Recent Developments in Advanced Approaches for Dispersion Modeling

Bob Paine, AECOM

Presented at the CIBO Focus Workshop on Air Quality Modeling

June 12, 2012

AECOM

Outline of Presentation

- AERMOD modeling issues of concern
  - Low wind speed conditions
  - Complications in terrain situations
  - Applications in gentle slope cases
  - Distance applicability
  - Adding background to modeled concentrations
  - Fugitive emission modeling
  - Building downwash: light winds and sources with "fugitive heat releases"
  - NO to NO_2 conversion rate
  - Overpredictions for low mixing heights in daytime conditions
  - Modeling of sources with variable/intermittent emissions

Outline of Presentation, continued

- Approaches to address areas of concern
  - Corrections for low wind speed conditions
  - Sub-hourly AERMOD modeling
  - Site-specific met data in terrain situations
  - North Dakota 1-hour SO_2 evaluation study
  - Approaches in gentle slope cases
  - Extent of steady-state model application
  - Advances in modeling fugitive emissions
  - Building downwash adjustments
  - Advanced ambient ratio method for NO to NO_2 conversion
  - Fix to AERMOD formulation for penetrated plumes
  - Emissions variability processor (EMVAP)

Experience with AERMOD Accuracy

- AERMOD was extensively evaluated before promulgation in 2005
- User experiences since then have uncovered new concerns not previously found, or not evaluated
- EPA reliance on accurate modeling is more important than ever before due to very stringent NAAQS and new EPA policy to not apply SILs if new violation is modeled
- However, EPA resources to address modeling issues of concern are limited
- Involvement of model user community to help EPA address these problems is critical

What are AERMOD's Problems with Low Wind Speeds?

- AERMOD had limited evaluation for these conditions – very few hours with wind speed < 1 m/s
- Model formulation problems cause underestimates of turbulent mixing in stable conditions
- Result is very compact modeled plumes (stable)
- Vertical profiling results in possible underestimates of wind speed increase with height
- Modeled horizontal trajectories are perfectly level, so even modest terrain increases lead to plume impacts
- Plume travel time is assumed perfectly straight (and perfectly level) over many hours of transport
- Meander component of plume dispersion is too low
- Sonic anemometers and AERMINUTE has resulted in many more cases of wind speeds < 1 m/s

Phase 1: Meteorological Evaluation Study

- Requested by EPA; evaluation focused upon turbulence levels ("friction velocity")
- Three research-grade databases were selected for low wind speeds and sonic anemometer to get observed turbulence
- Sites chosen were Cardington (flat, grassy UK site), Bull Run (mixed land use in TN), winter study in Colorado
- Evaluation focused upon nocturnal, low wind conditions

Meteorological Evaluation Results

- Single-level friction velocity (turbulence) predictions by AERMET were found to be underestimated for low wind, stable hours
- An adjustment to the formulation was suggested by the data, and appeared to greatly improve the AERMET performance
- This adjusted formulation was successfully tested all three met databases

Phase 2: Tracer Database Evaluation

Study focused on 3 databases:

1. Bull Run, TN (tall stack, buoyant plume)
2. Idaho Falls, ID (low-level releases)
3. Oak Ridge, TN (low-level releases)

AERMOD worked well for Bull Run (daytime, convective low winds), so study focus was on the other databases, for which key conditions were stable cases

Tracer Evaluation Results

- AERMOD overpredicted by factor of 6 for Idaho Falls, and by factor of 20 for Oak Ridge at 100-m distance
- Better performance resulted from:
  - Corrections to turbulence in AERMET processing
  - Doubling of the minimum horizontal plume spread in AERMOD
  - Inclusion of direct turbulence observations (wind direction standard deviation – sigma-theta)
- Overpredictions were reduced to a factor of about 2

Interaction with EPA

- Results were documented, and entire database provided to EPA in Spring 2010
- EPA acknowledged results, but has not acted upon them
- New NAAQS implementation has occupied EPA attention during this period
- Hopefully, new effort to engage EPA with model user workgroup will provide results in next 1-2 years
- API is funding a sequel to the low wind speed study, and we expect to have EPA interaction throughout the process

Recent Low Wind Issues

- Implementation of AERMINUTE and proliferation of sonic anemometers increases low wind observations
- This makes low wind problems in AERMOD even worse
- Lower surface roughness parameterization with "AERSURFACE" reduces predicted turbulence and creates more low wind problems
- Low mechanical mixing heights due to above issues results in "laser beam" plumes at night due to questionable profiles of turbulence and temperature
- A possible related problem is downwash effects in near-calm winds in stable conditions

Why develop a sub-hourly AERMOD Capability?

- This is another way to tackle the low wind speed overprediction problem
- Sub-hourly meteorological data is now routinely available from both on-site met and 1-minute ASOS
- Hourly AERMOD predictions for low wind speeds overstate impacts for the coherent plume component
- In low winds, winds can go in several directions during an hour, resulting in multiple concentration "lobes"

New Procedure: AERMINUTEPlus/SHARP

- AERMINUTE has been enhanced under EPRI funding to output sub-hourly wind averages – we call this "AERMINUTEplus"
- Wind averaging is consistent with EPA's AERMINUTE
- Sub-Hourly AERMOD Run Procedure (SHARP)
- Sub-hourly periods are user-specified – from as high as 30 minutes each to as low as 2 minutes each (we recommend 10-15 minute periods)
- Effectively, the modeled plume is spread out by sending it into different directions during the hour
- Evaluation results to date look encouraging for the sub-hourly procedure

Optimizing AERMOD Performance in Complex Terrain Applications

- Key issues for complex terrain are plume rise, interaction with terrain, and dispersion
- AERMOD is designed to “penalize” use of single-level (10-m) meteorological data through conservative parameterizations
  - Turbulent mixing is minimized
  - Vertical temperature inversion is often too strong
- Actual measurements (e.g., tall tower / sodar) near plume level will override these parameterizations and reduce model overpredictions

Additional Comment: Building Downwash in Light Winds

- Unexpected AERMOD results have occurred for buoyant stacks with heights close to building heights
- Many recent AERMOD runs indicate predictions of peak concentrations for buoyant point sources due to building downwash in stable, nearly calm conditions
- This is contrary to expectations, since building wake expected to be weak in low winds, and plume rise highest in those conditions
- Once again, this is an area for more attention and comparisons of modeling to monitoring

