AERMOD for NON-MODELERS,
Part 1 - Fundamentals

Anthony J. Sadar, CCM
Allegheny County Health Department
Air Quality Program

March 31, 2017
Overview

- THE ATMOSPHERE
  - Constituents
  - Structure
- ATMOSPHERIC DYNAMICS
  - Temporal/spatial scale of events
- AIR POLLUTION DISPERSION
  - Sources → Dispersion → Receptors
- AIR DISPERSION MODELING
  - Observation—Theory—Models
  - Receptors = Sources / Dispersion
  - $C = \frac{Q S}{U}$
  - Empirical research
  - Statistical approach: $\chi = \frac{q}{(\pi u \sigma_y \sigma_z)}$ ...
Overview (Continued)

- **US EPA GUIDELINES**
  
  *Guideline on Air Quality Models (Revised), Appdx. W*

  Other guidance/clarification

- **AERMOD & AERSCREEN**
  
  Input requirements
  
  Output examples
  
  Interpretation of results
  
  Comparison between AERMOD and AERSCREEN

- **ADDITIONAL MODELS & APPLICATIONS**
  
  Requirements for regulatory modeling
The Atmosphere

- Constituents
- Structure
## Constituents

<table>
<thead>
<tr>
<th></th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Permanent</strong></td>
<td></td>
</tr>
<tr>
<td>Nitrogen (N₂)</td>
<td>78.1</td>
</tr>
<tr>
<td>Oxygen (O₂)</td>
<td>20.9</td>
</tr>
<tr>
<td>Argon (Ar)</td>
<td>0.9</td>
</tr>
<tr>
<td>Neon (Ne)</td>
<td>0.002</td>
</tr>
<tr>
<td><strong>Variable</strong></td>
<td></td>
</tr>
<tr>
<td>Water Vapor (H₂O)</td>
<td>0 - 4</td>
</tr>
<tr>
<td>Carbon Dioxide (CO₂)</td>
<td>0.04</td>
</tr>
<tr>
<td>Helium (He)</td>
<td>0.0005</td>
</tr>
<tr>
<td>Methane (CH₄)</td>
<td>0.0002</td>
</tr>
<tr>
<td>Krypton (Kr)</td>
<td>0.0001</td>
</tr>
</tbody>
</table>
Temperature changes with increasing altitude in atmosphere.
Atmospheric Boundary Layer (ABL)

- Bottom layer of troposphere starting at earth’s surface and extending to several km during sunny afternoons.
- Structure and height of ABL varies diurnally, during fair weather over land:
  - From tens of meters on mornings with a strong surface temperature inversion (when temperature increases with altitude) to several kilometers during sunny afternoons.
Atmospheric Dynamics

- Temporal/Spatial Scales of Events

Conditions of Note

- Topography
  - “Heat Island” Effect (Urban/Rural)
  - Land/Water (Diurnal “Sea Breeze”/“Land Breeze”)
  - Mountain/Valley (Diurnal Effects and Channeling)
- Elevation
Conditions of Note (Continued)

- Overview

Conditions of Note (Continued)

- Topography

Poll Question #1

- The Heat Island Effect occurs in the Atmospheric Boundary Layer. (True/False)
Poll Question #2

- Turbulence is a meso-scale temporal event. (True/False)
Air Pollution Dispersion

- Transport and Diffusion of Air Pollution

- Sources → Dispersion → Receptors
  - Sources include discharges from Points (stacks), Lines (roadways), Areas (fields), Volumes (stockpiles), et al.
  - Dispersion primarily includes wind and stability conditions
  - Receptors typically include populations within ~10 km of a source
Air Dispersion Modeling

• What is Modeling?

• Modeling Components:
  - Source considerations
  - Dispersion considerations
  - Receptor considerations
What Is Modeling?

- A scientific “model” is a tentative representation of an observation based on interpretation of available information; a tool used to simulate real-world conditions.

- “Air-dispersion modeling,” as described by the EPA, “uses mathematical formulations to characterize atmospheric processes that disperse a pollutant emitted by a source. Based on emissions and meteorological inputs, a dispersion model can be used to predict concentrations at selected downwind receptor locations.”

- Note that “verification of the truth of any model is an impossible task” (ASTM International, D6589–05, 2010).

- Models contain assumptions and limitations.
What Is Modeling? (Continued)

Adapted from: Numerical Weather and Climate Prediction, T. T. Warner, 2011, Fig. 1.1, p. 3.
Modeling Components

Sources → Dispersion → Receptors
Whence Highest Concentrations?

- Large Emission Rate
- Low Plume Rise
- Overlapping Plumes
- Stack-Tip Downwash
- Building-Induced Downwash
- Building Cavity
Whence Highest Conc.? (Continued)

- Proximity to Source(s)
- Terrain-Induced Downwash and Channeling
- High Terrain
- Short Ground Cover
- Stable/Stagnant Atmosphere
- Steady Wind Direction from Source(s) to Receptor(s)
Source Considerations

“Worst-case” conditions for emissions:

- Maximum particle/gas discharge
- Lowest release height
- Lowest in-vent/in-stack temperature
- Lowest exit gas velocity
- Shortest distance to property line
Dispersion Considerations

“Worst-case” meteorology:

- No precipitation
- Light winds from source to critical receptor(s)
- Strong ground-based temperature inversion (elevated inversion can also cause problems)

Note: Wind Direction is direction from which wind is blowing.
Receptor Considerations

“Worst-case” conditions for receptors:

- Closest, highest off-site location
- Plume centerline concentrations
- Elevated receptor for malodor investigations
Simple Relationship

- Sources $\rightarrow$ Dispersion $\rightarrow$ Receptors

- Receptors = Sources / Dispersion

  $\textit{or}$  
  \[ R = \frac{S}{D} \]
Simple Dispersion Formula

\[ C = \frac{Q^x S}{U} \]

