

AERMOD Technical Forum

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Presentation Outline

- Brief History of AERMOD
- Basic Physics of Air Dispersion in AERMOD
- Comparisons of AERMOD and ISCST3
- AERMOD Performance Evaluation
- AERMOD Consequence Analysis
- Other AERMOD Features
- Potential AERMOD Pitfalls
- Questions

Brief History of AERMOD

- **Developed** by AMS/EPA Regulatory Model Improvement Committee (**AERMIC**)
- **Proposed** as Replacement for ISCST3 Model in **April 2000**
- EPRI-sponsored **PRIME** Downwash Algorithms **Incorporated** in AERMOD in **2001**
- **Promulgated** as EPA's Preferred Model on **December 9, 2005**

AERMOD Design Criteria

- Up-to-date Science
- Simple – Captures Essential Physical Processes
- Robust – Applies Over Range of Meteorology
- Easily Implemented – Simple I/O, User-friendly
- Can Evolve – Easily Updated

Basic Physics of Dispersion

- Air Dispersion is Driven by Two Main Forces – **Buoyancy** Effects and **Shear** Stress Effects
- **Buoyancy** Controlled by **Solar Heating** (Day) and **Radiative Cooling** (Night)
- **Shear Stress** (Friction) Controlled by **Surface Roughness** Elements and Aerodynamic Effects

Physics of Dispersion - Daytime

- **Buoyancy** Caused by Daytime Solar Heating **Generates** Large Scale **Convective Cells**
- **Convection** Causes Rapid **Vertical Spread** of Plumes and Growth of the **Mixed Layer**
- Strength of **Convection** Controlled by **Solar Angle** (time-of-day, season and latitude), **Cloud Cover** and **Surface Characteristics** (Albedo and Bowen Ratio)

Physics of Dispersion - Daytime

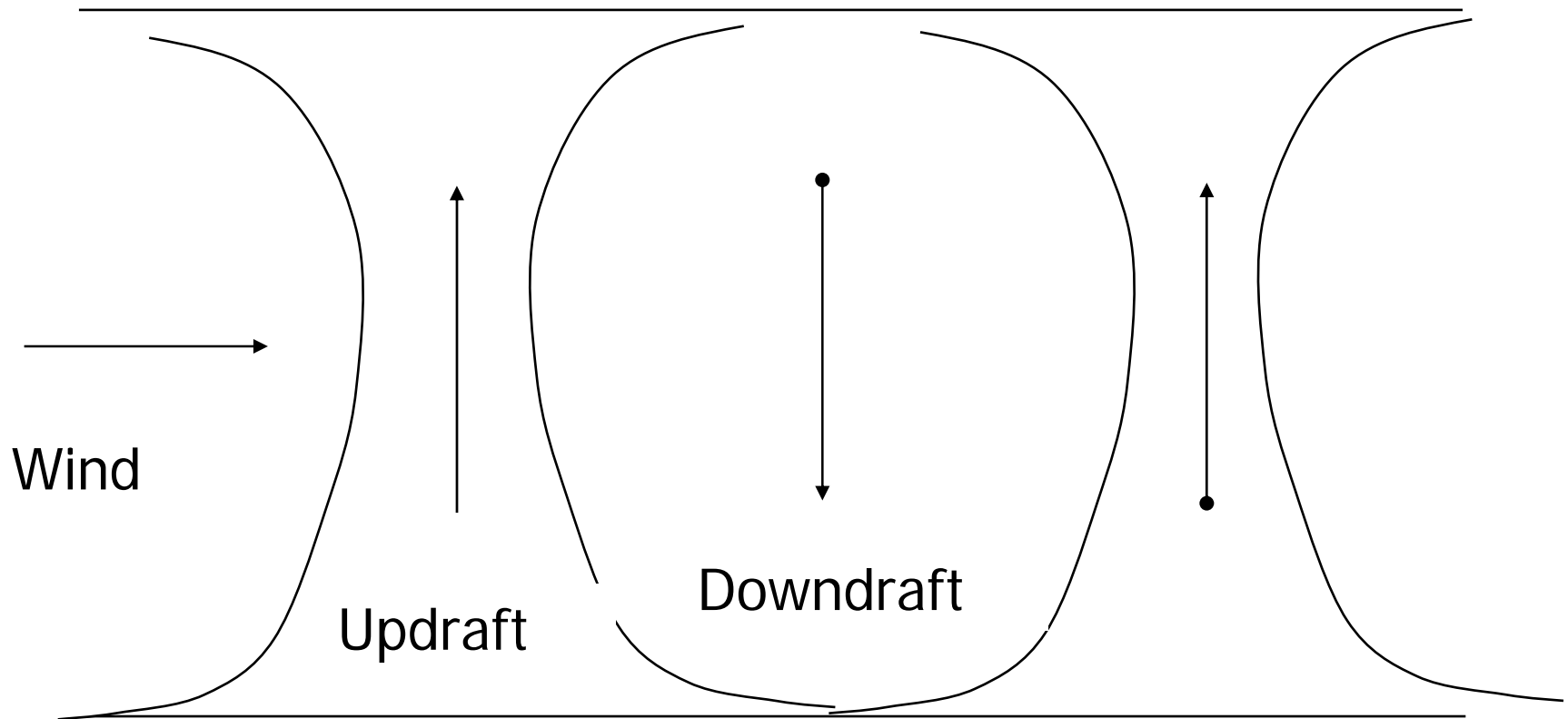
- **Albedo**

- Measure of reflectivity of surface, from 0 to 1
- Typical values ranges from about 0.1 for water to 0.6 or higher for full snow cover