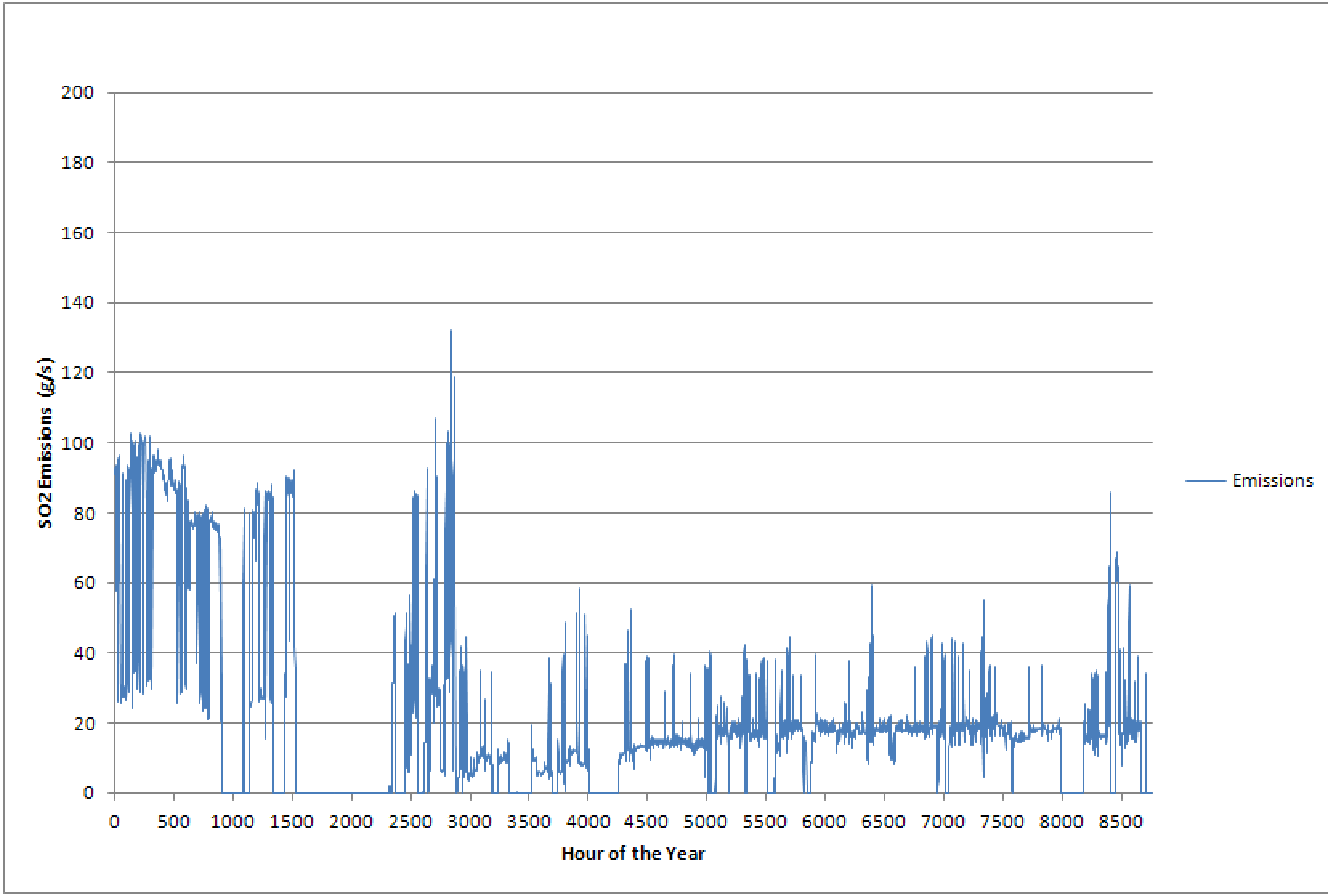
EPA Appendix W Modeling Procedures

- Modeled emission rate input (for short-term averages) is:
  - Emission limit x operating level x operating factor
    (lb/MMBtu) (MMBtu/hr) (hours/year)
  - Max. emission limit x design capacity x continuous operation
- Modeling continuous operation for intermittent sources or maximum emission limits for variable emission sources is of concern, particularly for a probabilistic NAAQS

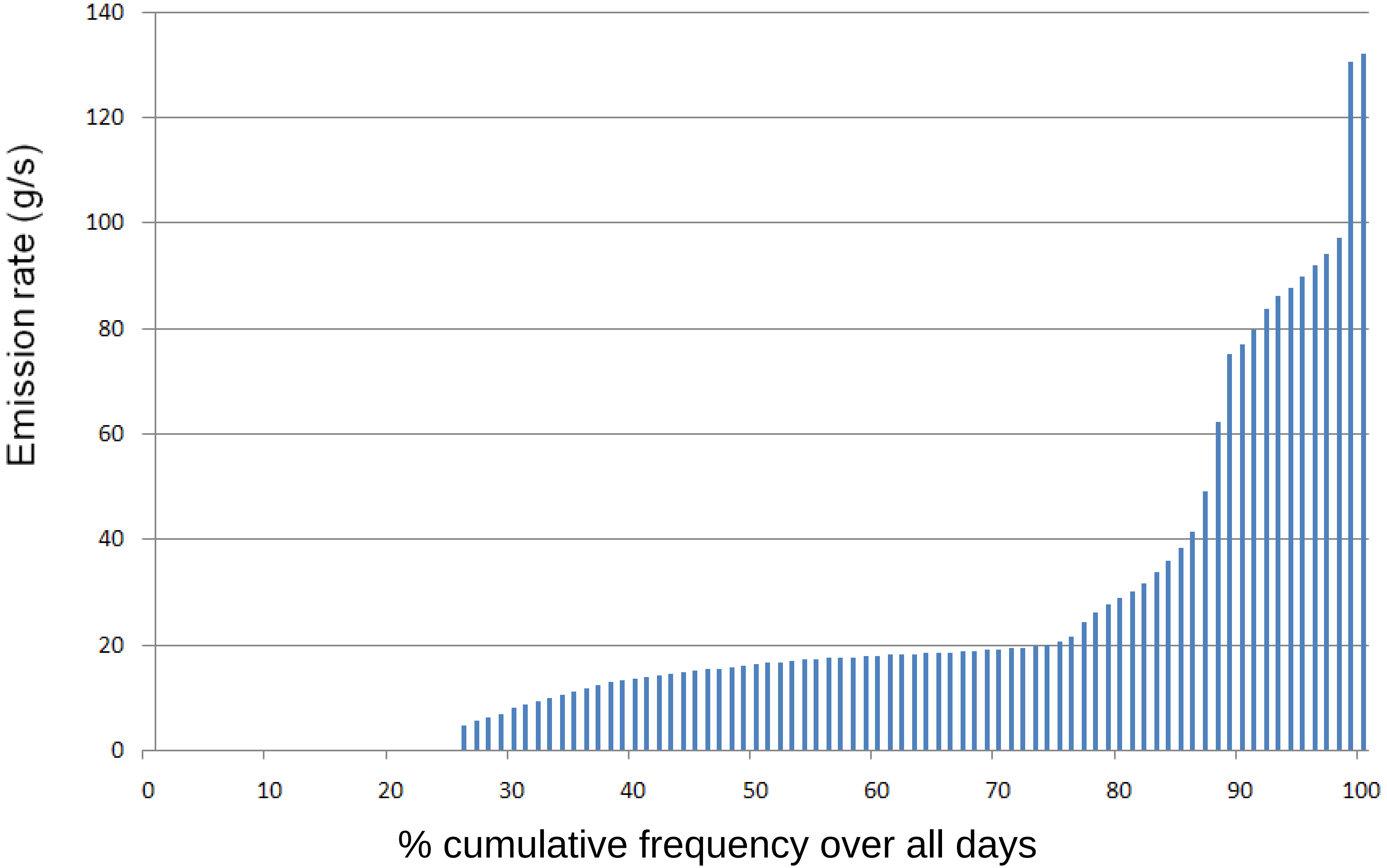
Emission Rate Variability

- Large variation often possible over the course of a year
- Intermittent sources (e.g., emergency backup engines or bypass stacks) present modeling challenges
- For these sources, assuming fixed peak 1-hour emissions on a continuous basis <u>will</u> result in unrealistic modeled results
- Better approach is to assume a prescribed <u>distribution</u> of emission rates
- EMVAP (Emissions Variability Processor), described below, uses this information to develop alternative ways to indicate modeled compliance using a range of emission rates <u>instead of just one value</u>

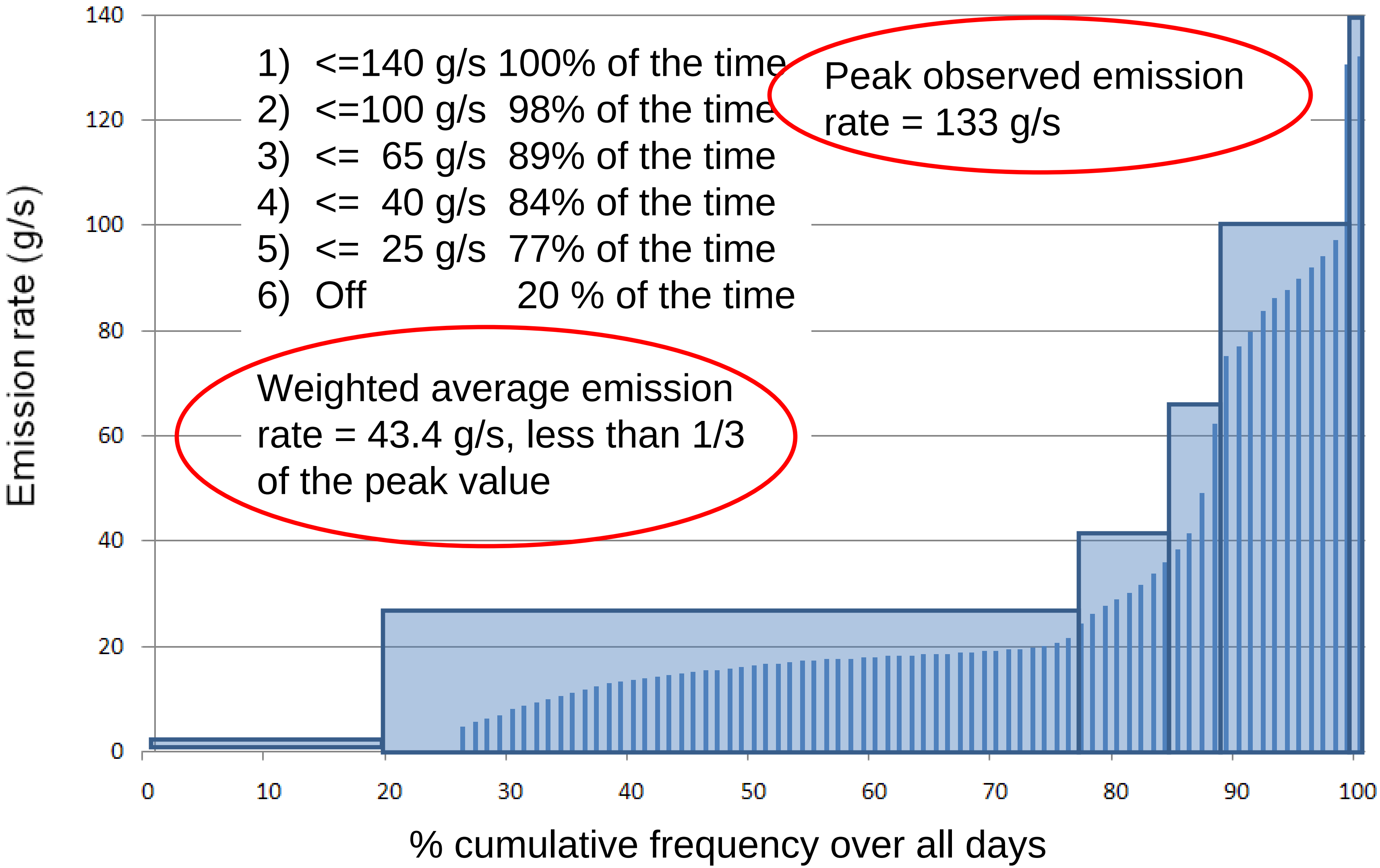
Example of Hourly Emissions Sequence



Example Emission Cumulative Frequency Distribution



Example Emission Cases for EMVAP



Approach ("EMVAP") for Multiple Allowable Emissions Modeling

- Create an emissions frequency distribution
- Model the source with unit emissions (up to 5 "real" years) – different runs maybe needed over a range of exhaust parameters
- Create many (e.g. 1,000) simulated annual realizations of conc. with random number generator for emission rate
- Randomly assign an emission rate multiplier for each hour using the source-specific emissions distribution
- Process summary statistics over each year/receptor
- Use post-processing software to add concentrations for multiple sources plus background