Where,  
- \( C \) is pollutant concentration (g/m\(^3\))
- \( Q \) is rate of emissions exiting source (g/s)
- \( S \) is stability of atmosphere (m\(^{-2}\))
- \( U \) is horizontal wind speed (m/s)
How Does Emission Rate Affect C?

\[ C = \frac{Q^x S}{U} \]
How Does Wind Speed Affect C?

\[ C = \frac{Q_x S}{U} \]
Poll Question #3

- All else being equal, a pollutant concentration at a nearby receptor will be higher with a higher stack. (True/False)
Poll Question #4

- All else being equal, a pollutant concentration at a nearby receptor will be lower at low wind speed. (True/False)

\[ C = \frac{Q^x S}{U} \]
How Does Stability Affect $C$?

$$C = \frac{Q^x S}{U}$$
Traditionally, stability of lower atmosphere has been delineated as:

<table>
<thead>
<tr>
<th>Classification</th>
<th>Definition</th>
<th>Typical Weather Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Strong Instability</td>
<td>Sunny with sun ≥60° above horizon, light winds</td>
</tr>
<tr>
<td>B</td>
<td>Moderate Instability</td>
<td>Sunny with sun between 35° and 60° above horizon, light winds</td>
</tr>
<tr>
<td>C</td>
<td>Slight Instability</td>
<td>Partly sunny with sun 15° to 35° above horizon, light to moderate winds</td>
</tr>
<tr>
<td>D</td>
<td>Neutral Stability</td>
<td>Cloudy skies day or night, winds at any speed or clear skies with moderate to strong winds</td>
</tr>
<tr>
<td>E</td>
<td>Slight Stability</td>
<td>Night: Mostly cloudy, light winds</td>
</tr>
<tr>
<td>F</td>
<td>Moderate Stability</td>
<td>Night: Partly cloudy or clear, light winds</td>
</tr>
</tbody>
</table>
Smokestack emissions that continuously exhaust to the ambient air are referred to as “plumes.” Plumes exhibit particular patterns depending upon atmospheric stability.
Plume Types

<table>
<thead>
<tr>
<th>Classification</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Strong Instability</td>
</tr>
<tr>
<td>B</td>
<td>Moderate Instability</td>
</tr>
<tr>
<td>C</td>
<td>Slight Instability</td>
</tr>
<tr>
<td>D</td>
<td>Neutral Stability</td>
</tr>
<tr>
<td>E</td>
<td>Slight Stability</td>
</tr>
<tr>
<td>F</td>
<td>Moderate Stability</td>
</tr>
</tbody>
</table>
Simple Dispersion Formula

\[ C = \frac{Q \times S}{U} \]

Where,  
\( C \) is pollutant concentration (g/m³)  
\( Q \) is rate of emissions exiting source (g/s)  
\( S \) is stability of atmosphere (m⁻²)  
\( U \) is horizontal wind speed (m/s)
Field observations suggested that smokestack emissions disperse in a “normal” way; that is, pollutants spread away from a centerline with a typical bell-shaped or Gaussian frequency distribution.
Plume Observations

Source: Hanna, et al., 1982

Fig. 4.9 Comparison of short- and long-term average plume position.
Statistical Approach

Bell-shaped Curve, Normal, or Gaussian Distribution

Source: http://scalesstudy.wordpress.com/2012/07/27/my-running-disorder/
Statistical Approach (Continued)

Probability Density Function:

\[ y = \frac{1}{\sigma (2\pi)^{1/2}} \exp\left[-0.5 \left(\frac{(x-\mu)^2}{\sigma^2}\right)\right] \]

Compare with the fundamental Gaussian plume equation:

\[ \chi = \frac{q}{\sigma_y \sigma_z (\pi) u} \exp\left[-0.5 \left(\frac{H^2}{\sigma_z^2}\right)\right] \]
Gaussian Plume Model

Source: www.lete.poli.usp.br/Guenther/aula_4/Plumes.pdf
The bell-shaped curves represent a distribution of contaminants across the horizontal (cross-wind) and vertical axis.

Fundamental Gaussian Plume Equation:

\[ \chi = \frac{q}{\left(\pi u \sigma_y \sigma_z\right)} \exp \left[-0.5 \left(\frac{H^2}{\sigma_z^2}\right)\right] \]
Gaussian Distribution (Continued)

Fundamental Gaussian Plume Equation:

$$\chi = \frac{q}{(\pi u \sigma_y \sigma_z)} \exp \left[-0.5 \left(\frac{H^2}{\sigma_z^2}\right)\right]$$

$$C = \frac{Q_x S}{U}$$

Where, $\chi =$ ambient air concentration (g/m$^3$),
$q =$ emission rate (g/s), $\pi = 3.1416$, $u =$ wind speed (m/s), $\sigma_y \sigma_z =$ dispersion parameters (m$^2$), and $H =$ effective plume height (m).
Gaussian Plume Cross Section

Fig. 4.2 Cross section through Gaussian plume with $\sigma_y = 20 \text{ m}$, $\sigma_z = 10 \text{ m}$, and centerline concentration of 1.0.

Source: Hanna, et al., 1982
Poll Question #5

- If a plume concentration is distributed normally, pollutant concentration will be highest along the centerline. (True/False)
Dispersion Parameters ($\sigma_y$ and $\sigma_z$)

Figure 3.2. Horizontal dispersion coefficient as a function of downwind distance from the source.

Figure 3.3. Vertical dispersion coefficient as a function of downwind distance from the source.

Source: Turner, 1970
Good Engineering Practice Stack Height ($H_{GEP}$)

$H_{GEP}$ is the greater of:

- 65 meters
- For stacks built before 1/12/1979: $H_{GEP} = 2.5 \times H$, where $H$ is height of nearby structure(s)
- For all other stacks: $H_{GEP} = H + 1.5 \times L$, where $L$ is lesser of $H$ or projected width of nearby structure(s).
- Height demonstrated by an approved fluid model or field study
Fig. 5.17 — General arrangement of flow zones near a sharp-edged building.

