Source Characterization Issues for Near-Field (AERMOD) Modeling

American Iron and Steel Institute Presentation
at EPA's 11th Modeling Conference

August 12, 2015

Outline of Presentation

There are source-related modeling issues that EPA should allow as source characterization refinements for more accurate predictions:

- “Highly industrialized areas” with large heat releases over a sizeable area can be modeled with urban dispersion option
- Stack plumes on or near buildings with fugitive heat releases can experience liftoff effects – reducing inaccurate downwash over-prediction

----------*Supplemental Issues Provided as Attachments*----------

- Evaluation results for a highly industrialized area modeled as urban
- Evaluation results for stacks near buildings with heat releases
- Modeling approach for plumes from adjacent stacks in a line that could partially merge, affecting final plume rise
- Modeling approach for plume rise from moist effluent – rise is higher than that for “dry” plumes due to heat of condensation

Documentation of These Source Characterization Techniques

- EPA has been provided with several technical documents by AISI
- The source characterization techniques included in these studies have been provided to EPA and will be placed in the docket for this rulemaking as AISI comments

Urban Dispersion for Highly Industrialized Areas

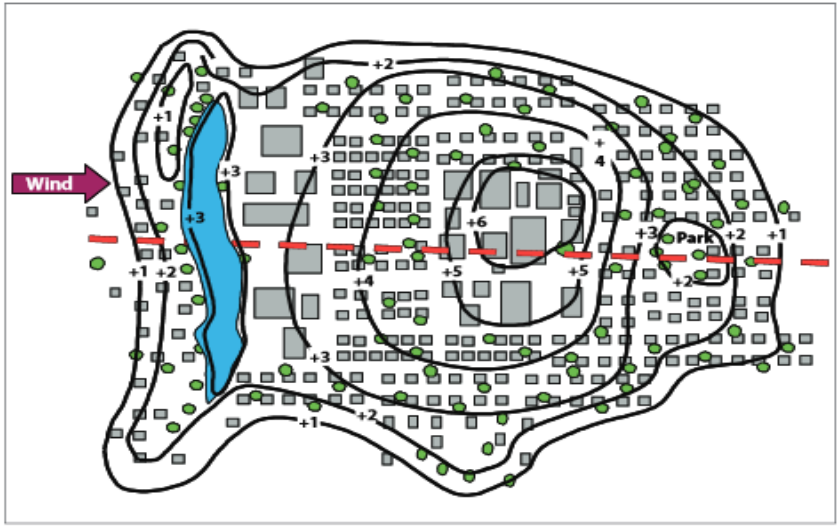
Highly Industrialized Areas: Consider Urban Dispersion with AERMOD

- An important source-related issue is large heat releases in an industrial complex setting
- Normal assignments of urban vs. rural can result in AERMOD over-prediction for this case
- Industrial processes in geographic areas with large heat releases but low population (i.e., Gary, IN and East Chicago, IN) would be modeled more accurately if considered as urban areas with large “effective populations”
- This would provide an appropriate urbanized treatment of mixing height and temperature lapse rate for dispersion calculations to handle releases within a highly industrialized area

Current AERMOD Modeling Guidance for Urban Areas

- Implementation guidance allows for urban designation based upon population or land use in a 3-km circle
- Most industrial facilities with large urban-like heat releases do not meet these criteria
- However, AERMOD formulation for urban areas provides for ways to parameterize the “effective urban population” for industrial complexes that act as urban heat islands

Conceptual urban heat island temperature map at night



Determining the "Effective Urban Population"

- The AERMOD urban formulation has a relationship between the urban-rural temperature difference ($\Delta Tu\text{-}r$) and the effective urban population (P):

$$\Delta Tu\text{-}r = \Delta Tmax\ [0.1\ \ln(P/Po) + 1.0],$$

where $\Delta Tmax$ = 12 deg C and Po = 2,000,000

- The urban-rural temperature difference can be measured for industrial complex areas with satellite data

- Or, engineering estimates can provide the excess heat release (flux, Hu), and this can be related to the urban-rural temperature difference (from the AERMOD formulation):

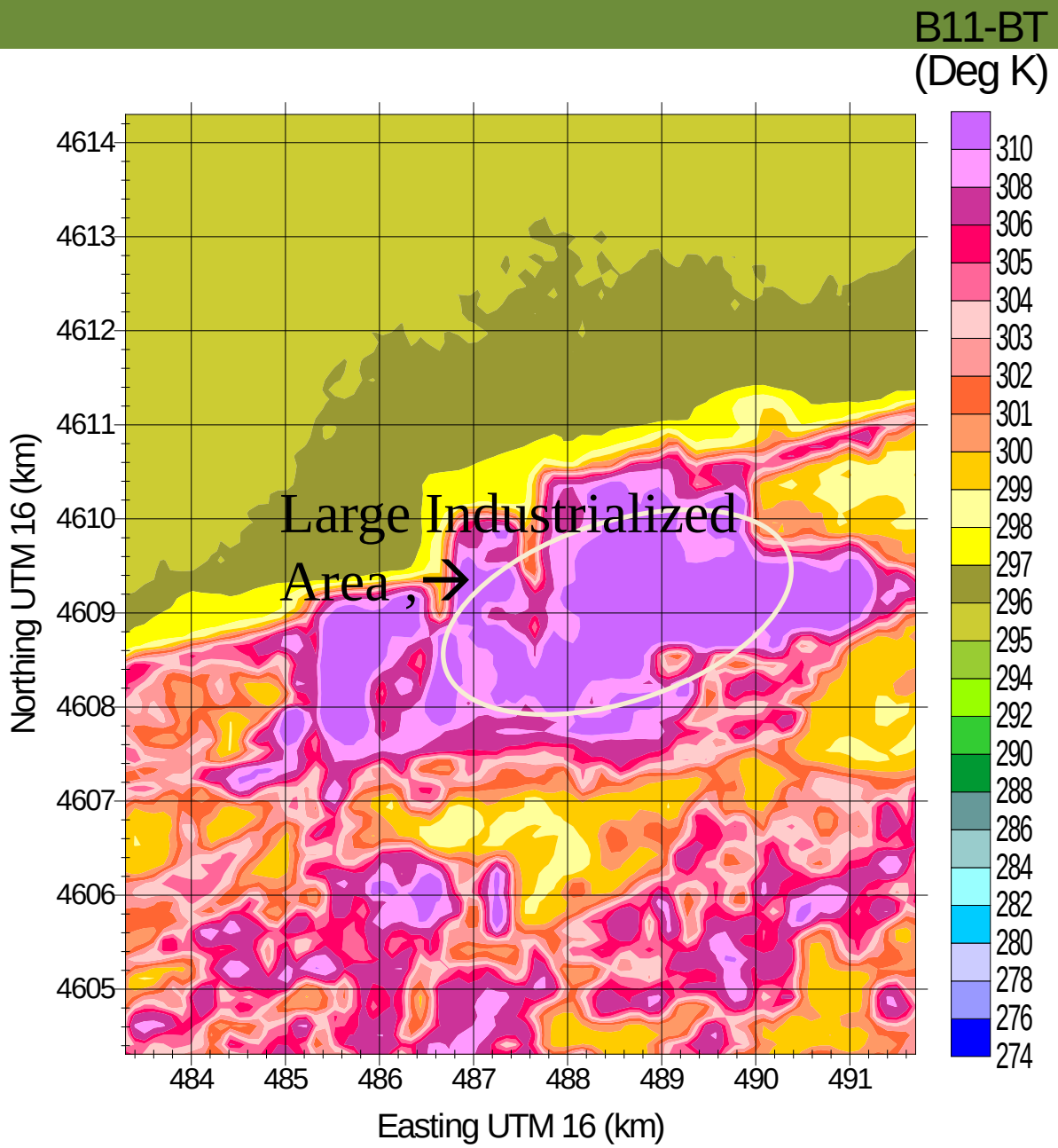
$$Hu = \alpha\ \rho\ c_p\ \Delta Tu\text{-}r\ u_*,\ (Hu \text{ in watts/m}^2,\ \Delta T \text{ in deg C})$$

where α, ρ, c_p, and u_* are known, so $\Delta T_{u\text{-}r} \sim Hu/4$

Measurements of Urban-Rural Temperature Difference

- The excess temperature in highly industrialized areas is now routinely available via satellite databases
- Available satellites are ASTER and LandSat 8
- Technical discussion of how to access these databases has been provided to EPA and will be supplied to the docket by AISI
- An example of an ASTER satellite temperature map is provided in the next slide and in Supplement A
- Brightness temperature" from satellite can be reviewed for industrial area and compared to urban areas to quantify the "industrial complex heat island" temperature excess
- These procedures are relatively new and are being refined and made more objective with ongoing experience