Random Selection Process

- In some cases, peak emissions occur in groups of hours
- The form of the 1-hour NO_2 and SO_2 standard involves only the highest concentration hour in any given day
- Therefore, it is likely conservative to distribute peak emission rates randomly rather than in groups for first EMVAP version
- Use of a random selection process, such as a Monte Carlo procedure, is appropriate
- But, sources that operate in tandem can be treated with the same sequence of random numbers

Purpose and Definition

- The EMVAP system is a probabilistic post-processor for AERMOD designed to more realistically model emission sources against short-term NAAQS
- The EMVAP system consists of three modules + AERMOD:
  - *EMDIST* emissions analyzer : aids in determining emission inputs for AERMOD runs
  - *EMVAP* probabilistic emission simulator: used to randomly generate modeled concentrations based on source emissions frequencies
  - *EMPOST* post-processor: takes EMVAP output and performs statistical analyses, generating modeled concentrations in the form of the NAAQS

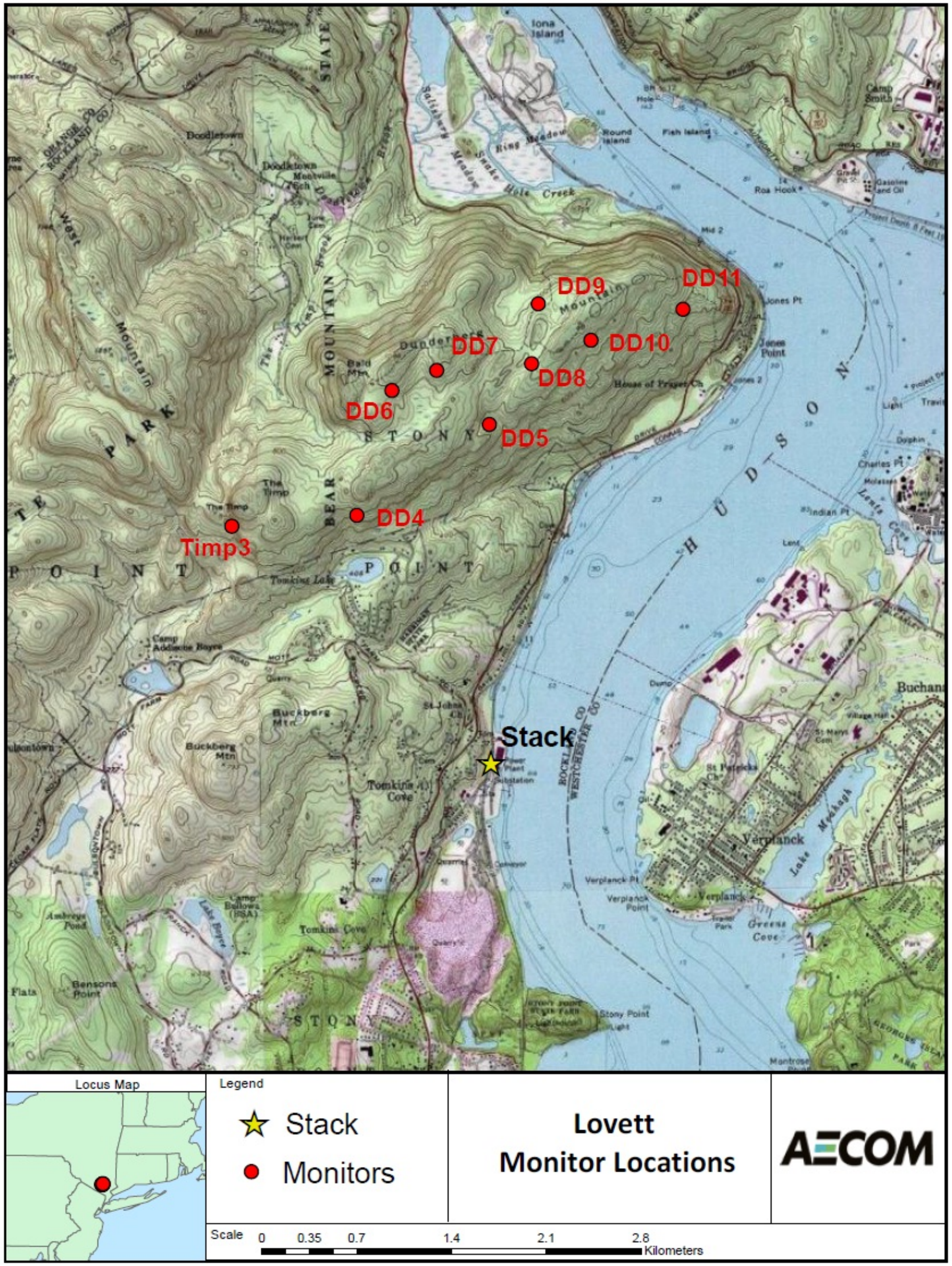
EMVAP Evaluation

- Selected 3 AERMOD Databases with variety of terrain settings
- Ran AERMOD with both actual and constant peak (allowable) hourly emissions – got 99^{th} percentile peak daily 1-hour max pre vs. obs
- Ran EMVAP to get the same result from median value over 1000 simulated years
- Expectation: EMVAP result would be between that of actual and allowable emissions

