Development, Maintenance and Evaluation of CALPUFF

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by:

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Model Development

Model Development

- CALPUFF system undergoes continual refinement and development, with new features and productivity enhancements. EPA provides no funding for development or maintenance activities.
- TRC has developed graphical interfaces and visualization tools which are distributed to the public without cost
- Technical developments are made within TRC both with and without external funding
  - EPRI PRIME downwash module
  - Flexible coordinate transformations
  - MMS updates for coastal applications
  - VISTAS enhancements
  - Forest Service enhancements
  - NASA and Forest Service sub-hourly Version 6

Model Development

- Technical developments are also contributed from other users and researchers
  - Hybrid puff-particle version - Switzerland
  - Large-particle settling (volcanic ash) - Italy
  - Solar radiation effects on canyon sidewalls and terrain shadowing - Italy
- TRC has implemented procedures to satisfy current regulatory needs without federal funding and distributes these codes to the public for free including:
  - EPA BART 98th percentile computations
  - Proposed 2008 FLM (FLAG) visibility method
- Processors are continuously updated to accept new or revised data formats
- TRC has develop interfaces to mesoscale prognostic meteorological models such as MM5, WRF, RUC, RAMS and Eta and distributes these codes to the public for free.

Model Development

- Graphical User Interfaces (GUIs)
  - **CALPRO**
    - Geophysical processors (TERREL, CTGCOMP, CTGPROC, MAKEGEO)
    - Surface meteorological data processor (SMERGE)
    - Upper air data processor (READ62)
    - Precipitation processors (PXTRACT, PMERGE)
  - **COORDS**
    - Converts to/from any of the following Geodetic, UTM, Lambert Conic Conformal, Tangential Transverse Mercator, Polar Stereographic, Equatorial Mercator, Lambert Azimuthal Equal Area
    - Datums (~150 different datums available worldwide, including WGS-84, NAD-27, NAD-83)
  - **BUOY**
    - Processes buoy data and creates SEA.DAT files
  - **UAMAKE**
    - Extracts data from a prognostic (e.g., MM5) file to create soundings as replacements for missing upper air data

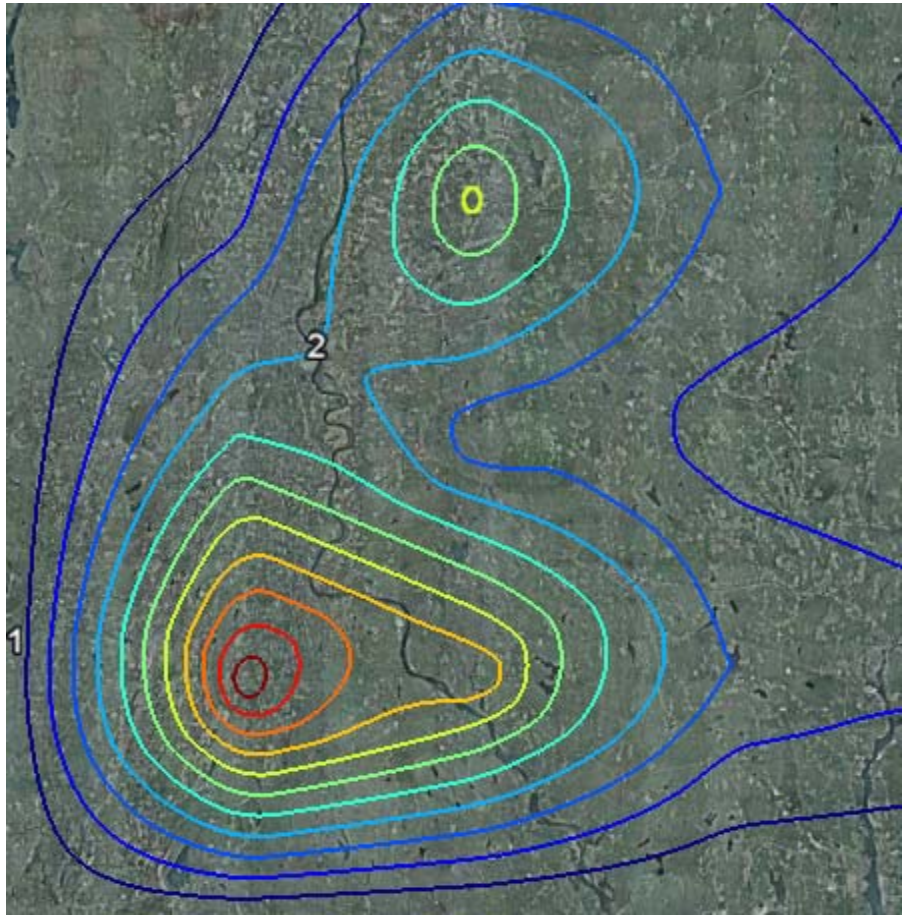
Model Development

- Graphical User Interfaces (GUIs)
  - **PRTMET**
    - Produces vector plots, contour plots of meteorological fields
    - Time series files for plotting
    - Uses Surfer plotting package (Golden Software package)
  - **CALVIEW**
    - Displays vector/contour/3-D perspective plots
    - Animations
  - **CALWindRose**
    - Wind rose plotting software
    - Displays wind roses directly from SURF.DAT, UP.DAT, CALMET.DAT or 3D.DAT files
  - **SurfSizer**
    - Utility working with Surfer to quickly re-size plots
  - **SurfExporter**
    - Utility working with Surfer to quickly export plots in various formats (BMP, JPG, TIF, etc.) and user-specified resolution

Model Development

- Graphical User Interfaces (GUIs)
  - **SIA Generator**
    - Develops a radius of concentration values above a threshold
    - Useful for determining the Significant Impact Area (SIA)
  - **PICtoReport**
    - Imports image files into PowerPoint or Word
    - Automatic sizing and centering of each image
    - Works with PNG, BMP, JPG, TIF, GIF and BLN files
  - **CALPUFF Plot (currently in testing phase)**
    - Generates KML files from BPIP input files
    - Enables 3D viewing of building layout in Google Earth
    - Useful for QA and display purposes
    - *New:* Ability to overlay concentration isopleths on base map

Sample of CALPRO Google Earth Interface



Model Development

- Graphical User Interfaces (GUIs)
  - **FEPS2BAEM**
    - Fire Emission Production Simulator (FEPS) is a Forest Service model that predicts fuel consumption and emissions from wildfires and controlled burns
    - FEPS2BAEM converts FEPS output data to the CALPUFF buoyant area source emissions file format (BAEMARB.DAT)
  - **ScavCoeff**
    - Estimates size-dependent wet scavenging coefficients for liquid and frozen precipitation
    - For particulate matter < 20 μm diameter
  - **AER2CAL**
    - Converts AERMOD output concentration files into CALPUFF formatted concentrations files
    - Allows use of CALPUFF postprocessing tools with AERMOD output
    - Contour plots, animations, base maps, etc.