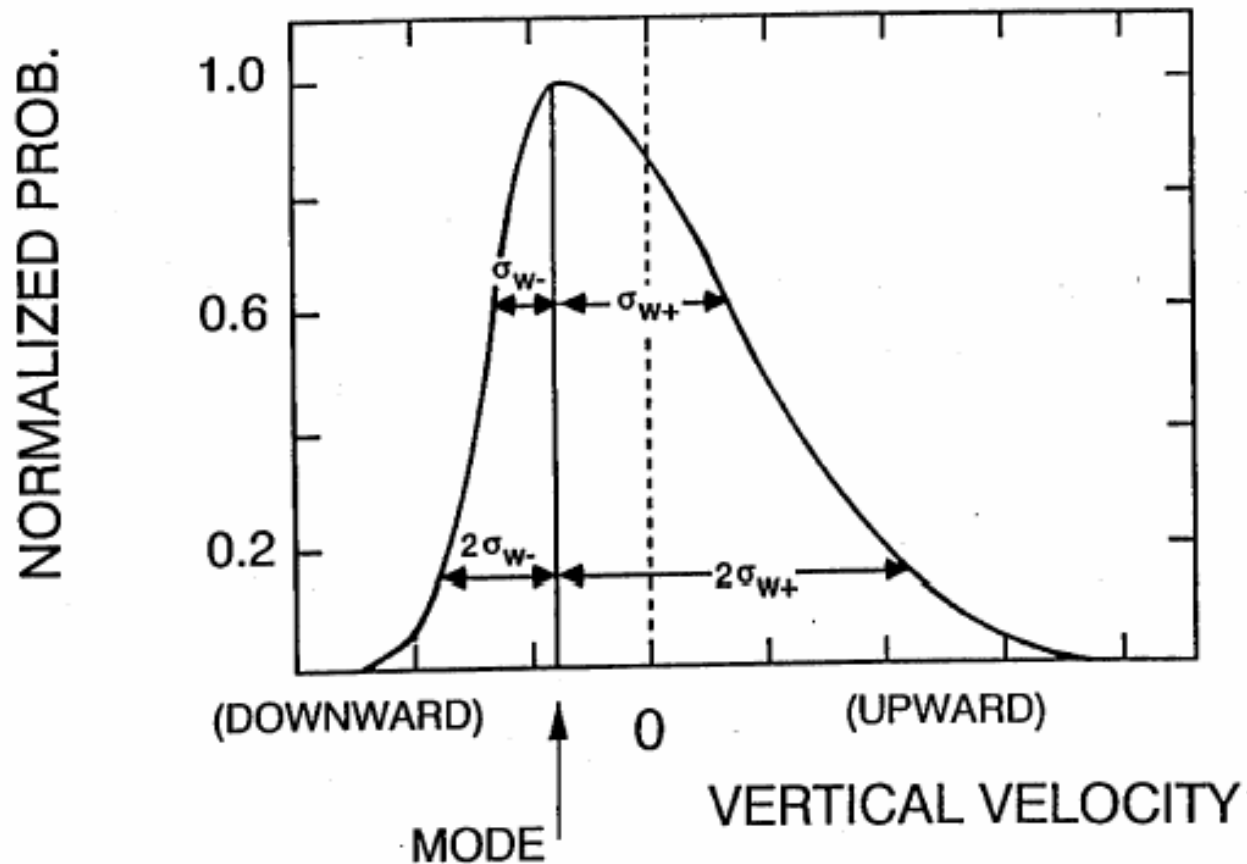
- **Bowen Ratio**

- Ratio of sensible to latent heat flux
- Determines how much solar heating goes to evaporation of surface moisture
- Ranges from about 0.1 (very wet) to 10 (very dry)

Convective Boundary Layer Structure

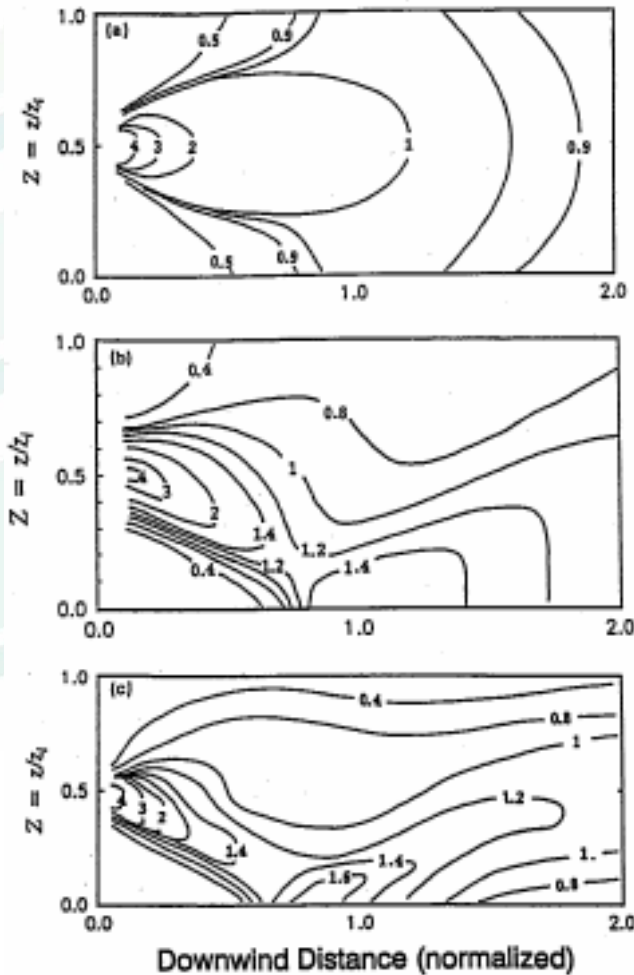


Vertical Velocity Distribution in CBL



CBL Dispersion Comparisons - CWIC

- ISCST3
- AERMOD
- Tank Study



Physics of Dispersion - Nighttime

- **Radiative Cooling** at Night Causes **Stable** Lapse Rate to Develop – **Suppresses** Propagation of **Turbulence**
- Generation of **Turbulence Dominated by** Friction-Induced **Shear Stress**
- Turbulence **Intermittent**; Low-level Jets and Gravity Waves may Contribute
- Shear Stress or **Mechanical Turbulence** Controlled by **Wind Speed** and **Surface Roughness**

Physics of Dispersion - Nighttime

- **Surface Roughness Length (z_0)**
 - Height at which wind speed goes to zero (0), based on theoretical logarithmic profile
 - Related to the surface roughness elements, but is not = height of elements
 - Ranges from less than 0.001m (1mm) over water to 1.0m or higher for forests and urban areas
 - May vary by season and wind sector

AERMOD vs. ISCST3

- **Theoretical Similarities**
 - Both AERMOD and ISCST3 are Steady-State Plume Models
- **Theoretical Differences**
 - AERMOD Similarity Theory vs. ISCST3 PG-Stability
 - AERMOD Terrain uses Critical Dividing Streamline vs. ISCST3 Terrain uses COMPLEX1 Screen Model
 - AERMOD uses PRIME Downwash vs. ISCST3 Huber-Snyder and Schulman-Scire Downwash
 - *PRIME downwash accounts for location of stack relative to building; ISCST3 downwash assumes stack and building are collocated. PRIME also includes cavity algorithm.*

AERMOD vs. ISCST3

- **Theoretical Differences (cont.)**
 - AERMOD uses Non-Gaussian Vertical Dispersion for Convective (Unstable) Conditions vs. ISCST3 Gaussian Vertical Dispersion for All Conditions
 - AERMOD Partial Penetration of Plume Through Mixing Height vs. No Partial Penetration for ISCST3
 - AERMOD Urban Option Scaled by Population vs. ISCST3 Non-varying Urban Option
 - AERMOD Incorporates Horizontal Plume Meander

AERMOD vs. ISCST3

- **Practical Similarities**

- AERMOD Model Inputs and Outputs are Intentionally Similar to ISCST3 Model – AERMOD Code Developed from ISC Code