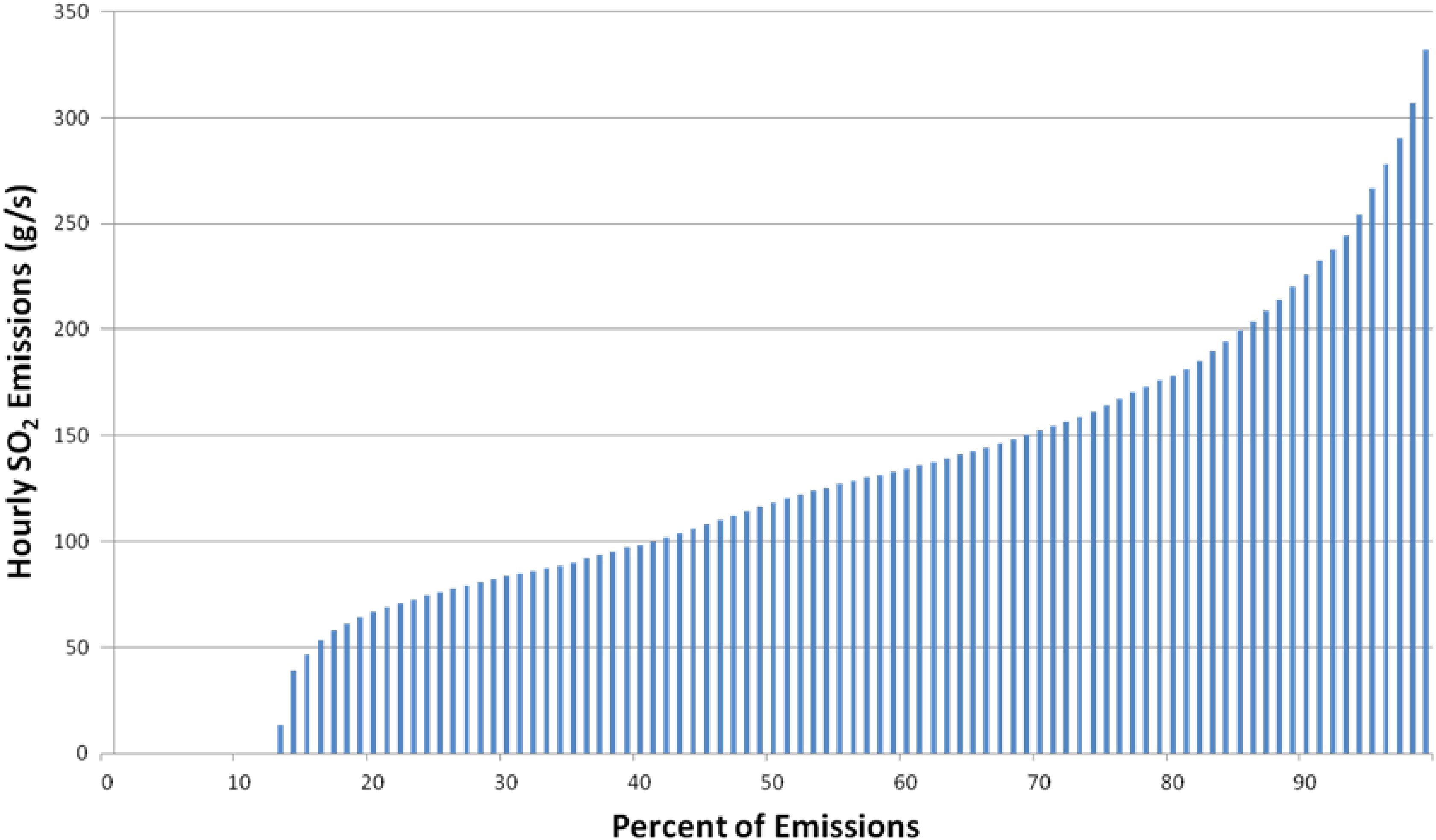
Evaluation Databases

- Lovett Generating Station – complex terrain (Hudson River Valley)
  - 1 full year test case, 8 monitors
- Clifty Creek Generating Station – Ohio River gorge
  - 1 full year with 3 units with differing load profiles, 6 monitors
- Kincaid Power Station – flat corn fields of Illinois
  - Partial year case, 1 stack, 28 monitors

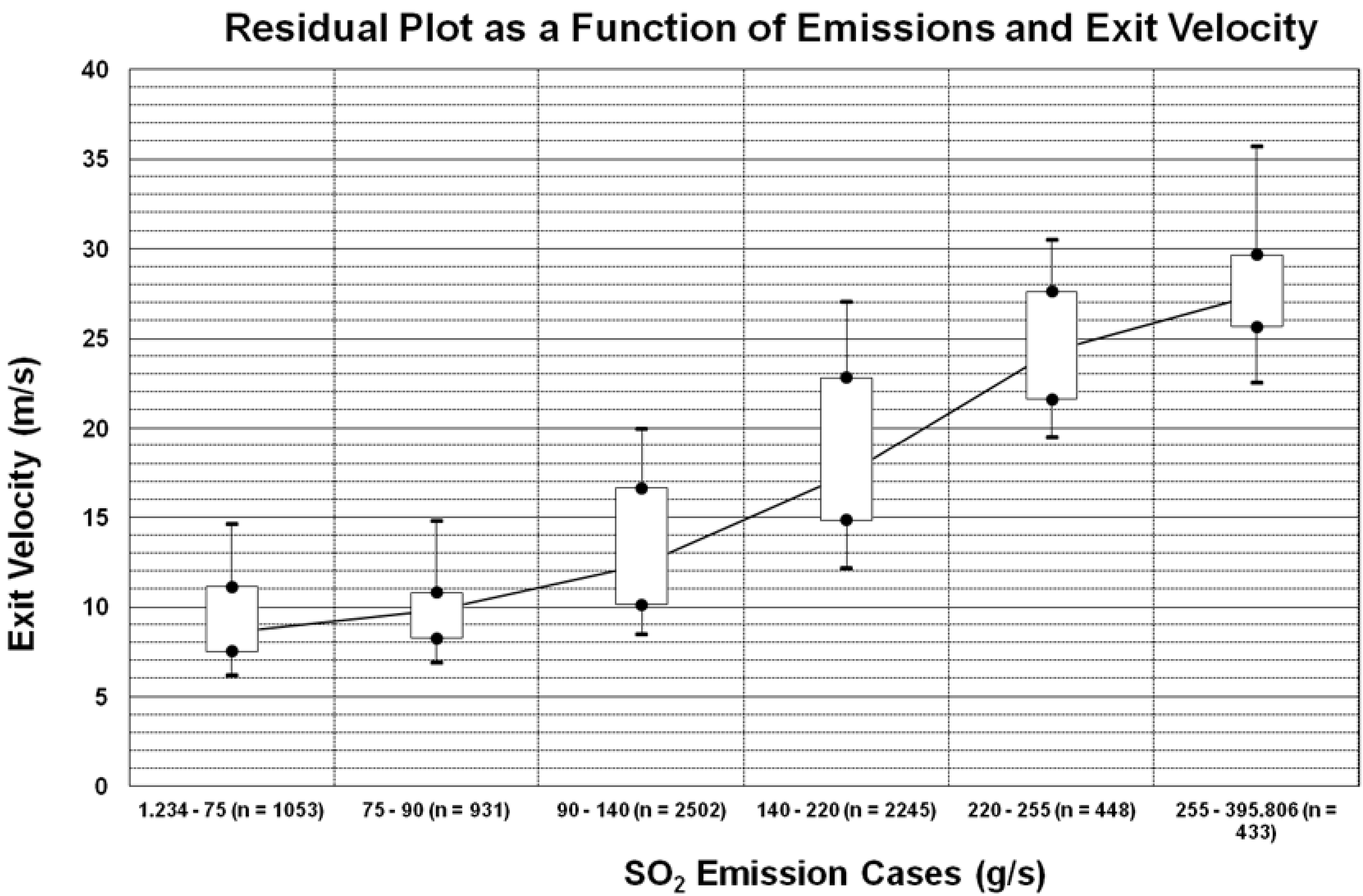
Lovett

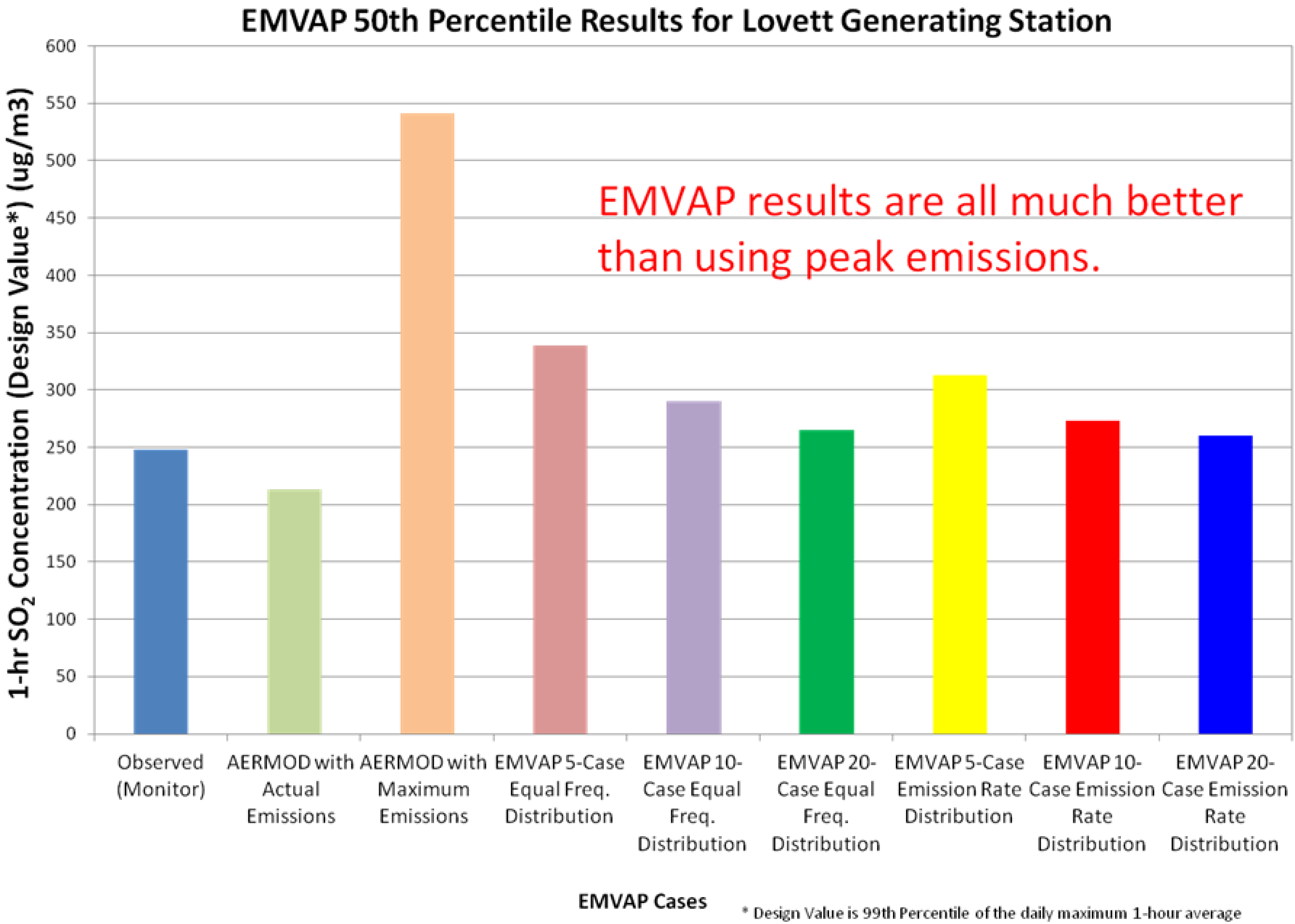

DD9
DD11
DD7
DD10
DD8
DD6
DD5
DD4
Timp3
Stack
HUDSON
Locus Map
Legend
Stack
Monitors
Lovett
Monitor Locations
AECOM
Scale 0 0.35 0.7 1.4 2.1 2.8 Kilometers