Model Development

- Additional processor options and datasets
  - Terrain data options include 30arcsec (900m), 3 arcsec (90 m), 1 arcsec (30m) USGS DEMs, SRTM data format, generic data formats
  - Landuse – new option to process NLCD format
- Repartitioning of HNO_3/NO_3 (POSTUTIL)
  - Source contribution analysis
  - Streamlined one-step ALM processing
  - Non-linear chemistry effects (NO_3)
  - Computation of total S and N deposition
- **No-Observations version of CALMET**
  - Uses gridded 3-D data fields as initial guess fields
  - Adjusts winds for fine-scale terrain effects on CALMET grid
  - Allows forecast applications

Model Development - CALMET

- **New interface programs**
  - WRF
  - NCEP models: ETA and RUC2
  - RAMS
  - MM5 (Version 3)
  - enhanced output (3D.DAT, 2D.DAT files)

- **SEA.DAT files** created from MM5 model using high resolution sea-surface temperature data

- **COARE Algorithms**

- **Convective mixing over water**
  - Maul-Carson (M-C) scheme and Batchvarova-Gryning (B-G) scheme (1994)

Model Development - CALPUFF

- Boundary condition module
- Rain hat option on stacks
- Mass balance/flux tracking options
- Horizontal puff splitting
- NH_3 as an active species
- New turbulence profile option using AERMOD profile
  - Original CALPUFF turbulence parameterization
  - AERMOD turbulence profiles
- AERMOD met data options
  - Option in CALPUFF to read AERMOD met data files
  - Utility to create AERMOD met files from 3-D CALMET output

Model Development - CALPUFF

- Time Step < 1 Hour (CALMET, CALPUFF)
- Secondary organic aerosol module
- Terrain enhancement of precipitation
- Fogging and icing (cooling towers)
  - Visible plume lengths
  - Frequency of plume-induced fogging and icing
- Turbulence advection
- Platform downwash
- Back trajectory analysis

Model Development – On-going

- Nested grid option
- Option to name receptor sets and process by receptor group
- Meteorological evaluation software (METSERIES and METCOMP)
  - Wind rose (graphics completed)
  - Time series plots
  - Scatter plots
  - Statistics
  - X-Z cross sections
  - Standard report
- Enhanced animation options
  - Create, name and save animation files for future playing (completed)
  - Display of puff movements and growth (on-going)

Model Maintenance

Model Maintenance

- With few exceptions, all model maintenance is done without contractual funding support
- Investigate all reported issues. Request detailed error reports and test datasets from user
- About 75% found to be due to data problems, hardware problems or input errors
- Bugs are isolated and fixed with detailed updates to in-code documentation and version/level journaling
- Model Change Bulletin (MCB) updated
- Updated code(s) run in EPA CALPUFF Update Tool and results sent to EPA

Model Maintenance

CALPUFF MCB History

CALPUFF		EPA Action	
Official Version		FR Notice	April 15, 2003
MCB-A	July 16, 2004	Accepted	June, 2006
MCB-B MCB-C – VISTAS MCB-D	December 16, 2005 May 1, 2007 June 23, 2007	Accepted	June 29, 2007
MCB-E	February 14, 2008	No Action	
MCB-E (Part 2)	June 27, 2008	No Action	

Note: MCB-C contains all fixes in VISTAS version released August 4, 2006

Model Maintenance – The Plan

- TRC
  - provides developmental model version as a mechanism for quickly evaluating bug-fixes and model enhancements
- EPA action at periodic intervals
  - reviews bug fixes and considers new options and features
    - accept/recommend new features
    - suggest changes/modifications
- Accepted features placed in regulatory recommended option set
- Other features may be retained for additional testing, or abandoned or not recommended for regulatory use

Model Maintenance - Reality

- Problems with Review Process
  - Long delay in EPA reviewing bug fixes
  - EPA review of model enhancements on hold
- Example Enhancement
  - Surface station data assigned to grid cells using nearest-station in EPA-approved CALMET
  - Surface station data interpolated to grid cells using $1/R^2$ weights in VISTAS CALMET
  - Nearest-station technique leads to sharp gradients
  - EPA criticizes sharp gradients yet has not considered this enhancement which was in the VISTAS code and removed at EPA's insistence in the current EPA-approved code

Model Maintenance

- Earth Tech/TRC commitments have been scrupulously adhered to:
  - Model maintenance continues to be done by TRC without EPA support
  - Agreement to keep regulatory model unchanged on web site
  - EPA determines “EPA-approved” version
- What has happened to process?
  - Changes at EPA in management and staff
  - EPA Modeling Group – some loss of institutional memory and continuity?

Model Maintenance

- EPA presentations at 2007 and 2008 R/S/L Modelers Workshops contain misleading statements about CALPUFF, and include examples that do not reflect good modeling practice
- CALPUFF Regulatory Update (June 2008 R/S/L Workshop)
  - “Lack of adequate documentation”
    - “New MREG option in CALMET not well-documented”
    - “User’s guide last updated in 2000”
    - “Many important technical details are not documented, except in code”
  - “serious unresolved technical concerns”

Model Maintenance

- Documentation?
  - 885 pages of detailed technical documentation and user guide updates in March 2006 describing MMS changes
  - 853 pages of documentation in original user guides
  - Compares well in technical detail and content with AERMOD documentation
- Why should this be known to EPA? MMS project changes were the subject of the EPA oversight:
  - EPA represented on Scientific Review Board for MMS project (John Irwin, Modeling Group, OAQPS)
  - MMS presentation was made at June 2007 EPA R/S/L Modelers Workshop. Updated User's Guides available online since early 2006 (listed in presentation)
  - Multiple references made to MMS reports by TRC to EPA during VISTAS model review

Model Maintenance

- Constructive criticism and helpful suggestions are always welcome, but vague references to problems without backup and data are not helpful or constructive.
- CALMET MREG Option?
  - Option formulated by TRC with EPA review
  - Input file language presents option choices
- Unresolved Technical Concerns?
  - Issue was default value for new CALMET input variable. Value resolved to EPA satisfaction (May 2007)