Flow Around Buildings

Slide adapted from: Sec. 5-5 by Halitsky, 1968 in Slade, 1968
Flow Around Buildings (Continued)

Figure 5-2 – Building Downwash

Source: Saskatchewan Air Quality Modeling Guideline, March 2012
Plume rise is also important to pollution dispersal. Plume rise is primarily a function of exit gas temperature and momentum. Generally,

- Higher temperature = higher plume rise.
- Higher momentum = higher plume rise.
- Higher plumes = lower ground-level pollutant concentrations.
Poll Question #6

- Buildings can cause plume downwash. (True/False)
Types of Mathematical Air Quality Models

- *Lagrangian models* simulate dispersion or reactions in parcels of air that move along with the wind trajectory.

- *Eulerian* approaches divide the problem domain into fixed grid cells. Various methods are then used to solve equations over the full domain.
Which Models Use Which Math?

- **Lagrangian models**
  - Dispersion models (e.g., AERMOD, SCICHEM)
  - Trajectory models (e.g., HYSPLIT)

- **Eulerian**
  - Photochemical grid models (e.g., CMAQ, CAMx)

Slide adapted from: Julie McDill, MARAMA
Summary

- **THE ATMOSPHERE**
  - Constituents
  - Structure

- **ATMOSPHERIC DYNAMICS**
  - Temporal/spatial scale of events

- **AIR POLLUTION DISPERSION**
  - Sources → Dispersion → Receptors

- **AIR DISPERSION MODELING**
  - Observation—Theory—Models
  - Receptors = Sources / Dispersion
  - C = QS / U
  - Empirical research
  - Statistical approach: $\chi = q / (\pi u \sigma_y \sigma_z)$...
Topics for Part 2 (April 7, 2017)

- US EPA GUIDELINES
  - Guideline on Air Quality Models, Appdx. W
  - Preferred and Recommended Dispersion Models
  - Examples of Other Models (CAMx and WRF)
- AERMOD & AERSCREEN
  - Input requirements
  - Output examples
  - Comparison between AERMOD and AERSCREEN
- AERSCREEN Operation
- MODELING GUIDANCE AND SUPPORT
References
Links to Resources

- **Practical Meteorology, 2015:**
  [https://www.eoas.ubc.ca/books/Practical_Meteorology/](https://www.eoas.ubc.ca/books/Practical_Meteorology/)

- **Meteorology and Atomic Energy 1968:**

- **Workbook of Atmospheric Dispersion Estimates, 1970:**

- **Handbook on Atmospheric Diffusion, 1982:**

- **Handbook of Atmospheric Science: Principles and Applications, 2003:**

- **EPA’s Support Center for Regulatory Atmospheric Modeling (SCRAM) Website:**
  [https://www.epa.gov/scram](https://www.epa.gov/scram)

- **“Guideline on Air Quality Models” (40 CFR 51):**
  [https://www3.epa.gov/ttn/scram/appendix_w/2016/AppendixW_2017.pdf](https://www3.epa.gov/ttn/scram/appendix_w/2016/AppendixW_2017.pdf)
QUESTIONS & ISSUES

Anthony.Sadar@AlleghenyCounty.US
AERMOD for NON-MODELERS, Part 2 - Overview

Anthony J. Sadar, CCM
Allegheny County Health Department
Air Quality Program

April 7, 2017
Review

- THE ATMOSPHERE
  - Constituents
  - Structure

- ATMOSPHERIC DYNAMICS
  - Temporal/spatial scale of events

- AIR POLLUTION DISPERSION
  - Sources → Dispersion → Receptors

- AIR DISPERSION MODELING
  - Observation—Theory—Models
  - Receptors = Sources / Dispersion
  - C = QS / U

Empirical research

Statistical approach: \( \chi = \frac{q}{\pi u \sigma_y \sigma_z} \)...
Topics for Today

- US EPA GUIDELINES
  
  *Guideline on Air Quality Models, Appdx. W*
  Preferred and Recommended Dispersion Models
  Examples of Other Models (CAMx and WRF)

- AERMOD & AERSCREEN
  
  Input requirements
  Output examples
  Comparison between AERMOD and AERSCREEN

- AERSCREEN Operation

- MODELING GUIDANCE AND SUPPORT
Guideline on Air Quality Models
"Appendix W" – 40 CFR 51, January 17, 2017

- AERMOD is Preferred Dispersion Model
  Out to 50 km

https://www3.epa.gov/ttn/scram/appendix_w/2016/scram_appendix_w_2016.pdf

"The effective date of this action has been deferred to May 22, 2017."

EPA’s Support Center for Regulatory Atmospheric Modeling (SCRAM) Website

https://www.epa.gov/scram
EPA “Approved” Models

- **AERMOD**
  - AMS/EPA Regulatory Model

- **CAMx**
  - Comprehensive Air quality Model with extensions

- **CMAQ**
  - Community Multiscale Air Quality model

- **CALPUFF**
  - Originally sponsored by CA Air Resources Board
Types of Mathematical Air Quality Models

- **Lagrangian models** simulate dispersion or reactions in parcels of air that move along with the wind trajectory.

- **Eulerian** approaches divide the problem domain into fixed grid cells. Various methods are then used to solve equations over the full domain.

Slide adapted from: Julie McDill, MARAMA
Which Models Use Which Math?