100-m resolution LandSat 8 TIR observed brightness temperature for long wavelength: late morning fly-over (10:30 AM) for a highly industrialized area



Band 11 BT Estimate at 10:30 LST for July 11, 2013

Building Downwash Issues: Low Winds and Source-related Fugitive Heat "LIFTOFF" Effects

Building Downwash Complications for Light Winds and Source-Related Effects

- AERMOD *predicted* building downwash effects – sometimes very high concentrations - can occur with nearly calm winds in stable conditions (especially with rural dispersion)
- The peak predictions under these conditions are not expected and have not been adequately evaluated
- These conditions are discussed in Alan Robins chapter on "Flow and dispersion around buildings in light wind conditions" in *Stably Stratified Flows*, edited by Castro and Rockliff, 1994
- Plume lift-off considerations are discussed in "Lift-off of ground-based buoyant plumes" in *Journal of Hazardous Materials*, 1998, by Hanna, Briggs, and Chang

Comments on Light Wind Downwash Issues

- These cases are associated with extreme stability conditions
- Characteristics of flow and dispersion near buildings in these conditions may be quite unlike those in neutral cases
- Source-related effects become important due to weak ambient turbulence effects in light winds
- In light winds with significant wind meander, building wake effects are very unsteady, but AERMOD does not* accommodate this effect in the current formulation
- In fact, AERMOD's meander treatment for low winds only applies to non-downwash dispersion, and was never implemented in the PRIME model implementation within AERMOD

*Vlad Isakov , Todd Sax , Akula Venkatram , David Pankratz , James Heumann & Dennis Fitz (2004) Near-Field Dispersion Modeling for Regulatory Applications, Journal of the Air & Waste Management Association, 54:4,473-482, DOI: 10.1080/10473289.2004.10470920

How to Adjust for this Light Wind Effect?

- Suggested approach would be to reduce downwash impact for very low winds due to wind direction unsteadiness / meander
- The Danish OML model accounts for the intermittent nature of the downwash (see Genikhovich-Snyder approach in http://www2.dmu.dk/1_viden/2_Publikationer/3_arbrapporter/rapporter/AR123.pdf, Section 5.2)
- Basically, the downwash vs. non-downwash treatment is weighted by a factor depending upon the wind intermittency

Downwash for Sources with Excess Heat Releases

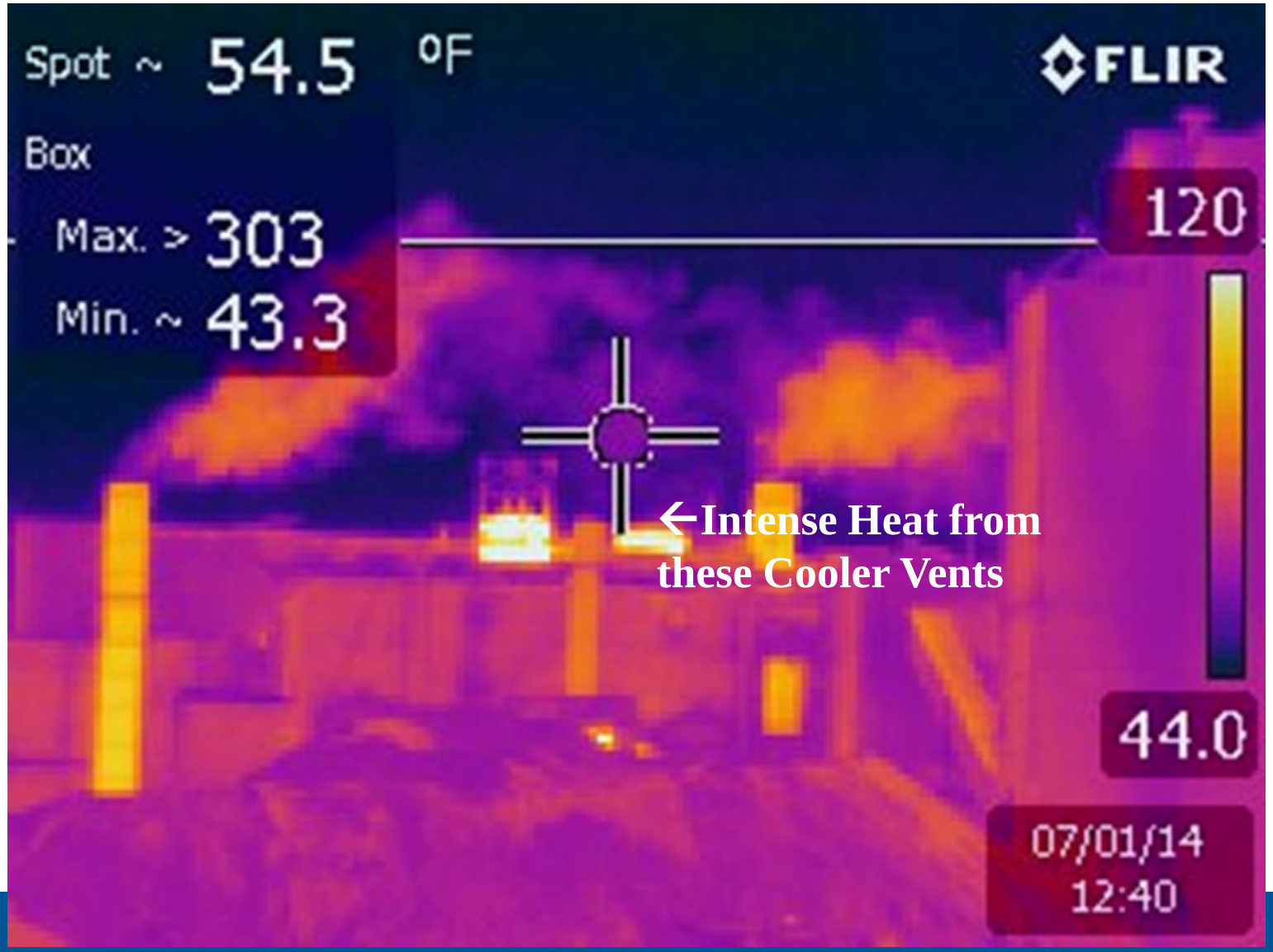
- In cases with significant heat releases, plumes will resist downwash effects, especially in light wind cases, and lift off from the building – PRIME does not consider this effect
- Heat can be estimated with a buoyancy flux term, Fb
- Hanna, Briggs, and Chang suggest a combined dimensionless buoyancy flux, $F^{**} = Fb/(U^3W)$, where Fb is the buoyancy flux, U is the wind speed and W is the initial plume width
- "LIFTOFF" approach for AERMOD is similar to low wind intermittency: uses a weighting factor between lift-off conditions (no downwash) and non-lift-off conditions (normal downwash) ranging from 0 to 1 from Hanna, Briggs, Chang paper: exp (-6F**^0.4)