Model Maintenance

VISTAS CALMET technical enhancements in v5.8 awaiting EPA review

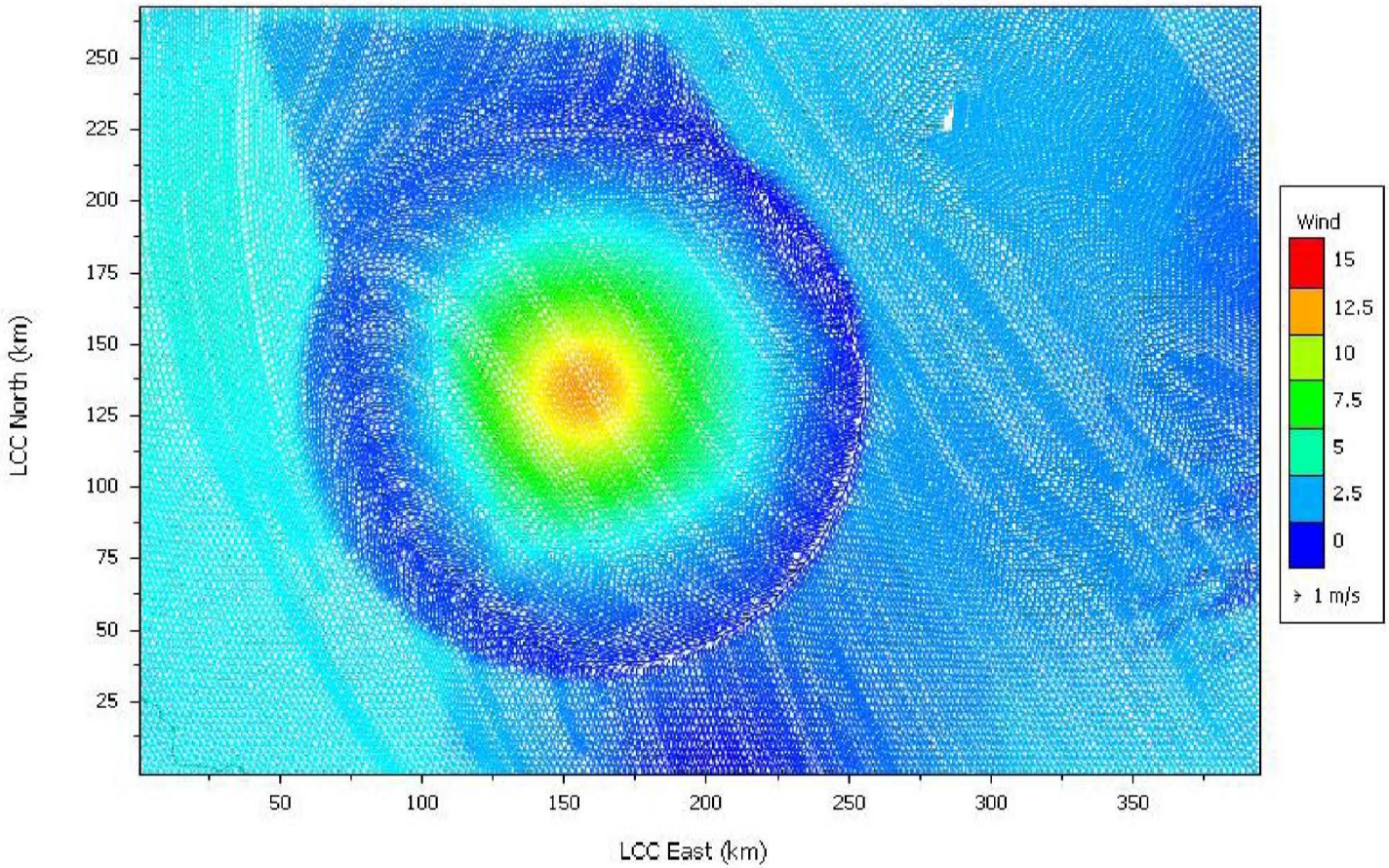
- Fully interpolated 2D fields for surface-layer temperature and density instead of nearest-station selection of surface meteorological data
- Use consistent surface-layer stability correction profiles throughout
- Recognize convective over-water boundary layer (instead of using neutral boundary layer formulations from OCD)
- Use Coupled Ocean Atmosphere Response Experiment (COARE) bulk flux model for overwater fluxes in place of older OCD methods
- Updated convective boundary layer parameterization following Batchvarova and Gryning

Model Maintenance

- EPA CALPUFF studies used in EPA presentations have not been open review by TRC or the public
- Important for transparency that all modeling files on which decisions/memos are based are made promptly public
  - Results presented in public forums rather than communicated directly
  - Modeling and data files not available
  - Lack of constructive criticism with a focus on resolving issues

Wind Field Bull's Eye

From Bret Anderson (USEPA Region 7)'s presentation at the 2007 Regional State Local Modelers Workshop
"Illustration of meteorological issues – CALMET diagnostic meteorological model",



When MM5 does not match the observations

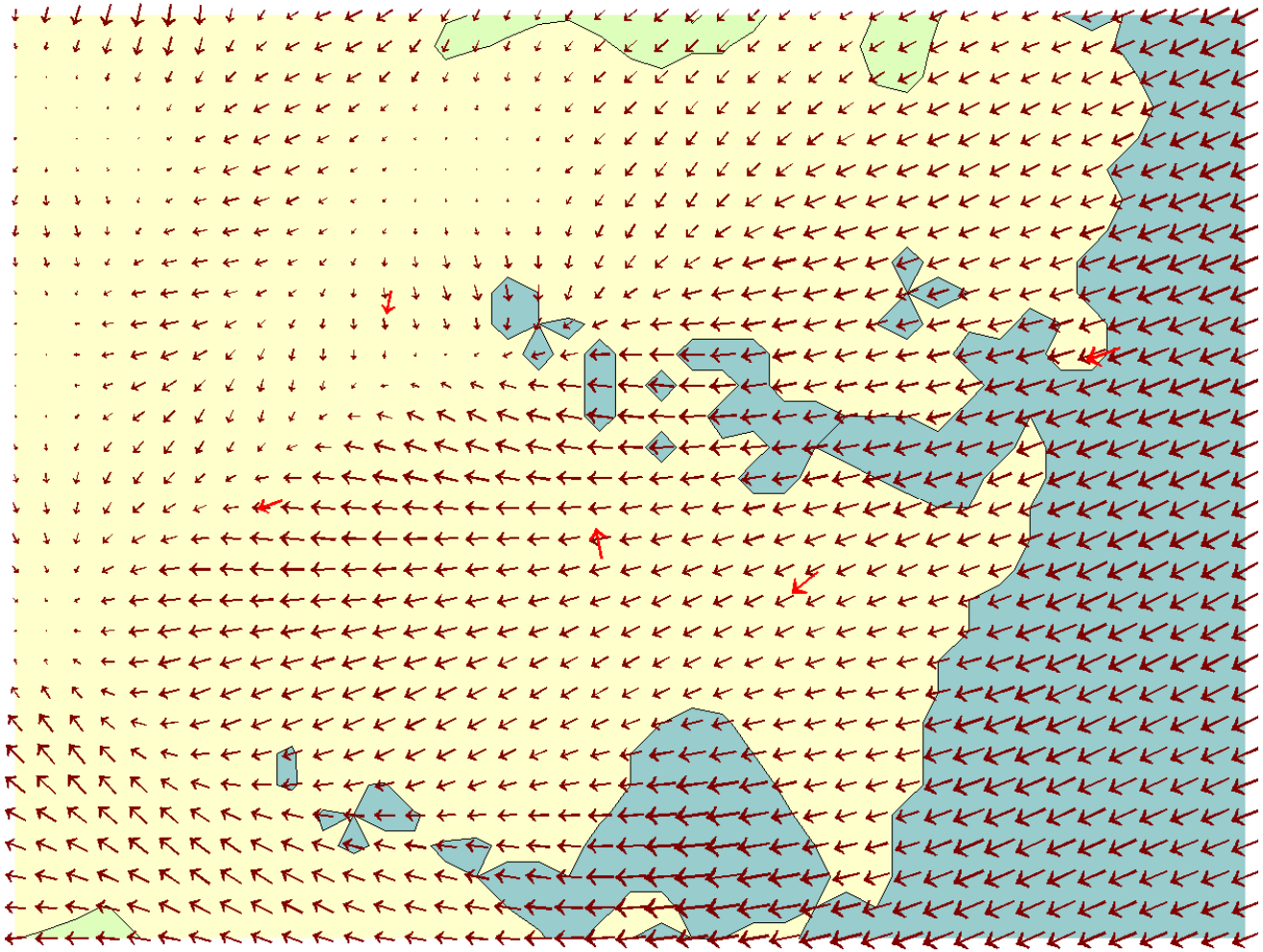
- Bull's eye features is a result of MM5 winds not matching observations. Issue may be with MM5 or a non-representative observation
- Solution:
  - (1) Pure NOOBS mode : MM5 only fields
  - (2) Pure observation mode
  - (3) Hybrid mode with MM5 as initial guess field, small R1-R2, matching the observations right at the stations and MM5 fields away from them
  - (4) Hybrid mode with poorly selected large R1/R2, creating a bull's eye, with station winds clashing with MM5 fields