- **Lagrangian models**
  - Dispersion models (e.g., AERMOD, SCICHEM)
  - Trajectory models (e.g., HYSPLIT)

- **Eulerian**
  - Photochemical grid models (e.g., CMAQ, CAMx)
CAMx Dispersion Model

- Uses nested three-dimensional grids
- Accounts for average species concentration changes over time within each grid cell volume via:
  - Horizontal advection
  - Vertical transport
  - Sub-grid scale turbulent diffusion
  - Dry deposition and wet scavenging
  - Chemical/photochemical reactions
  - Secondary aerosol formation/partitioning
Example of Horizontal Grid Nesting (Fig. 2-2, pg. 2-5)
CAMx Horizontal Grid Nesting

ACHD Proposed CAMx Domain

<table>
<thead>
<tr>
<th>Scale</th>
<th>Grid Size</th>
<th>Coordinates</th>
</tr>
</thead>
<tbody>
<tr>
<td>36 km</td>
<td>148 x 112</td>
<td>(-2736, -2088) to (2592, 1944)</td>
</tr>
<tr>
<td>12 km</td>
<td>174 x 117</td>
<td>( 72, -540) to (2160, 864)</td>
</tr>
<tr>
<td>04 km</td>
<td>54 x 60</td>
<td>(1296, 48) to (1512, 288)</td>
</tr>
<tr>
<td>0.8 km</td>
<td>75 x 60</td>
<td>(1392, 144) to (1452, 192)</td>
</tr>
</tbody>
</table>

Source: ENVIRON
Weather Research and Forecasting (WRF) Model

- State-of-the-science mesoscale numerical weather prediction system developed by NCAR, NOAA, et al.
- Used worldwide for both operational forecasting and atmospheric research
- “Community model” that undergoes continuous evaluation and frequent updates
- Operates like CAMx, using 3-D grid cells
- Coupled with AERMET and AERMOD via the Mesoscale Modeling Interface (MMIF) program
# AERMOD vs. CAMx

<table>
<thead>
<tr>
<th>AERMOD</th>
<th>CAMx</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gaussian, straight line dispersion</td>
<td>Concentrations within 3-D box</td>
</tr>
<tr>
<td>Generally non-reactive plume</td>
<td>Chemical/photochemical reactions</td>
</tr>
<tr>
<td>Impact distance limited to 50 km</td>
<td>Practically unlimited distance</td>
</tr>
<tr>
<td>Models impact from individual sources to specific receptor points</td>
<td>Generally does not model direct impact of point sources to nearby receptors</td>
</tr>
<tr>
<td>Simple construction, direct and quick operation</td>
<td>Complex construction and more sophisticated, time-consuming operation</td>
</tr>
</tbody>
</table>
Poll Question #7

- CAMx is typically used for permit modeling of stationary industrial sources. (True/False)
What is *Dispersion* Modeling?

- **Lagrangian Model**
- **Purpose:** Estimate effect of
  - local sources
  - near-field receptors
  - local atmosphere
  - pollutants **not** affected by chemical transformation
- **Example:** AERMOD

Slide adapted from: Julie McDill, MARAMA
AERMOD modeling system

- Regulatory components
  - AERMOD: dispersion model
  - AERMAP: terrain processor
  - AERMET: meteorological processor
  - BPIPPRIME: building processor

- Non-regulatory component
  - AERSURFACE: surface characteristics processor for AERMET
  - AERMINUTE: ASOS 1-minute wind processor for AERMET
  - AERSCREEN: screening version of AERMOD

Recall: Sources → Dispersion → Receptors
AERMOD Modeling System Algorithms

- Dispersion in Convective and Stable ABLs
- Plume Rise and Buoyancy
- Plume Incursion Into Elevated Inversions and Re-entrainment
- Computation of Vertical Profiles of Temp., Wind, and Turbulence
- Site-specific Meteorology Beneficial
- Prognostic Meteorological Data Acceptable (e.g., WRF/MMIF)
AERMOD System Algorithms (Continued)

- Urban Nighttime Boundary Layer
- Receptor Considerations On All Types of Terrain
- Building Wake Effects
- Improvement in Characterizing Basic ABL Parameters
- Treatment of Plume Meander
Poll Question #8

- AERMOD is usually used for permit modeling of stationary industrial sources. (True/False)
Poll Question #9

- For modeling demonstrations, site specific meteorology is preferred if available. (True/False)
AERMOD Run Example

- How Is AERMOD Used In Regulatory Work, Such As SIP Preparation?
Allegheny County SO$_2$ NAA

City of Clairton
City of Duquesne
City of McKeesport
Borough of Braddock
Borough of Dravosburg
Borough of East McKeespo
Borough of East Pittsburgh
Borough of Elizabeth
Borough of Glassport
Borough of Jefferson Hills
Borough of Liberty
Borough of Lincoln
Borough of North Braddock
Borough of Pleasant Hills
Borough of Port Vue
Borough of Versailles
Borough of Wall
Borough of West Elizabeth
Borough of West Mifflin
Elizabeth Township
Forward Township
North Versailles Township
AERMOD Example Output

Modeling Results for 2011 (Contours every 100 µg/m$^3$)

a. NWS Surface and Upper Air
b. Liberty Surface with NWS Upper Air

c. Liberty with BETA LowWind2*
d. WRF/MMIF

* Note: Liberty with LowWind1 yielded similar results.

Slide adapted from: ACHD’s AWMA Presentation, 2014
"Q-Q Plot" of Results

Observed data excludes periods when desulfurization breakdowns occurred (not modeled).

Note: AERMOD concentrations include calm hours. Calm hours lead to impacts of 0.0 μg/m³ for all receptors in AERMOD.

