direction. For the Long Term model, the Dsbh parameter consists of 16 direction-specific building heights beginning with the flow vector for the north sector, and proceeding clockwise to north-northwest. Some examples of building height inputs are presented below:

```
SO BUILDHGT  STACK 1  34. 34. 34. 34. 34. 34. 34. 34. 34. 34. 34. 34.
SO BUILDHGT  STACK 1  34. 34. 34. 34. 34. 34. 34. 34. 34. 34. 34. 34.
SO BUILDHGT  STACK 1  34. 34. 34. 34. 34. 34. 34. 34. 34. 34. 34. 34.

SO BUILDHGT  STACK 1  36*34

SO BUILDHGT  STACK 1-STACK 10  33*34.0  3*0.0

SO BUILDHGT  STACK 1  35.43  36.45  36.37  35.18  35.92  29.66  25.50  20.56
SO BUILDHGT  STACK 1  15.0   20.56  25.50  29.66  32.92  35.18  36.37  36.45
SO BUILDHGT  STACK 1  35.43  33.33  35.43  36.45   0.00  35.18  32.92  29.66
SO BUILDHGT  STACK 1  25.50  20.56  15.00  20.56  25.50  29.66  32.92  35.18
SO BUILDHGT  STACK 1  36.37  36.45  35.43  33.33
```

The first example illustrates the use of repeat cards if more than one card is needed to input all of the values. The values are processed in the order in which they appear in the input file, and are identified as being repeat cards by repeating the Srcid parameter. The first and second examples produce identical results within the model. The second one illustrates the use of a repeat value that can simplify numerical input in some cases. The field "36*34.0" is interpreted by the model as "repeat the value 34.0 a total of 36 times." This is also used in the third example where the building height is constant for directions of 10 degrees through 330 degrees, and then is set to 0.0 (e.g. the stack may be outside the region of downwash influence) for directions 340 through 360. The third example also uses a source range rather than a single source ID. The last example illustrates building heights which vary by direction, and shows that the number of values on each card need not be the same. For improved readability of the input file, the user may want to put the numerical inputs into "columns," but there are no special rules regarding the spacing of the parameters on this keyword.

The LOWBOUND keyword is no longer used to exercise the non-regulatory default option of calculating "lower bound" concentration or deposition values for downwash sources subject to enhanced lateral plume spread by super-squat buildings (width is more than five times the height). Such a distinction is not made in PRIME. Also, note that PRIME has not been implemented in the long-term model ISCLT, so the associated instructions should be ignored.

3. Example (Test Case)

A test case has been provided to illustrate the application of ISC-PRIME and the modified BPIP. Files needed to run this test case are packaged in a self-extracting ZIP-file named PRIMETST.EXE. After copying this file to a directory on your hard disk, open a DOS window and execute PRIMETST. The following files will be extracted to your disk:

BPIP.INP	Input file for BPIP
BPIP.SUM	Summary output file for BPIP run
BPIP.OUT	Results file for BPIP run
BPIPPRM.EXE	BPIP-PRIME executable file
MET.ASC	ASCII meteorological data file for ISCST runs (1 year)
PRIMETST.INP	Input file for ISC-PRIME test case
PRIMETST.OUT	Results file for ISC-PRIME test case
ISC3P.EXE	ISC-PRIME executable file

The test case addresses the following configuration (see Figure 3):

Building Dimensions (L,W,H)	75, 50, 50 (m)
Building Orientation	Long side aligns N-S
Stack Height	65 (m)
Stack Location1	10 m East of Center of East Wall

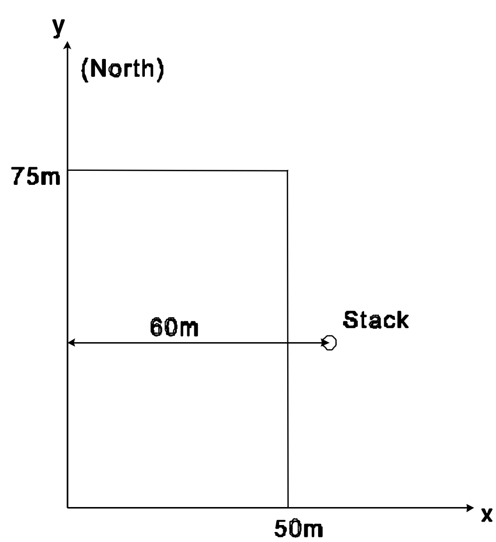

Figure 3. Building/stack configuration for test case.