So 3 good ways to run CALMET without creating a sharp discontinuity and 1 bad way, creating a bulls' eye

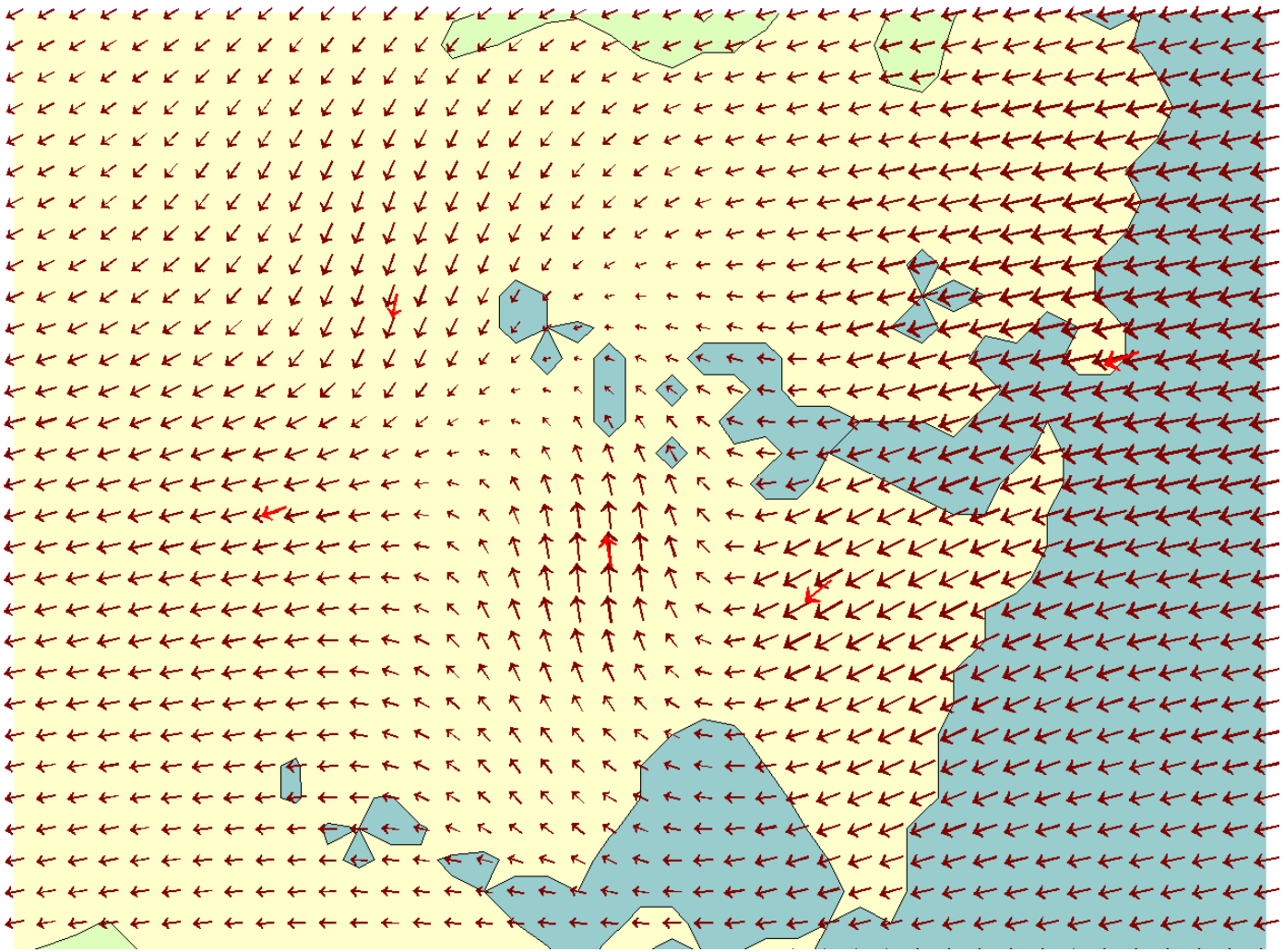
How to run CALMET when MM5 does not match the observations

- Sydney Harbor – Summer sea breeze
- Local observation at odds with mesoscale features
- MM5 at 1.33 km resolution
- 5 surface stations, 1 buoy, 1 upper air station (not used in hybrid)
- Plots: 40km x 30km ; resolution: 1km