Source: ACHD’s AWMA Presentation, 2014
AERMOD Performance for complex terrain

LOVETT SO2 COMPLEX TERRAIN EVALUATION
Q-Q Plot of 1-Hour Concentrations

10/20/2011
U.S. Environmental Protection Agency

Source: U.S.EPA
AERMOD & AERSCREEN

- Comparison between AERMOD and AERSCREEN
AERMOD vs. AERSCREEN Input

---

**STACKDATA**

**Emission Rate:** 1.0000 g/s
**Stack Height:** 108.90 meters 357.80 feet
**Stack Diameter:** 9.300 meters 30.50 inches
**Stack Temperature:** 395.34 K 79.30 Deg F
**Exit Velocity:** 13.9000 m/s 44.71 ft/s

**Stack Flow Rate:** 6248 SCFM

**Model Data:**
- **Dist to Ambient Air:** 30.00 meters 120.00 feet
- **Stack Height:** 108.90 meters 357.80 feet
- **Stack Diameter:** 9.3000 meters 30.50 inches
- **Stack Temperature:** 395.34 K 79.30 Deg F
- **Exit Velocity:** 13.9000 m/s 44.71 ft/s

**BUILDING DATA**

**Building Height:** 34.00 meters 112.00 feet
**Max Building Dimension:** 120.00 meters 393.00 feet
**Min Building Dimension:** 60.00 meters 196.00 feet
**Building Orientation:** 90.00 degrees
**Stack Direction:** 29.00 degrees
**Stack Distance:** 67.00 meters 219.00 feet

**TERRAIN DATA**

Input coordinates are UTM Source Longitude: 86.868500 deg 579000.00 North Source Latitude: 44.399700 deg 610000.00 West UTM Zone: 17

**METEOROLOGY DATA**

**Min/Max Temperature:** 261.4 / 313.1 K 10.9 / 103.9 Deg F
**Minimum Wind Speed:** 1.5 m/s
**Anemometer Height:** 100.00 meters

**AEERSCREEN output file:** AEERSCREEN.OUT

---

AEERSCREEN Run is Ready to Begin - Choose Option to Proceed 

1. Change Source Data;
2. Change Building Data;
3. Change Terrain Data;
4. Change Meteorology Data;
5. Change Title;
6. Change Output Filename;
7. Stop AEERSCREEN;
8. Hit (Enter) to Start Run
Output examples

** AERMOD **

*** AERMOD - VERSION 12345 ***
*** Power Station - Pennsylvania ***
*** Evaluation of Compliance with the 1-hour NAAQS for SO2 ***
*** 08/20/13 ***
*** 11:23:05 ***
**MCDEL0PTs: RegDFULT CONC ELEV ***

** THE SUMMARY OF MAXIMUM 4TH-HIGHEST MAX DAILY 1-HR RESULTS AVERAGED OVER 5 YEARS ***

** CONC OF SO2 IN MICROGRAMS/M**3 **

<table>
<thead>
<tr>
<th>GROUP ID</th>
<th>AVERAGE CONC</th>
<th>RECEPTOR (XR, YR, 2ELEV, 2HILL, ZFLAG) OF TYPE</th>
<th>NETWORK</th>
<th>GRID-ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALLOW</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1ST HIGHEST VALUE IS 631.61298 AT ( 602669.00, 4487354.00, 403.82, 406.24, 0.00) DC</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2ND HIGHEST VALUE IS 599.09749 AT ( 602669.00, 4487354.00, 396.41, 406.24, 0.00) DC</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3RD HIGHEST VALUE IS 581.73072 AT ( 602669.00, 4487354.00, 387.35, 406.35, 0.00) DC</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4TH HIGHEST VALUE IS 576.56683 AT ( 602669.00, 4487354.00, 402.52, 410.88, 0.00) DC</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5TH HIGHEST VALUE IS 573.60844 AT ( 602669.00, 4487354.00, 390.66, 406.24, 0.00) DC</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6TH HIGHEST VALUE IS 564.01710 AT ( 602669.00, 4487354.00, 365.07, 410.88, 0.00) DC</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7TH HIGHEST VALUE IS 560.29591 AT ( 602669.00, 4487354.00, 391.04, 410.88, 0.00) DC</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8TH HIGHEST VALUE IS 555.15129 AT ( 602669.00, 4487354.00, 396.78, 410.88, 0.00) DC</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9TH HIGHEST VALUE IS 549.04222 AT ( 602669.00, 4487354.00, 352.50, 410.88, 0.00) DC</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10TH HIGHEST VALUE IS 545.95201 AT ( 602669.00, 4487354.00, 379.76, 397.35, 0.00) DC</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

MAXIMUM

<table>
<thead>
<tr>
<th>GROUP ID</th>
<th>AVERAGE CONC</th>
<th>RECEPTOR (XR, YR, 2ELEV, 2HILL, ZFLAG) OF TYPE</th>
<th>NETWORK</th>
<th>GRID-ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>1ST HIGHEST VALUE IS 424.25762 AT ( 602669.00, 4487354.00, 403.82, 406.24, 0.00) DC</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2ND HIGHEST VALUE IS 402.81070 AT ( 602669.00, 4487354.00, 396.41, 406.24, 0.00) DC</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3RD HIGHEST VALUE IS 391.33982 AT ( 602669.00, 4487354.00, 387.35, 406.35, 0.00) DC</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4TH HIGHEST VALUE IS 389.24984 AT ( 602669.00, 4487354.00, 402.52, 410.88, 0.00) DC</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5TH HIGHEST VALUE IS 385.97469 AT ( 602669.00, 4487354.00, 390.66, 406.24, 0.00) DC</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6TH HIGHEST VALUE IS 379.63943 AT ( 602669.00, 4487354.00, 365.07, 410.88, 0.00) DC</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7TH HIGHEST VALUE IS 377.15349 AT ( 602669.00, 4487354.00, 391.04, 410.88, 0.00) DC</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8TH HIGHEST VALUE IS 375.79339 AT ( 602669.00, 4487354.00, 396.78, 410.88, 0.00) DC</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9TH HIGHEST VALUE IS 369.74533 AT ( 602669.00, 4487354.00, 352.50, 410.88, 0.00) DC</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10TH HIGHEST VALUE IS 367.70703 AT ( 602669.00, 4487354.00, 379.76, 397.35, 0.00) DC</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*** RECEPTOR TYPES: GC = GRIDCAST GP = GRIDPOLR DC = DISCCART DP = DISCPOLR ***
## Output examples