Frequency Distribution of SO_2 Emissions at Lovett, 1988

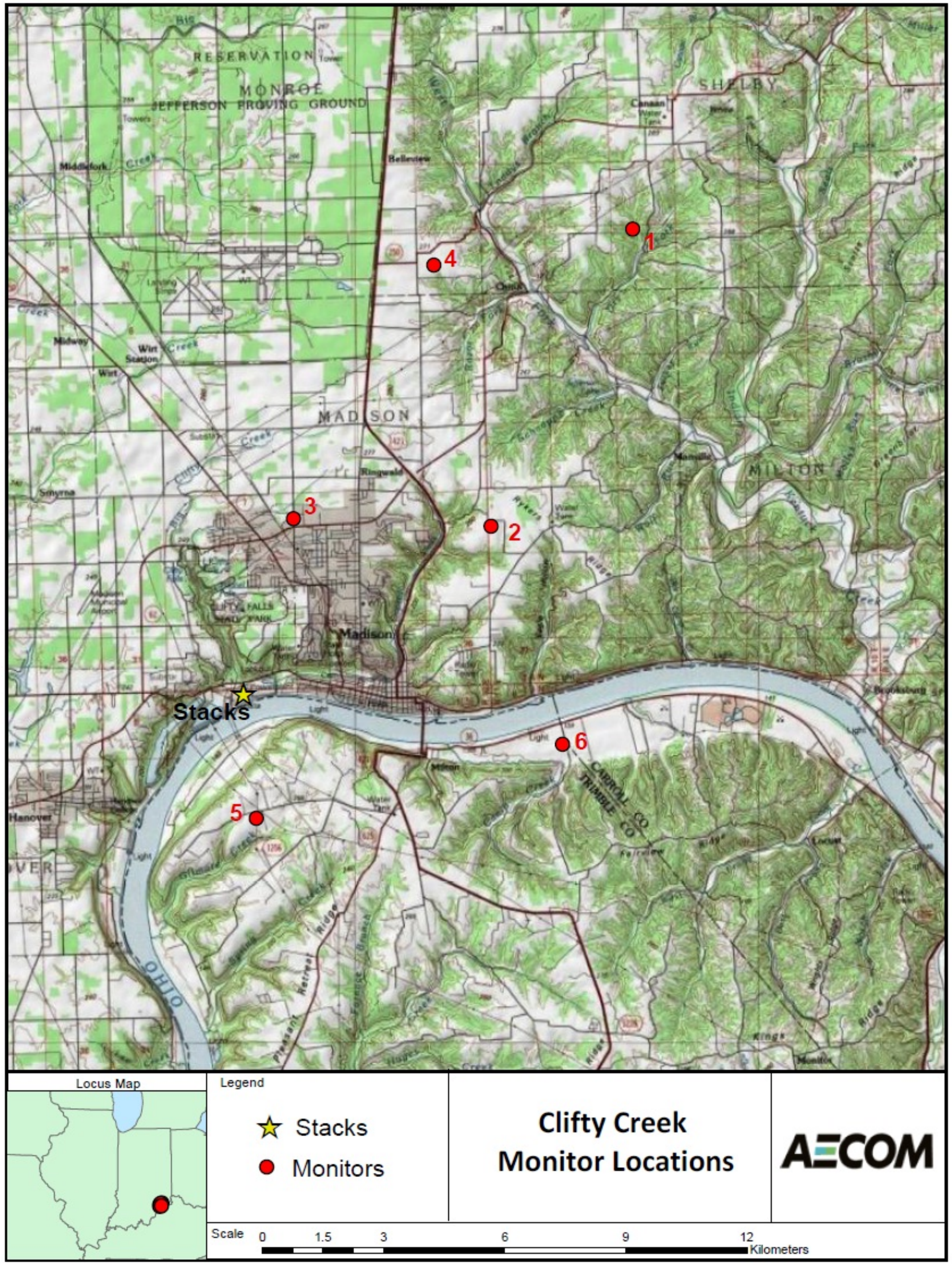


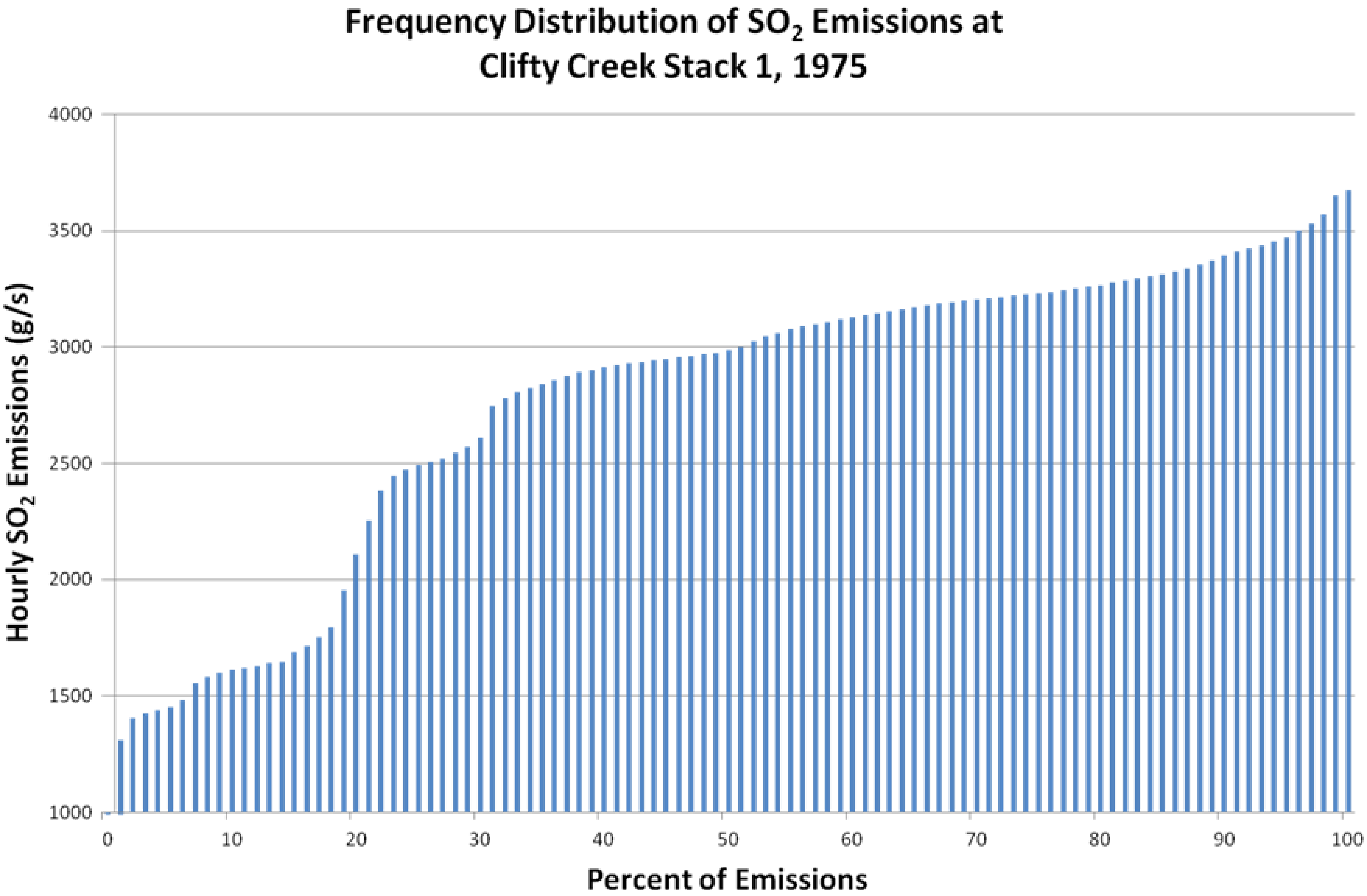
Lovett Generating Station – Exit Velocity vs. Emission Rate