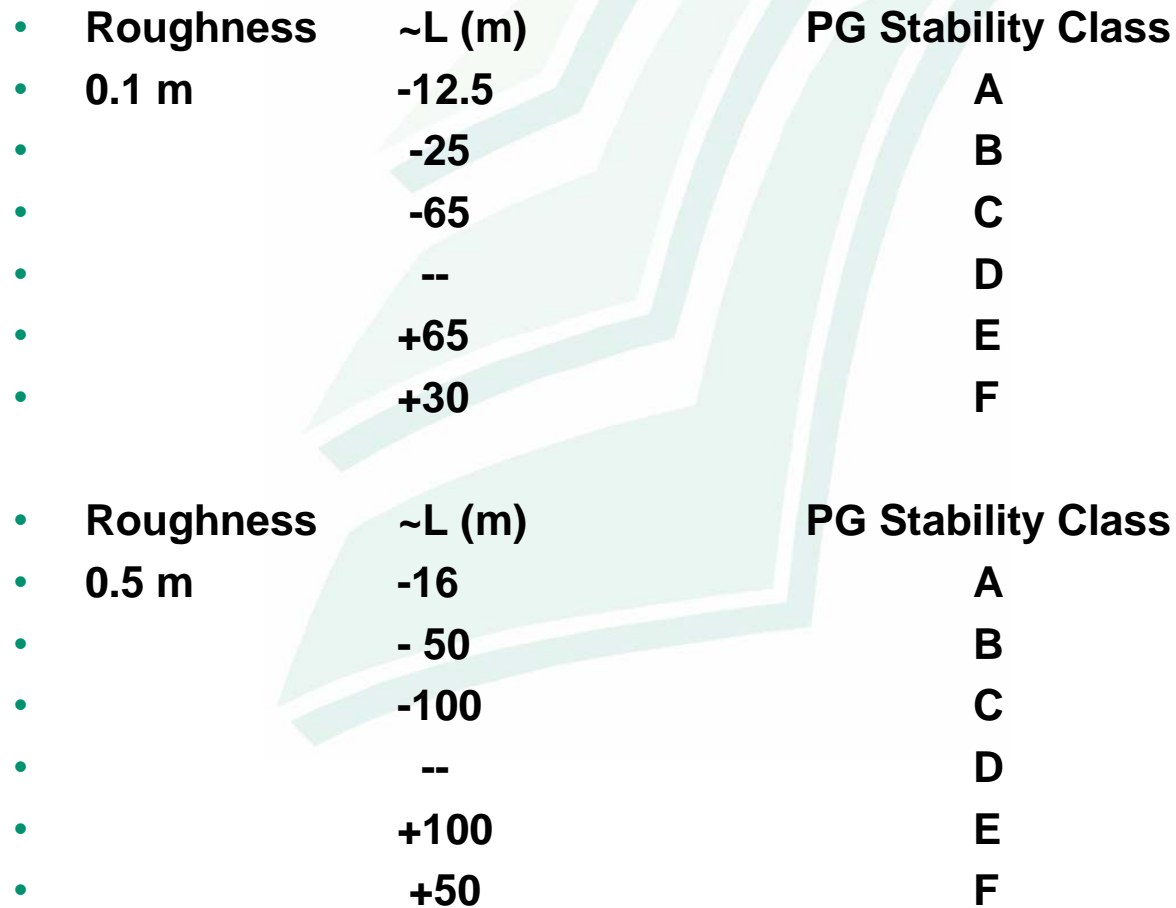
- **Practical Differences**

- AERMOD Terrain Algorithms Require Special Terrain Data Processing – Performed by AERMAP
- AERMOD Meteorological and Dispersion Algorithms Require Special Meteorological Data Processing – Performed by AERMET
- AERMET Requires User-specified Surface Characteristics: Albedo, Bowen Ratio and Surface Roughness Length

AERMOD Similarity Theory Concepts

- Wind, Temperature and Turbulence are **Scaled** with Height Based on **Similarity Theory**
- Mechanical (Shear Stress) Turbulence Scaled by **Friction Velocity (u_*)**
- Convective Turbulence Scaled by **Convective Velocity Scale (w_*)**
- **Monin-Obukhov Length (L)** Stability Parameter
 - Positive for stable conditions; negative for unstable
 - ~ Height at which friction and buoyant forces balance