**AERSCREEN**

<table>
<thead>
<tr>
<th>CALCULATION PROCEDURE</th>
<th>MAXIMUM 1-HOUR CONC (ug/m³)</th>
<th>SCALED 3-HOUR CONC (ug/m³)</th>
<th>SCALED 8-HOUR CONC (ug/m³)</th>
<th>SCALED 24-HOUR CONC (ug/m³)</th>
<th>SCALED ANNUAL CONC (ug/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ELEVATED TERRAIN</td>
<td>763.3</td>
<td>763.3</td>
<td>686.9</td>
<td>458.0</td>
<td>76.33</td>
</tr>
</tbody>
</table>

**DISTANCE FROM SOURCE**: 127.00 meters directed toward 110 degrees
**RECEPTOR HEIGHT**: 9.10 meters

**IMPACT AT THE AMBIENT BOUNDARY**: 437.5 437.5 393.7 262.5 43.75

**DISTANCE FROM SOURCE**: 30.00 meters directed toward 110 degrees
**RECEPTOR HEIGHT**: 0.70 meters
AERSCREEN Operation

- What is AERSCREEN?
- Model Run Demonstration
What Is AERSCREEN?

- Screening model based on AERMOD
- Estimates "worst-case" 1-hour concentrations from a single source
- Does not need hourly meteorological data (MAKEMET)
- Includes conversion factors to estimate "worst-case" 3-hour, 8-hour, 24-hour, and annual concentrations (Note: These conversion factors are conservative!)
- Estimated concentration = or > than AERMOD
- Degree of conservatism depends on application
What’s So Good About AERSCREEN?

- EPA approved (replaced SCREEN3)
- Provides more realistic, yet typically conservative values
  - more-sophisticated treatment of building wake effects
  - handles winds at 0.5 m/s, et al.
  - incorporates terrain impacts
- Familiar operation
- Quick and easy to run
- But, *plug & chug* can be *GI/GO*
AERSCREEN vs. SCREEN3

- Building Wake Effects Modeled With BPIIPPRM
- Incorporates More Detailed Meteorology
  - Albedo, Bowen Ratio, Surface Roughness
- More-Realistic/Site-Specific Terrain Impacts Modeled
AERSCREEN results are generally more conservative than AERMOD results. (True/False)
AERMOD & AERSCREEN Comparison

- AERMOD simulates numerous sources simultaneously while AERSCREEN is limited to a single source
- Both models:
  - Vertical or horizontal stack, capped stack, rectangular or circular area, flare stack, volume release
  - Building downwash option
- AERSCREEN results typically more conservative than AERMOD results
Operation Of AERSCREEN

- Interactive command-prompt application that runs via interfaces with: site-specific matrix of meteorology, terrain and building input, and AERMOD
- Release conditions: Vertical uncapped or capped stack, horizontal stack, rectangular or circular area, flare, or volume source
- Models NO$_x$ to NO$_2$ conversion

“Default” values
- When in doubt... follow the instructions
- “The Usual Suspects” (typical pitfalls)
- Does the answer make sense?
“Default” Values

- Model Mode = Rural (+ try Urban)
- Min/Max Temperatures = 250.0 K / 310.0 K
- Stack Temperature = “0,” for ambient temperature
- Minimum Wind Speed = 0.5 m/s
- Anemometer Height = 10.0 m
- Surface Characteristics = “2,” AERMET seasonal tables
- Dominant Surface Profile = “6,” grassland (+ try others)
- Dominant Climate Type = “1,” Average Moisture
- Others
“The Usual Suspects”

- Mistyping
- Misconstruing instructions
- Mixed or incorrect units
- Mis-assigning file names or extensions
- Misunderstanding “wind direction”
- Others

*Don’t Forget to Ask Yourself:* Does the answer make sense?
Modeling Issues

- Malodors
- Air toxics
- “Guideline on Air Quality Models,” 40 CFR Part 51, Appendix W
- Others
Before using AERSCREEN, users must have the latest AERMOD executable ("16216r" or later) AERMAP terrain preprocessor BPIPEPRIME executables. These can be downloaded from the AERMOD Modeling System section. [Source: SCRAM Website.]

https://www.epa.gov/scram
Nominal Industrial Source
Example Input File (AERSCREEN 11126)

<table>
<thead>
<tr>
<th></th>
<th>METRIC</th>
<th>ENGLISH</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>STACKDATA</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extension Rate</td>
<td>1.8980 g/s</td>
<td>4.222 lb/hr</td>
</tr>
<tr>
<td>Stack Height</td>
<td>100.00 meters</td>
<td>328.08 feet</td>
</tr>
<tr>
<td>Stack Diameter</td>
<td>9.5000 meters</td>
<td>374.01 inches</td>
</tr>
<tr>
<td>Stack Temperature</td>
<td>300.0 K</td>
<td>572.0 Deg F</td>
</tr>
<tr>
<td>Exit Velocity</td>
<td>15.000 m/s</td>
<td>59.21 ft/s</td>
</tr>
<tr>
<td>Stack Flow Rate</td>
<td>37400 SCFM</td>
<td></td>
</tr>
<tr>
<td>Model Mode</td>
<td>Rural</td>
<td></td>
</tr>
<tr>
<td>Dist to Ambient Air</td>
<td>30.0 meters</td>
<td>98.0 feet</td>
</tr>
</tbody>
</table>

| **BUILDING DATA**    |        |         |
| Building Height      | 34.0 meters | 111.5 feet |
| Max Building Dimension | 120.0 meters | 393.7 feet |
| Min Building Dimension | 10.0 meters | 33.0 feet |
| Building Orientation | 90.0 degrees |       |
| Stack Direction      | 26.4 degrees |       |
| Stack Distance       | 67.0 meters | 219.8 feet |

| **TERRAIN DATA**      |        |         |
| Input coordinates are UTM |       |
| Source Longitude     | 98.0858 deg | 520000.0 Easting |
| Source Latitude      | 40.4799 deg | 4470000. Westing |
| UTM Zone             | 17 | Reference Datum: 4 (NAD 83) |
| Source Elevation     | 585.0 meters |       |
| Probe distance       | 25000. meters | 82062. feet |
| No Flagpole receptors|        |         |
| No Discrete receptors|        |         |

| **METEOROLOGY DATA**  |        |         |
| Min/Max Temperature   | 261.4 / 313.1 K | 108.9 / 183.9 Deg F |
| Minimum Wind Speed    | 1.5 m/s |       |
| Barometric Pressure   | 10.0000 inches |       |
| Dominant Surface Profile | Grassland |        |
| Dominant Climate Type | Average Moisture |       |