The input file for BPIP contains the following information:

```
'PRIME test case'
'ST'
'METERS'  1.0
'UTMN'  0.0
   1
'unit1 '         1   0.0
         4    50.00
   0.0     0.0
   0.0    75.0
  50.0    75.0
  50.0     0.0
   1
'unit1'        .00     65.00      60.    37.5
```

This is the standard input file. The output from BPIP_PRIME is:

```
                             BPIP (Dated: 95086)
PRIME test case

============================
BPIP PROCESSING INFORMATION:
============================

The ST flag has been set for processing for an ISCST2 run.

Inputs entered in METERS will be converted to meters using a conversion factor
of 1.0000.  Output will be in meters.

UTMP is set to UTMN.  The input is assumed to be in a local X-Y coordinate
system as opposed to a UTM coordinate system.  True North is in the positive Y
direction.

Plant north is set to   0.00 degrees with respect to True North.

PRIME test case

                 PRELIMINARY* GEP STACK HEIGHT RESULTS TABLE
                           (Output Units: meters)
                          Stack-Building                   Preliminary*
               Stack      Base Elevation       GEP**       GEP Stack
Stack Name     Height     Differences          EQN1        Height Value

Unit 1         65.0       0.00                 125.00      125.00

*   Results are based on Determinants 1 & 2 on pages 1 & 2 of the GEP
    Technical Support Document.  Determinant 3 may be investigated for
    additional stack height credit.  Final values result after Determinant 3
    has been taken into consideration.
**  Results were derived from Equation 1 on page 6 of GEP Technical Support
    Document.  Values have been adjusted for any stack-building base elevation
    differences.

    Note:  Criteria for determining stack heights for modeling emission
    limitations for a source can be found in Table 3.1 of the GEP Technical
    Support Document.
```

```
                        BPIP (Dated: 95086)
DATE :  0/ 0/ 0
TIME :  0: 0: 0


PRIME test case

BPIP output is in meters

SO BUILDHGT Unit 1   50.00   50.00   50.00   50.00   50.00   50.00
SO BUILDHGT Unit 1   50.00   50.00   50.00   50.00   50.00   50.00
SO BUILDHGT Unit 1   50.00   50.00   50.00   50.00   50.00   50.00
SO BUILDHGT Unit 1   50.00   50.00   50.00   50.00   50.00   50.00
SO BUILDHGT Unit 1   50.00   50.00   50.00   50.00   50.00   50.00
SO BUILDHGT Unit 1   50.00   50.00   50.00   50.00   50.00   50.00
SO BUILDWID Unit 1   62.26   72.64   80.80   86.51   89.59   89.95
SO BUILDWID Unit 1   87.58   82.54   75.00   82.54   87.58   89.95
SO BUILDWID Unit 1   89.59   86.51   80.80   72.64   62.26   50.00
SO BUILDWID Unit 1   62.26   72.64   80.80   86.51   89.59   89.95
SO BUILDWID Unit 1   87.58   82.54   75.00   82.54   87.58   89.95
SO BUILDWID Unit 1   89.59   86.51   80.80   72.64   62.26   50.00
SO BUILDLEN Unit 1   82.54   87.58   89.95   89.59   86.51   80.80
SO BUILDLEN Unit 1   72.64   62.26   50.00   62.26   72.64   80.80
SO BUILDLEN Unit 1   86.51   89.59   89.95   87.58   82.54   75.00
SO BUILDLEN Unit 1   82.54   87.58   89.95   89.59   86.51   80.80
SO BUILDLEN Unit 1   72.64   62.26   50.00   62.26   72.64   80.80
SO BUILDLEN Unit 1   86.51   89.59   89.95   87.58   82.54   75.00
SO XBADJ    Unit 1  -47.35  -55.76  -62.48  -67.29  -70.07  -70.71
SO XBADJ    Unit 1  -69.21  -65.60  -60.00  -65.60  -69.21  -70.71
SO XBADJ    Unit 1  -70.07  -67.29  -62.48  -55.76  -47.35  -37.50
SO XBADJ    Unit 1  -35.19  -31.82  -27.48  -22.30  -16.44  -10.09
SO XBADJ    Unit 1   -3.43    3.34   10.00    3.34   -3.43  -10.09
SO XBADJ    Unit 1  -16.44  -22.30  -27.48  -31.82  -35.19  -37.50
SO YBADJ    Unit 1   34.47   32.89   30.31   26.81   22.50   17.50
SO YBADJ    Unit 1   11.97    6.08    0.00   -6.08  -11.97  -17.50
SO YBADJ    Unit 1  -22.50  -26.81  -30.31  -32.89  -34.47  -35.00
SO YBADJ    Unit 1  -34.47  -32.89  -30.31  -26.81  -22.50  -17.50
SO YBADJ    Unit 1  -11.97   -6.08    0.00    6.08   11.97   17.50
SO YBADJ    Unit 1   22.50   26.81   30.31   32.89   34.47   35.00
```

The new variables BUILDLEN, XBADJ, and YBADJ are added to the standard variables BUILDHGT and BUILDWID, and are reported in the same format. Data for each start with flow towards 10 degrees CW from North, and are reported at 10 degree intervals. A flow direction of 90 degrees places the flow along the x-axis shown in Figure 2, so that the actual building dimensions are recovered. For this direction, the center of the upwind face of the projected building lies60 m upwind of the source, so xbadj (measured positive along the flow) is -60 m, and ybadj is 0 m. For a flow direction of 270 degrees, the center of the upwind face of the projected building lies 10 m downwind of the source, soxbadj is 10 m.