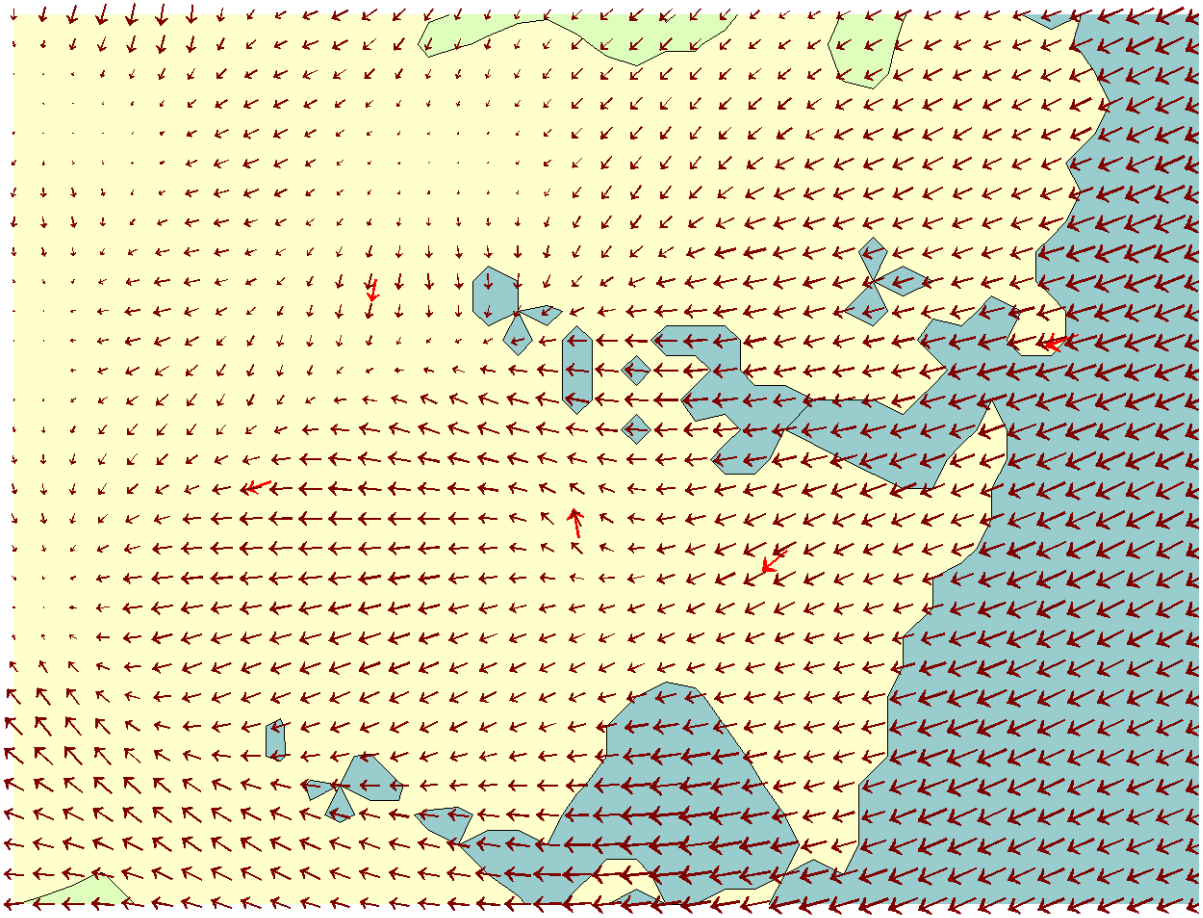
Solution 1: Run in NOOBS



Solution 2: run in OBS-only

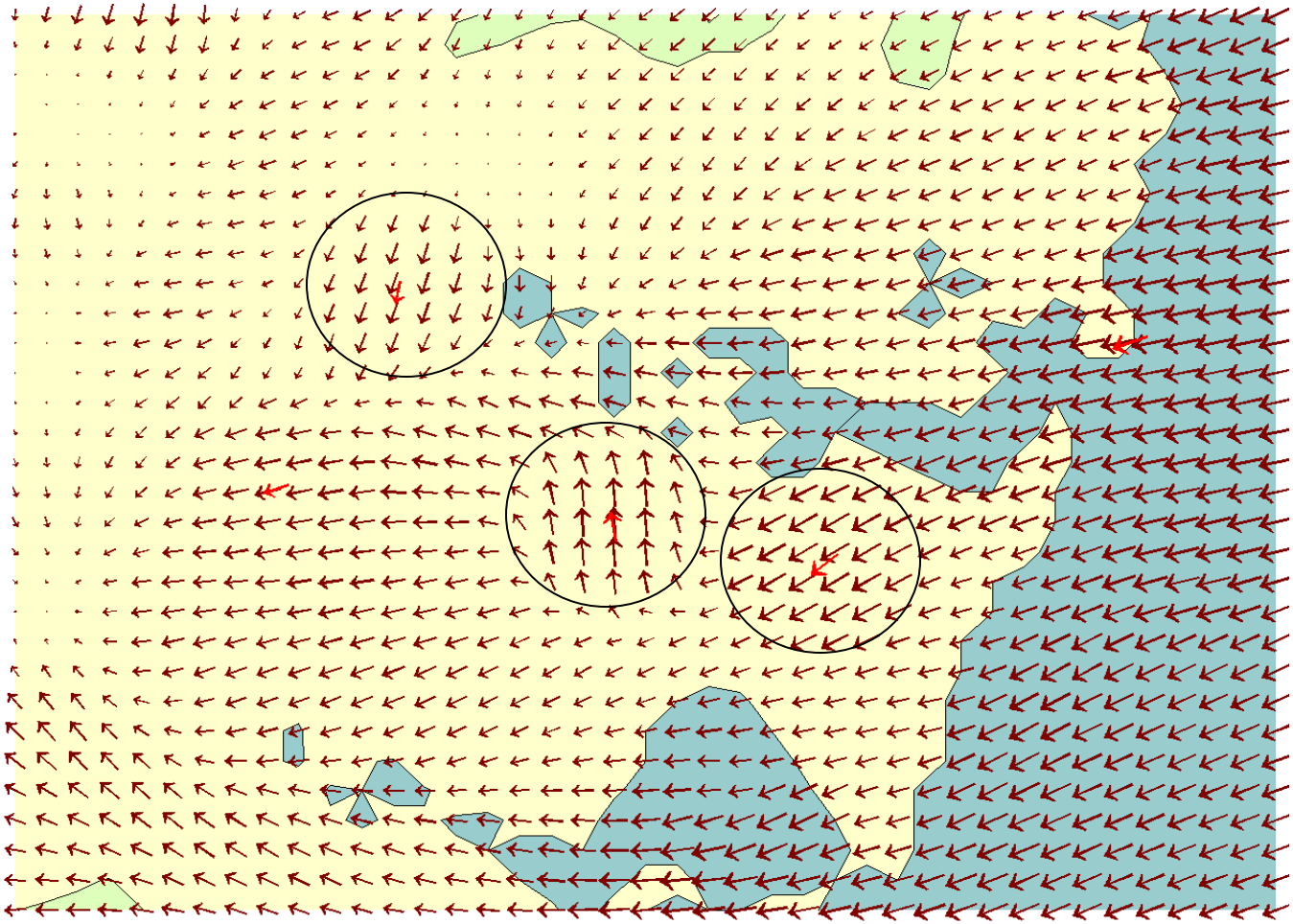


Solution 3 : Hybrid with R1<<RMAX1



R1=1km – RMAX1=20km

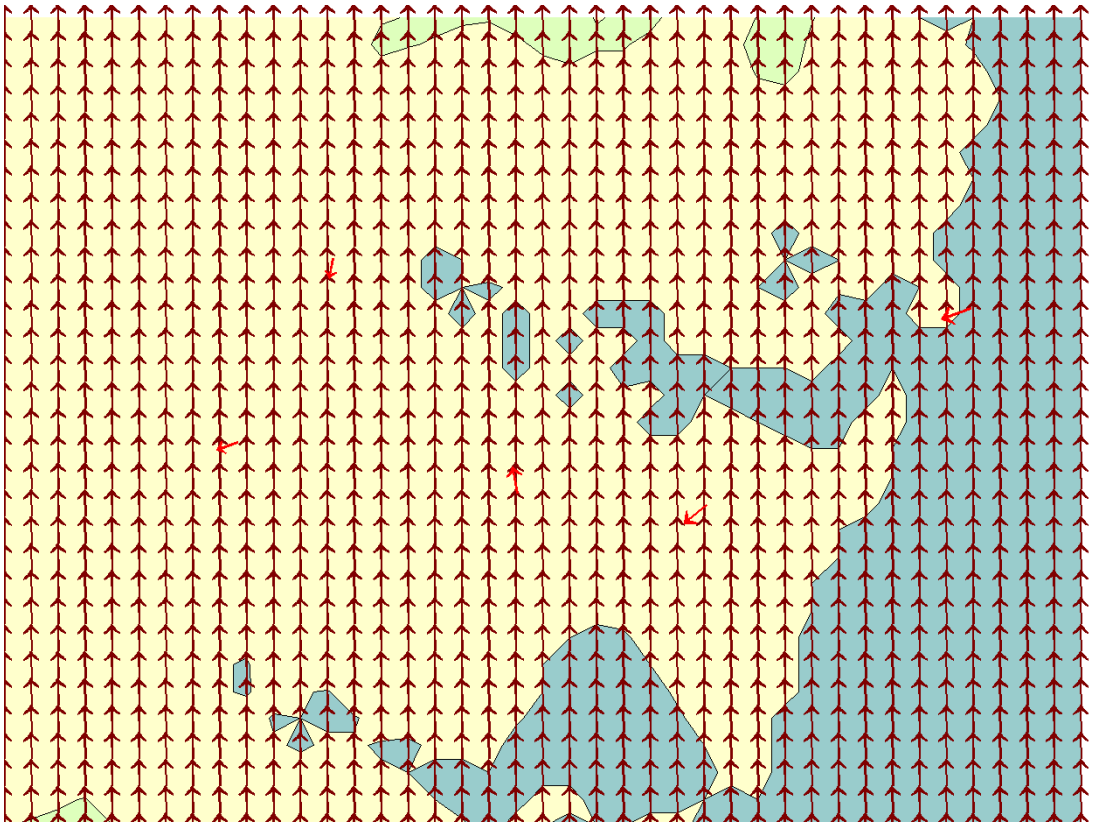
4. EPA's bull's eye no-solution: hybrid with R1>>RMAX1



R1=20km – RMAX1=3km

AERMOD

- And what would AERMOD do in this region?



- An infinite radius bull's eye, only matching one station and not representing observations at any other sites….

Solution for Better EPA and Community Input?

Establish Science Advisory Committee

- TRC-organized CALPUFF technical committee
- Provide objective, unbiased advice
- Identify model improvements
- Possible Members:
  - EPA
  - FLMs
  - MMS
  - PBL Expert
  - Dispersion Modeling Expert
  - 2-3 Active Users (Consultants or Industry)
  - One public meeting per year via web-link
- New web-based user group (or promote existing e-list at Washington (Clint Bowman))

Model Applicability and Evaluation

Model Applicability – Near-Field: AERMOD vs. CALPUFF

Feature	AERMOD	CALPUFF
Causality effects considered?	**No – plume extend to infinity**	**Yes**
Spatial variability of surface characteristics	**Land use variability allowed in wind sectors centered at met. station**	**Full variability – uses 2-D grid**