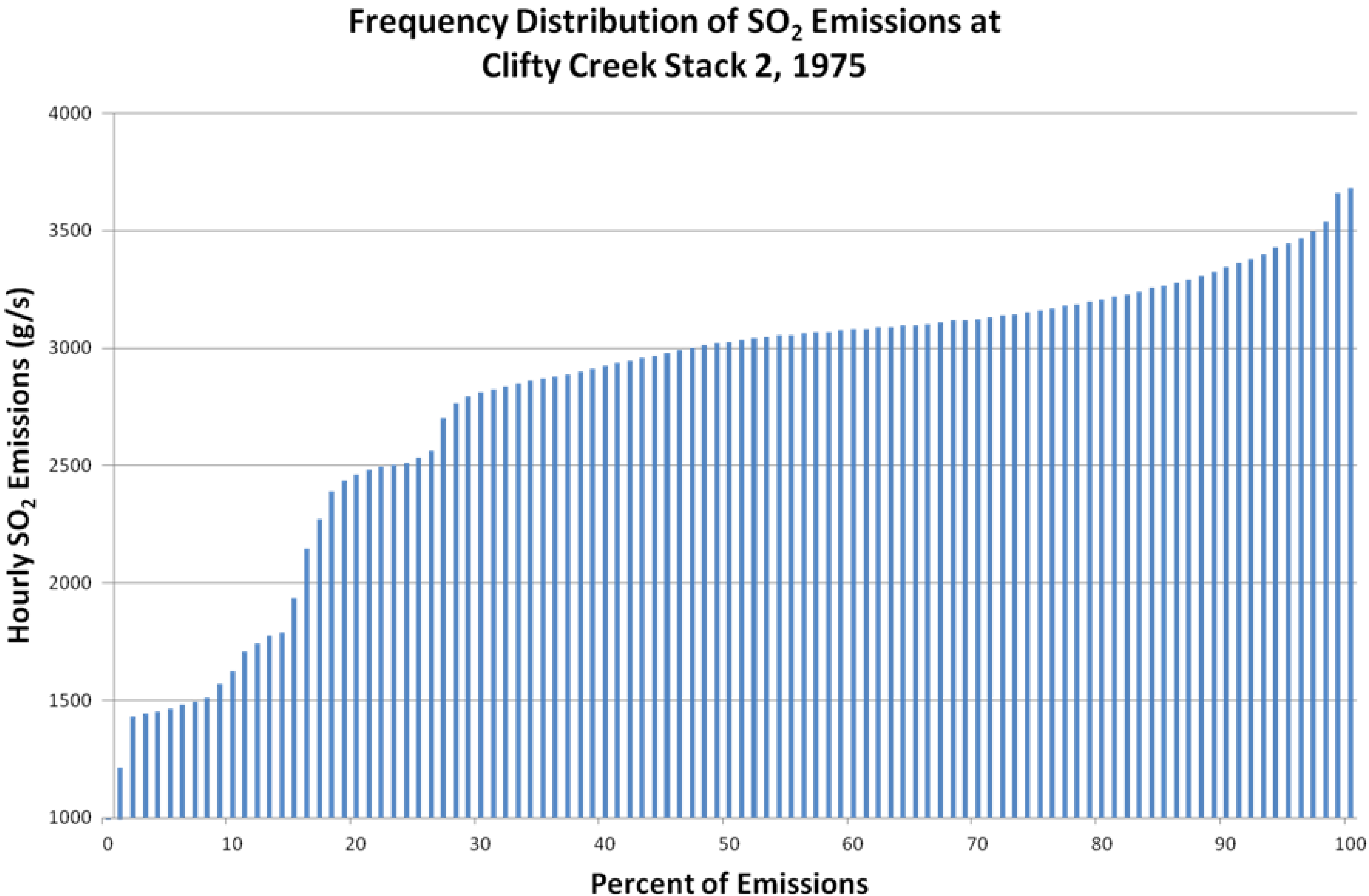

EMVAP 50th Percentile Results for Lovett Generating Station
1-hr SO_2 Concentration (Design Value*) (ug/m3)
600
550
500
450
400
350
300
250
200
150
100
50
0
EMVAP results are all much better than using peak emissions.
Observed (Monitor)
AERMOD with Actual Emissions
AERMOD with Maximum Emissions
EMVAP 5-Case Equal Freq. Distribution
EMVAP 10-Case Equal Freq. Distribution
EMVAP 20-Case Equal Freq. Distribution
EMVAP 5-Case Emission Rate Distribution
EMVAP 10-Case Emission Rate Distribution
EMVAP 20-Case Emission Rate Distribution
EMVAP Cases
* Design Value is 99th Percentile of the daily maximum 1-hour average