The data records from BPIP.OUT are copied directly into the ISC-PRIME input file, to the SO pathway. Everything else in the file is the same as that used in a standard ISCST run. The user should run the test case to verify its implementation.

```
PRIMETST.INP:
```

```
CO STARTING
CO TITLEONE Test case for PRIME
CO MODELOPT CONC DFAULT RURAL
CO AVERTIME 3 24 PERIOD
CO POLLUTID SO2
CO RUNORNOT RUN
CO FINISHED

SO STARTING
**                              X       Y       Z
SO LOCATION  Unit1   POINT    0.0     0.0     0.0

**                     Q        HS      T      W     D
SO SRCPARAM  Unit1   500.00   65.00   425.   15.0   5.

SO BUILDHGT Unit 1    50.00   50.00   50.00   50.00   50.00   50.00
SO BUILDHGT Unit 1    50.00   50.00   50.00   50.00   50.00   50.00
SO BUILDHGT Unit 1    50.00   50.00   50.00   50.00   50.00   50.00
SO BUILDHGT Unit 1    50.00   50.00   50.00   50.00   50.00   50.00
SO BUILDHGT Unit 1    50.00   50.00   50.00   50.00   50.00   50.00
SO BUILDHGT Unit 1    50.00   50.00   50.00   50.00   50.00   50.00
SO BUILDWID Unit 1    62.26   72.64   80.80   86.51   89.59   89.95
SO BUILDWID Unit 1    87.58   82.54   75.00   82.54   87.58   89.95
SO BUILDWID Unit 1    89.59   86.51   80.80   72.64   62.26   50.00
SO BUILDWID Unit 1    62.26   72.64   80.80   86.51   89.59   89.95
SO BUILDWID Unit 1    87.58   82.54   75.00   82.54   87.58   89.95
SO BUILDWID Unit 1    89.59   86.51   80.80   72.64   62.26   50.00
SO BUILDLEN Unit 1    82.54   87.58   89.95   89.59   86.51   80.80
SO BUILDLEN Unit 1    72.64   62.26   50.00   62.26   72.64   80.80
SO BUILDLEN Unit 1    86.51   89.59   89.95   87.58   82.54   75.00
SO BUILDLEN Unit 1    82.54   87.58   89.95   89.59   86.51   80.80
SO BUILDLEN Unit 1    72.64   62.26   50.00   62.26   72.64   80.80
SO BUILDLEN Unit 1    86.51   89.59   89.95   87.58   82.54   75.00
SO XBADJ    Unit 1   -47.35  -55.76  -62.48  -67.29  -70.07  -70.71
SO XBADJ    Unit 1   -69.21  -65.60  -60.00  -65.60  -69.21  -70.71
SO XBADJ    Unit 1   -70.07  -67.29  -62.48  -55.76  -47.35  -37.50
SO XBADJ    Unit 1   -35.19  -31.82  -27.48  -22.30  -16.44  -10.09
SO XBADJ    Unit 1    -3.43    3.34   10.00    3.34   -3.43  -10.09
SO XBADJ    Unit 1   -16.44  -22.30  -27.48  -31.82  -35.19  -37.50
SO YBADJ    Unit 1    34.47   32.89   30.31   26.81   22.50   17.50
SO YBADJ    Unit 1    11.97    6.08    0.00   -6.08  -11.97  -17.50
SO YBADJ    Unit 1   -22.50  -26.81  -30.31  -32.89  -34.47  -35.00
SO YBADJ    Unit 1   -34.47  -32.89  -30.31  -26.81  -22.50  -17.50
SO YBADJ    Unit 1   -11.97   -6.08    0.00    6.08   11.97   17.50
SO YBADJ    Unit 1    22.50   26.81   30.31   32.89   34.47   35.00

SO SRCGROUP ALL
SO FINISHED

RE STARTING
RE GRIDPOLR unit1 STA
                  ORIG unit1
                  DIST 175. 350. 500. 1000.
                  GDIR 36 10 10
RE GRIDPOLR unit1 END
RE FINISHED

ME STARTING
ME INPUTFIL met.asc
ME ANEMHGHT 10.
ME SURFDATA 14739 1990
ME UAIRDATA 14764 1990
```

```
ME FINISHED

OU STARTING
OU RECTABLE 3  first
OU RECTABLE 24 first
OU MAXTABLE ALLAVE 50
OU FINISHED
```

4. References

Schulman, L.L., D.G. Strimaitis, and J.S. Scire (1998). Development and Evaluation of the PRIME Plume Rise and Building Downwash Model. Submitted to *Journal of the Air & Waste Management Association.*