Policy on treating surface variability	**AERMOD looks <u>upwind</u> of *met. station* in a radius of 1-km to characterize turbulence up to <u>50-km downwind</u> of *source***	**CALPUFF determines surface conditions in each grid cell and applies it to a puff as it passes that cell. <u>Downwind</u> conditions of each and every source are evaluated on a puff-by-puff basis**
Horizontal wind variability	**None. Single station wind is applied over entire modeling domain**	**Full variability considered when CALMET meteorological dataset used**
Calm winds	**Not treated – removed from the analysis**	**Calm winds treated**
Mass accumulation during stagnation. Memory?	**Not treated. AERMOD has no memory of pollutants emitted during previous hours**	**CALPUFF retains previous hours emissions within domain and evaluates impacts from them**
Coastal effects, fumigation	**No coastal TIBL or fumigation algorithm**	**Overwater turbulence module and TIBL algorithm to treat coastal fumigation**

Model Applicability – Complex Terrain

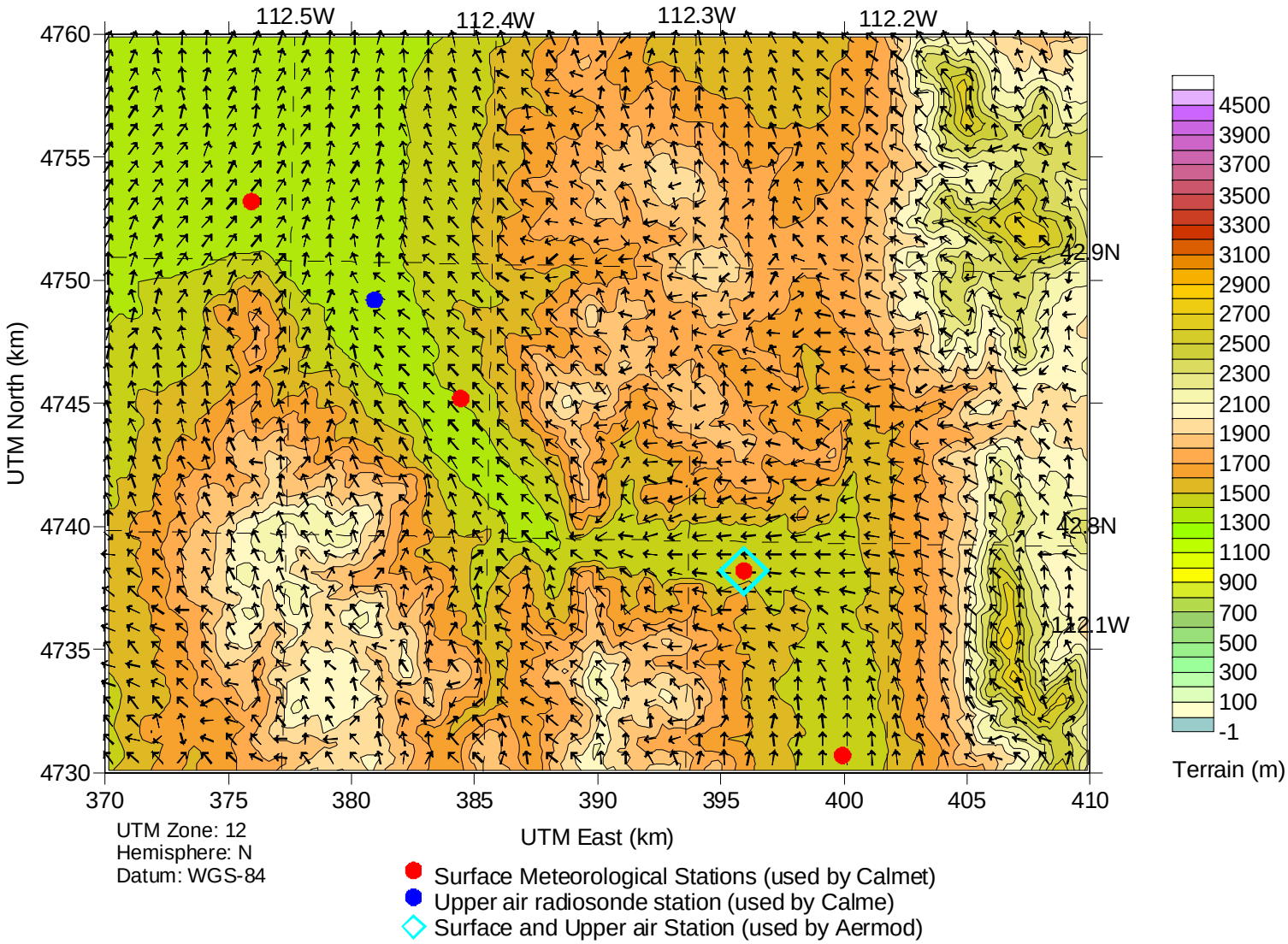
- EPA indicates AERMOD is suitable for complex terrain permitting applications
- Main Issues with AERMOD
  - Use of a single meteorological field to characterize flow for facility + all background sources
  - Use of surface characteristics ***upwind*** of meteorological station to characterize ***downwind*** turbulence of all sources
  - Causality effects (plume go to infinity each hour)
  - Use of straight-line trajectories