AERSCREEN output file: AERSCREEN.OUT

--- AERSCREEN Run is Ready to Begin - Choose Option to Proceed ---
1 - Change Source Data;
2 - Change Building Data;
3 - Change Terrain Data;
4 - Change Meteorology Data;
5 - Change Title;
6 - Change Output Filename;
7 - Start AERSCREEN;
Hit (Enter) to Start Run

Note that the most recent version of the model is AERSCREEN 16216.
AERSCREEN Modeling Results (Without and With Building)

### AERSCREEN Modeling Results for Nominal Industrial Source in Crafton Area (no building)

<table>
<thead>
<tr>
<th>STACK HEIGHT (m)</th>
<th>MAX. 1-HR CONC. (µg/m³)</th>
<th>DISTANCE FROM STACK (m)</th>
<th>DIRECTED TOWARD (°)</th>
<th>RECEPTOR HEIGHT (m)</th>
<th>IMPACT AT BOUNDARY (µg/m³)</th>
<th>DIRECTED TOWARD (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>3709</td>
<td>203</td>
<td>150</td>
<td>10.0</td>
<td>28</td>
<td>140</td>
</tr>
<tr>
<td>50</td>
<td>1336</td>
<td>573</td>
<td>80</td>
<td>49.9</td>
<td>0.0</td>
<td>140</td>
</tr>
<tr>
<td>100</td>
<td>690</td>
<td>840</td>
<td>70</td>
<td>99.8</td>
<td>0.0</td>
<td>140</td>
</tr>
<tr>
<td>200</td>
<td>4</td>
<td>790</td>
<td>80</td>
<td>111.0</td>
<td>0.0</td>
<td>10</td>
</tr>
</tbody>
</table>

### AERSCREEN Modeling Results for Nominal Industrial Source in Crafton Area (including 34m H x 120m x 60m building as in example run from AERSCREEN User's Guide)

<table>
<thead>
<tr>
<th>STACK HEIGHT (m)</th>
<th>MAX. 1-HR CONC. (µg/m³)</th>
<th>DISTANCE FROM STACK (m)</th>
<th>DIRECTED TOWARD (°)</th>
<th>RECEPTOR HEIGHT (m)</th>
<th>IMPACT AT BOUNDARY (µg/m³)</th>
<th>DIRECTED TOWARD (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>5290</td>
<td>154</td>
<td>90</td>
<td>9.9</td>
<td>474</td>
<td>360</td>
</tr>
<tr>
<td>50</td>
<td>1314</td>
<td>579</td>
<td>90</td>
<td>49.9</td>
<td>44</td>
<td>140</td>
</tr>
<tr>
<td>100</td>
<td>747</td>
<td>792</td>
<td>100</td>
<td>100.0</td>
<td>0.3</td>
<td>220</td>
</tr>
<tr>
<td>200</td>
<td>4</td>
<td>790</td>
<td>80</td>
<td>111.0</td>
<td>0.0</td>
<td>10</td>
</tr>
</tbody>
</table>

**Additional Stack Parameters:** Emission Rate = 1 g/s; Inner Diameter = 0.5 m; Exit Temperature = 300 K; Exit Velocity = 15 m/s
Figure 11. Stack and building orientation for a building oriented 90 degrees to north and stack oriented 45 degrees to north.  
Plane View of Building and Stack Orientation for Example AERSCREEN Run

(Source: AERSCREEN User’s Guide, U.S. EPA, 3/2011, Figure 35, pg. 56)
## AERMET Guidance: Albedo

### Table 4-1

**Albedo of Ground Covers by Land-Use and Season**

<table>
<thead>
<tr>
<th>Land-Use</th>
<th>Spring</th>
<th>Summer</th>
<th>Autumn</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water (fresh and sea)</td>
<td>0.12</td>
<td>0.10</td>
<td>0.14</td>
<td>0.20</td>
</tr>
<tr>
<td>Deciduous Forest</td>
<td>0.12</td>
<td>0.12</td>
<td>0.12</td>
<td>0.50</td>
</tr>
<tr>
<td>Coniferous Forest</td>
<td>0.12</td>
<td>0.12</td>
<td>0.12</td>
<td>0.35</td>
</tr>
<tr>
<td>Swamp</td>
<td>0.12</td>
<td>0.14</td>
<td>0.16</td>
<td>0.30</td>
</tr>
<tr>
<td>Cultivated Land</td>
<td>0.14</td>
<td>0.20</td>
<td>0.18</td>
<td>0.60</td>
</tr>
<tr>
<td>Grassland</td>
<td>0.18</td>
<td>0.18</td>
<td>0.20</td>
<td>0.60</td>
</tr>
<tr>
<td>Urban</td>
<td>0.14</td>
<td>0.16</td>
<td>0.18</td>
<td>0.35</td>
</tr>
<tr>
<td>Desert Shrubland</td>
<td>0.30</td>
<td>0.28</td>
<td>0.28</td>
<td>0.45</td>
</tr>
</tbody>
</table>
AERMET Guidance: Bowen Ratio