Evaluation Testing of LIFTOFF concept: Hot Industrial Process Building Areas

- Studies cited by Hanna, Briggs, and Chang paper
- Recently-completed study of facility with large fugitive heat releases near buildings
  - 4 SO_2 monitors in various directions around the site in areas of peak AERMOD predictions (see Supplement B)
  - Continuous emissions data, representative meteorological data
  - Default modeling approach over-predicts by a factor up to 4
  - LIFTOFF buoyancy flux determined from engineering estimates and/or satellite thermal imagery
  - LIFTOFF modeling approach shows much less over-prediction bias in field evaluation results summarized in Supplement B

In This Case, AERMOD Indicates a Potential Building Downwash Issue

But, the Building has “Fugitive Heat” Releases That Affect Downwash Characteristics



Summary Comments on Other Source Characterization Issues – Written Comments Coming

- AERMOD Implementation Guide or Appendix W should clarify that stack flues that are “touching” (or nearly so – e.g., spacing gap within 1 diameter) should be modeled as fully merged
- This issue was previously addressed in C/H Record 91-II-01
- Partial plume rise enhancement for stacks in a row can be accommodated as a source characterization technique
- Plume rise models are available for exhaust streams with substantial moisture
- In this case, relative humidity is a factor in the final rise
- Hourly effective temperature input to AERMOD can be computed to accommodate the moist plume rise heat of condensation

AISI Recommendations for Source Characterization

- Appendix W should clarify that case-by-case source characterization refinements are not alternative model options, and should be allowed with adequate documentation
- Besides urban characterization for large industrialized areas, other source characterization issues are:
  - Plume liftoff (reduced or no building downwash) for sources on or near buildings with fugitive heat releases
  - Partial plume merging external to stacks in a row
  - Adjustments to plume rise due to their moisture content
- Each of these issues can be addressed by source characterization approaches that improve the hourly emissions-related input to AERMOD, but do not change the AERMOD model itself
- AISI requests these techniques be acknowledged as viable source characterization options in Appendix W and the pending AERMOD implementation guidance document

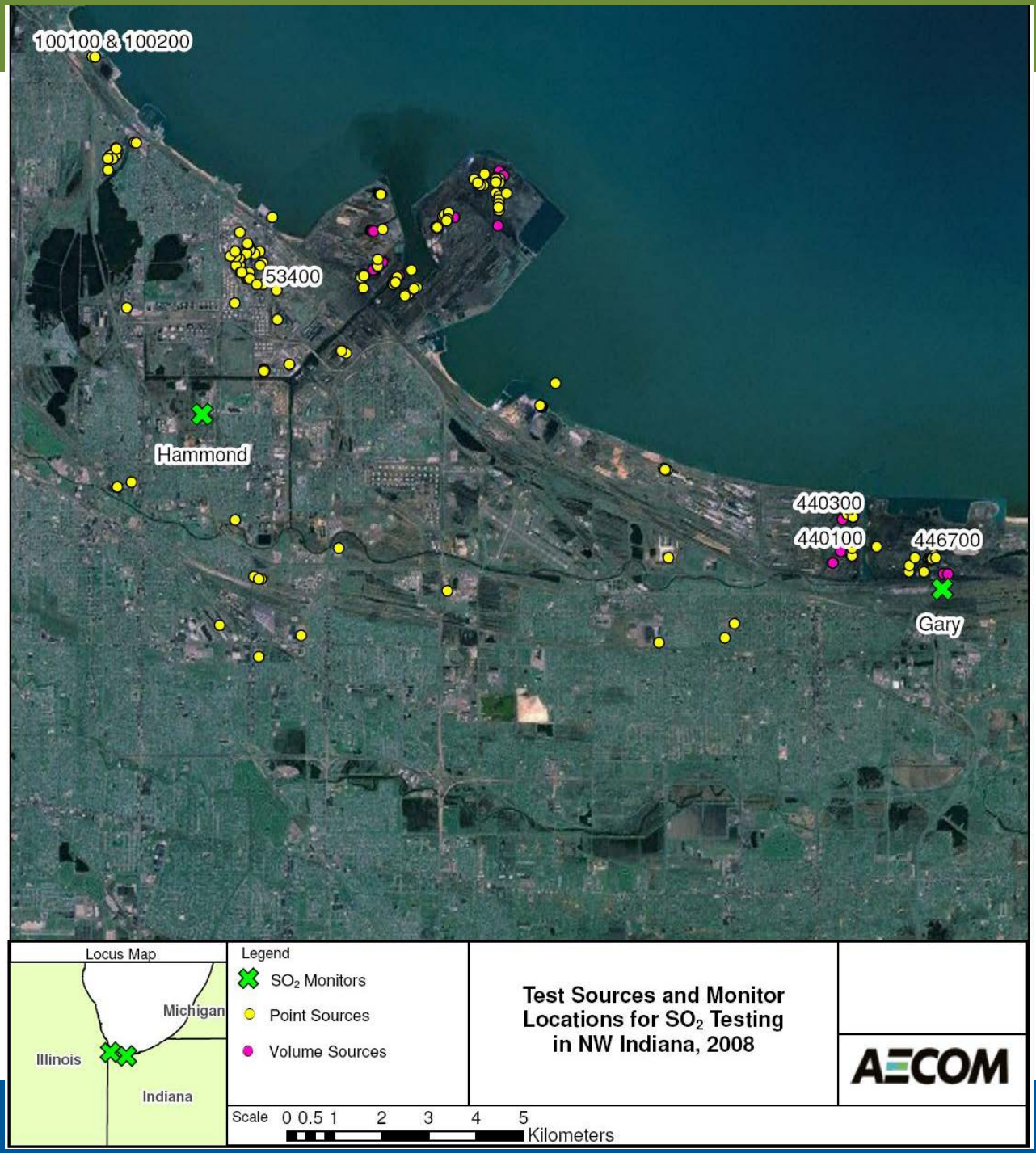
Supplementary Information on Source Characterization Issues

Supplement A

Evaluation of Urban Treatment of Industrial Complex Heat Islands

AISI field database tested to illustrate how urban dispersion with large effective population improves AERMOD performance:

NW Indiana SO_2 evaluation database for AERMOD using actual emissions for 2008

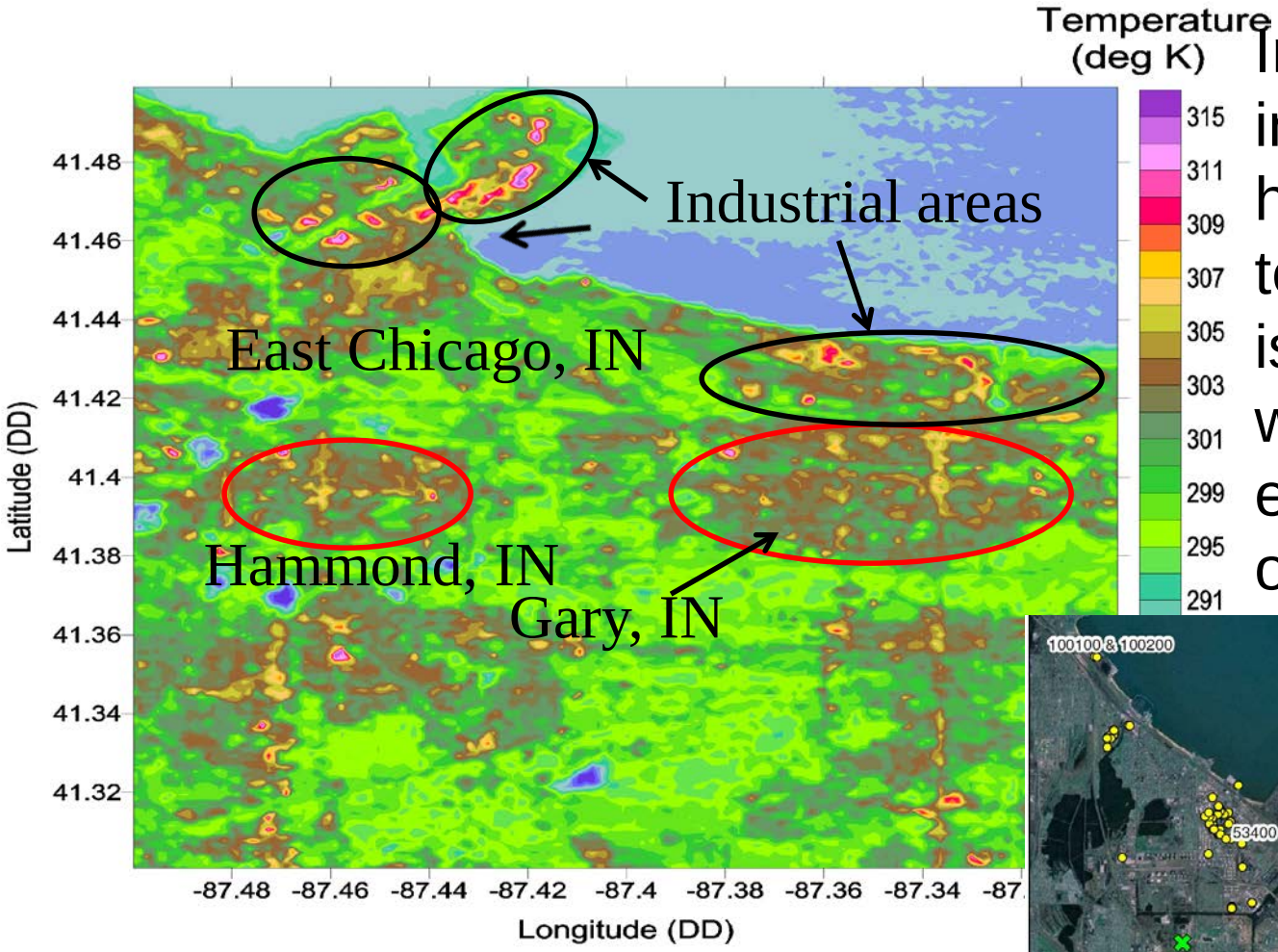


NW Indiana Sources and Two Local SO_2 Monitors

Large & complex manufacturing facilities, including steel

Stack (point) and fugitive (volume) SO_2 sources

Industrial case study: the NW Indiana Coastline



Brightness temperature from ASTER band
June 10, 2008 for 1200 LST

In this case, the industrial complex heat island temperature excess is >= 11-12 deg C, which leads to an effective population of ~1,000,000

Effective Population Versus Industrial Complex Excess Temperature from Equation Already Shown

delta T (K)	population
8	~70,000
9	~165,000
10	~380,000
11	~900,000
12	2,000,000
13	~4,600,000
14	~10,500,000
15	~24,000,000

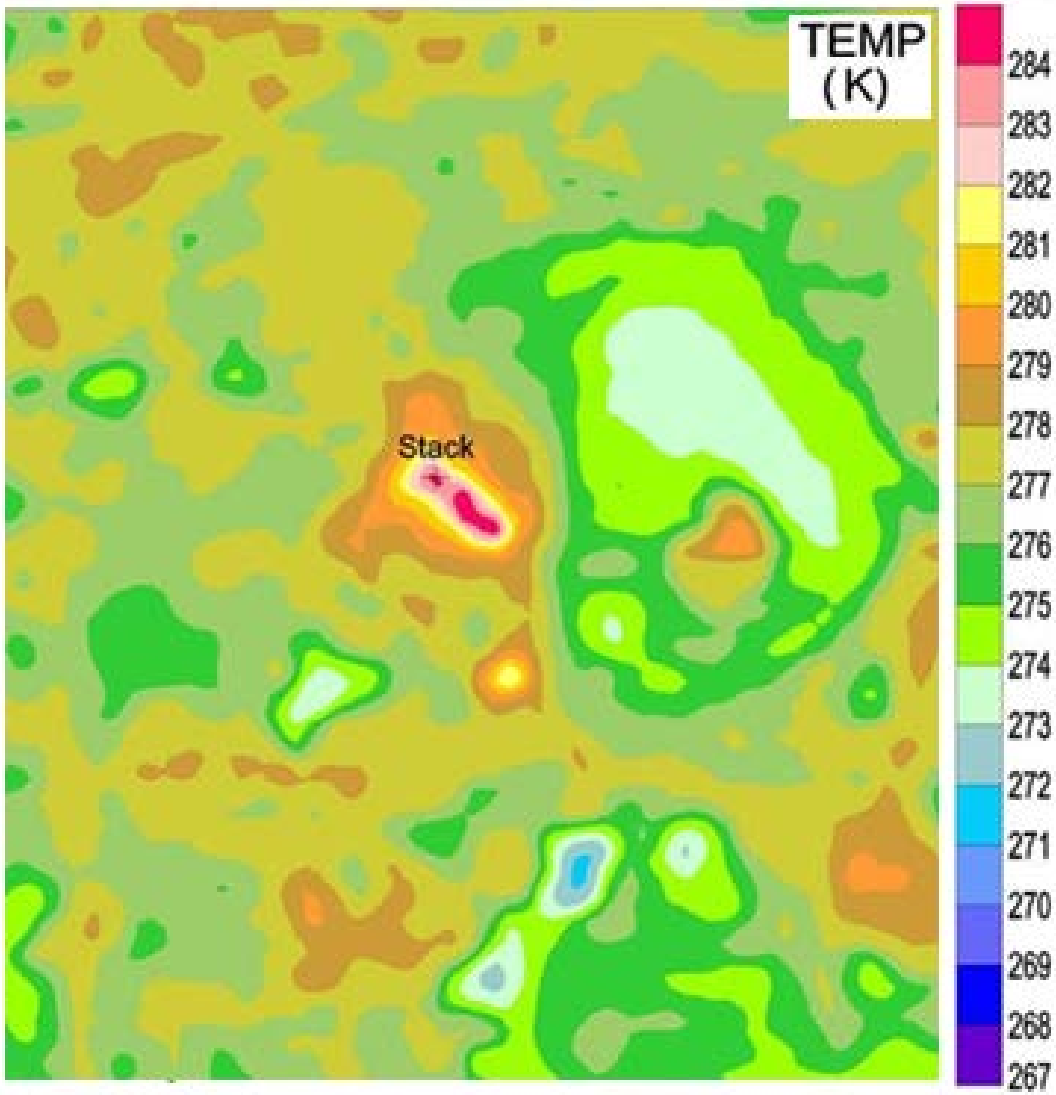
Urban Industrial Complex Evaluation Results to Date

- For NW Indiana database with 2 monitors, urban dispersion option and low wind options improve AERMOD performance for industrial complex heat islands
- AERMOD run with rural or low urban population approach over-predicts by about a factor of 6-10 at the monitors
- Use of larger population for urban treatment plus beta u* option brings AERMOD within a factor of 2 of observations
- For sources such as smelters or steel mills, site applications for the urban dispersion option as well as LIFTOFF could improve AERMOD model performance