Model Applicability – Complex Terrain

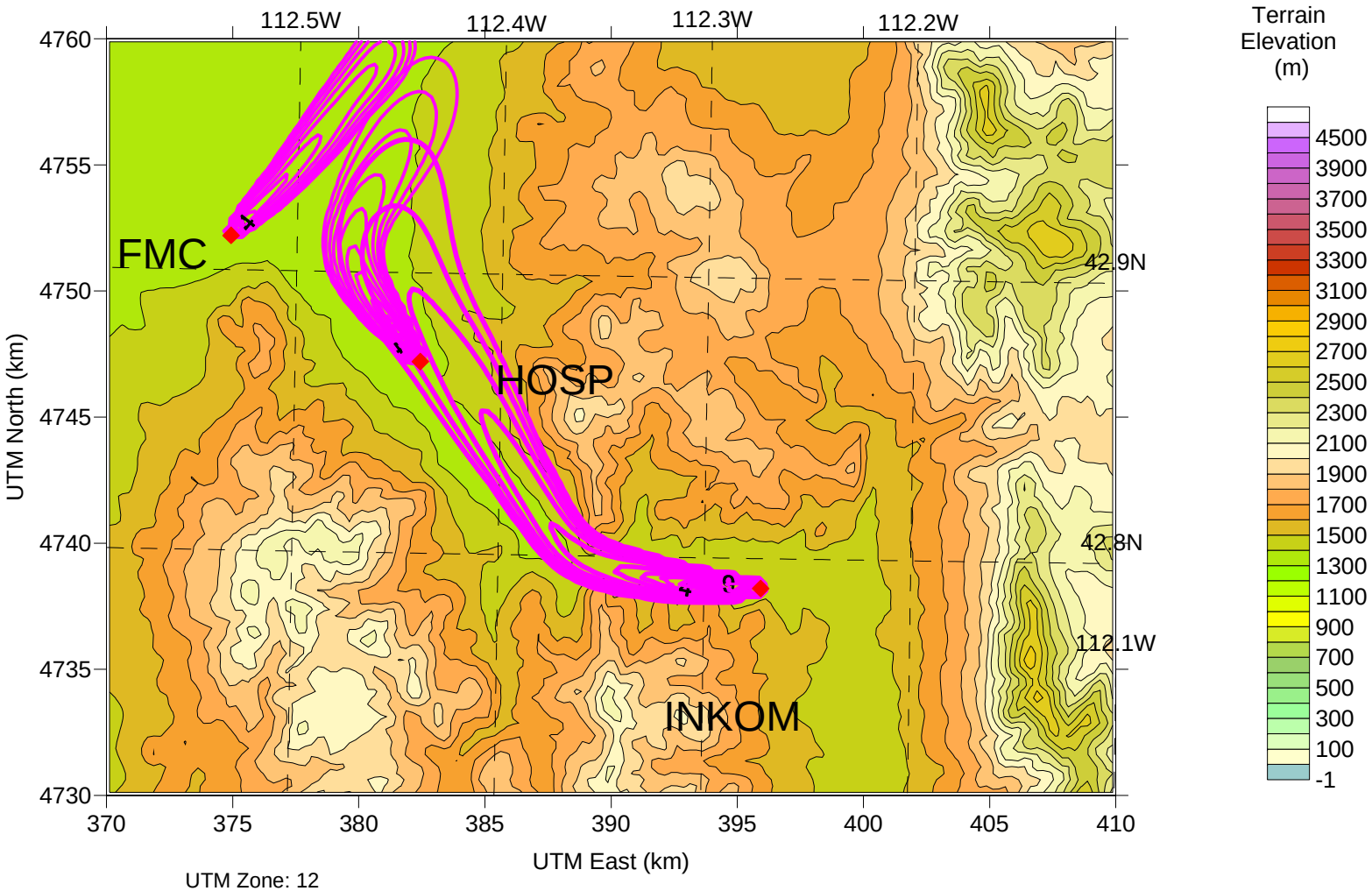
- EPA's argument that AERMOD is OK in complex flow regimes because only line of sight impact matters is flawed for 2 major reasons
  - NAAQS and PSD increments are ***cumulative*** standards, not single facility standards. Interacting sources matter in assessing compliance with the standards.
  - Non-peak concentrations are important in assessing significant contribution above/below the SILs.
    - Facility contribution above the SIL to a violation is considered a significant contribution