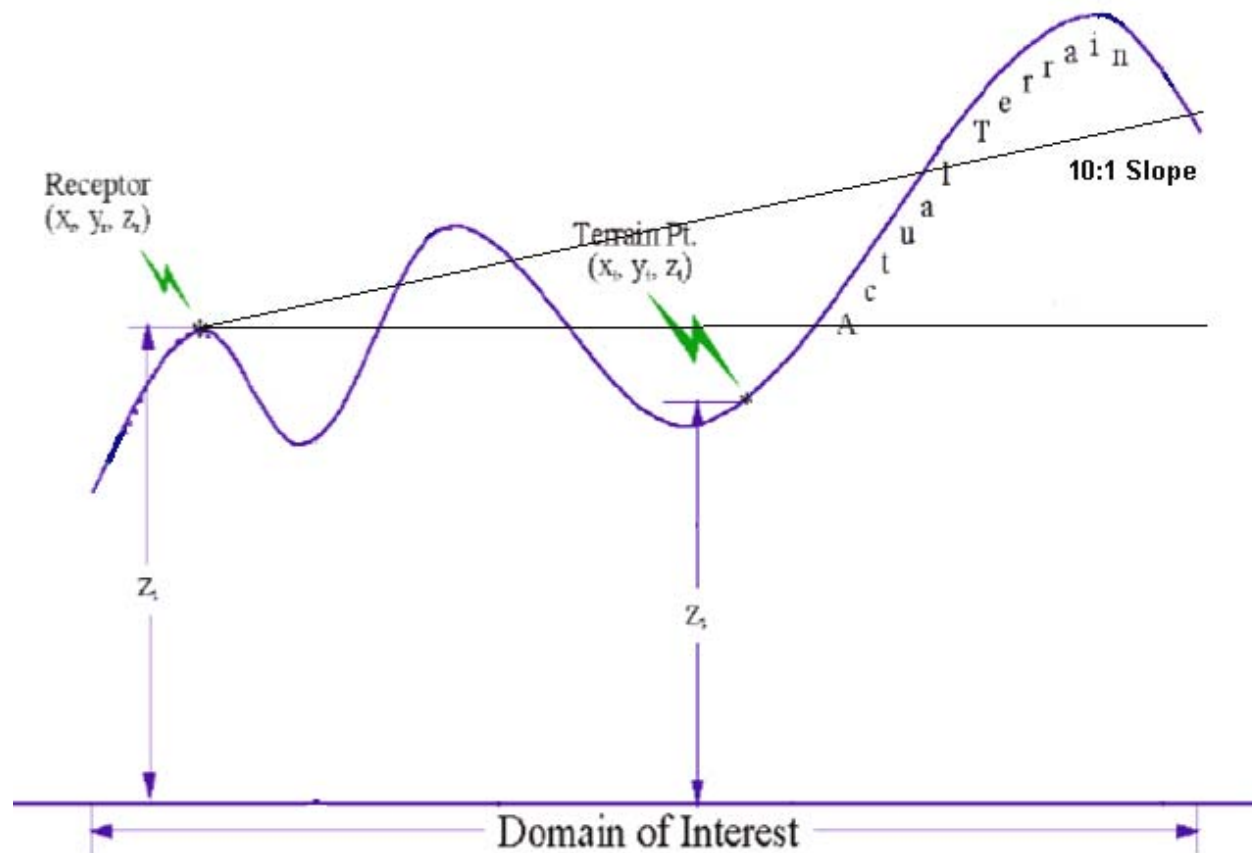
Monin-Obukhov Length vs. PG Class



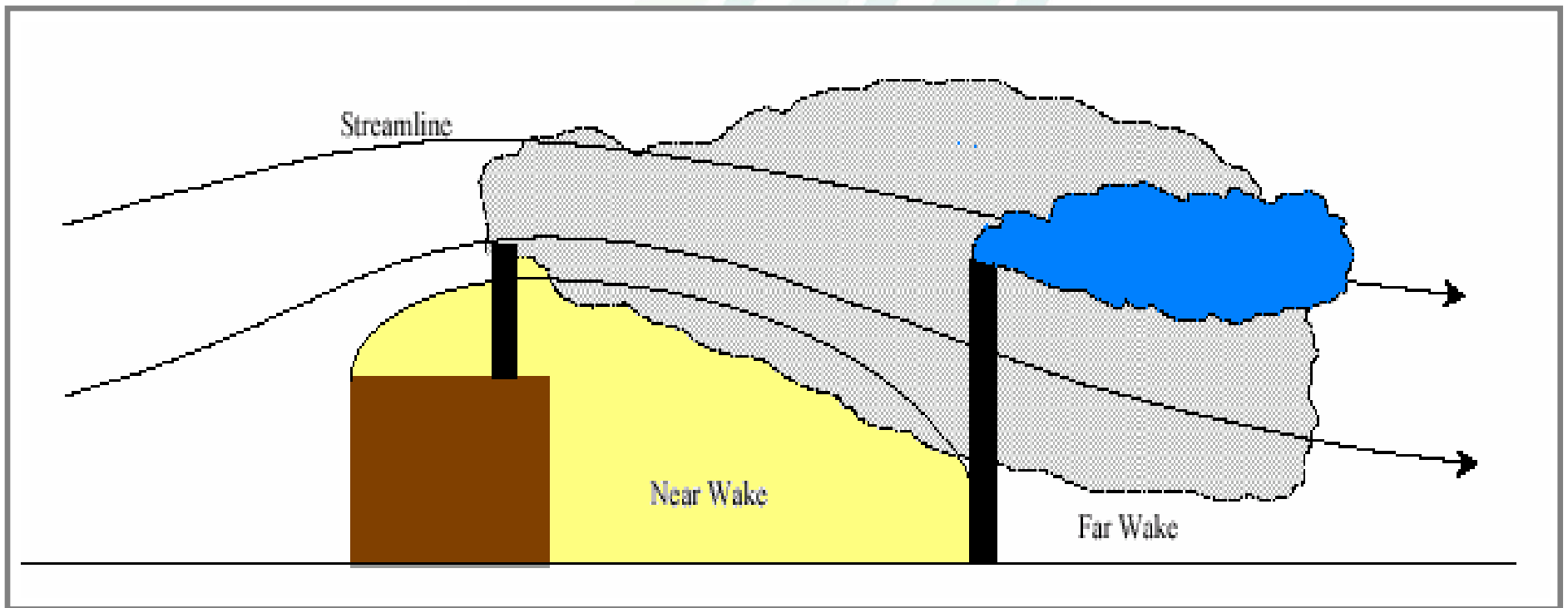
AERMOD Terrain Treatment

- Uses CDTM+ Dividing Streamline Height Concept
 - Portion of plume above dividing streamline goes over the hill (terrain-responding plume)
 - Portion of plume below dividing streamline impacts or goes around hill (horizontal plume)
- Requires Representative “Hill Height Scale” for Each Receptor
- AERMAP Determines “Hill Height Scale” Based on Highest Terrain Above a 10:1 Slope