Supplement B

Plume Liftoff in Cases of Fugitive Heat Releases from Buildings

Brightness Temperature Satellite Analysis

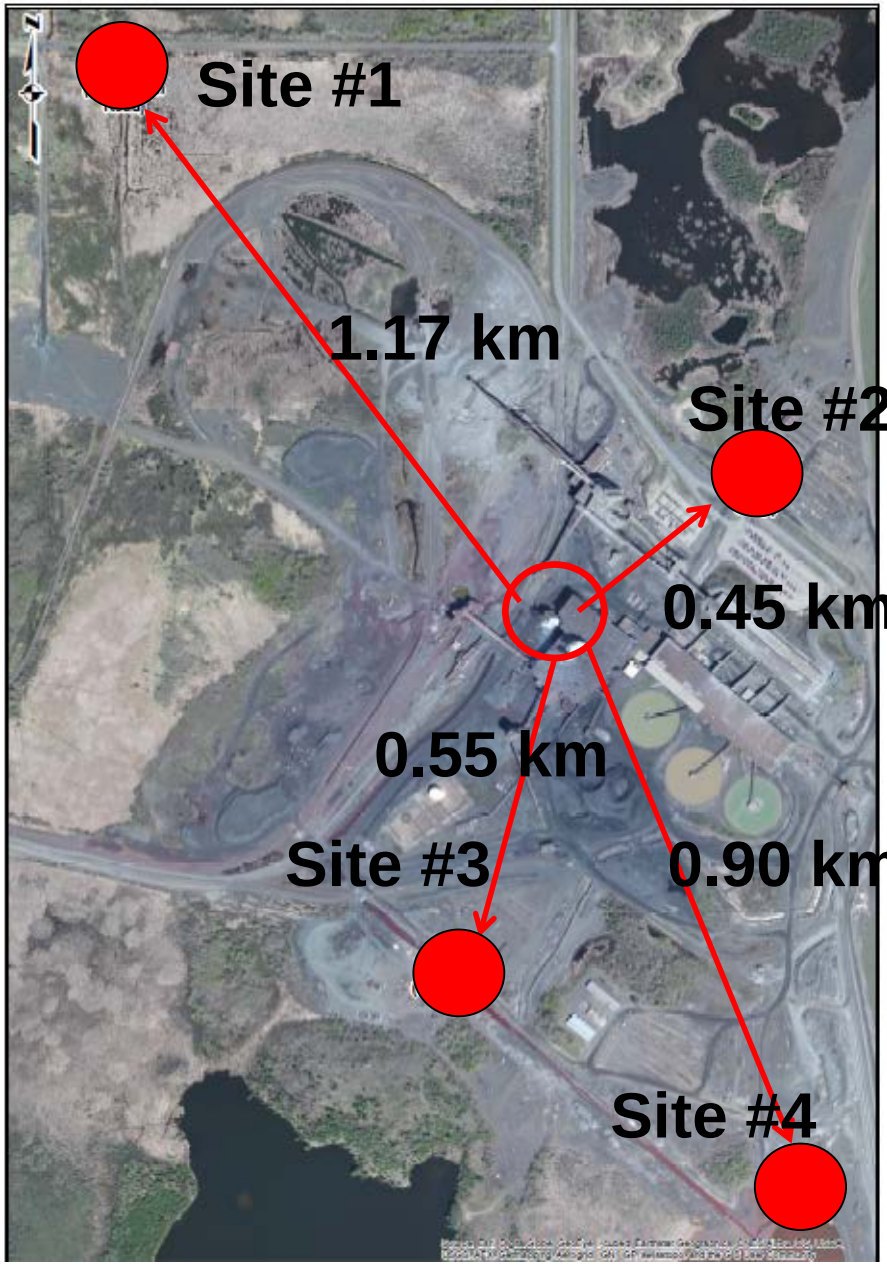


April 21, 2013, 2200 LST

LandSat 8 TIR Band 11 Radiance Temperature:

7 to 8 deg C temperature excess, or about 30 watts/m^2

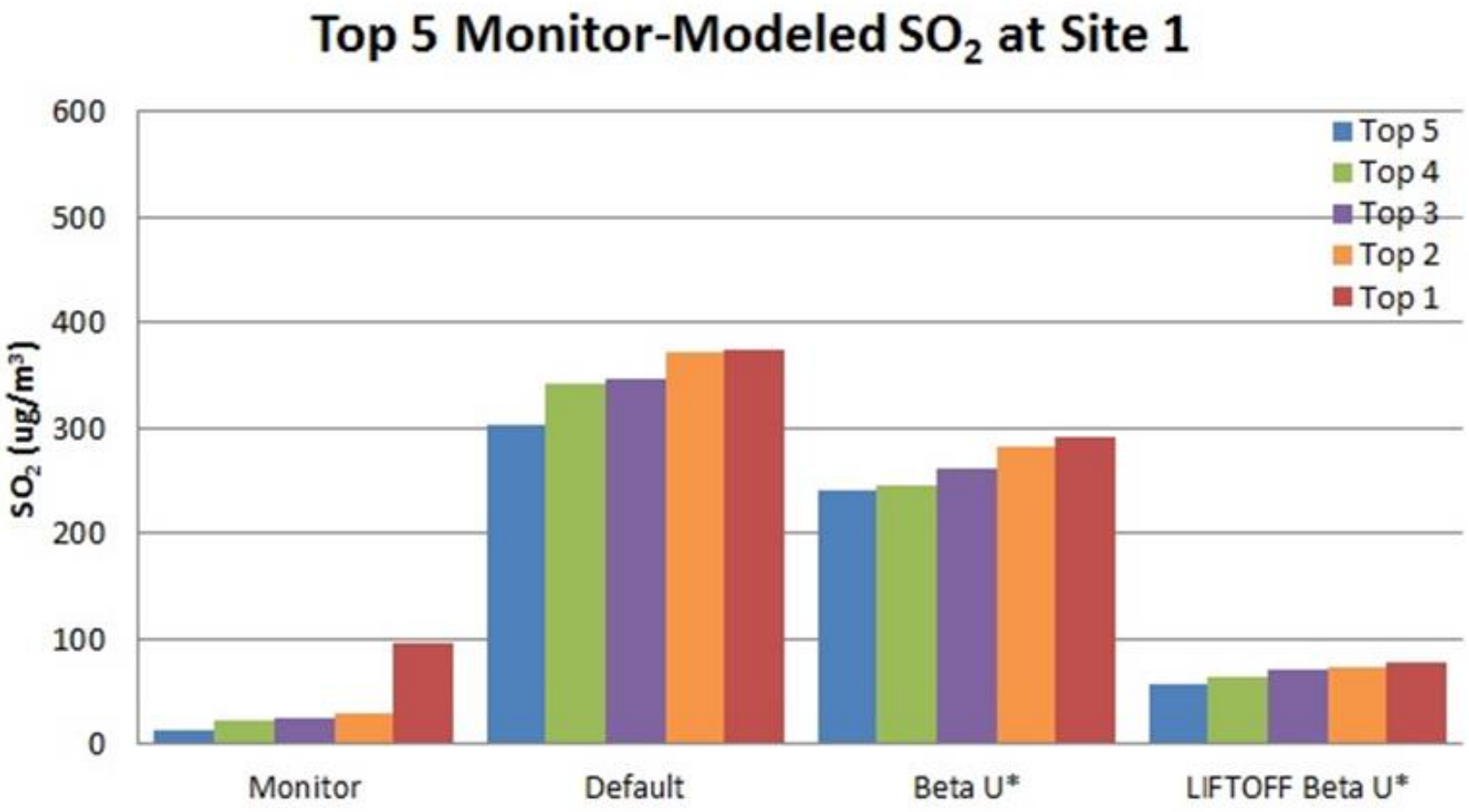
Area of heating is about 300 x 600 m



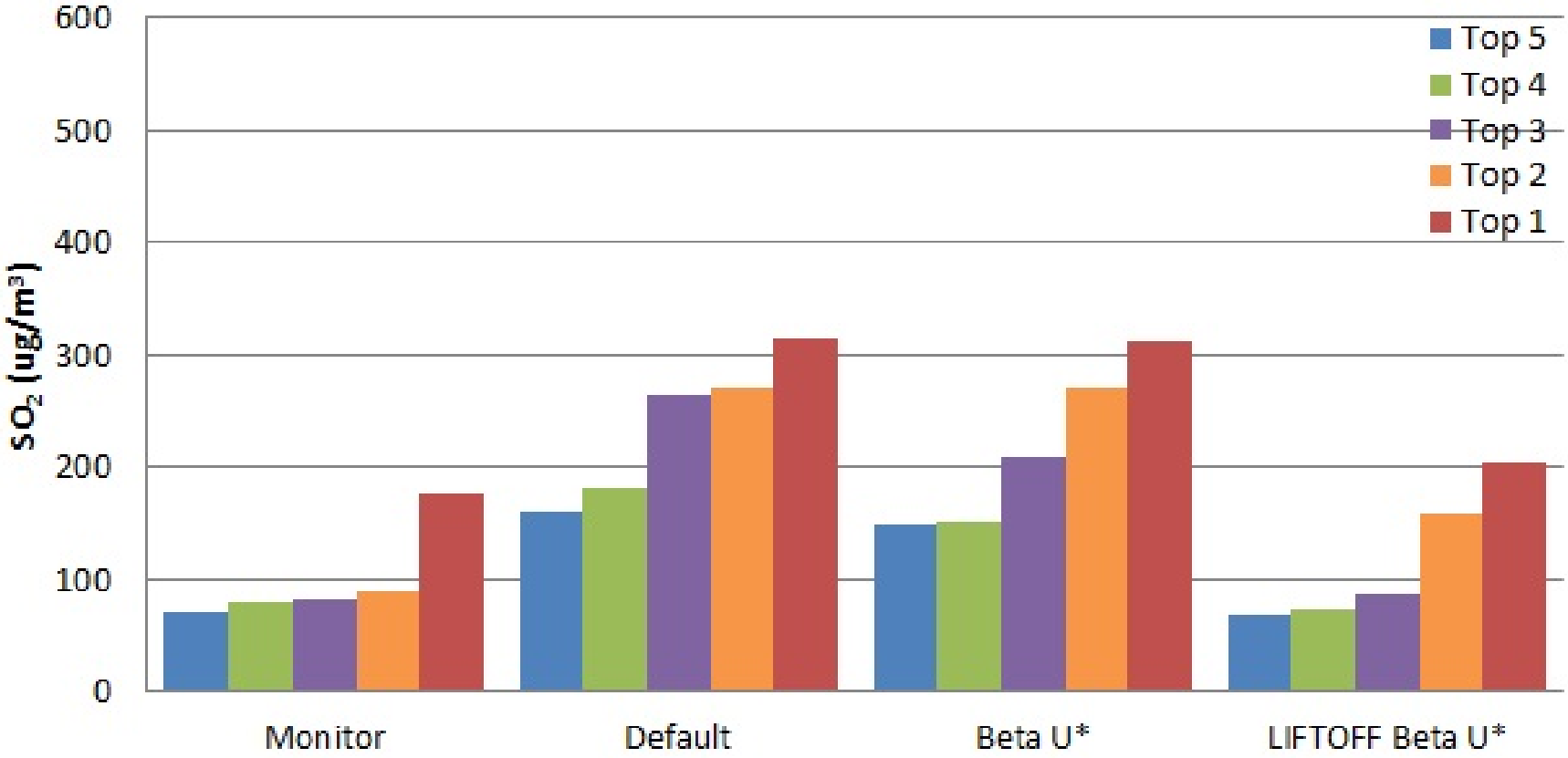
SO_2 Monitoring Sites

Results of AERMOD Evaluation on this Database

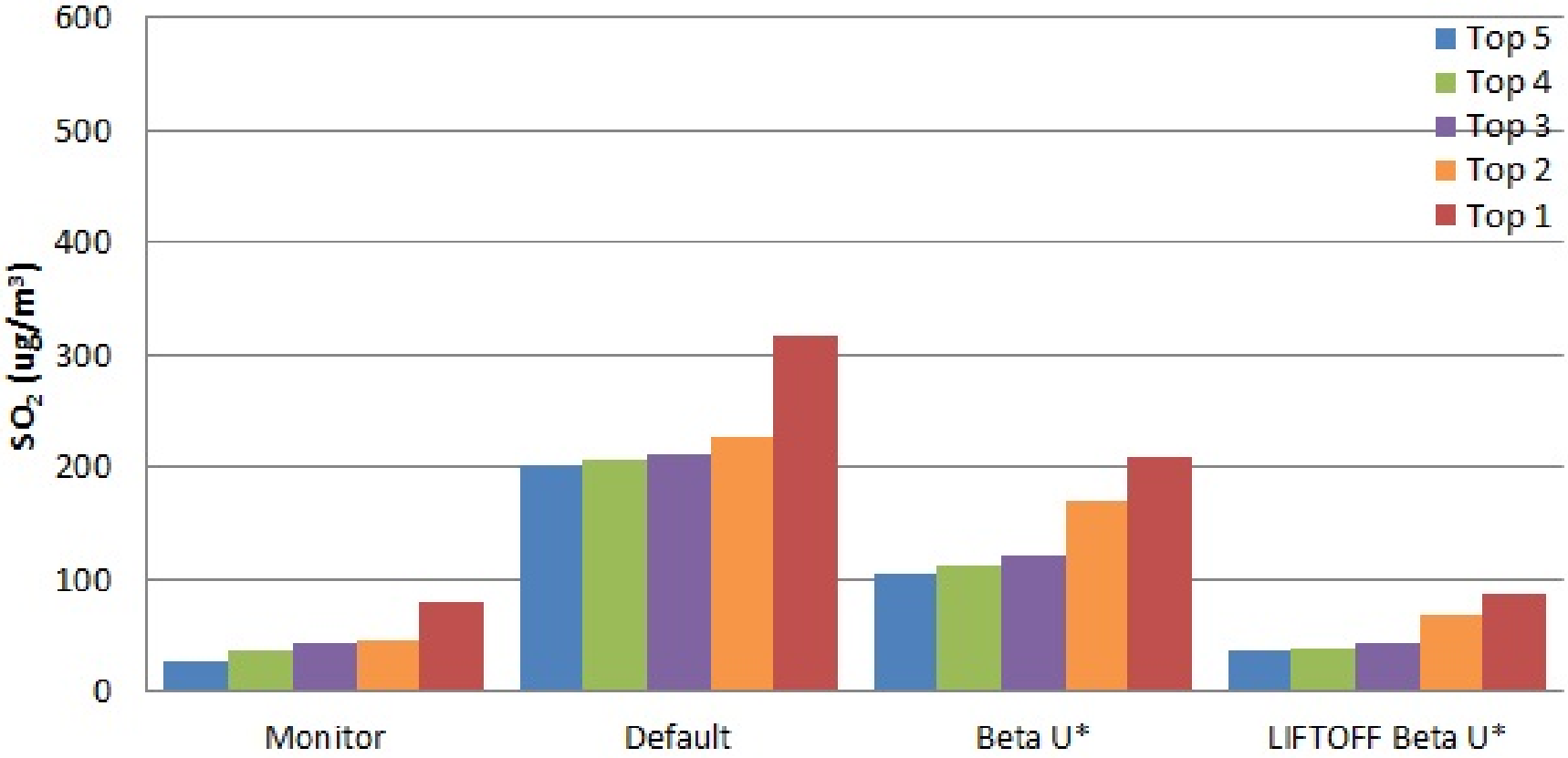
- Continuous SO_2 ambient monitoring data was collected
- Continuous hourly emissions were paired with representative met data for input to AERMOD
- AERMOD v 14134 predictions were compared to monitored values (top 5 peak daily 1-hour max values) for:
  - Default AERMET/Default AERMOD
  - Adj u* AERMET/Default AERMOD
  - Adj u* AERMET/ LIFTOFF using AERMOD
- Evaluation results shown in the next 4 slides for the 4 monitoring sites show that the last option (Adj u* AERMET with LIFTOFF using AERMOD) is clearly the best performing model
- The results of this field study have been submitted to a peer-reviewed journal