Clifty Creek

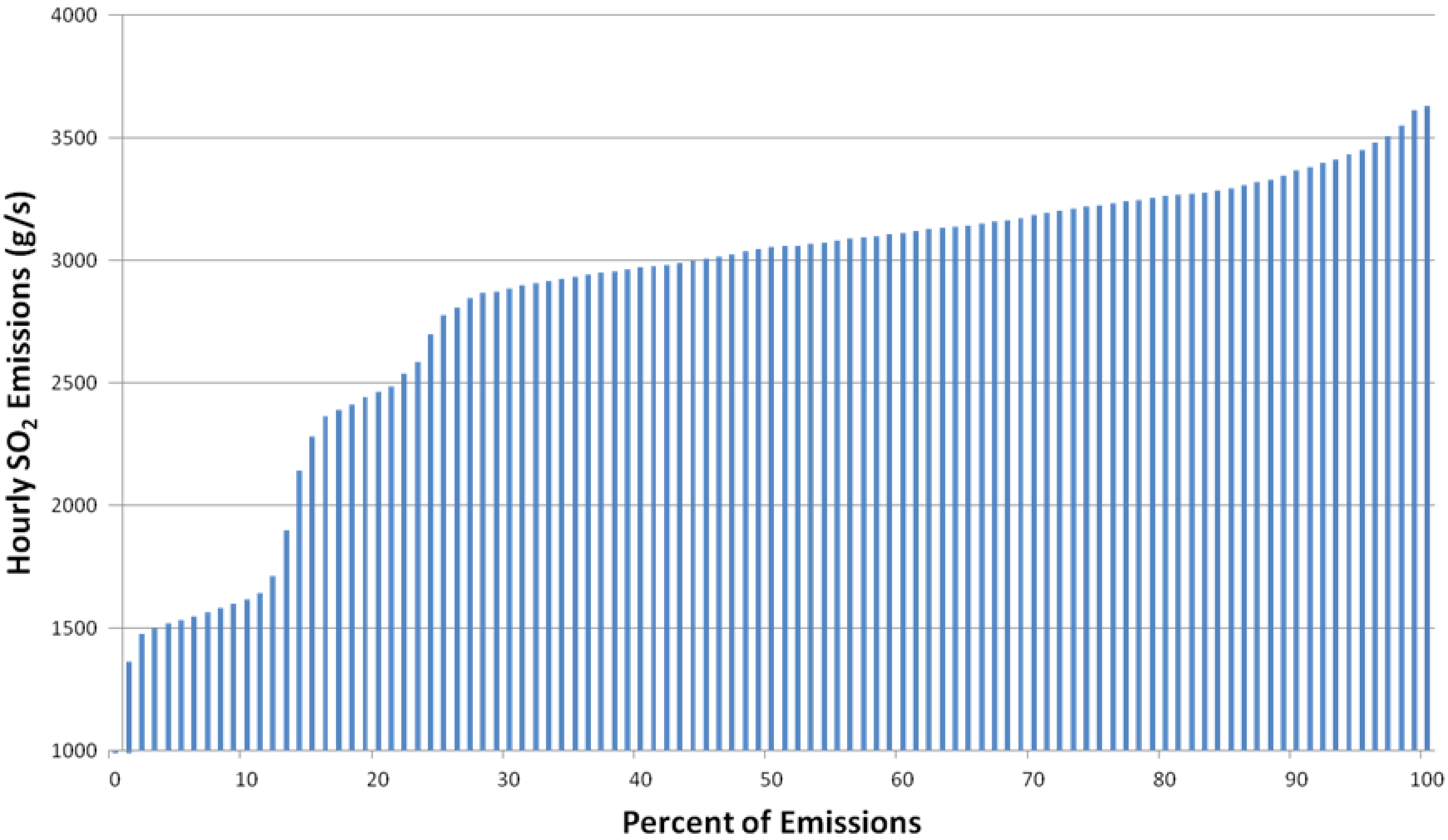


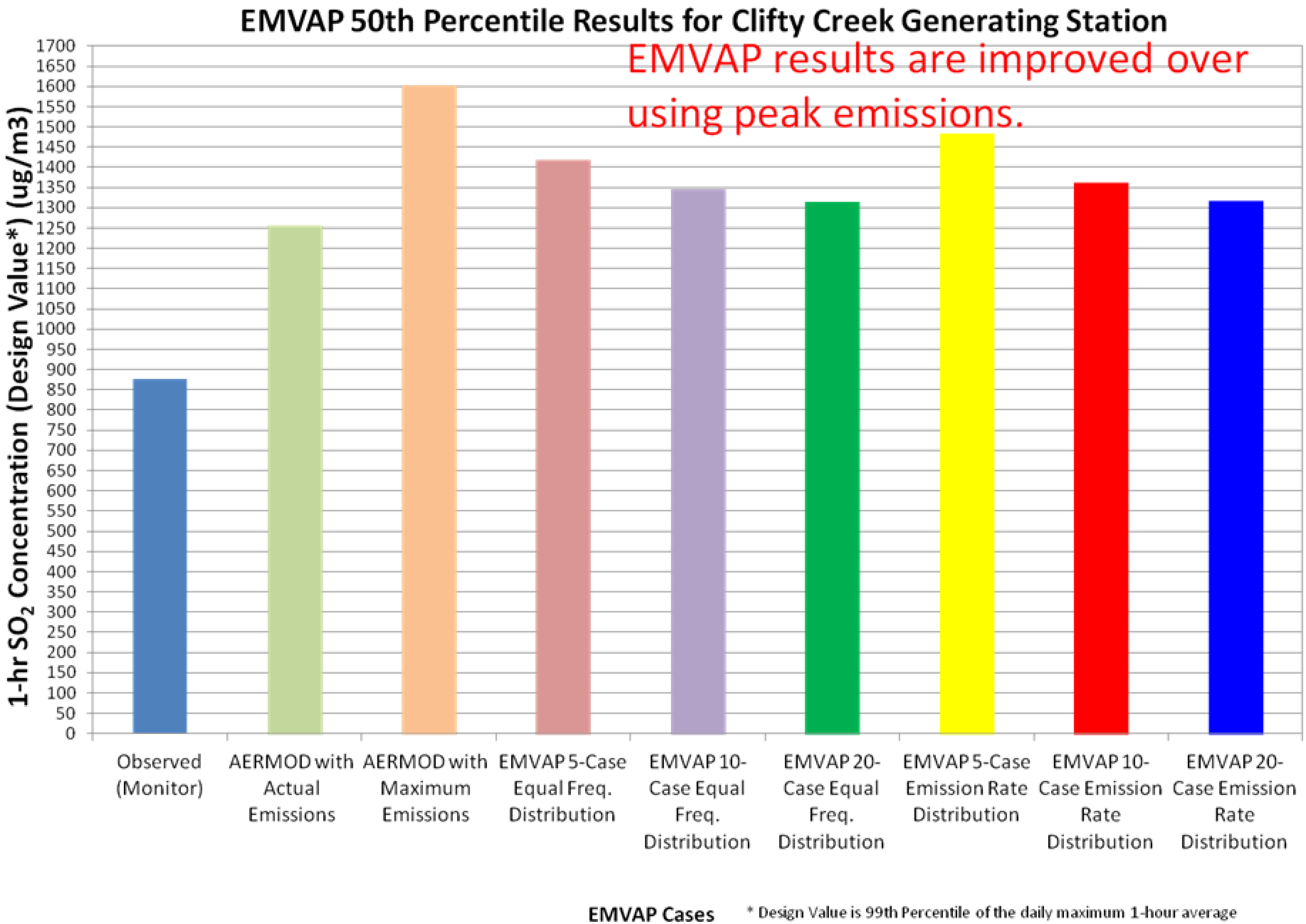


Frequency Distribution of SO_2 Emissions at Clifty Creek Stack 1, 1975
Hourly SO_2 Emissions (g/s)
4000
3500
3000
2500
2000
1500
1000
0
10
20
30
40
50
60
70
80
90
100
Percent of Emissions

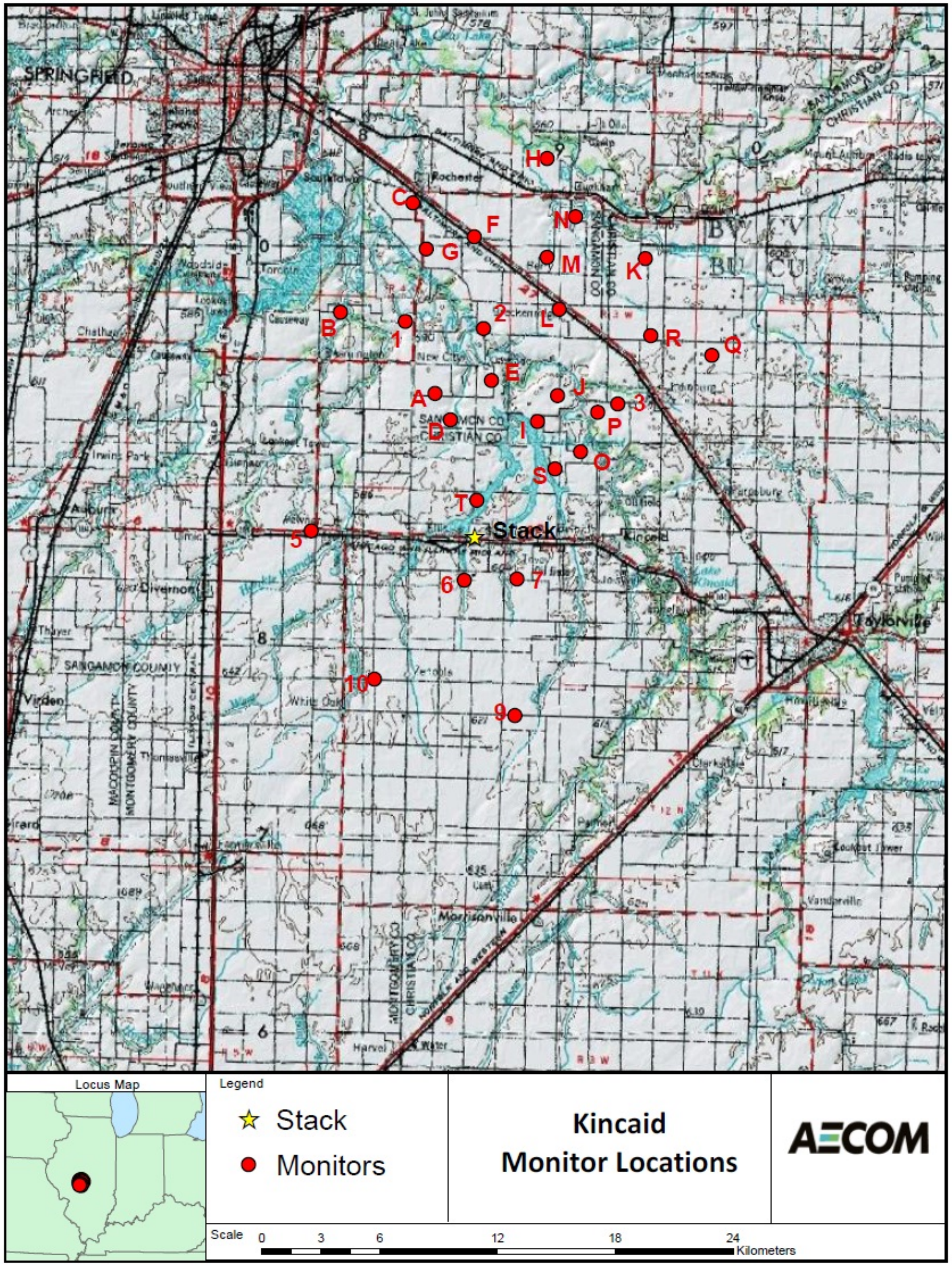

Frequency Distribution of SO_2 Emissions at
Clifty Creek Stack 2, 1975
Hourly SO_2 Emissions (g/s)
4000
3500
3000
2500
2000
1500
1000
0
10
20
30
40
50
60
70
80
90
100
Percent of Emissions

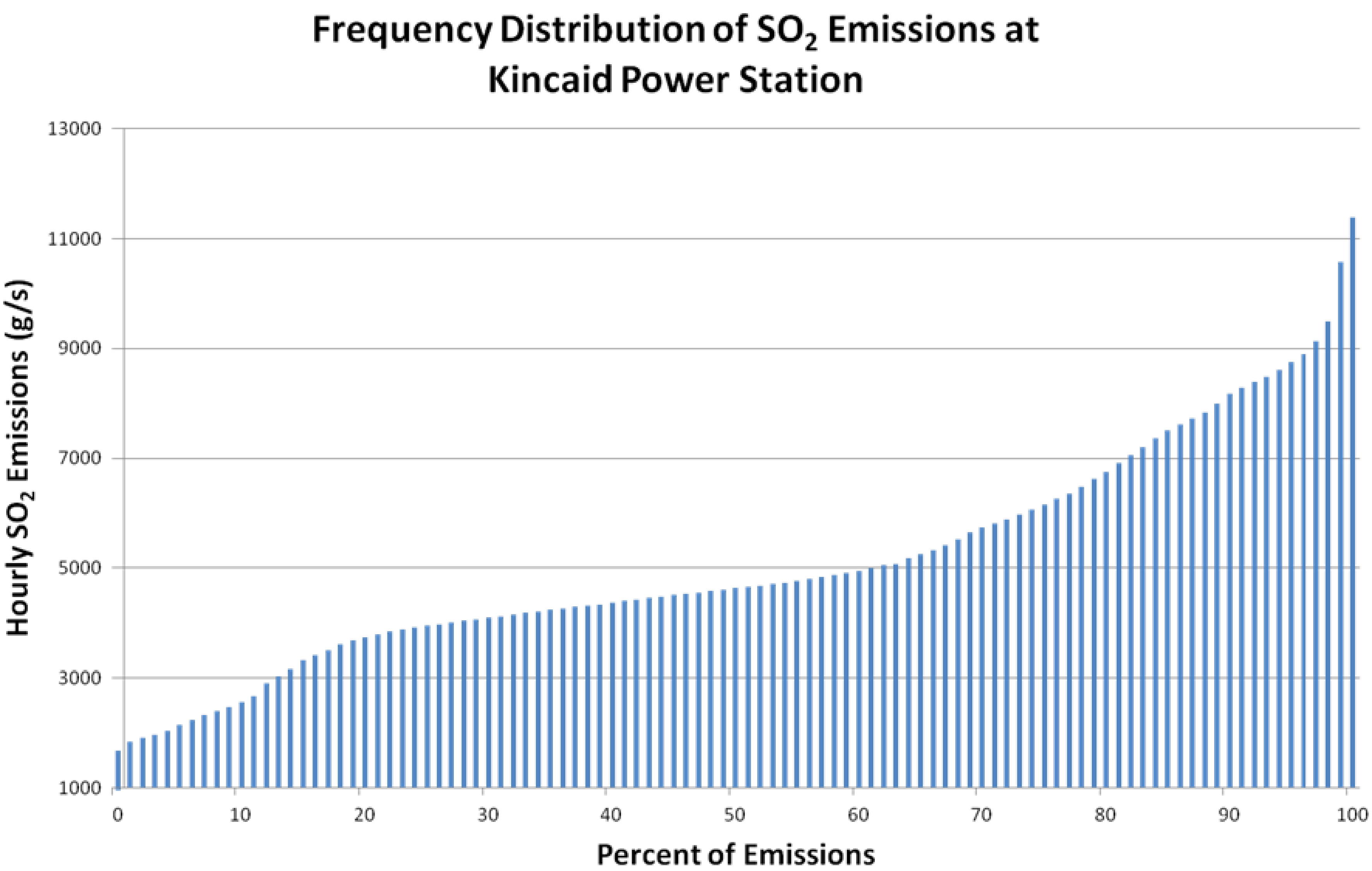
Frequency Distribution of SO_2 Emissions at Clifty Creek Stack 3, 1975