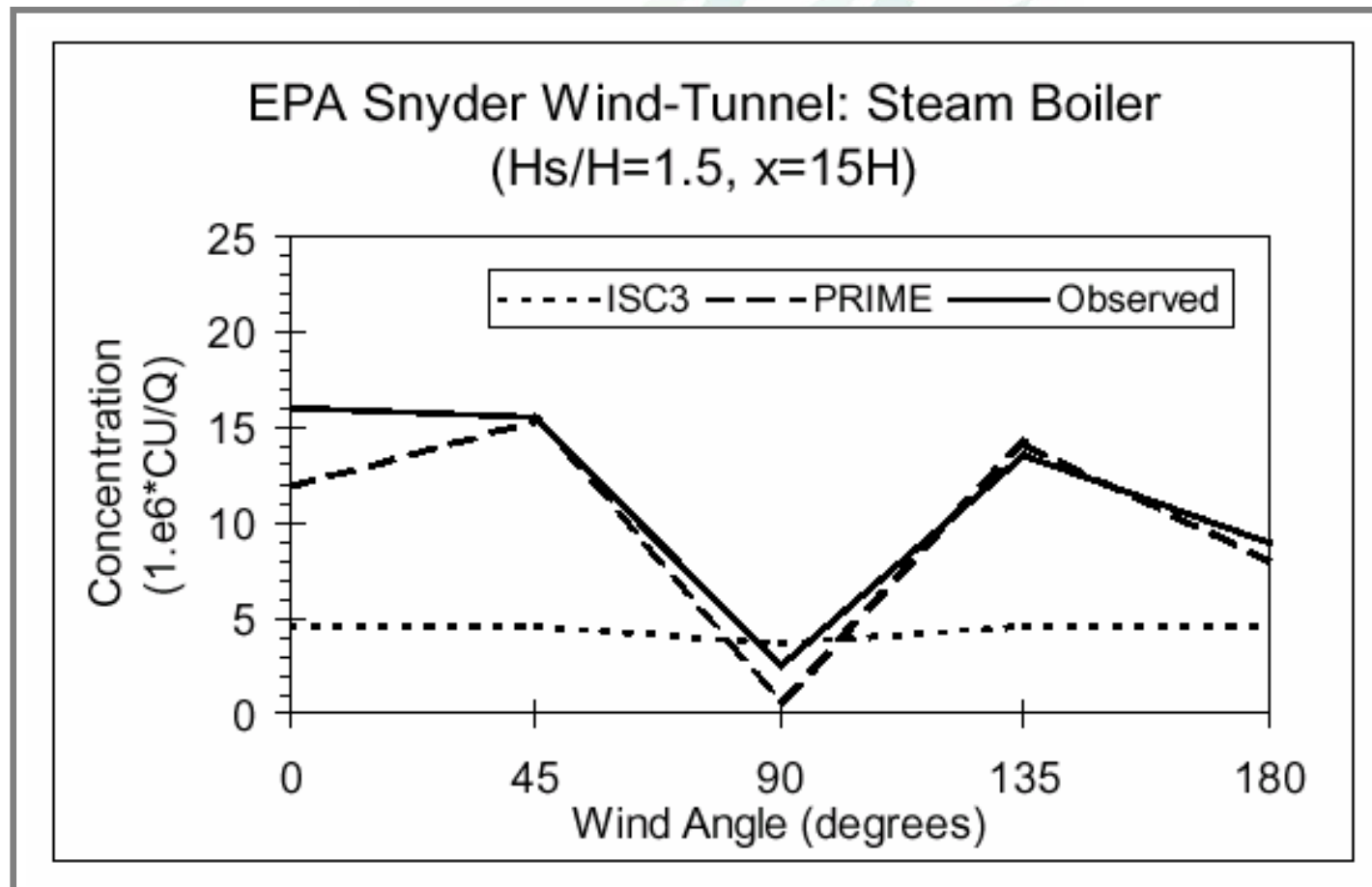
AERMOD Terrain Treatment



PRIME Building Downwash in AERMOD



PRIME Wind-Tunnel Evaluation

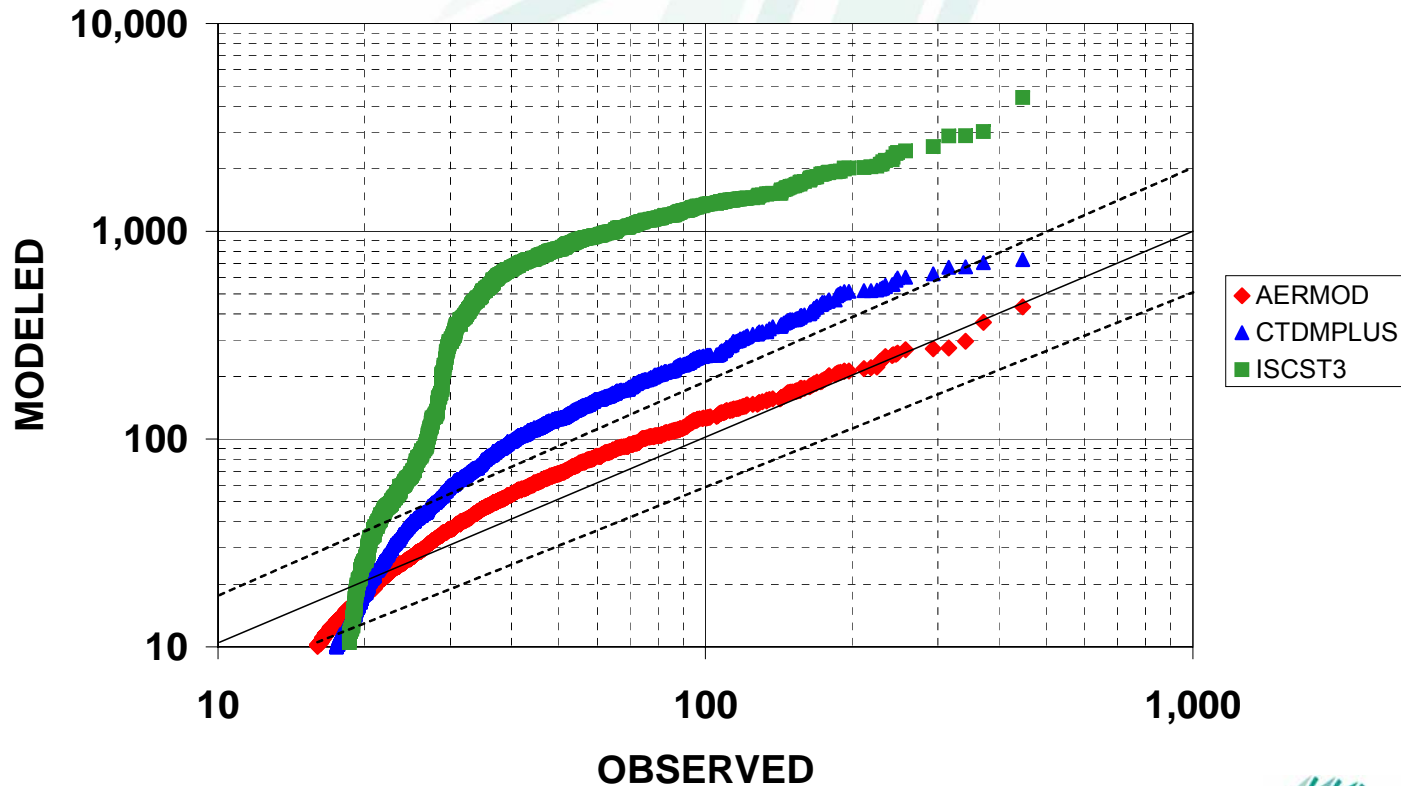


AERMOD Performance Evaluation

- Evaluated on Total of 17 Field Study Databases
 - 10 without Building Downwash, 7 with Downwash
 - 13 with Flat or Rolling Terrain, 4 with Complex Terrain
- Developmental and Independent Evaluations
- Compared to ISCST3 for Non-downwash Databases and CTDMPPLUS for Complex Terrain Databases
- Compared to ISC-PRIME for Downwash Databases
- AERMOD Consistently Outperformed ISCST3, ISC-PRIME and CTDMPPLUS