<table>
<thead>
<tr>
<th>Land-Use</th>
<th>Spring</th>
<th>Summer</th>
<th>Autumn</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water (fresh and sea)</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>1.5</td>
</tr>
<tr>
<td>Deciduous Forest</td>
<td>0.7</td>
<td>0.3</td>
<td>1.0</td>
<td>1.5</td>
</tr>
<tr>
<td>Coniferous Forest</td>
<td>0.7</td>
<td>0.3</td>
<td>0.8</td>
<td>1.5</td>
</tr>
<tr>
<td>Swamp</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>1.5</td>
</tr>
<tr>
<td>Cultivated Land</td>
<td>0.3</td>
<td>0.5</td>
<td>0.7</td>
<td>1.5</td>
</tr>
<tr>
<td>Grassland</td>
<td>0.4</td>
<td>0.8</td>
<td>1.0</td>
<td>1.5</td>
</tr>
<tr>
<td>Urban</td>
<td>1.0</td>
<td>2.0</td>
<td>2.0</td>
<td>1.5</td>
</tr>
<tr>
<td>Desert Shrubland</td>
<td>3.0</td>
<td>4.0</td>
<td>6.0</td>
<td>6.0</td>
</tr>
</tbody>
</table>
### TABLE 4-3
SURFACE ROUGHNESS_LENGTH, IN METERS, BY LAND-USE AND SEASON

<table>
<thead>
<tr>
<th>Land-Use</th>
<th>Spring</th>
<th>Summer</th>
<th>Autumn</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water (fresh and sea)</td>
<td>0.0001</td>
<td>0.0001</td>
<td>0.0001</td>
<td>0.0001</td>
</tr>
<tr>
<td>Deciduous Forest</td>
<td>1.00</td>
<td>1.30</td>
<td>0.80</td>
<td>0.50</td>
</tr>
<tr>
<td>Coniferous Forest</td>
<td>1.30</td>
<td>1.30</td>
<td>1.30</td>
<td>1.30</td>
</tr>
<tr>
<td>Swamp</td>
<td>0.20</td>
<td>0.20</td>
<td>0.20</td>
<td>0.05</td>
</tr>
<tr>
<td>Cultivated Land</td>
<td>0.03</td>
<td>0.20</td>
<td>0.05</td>
<td>0.01</td>
</tr>
<tr>
<td>Grassland</td>
<td>0.05</td>
<td>0.10</td>
<td>0.01</td>
<td>0.001</td>
</tr>
<tr>
<td>Urban</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Desert Shrubland</td>
<td>0.30</td>
<td>0.30</td>
<td>0.30</td>
<td>0.15</td>
</tr>
</tbody>
</table>
**AERSCREEN Results**

<table>
<thead>
<tr>
<th>Calculation Procedure</th>
<th>Maximum 1-Hour Conc. (µg/m³)</th>
<th>Scaled 3-Hour Conc. (µg/m³)</th>
<th>Scaled 8-Hour Conc. (µg/m³)</th>
<th>Scaled 24-Hour Conc. (µg/m³)</th>
<th>Scaled Annual Conc. (µg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elevated Terrain</td>
<td>763.3</td>
<td>763.3</td>
<td>686.9</td>
<td>458.0</td>
<td>76.33</td>
</tr>
</tbody>
</table>

Distance from Source: 127.00 meters directed toward 110 degrees
Receptor Height: 9.10 meters

Impact at the Ambient Boundary:
- Maximum: 437.5 (µg/m³)
- Scaled 3-Hour: 437.5 (µg/m³)
- Scaled 8-Hour: 393.7 (µg/m³)
- Scaled 24-Hour: 262.5 (µg/m³)
- Scaled Annual: 43.75 (µg/m³)

Distance from Source: 30.00 meters directed toward 110 degrees
Receptor Height: 0.70 meters
“Better ingredients ...”
Modeling Guidance and Support


EPA’s Support Center for Regulatory Atmospheric Modeling (SCRAM) Website

- Model formulation documents, user guides; addendums
- Model Change Bulletins
- Clarification memos (Ex., September 30, 2014 memo)

Model Clearinghouse

State and Local Modeling Guidance
Summary

- **THE ATMOSPHERE**
  - Constituents
  - Structure

- **ATMOSPHERIC DYNAMICS**
  - Temporal/spatial scale of events

- **AIR POLLUTION DISPERSION**
  - Sources ➔ Dispersion ➔ Receptors

- **AIR DISPERSION MODELING**
  - Observation—Theory—Models
  - Receptors = Sources / Dispersion
  - \( C = \frac{QS}{U} \)
  - Empirical research
  - Statistical approach: \( \chi = \frac{q}{(\pi u \sigma_y \sigma_z)} \)...
Summary (Continued)

- **US EPA GUIDELINES**
  
  *Guideline on Air Quality Models, Appdx. W*

  Other guidance/clarification

- **AERMOD & AERSCREEN**
  
  Input requirements

  Output examples

  Interpretation of results

  Comparison between AERMOD and AERSCREEN

- **ADDITIONAL MODELS & APPLICATIONS**

  Requirements for regulatory modeling
References
Links to Resources

- **Practical Meteorology, 2015:**
  [https://www.eoas.ubc.ca/books/Practical_Meteorology/](https://www.eoas.ubc.ca/books/Practical_Meteorology/)

- **Meteorology and Atomic Energy 1968:**

- **Workbook of Atmospheric Dispersion Estimates, 1970:**

- **Handbook on Atmospheric Diffusion, 1982:**

- **Handbook of Atmospheric Science: Principles and Applications, 2003:**

- **EPA’s Support Center for Regulatory Atmospheric Modeling (SCRAM) Website:**
  [https://www.epa.gov/scram](https://www.epa.gov/scram)

- **“Guideline on Air Quality Models” (40 CFR 51):**
  [https://www3.epa.gov/ttn/scram/appendix_w/2016/AppendixW_2017.pdf](https://www3.epa.gov/ttn/scram/appendix_w/2016/AppendixW_2017.pdf)