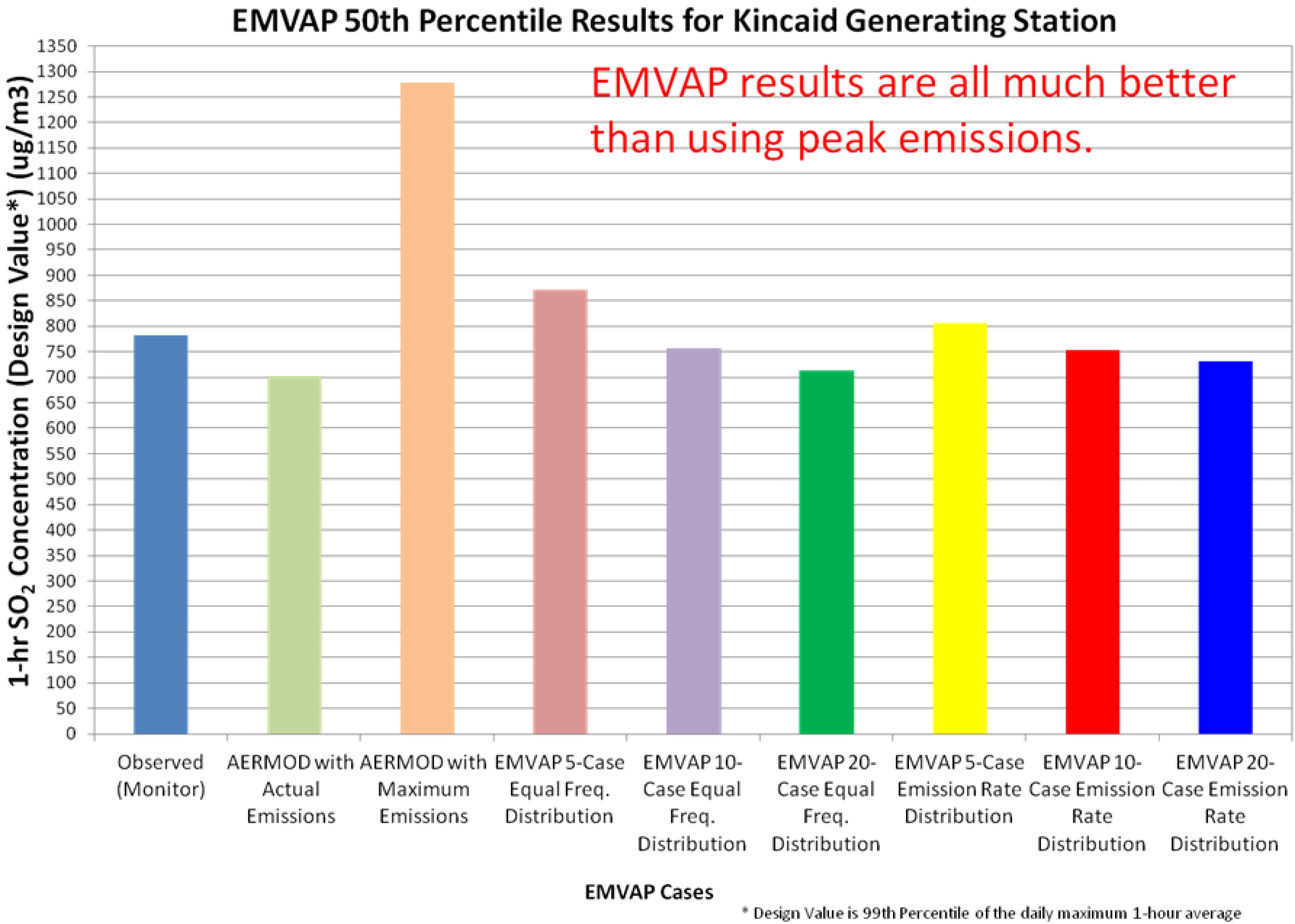

EMVAP 50th Percentile Results for Clifty Creek Generating Station
EMVAP results are improved over using peak emissions.
1-hr SO_2 Concentration (Design Value*) (ug/m3)
1700
1650
1600
1550
1500
1450
1400
1350
1300
1250
1200
1150
1100
1050
1000
950
900
850
800
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
Observed (Monitor)
AERMOD with Actual Emissions
AERMOD with Maximum Emissions
EMVAP 5-Case Equal Freq. Distribution
EMVAP 10-Case Equal Freq. Distribution
EMVAP 20-Case Equal Freq. Distribution
EMVAP 5-Case Emission Rate Distribution
EMVAP 10-Case Emission Rate Distribution
EMVAP 20-Case Emission Rate Distribution
EMVAP Cases
* Design Value is 99th Percentile of the daily maximum 1-hour average

Kincaid


Stack
Locus Map
Legend
Stack
Monitors
Kincaid
Monitor Locations
AECOM
Scale
0
3
6
12
18
24
Kilometers



Frequency Distribution of SO_2 Emissions at Kincaid Power Station
Hourly SO_2 Emissions (g/s)
13000
11000
9000
7000
5000
3000
1000
0
10
20
30
40
50
60
70
80
90
100
Percent of Emissions


EMVAP 50th Percentile Results for Kincaid Generating Station
EMVAP results are all much better than using peak emissions.
1-hr SO2 Concentration (Design Value*) (ug/m3)
1350
1300
1250
1200
1150
1100
1050
1000
950
900
850
800
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
Observed (Monitor)
AERMOD with Actual Emissions
AERMOD with Maximum Emissions
EMVAP 5-Case Equal Freq. Distribution
EMVAP 10-Case Equal Freq. Distribution
EMVAP 20-Case Equal Freq. Distribution
EMVAP 5-Case Emission Rate Distribution
EMVAP 10-Case Emission Rate Distribution
EMVAP 20-Case Emission Rate Distribution
EMVAP Cases
* Design Value is 99th Percentile of the daily maximum 1-hour average

Current Limits in EMVAP

- Receptors: no effective limit (tested so far with 10000 receptors)
- Source groups to be combined: 10 (can include groups with constant emissions, or background)
- Load cases per source group: 20
- Iterations: 5000 simulated years
- Years of modeled data per iteration: 5

Typical run time is a few minutes to an hour on a standard computing platform.

EMVAP Conclusions and Status

- EMVAP is currently operational for EPRI beta testing and consideration of implementation approaches
- Evaluation against field data shows expected results: critical predictions are somewhat higher than those from actual emissions and lower than those from peak emissions
- EPRI plans to release EMVAP and SHARP to the public in late June 2012
- Additional work on EMVAP for more complex situations (start-up, oil rig drilling campaigns) is planned that uses multiple-hour emission cases

Overall Conclusions

- Extensive user experience has uncovered several areas needing attention in AERMOD
- These issues have been made more important by tightening of several key ambient standards
- Several approaches / initiatives to mitigate these modeling challenges are underway
- EPRI is providing new AERMOD tools: EMVAP, SHARP, distance debug
- A revival of the low wind speed study is planned by API
- EPA needs to give these areas attention and work with the user community to improve AERMOD

Bob Paine
Technical Director, Air Quality Studies
AECOM

bob.paine@aecom.com
978-905-2352