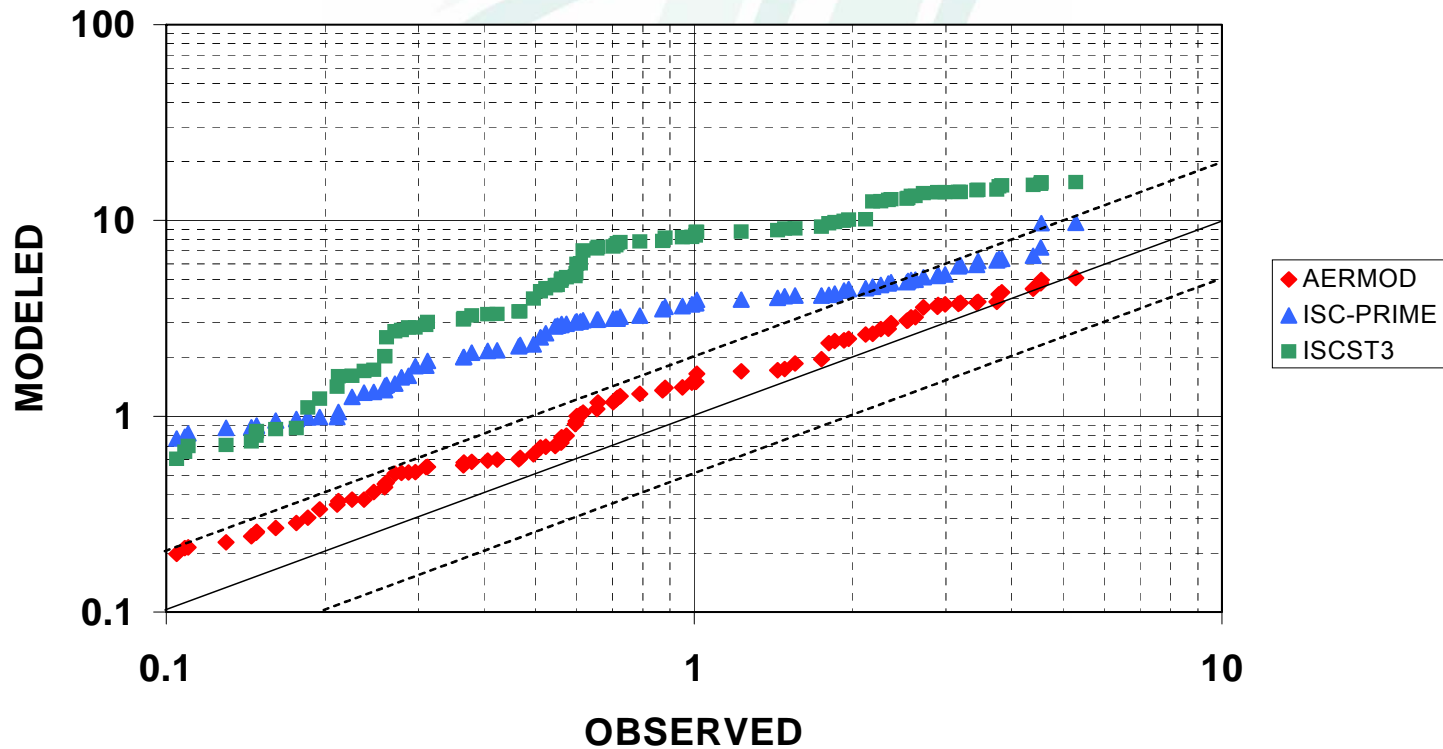
Complex Terrain Model Performance

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



Downwash Model Performance

ALASKA SO₂ DOWNWASH EVALUATION Q-Q Plot of 1-Hour Concentrations



AERMOD Consequence Analysis

- Model-to-Model Comparisons of AERMOD with ISCST3 and ISC-PRIME
- AERMOD vs. ISCST3 Results Vary by Source, Meteorology and Topography/Land Use
- AERMOD Generally Predicts Lower – More Realistic – Concentrations in Complex Terrain
- Peak Short-term Concentrations Similar for Tall Stacks in Rural/Flat Terrain with AERMOD Slightly Higher
- AERMOD/ISCST3 Ratio Generally Increases with Longer Averaging Time – ISCST3 Underpredicts Annual Averages

AERMOD Consequence Analysis

- Flat and simple terrain with point, volume and area sources
- Ratios of AERMOD-predicted high concentrations to ISCST3-predicted high concentrations

	1hour	3hour	24hour	Annual
average	1.04	1.09	1.14	1.33
high	4.25	2.82	3.15	3.89
low	0.32	0.26	0.24	0.30
No. cases	48	48	48	48

AERMOD Consequence Analysis

- Flat terrain and point sources with significant downwash
- Ratios of AERMOD-predicted high concentrations to ISCST3-predicted and ISC-PRIME (ISC3P) predicted high concentrations

	<u>ANNUAL</u>		<u>24-HR</u>		<u>3-HR</u>	
	<u>AER/ISC3</u>	<u>AER/ISCP</u>	<u>AER/ISC3</u>	<u>AER/ISCP</u>	<u>AER/ISC3</u>	<u>AER/ISCP</u>
ave	1.08	1.05	1.25	1.01	0.71	1.05
max	1.35	1.29	1.87	1.14	1.20	1.17
min	0.69	0.79	0.69	0.84	0.38	0.93
No. cases	6		6		6	