Top 5 Monitor-Modeled SO_2 at Site 1
600
500
400
300
200
100
0
SO_2 (ug/m³)
Top 5
Top 4
Top 3
Top 2
Top 1
Monitor
Default
Beta U*
LIFTOFF Beta U*

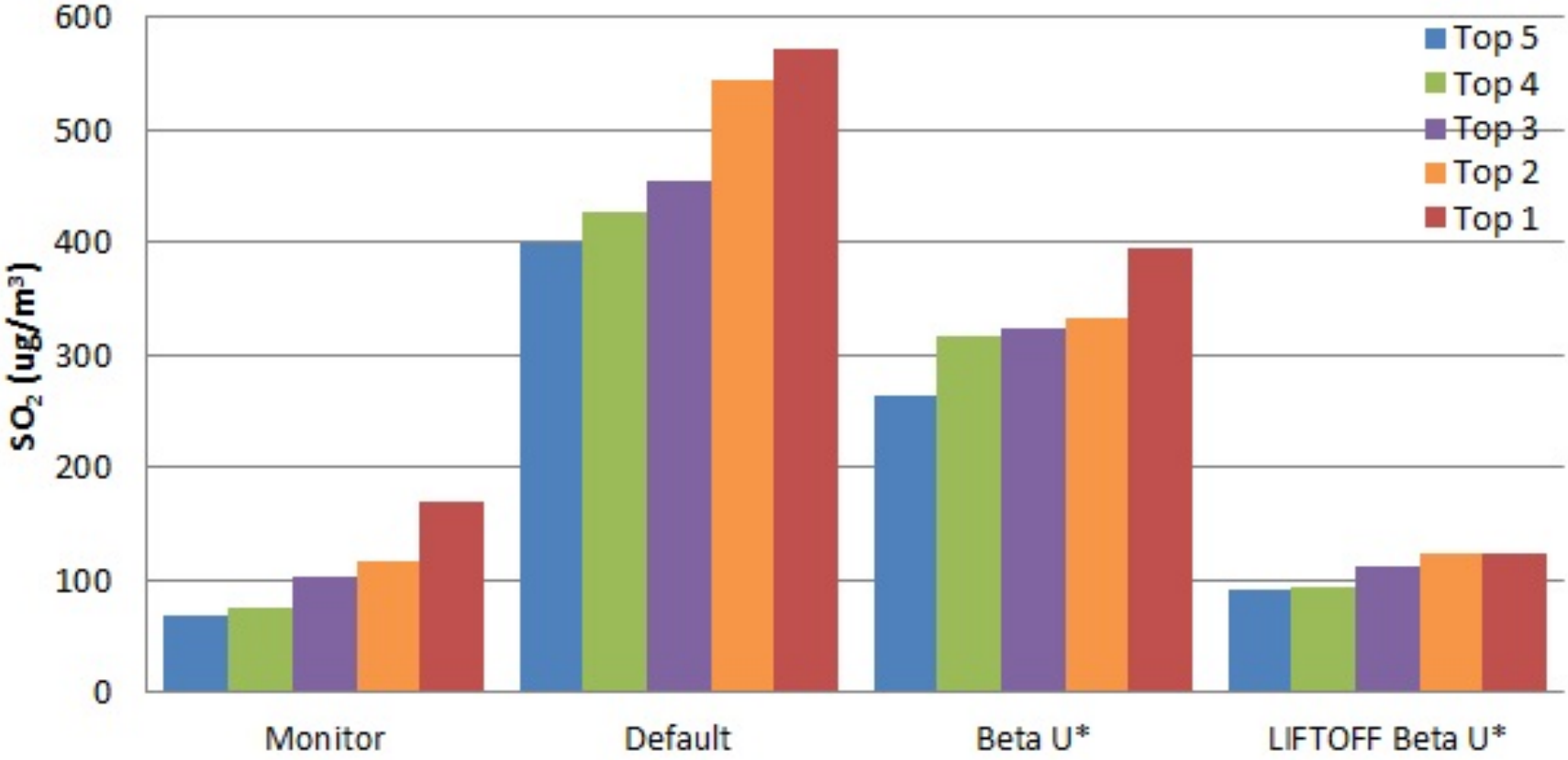
Top 5 Monitor-Modeled SO_2 at Site 2



Top 5 Monitor-Modeled SO_2 at Site 3



Top 5 Monitor-Modeled SO_2 at Site 4

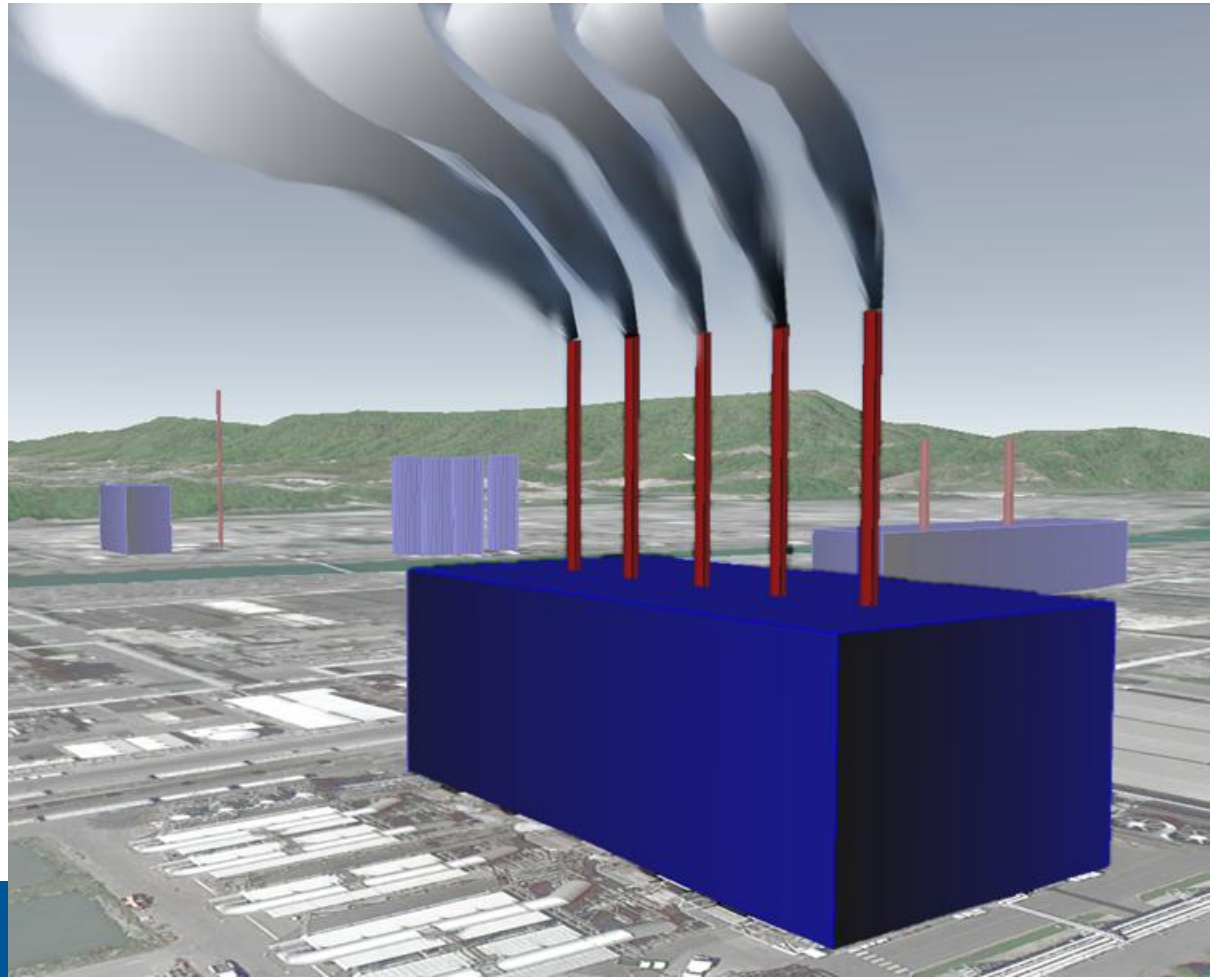


Supplement C

Merging of Plumes from Nearby Stacks, Especially Those in a Line: “AERLIFT”

Aligned Multiple Stacks

Currently, AERMOD considers each plume as an individual discrete plume unaffected by (or aware of) any nearby plumes.

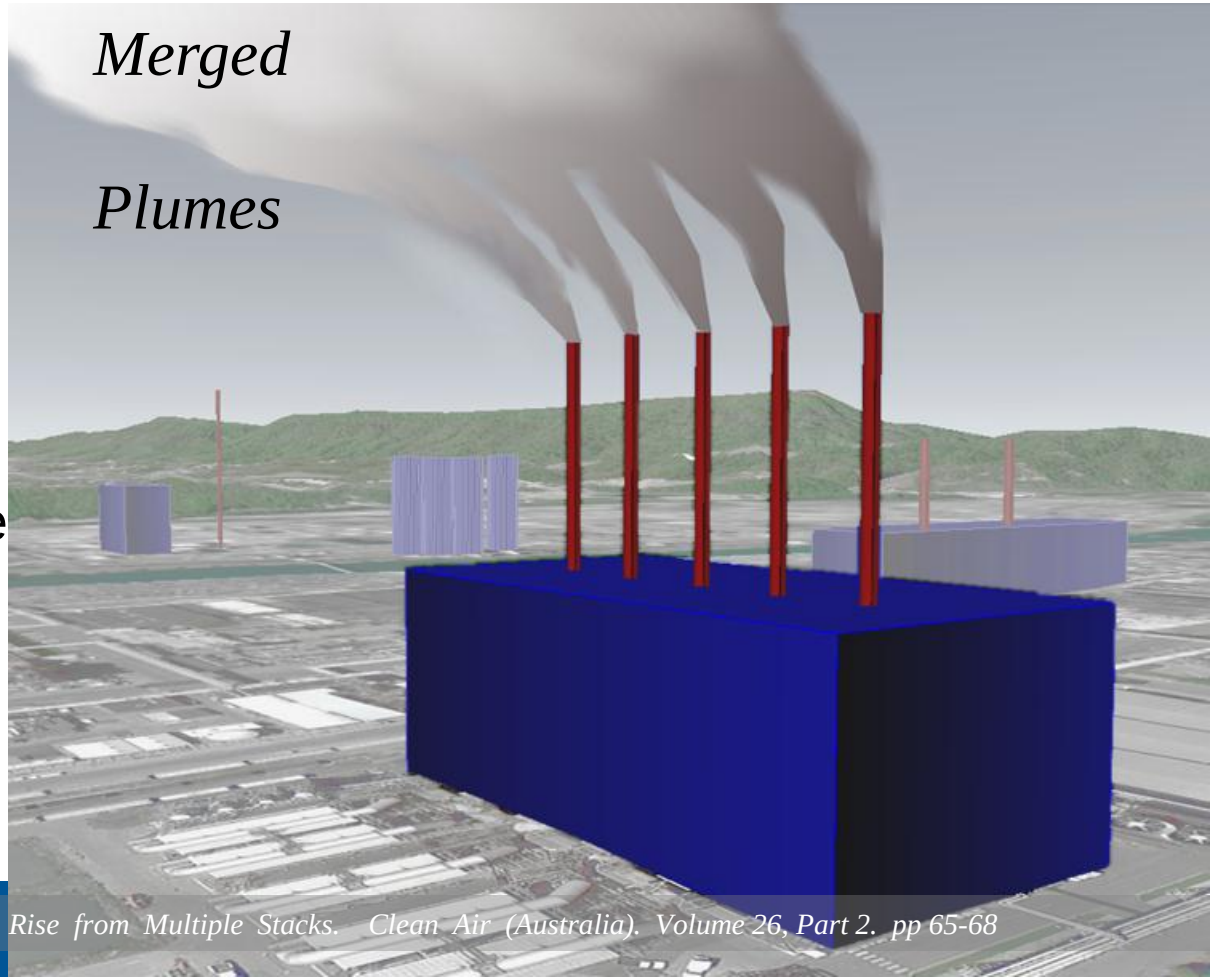


Aligned Multiple Sources

If the wind for an hour blows along the alignment angle of a row of stacks, it has been shown* that the stacks can be merged.

The amount of plume merging is determined on an hourly basis, and it depends upon the following variables:

- Stack separation distance
- Wind angle
- Individual stack plume rise



** Manins P, Carras J and Williams D, (1992), Plume Rise from Multiple Stacks. Clean Air (Australia). Volume 26, Part 2. pp 65-68*

AERLIFT Features

- A post-processor, AERLIFT, calculates the buoyancy flux enhancement associated with merged stack plumes. These calculations are done for each source, for each hour.
- Based on several key factors, each source is tested to determine if enhancement (or partial enhancement) should occur.
- This enhancement is performed by adjusting the hourly stack temperature and exit velocity.
- The new hourly emission file is then re-run with AERMOD for the final results.

AERLIFT Testing to Date

- Several field, wind tunnel, and water channel studies cited by researchers