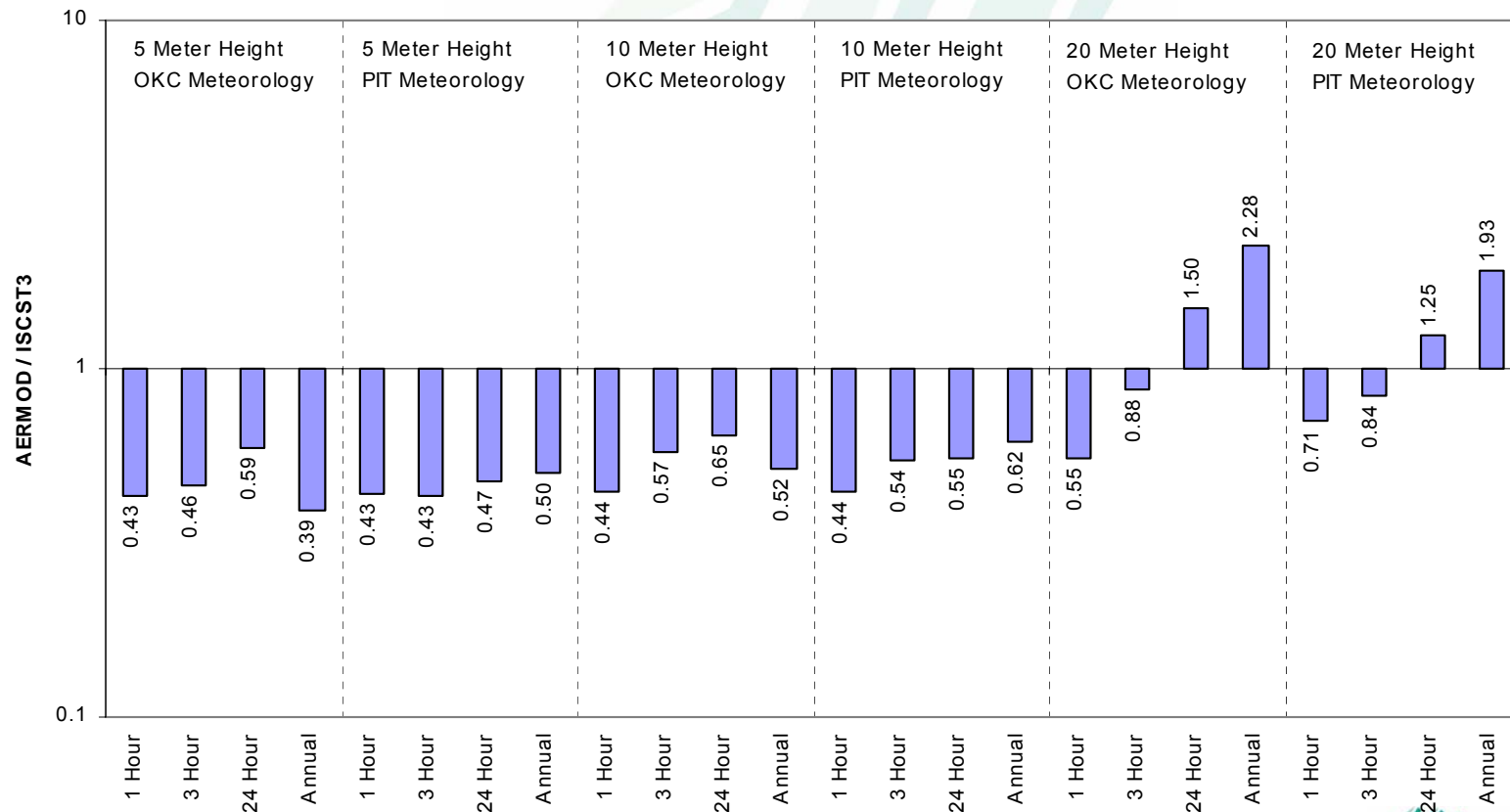
AERMOD Consequence Analysis

- Complex terrain with point sources
- Ratios of AERMOD-predicted high concentrations to ISCST3-predicted high concentrations

	<u>AER/ISC3</u>
AVE	0.24
MAX	0.79
MIN	0.07
No. of cases	196

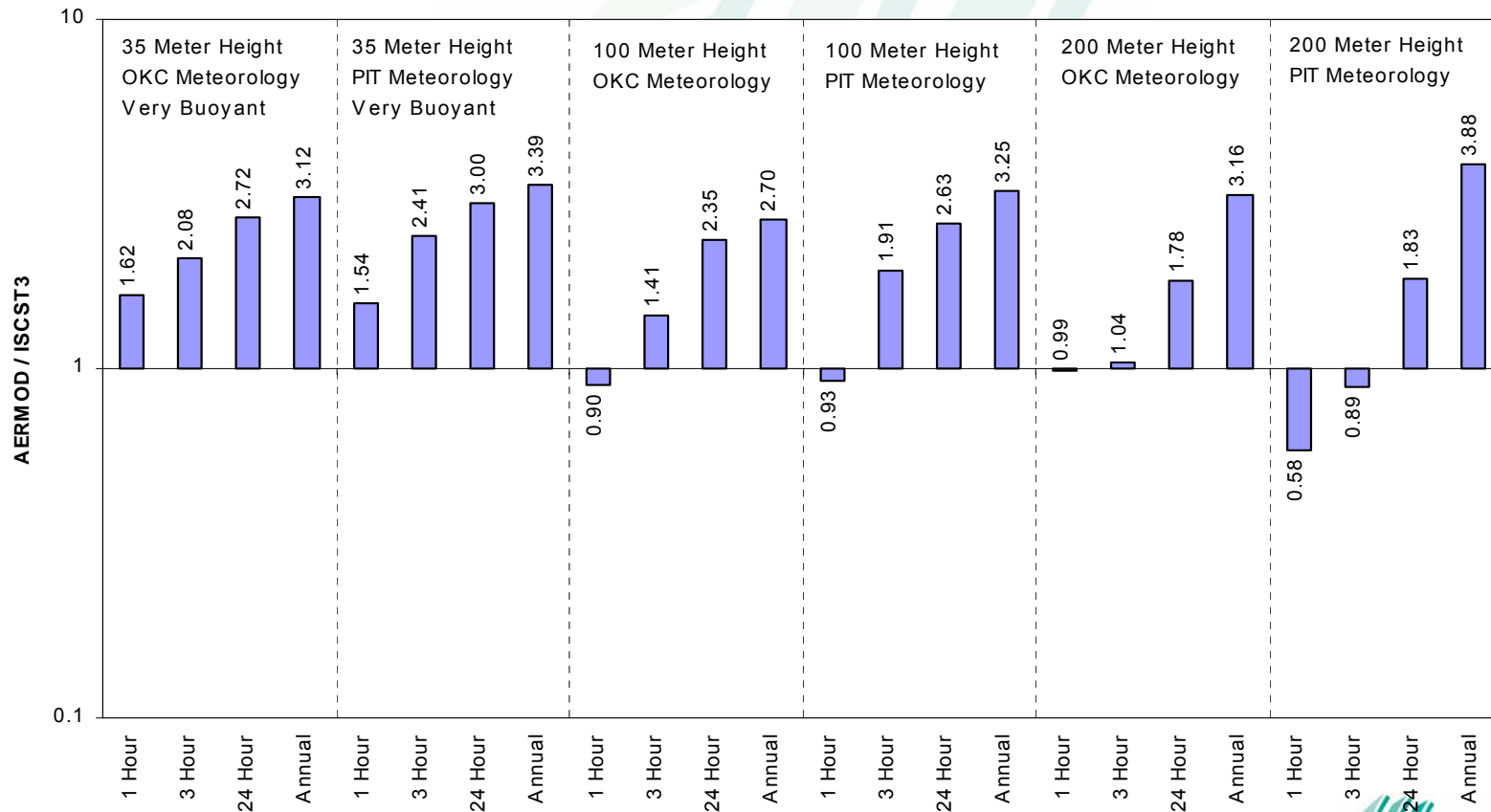
AERMOD Consequence Analysis

FIGURE 4-1. RATIOS OF HIGH-SECOND HIGH (PLUS HIGH ANNUAL) CONCENTRATIONS
RURAL, SHORT STACKS, NON-BUOYANT PLUME, FLAT TERRAIN