- Eastman Chemical Company field study: Kingsport, TN

Supplement D

Plume Buoyancy Adjustment for Moist Plumes: “AERMOIST”

AERMOD Does not Account for Moisture in Plume Rise Calculations

- AERMOD has no input for plume moisture
- When Briggs developed plume rise formulas in the 1970s, most stacks did not have scrubbers for emissions control
- Moisture plumes are now much more common, and it is appropriate to review this issue
- The key issue for enhanced plume rise is that there is an initial condensation of the plume moisture that liberates heat of condensation
- This additional heat increases plume buoyancy during the critical initial rise phase
- Evaporation later on will somewhat offset the heat of condensation, but this happens when the plume is more dilute and has reached final rise (or nearly so)

Approach for “AERMOIST”

- A pre-processor to AERMOD uses a validated moist plume rise model, IBJpluris*, to determine hourly adjustments in plume rise and then to create hourly adjusted stack temperatures for input to a “dry” model – AERMOD
- The IBJpluris plume rise predictions with moist plumes match very well the IBJpluris plume rise predictions with dry plumes with adjusted hourly stack temperatures
- The adjustments account for influence of ambient temperature and relative humidity on moist plume rise
- These adjusted temperatures are then used as input to AERMOD to account for the effects of moist plume rise

*Janicke, U. and L. Janicke, 2001. A three-dimensional plume rise model for dry and wet plumes, *Atm. Env.*, Vol 35:877-890.

AERMOIST Testing to Date

- Studies used to validate IBJpluris
- Comparison of adjusted dry plume rise to unadjusted moist plume rise in IBJpluris