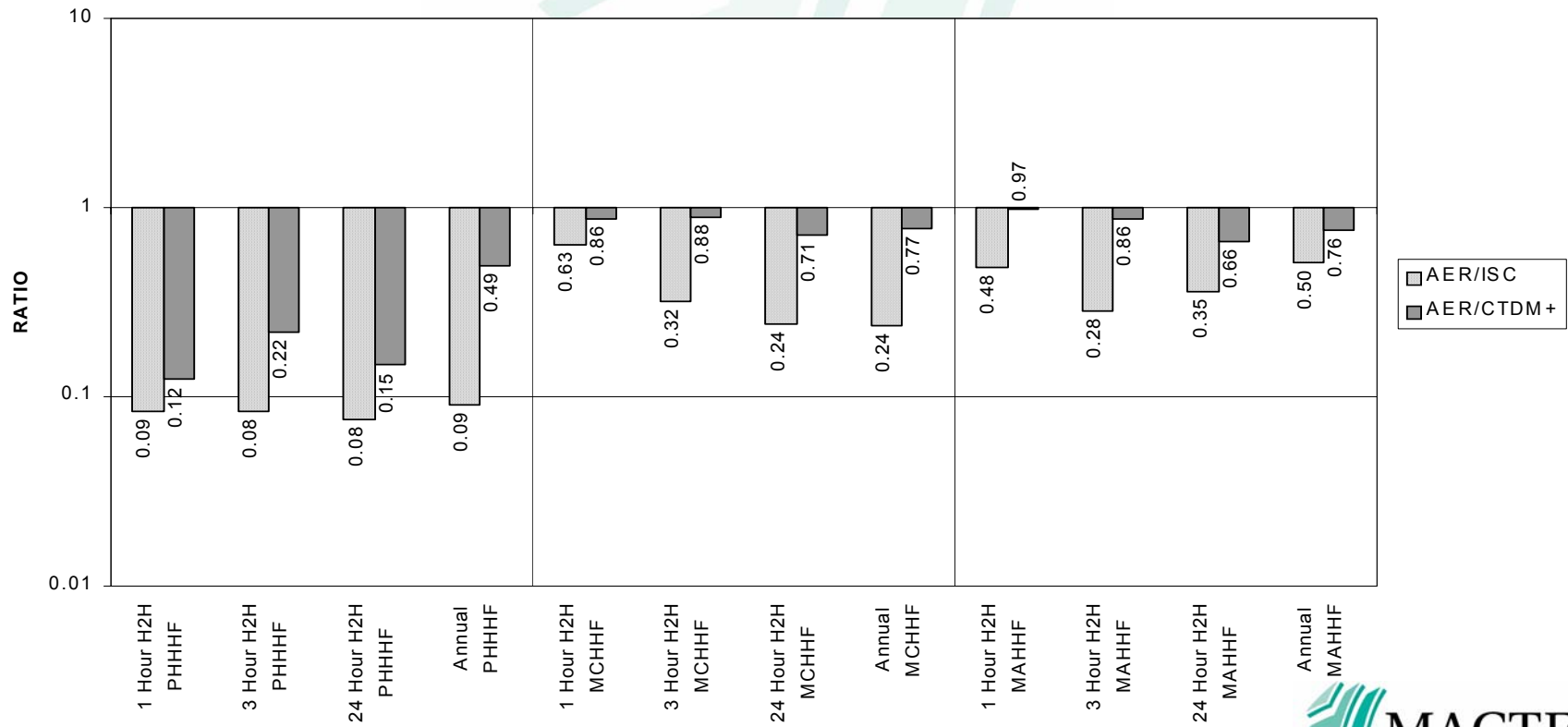
AERMOD Consequence Analysis

FIGURE 4-2. RATIOS OF HIGH-SECOND HIGH (PLUS HIGH ANNUAL) CONCENTRATIONS
RURAL, MEDIUM AND TALL STACKS, VERY BUOYANT, FLAT TERRAIN



AERMOD Consequence Analysis

FIGURE 4-18.
 RATIOS OF HIGH-SECOND HIGH (PLUS HIGH ANNUAL) CONCENTRATIONS
 AERMOD TO ISCST3(COMPLEX1) AND CTDMPUS
 COMPLEX TERRAIN
 HIGH STACK, HIGH BUOYANCY, HILL FAR FROM SOURCE



Additional AERMOD Features

- Non-regulatory Options for Modeling NO to NO₂ Conversion
 - Plume Volume Molar Ratio Method (**PVMRM**)
 - Ozone Limiting Method (**OLM**)
- Dry and Wet **Deposition** of Gases and Particles for Multimedia Risk Assessment Applications
- Still to Come...
 - **AERSCREEN**: Screening tool based on AERMOD for use without observed meteorological data
 - **AERSURFACE**: Processes land-use data to estimate surface characteristics (Albedo, Bowen Ratio, and Surface Roughness)

AERSCREEN Screening Model

- AERSCREEN Screening Model Consists of Two Components:
 - **MAKEMET** program generates matrix of meteorological conditions (.sfc and .pfl files) based on user-specified surface characteristics and temperature range
 - **ASCREEN** program provides command-prompt interface to AERMOD in SCREEN mode; incorporates MAKEMET, BPIPPRM and AERMAP; no area source option yet
- MAKEMET-generated Data used to Estimate Worst-case 1-hr Concentrations
- Scaling Factors for 3-, 8-, 24-hr and Annual Averages part of ASCREEN – Still Being Evaluated

AERSCREEN Screening Model

- Significant Testing To Date Shows Good Results
- Recent Testing Performed for Rugged Terrain Settings, with and without Building Downwash
- Options for Applications with Terrain and Downwash Still Being Evaluated
- Alpha Version Submitted to Regional Modelers on April 25, 2006; Comments Requested By Mid-May
- Beta Release As Soon As Possible After Regional/State Modelers Workshop in May

AERSURFACE Tool

- Tool Designed to Assist With Estimating Surface Characteristics for AERMET
- Existing Program Uses GEO.DAT File For Land Use Data
- New Version Being Designed:
 - Will use higher resolution NLCD data directly, bypassing MAKEGEO
 - More detailed Land Use category breakdown
 - More flexible options for domain size and direction sectors
- Draft Tool Expected by Fall 2006

Other New or Pending Features

- Bulk Richardson Number Option in AERMET (04300), Uses Low-level (10-2m) ΔT in lieu of Cloud Cover
- Options for Capped and Horizontal Releases
 - EPA Model Clearinghouse procedure not applicable for PRIME downwash algorithm
- Additional Options for Varying Emissions by Month, Hour-of-Day and Day-of-Week (MHRDOW & MHRDOW7)
- Multiple Urban Areas in Single Model Run
- Updated Processing for PM-2.5 Standard
- MM5-to-AERMOD Tool Under Development

AERMOD Limitations

- AERMOD is a Steady-State, Straight-Line Plume Model
 - Assumes uniform atmosphere across domain for each hour
 - Limited to near-field (< 50km) impact assessments
- AERMOD Applies to Continuous Releases – May Not Apply for Emergency Response
- AERMOD Does Not Address Multi-pollutant Photochemical Transformations (e.g. Ozone)

AERMOD Potential Pitfalls

- Small Urban Areas with Tall Stacks
- Urban Option with Urban Meteorological Data
- No Horizontal Meander for Area Sources
- Very Low Roughness with Light Winds
- Excessive Model Runtimes
- AERMAP Terrain Data Format Limitations

AERMOD Potential Pitfalls

- Surface Heterogeneity and Meteorological Data Representativeness
- Model Clearinghouse Procedure for Capped/Horizontal Releases with PRIME
- Area Sources in Terrain – Not Well-tested; Possible Issues with Sloped Terrain
- BPIP/PRM Issues – Prior BPIP Logic for Selecting Controlling Structure May Not Be Appropriate for PRIME

Important Points to Remember

- Many AERMOD Inputs are Same/Similar to ISCST3
- Biggest Challenge Will Likely Be Met Data Processing
 - Unfamiliar data formats
 - AERMET requires full upper air soundings
 - **Specification of surface characteristics**
- Coordination with Regulatory Agency on Key Issues
 - Modeling protocol may be needed
- New Boundary Layer Modeling Concepts in AERMOD
 - Similarity parameters – u_* , w_* and L – important for QA and interpretation of results

Questions



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