Wind Vectors (10m) – Complex Terrain with Channeled Flow

10m Calmet wind field 6 Jan (23h00) - 7 Jan (05h00) 1993



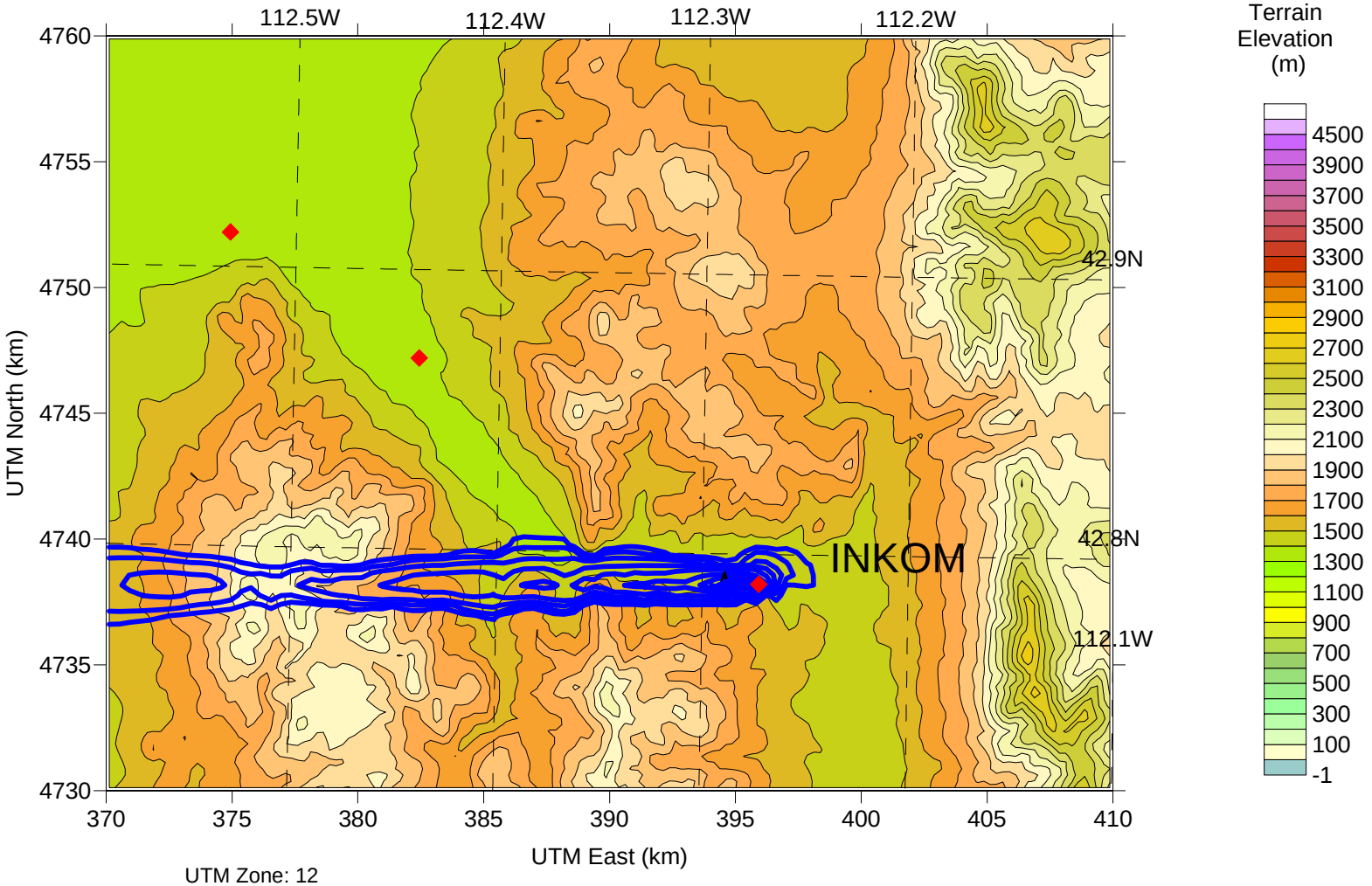
CALPUFF – Cumulative Impacts



UTM Zone: 12
Hemisphere: N
Datum: WGS-84

CALPUFF shows channeling of flow. Background plumes interact to produce cumulative impacts in valley.

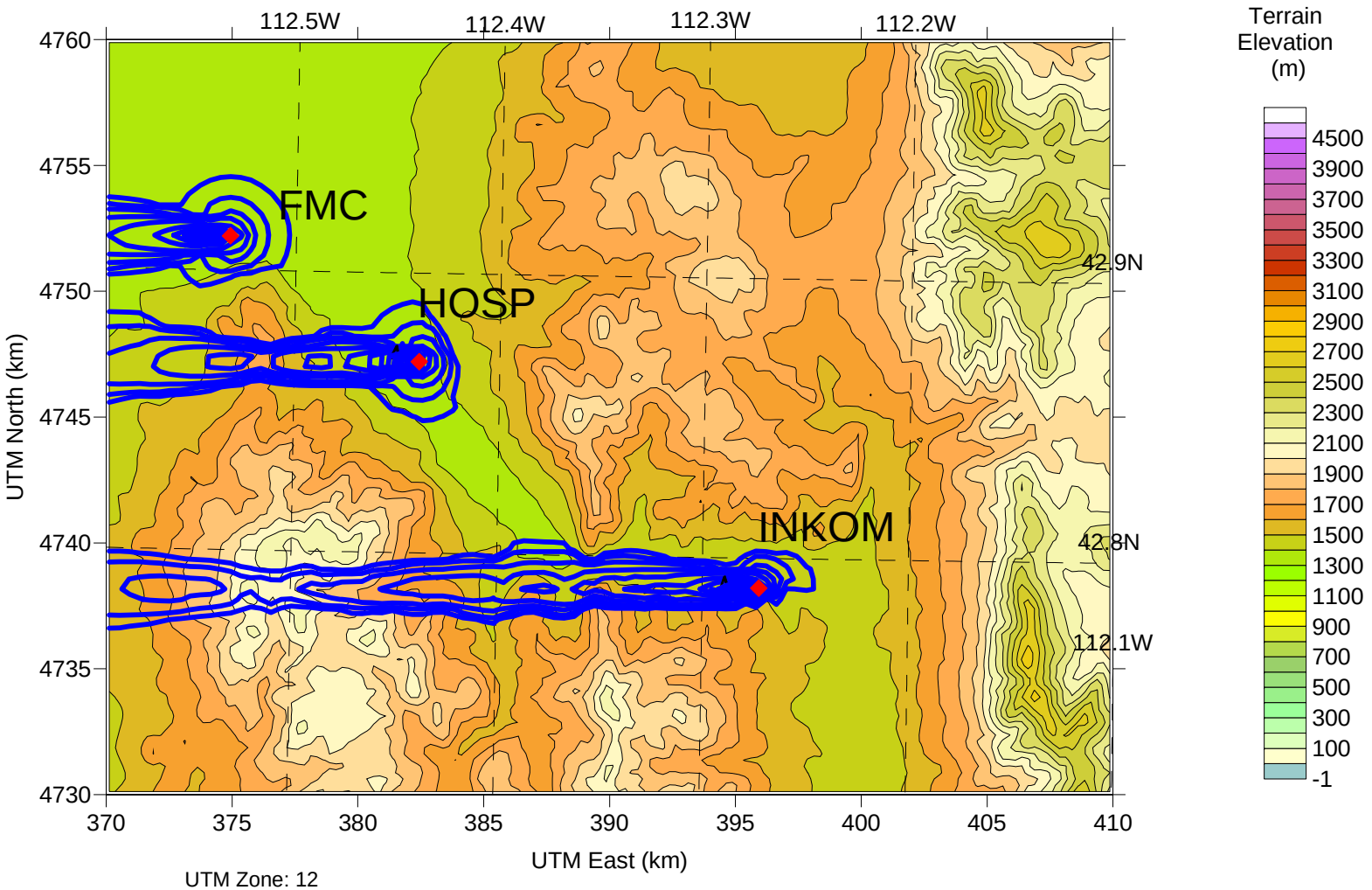
AERMOD Impacts – INKOM Source



UTM Zone: 12
Hemisphere: N
Datum: WGS-84

AERMOD produces straight-line impacts in terrain using INKOM met. data. Note the lack of channeling of the flow into the NW-SE oriented valley.

AERMOD – Cumulative Impacts



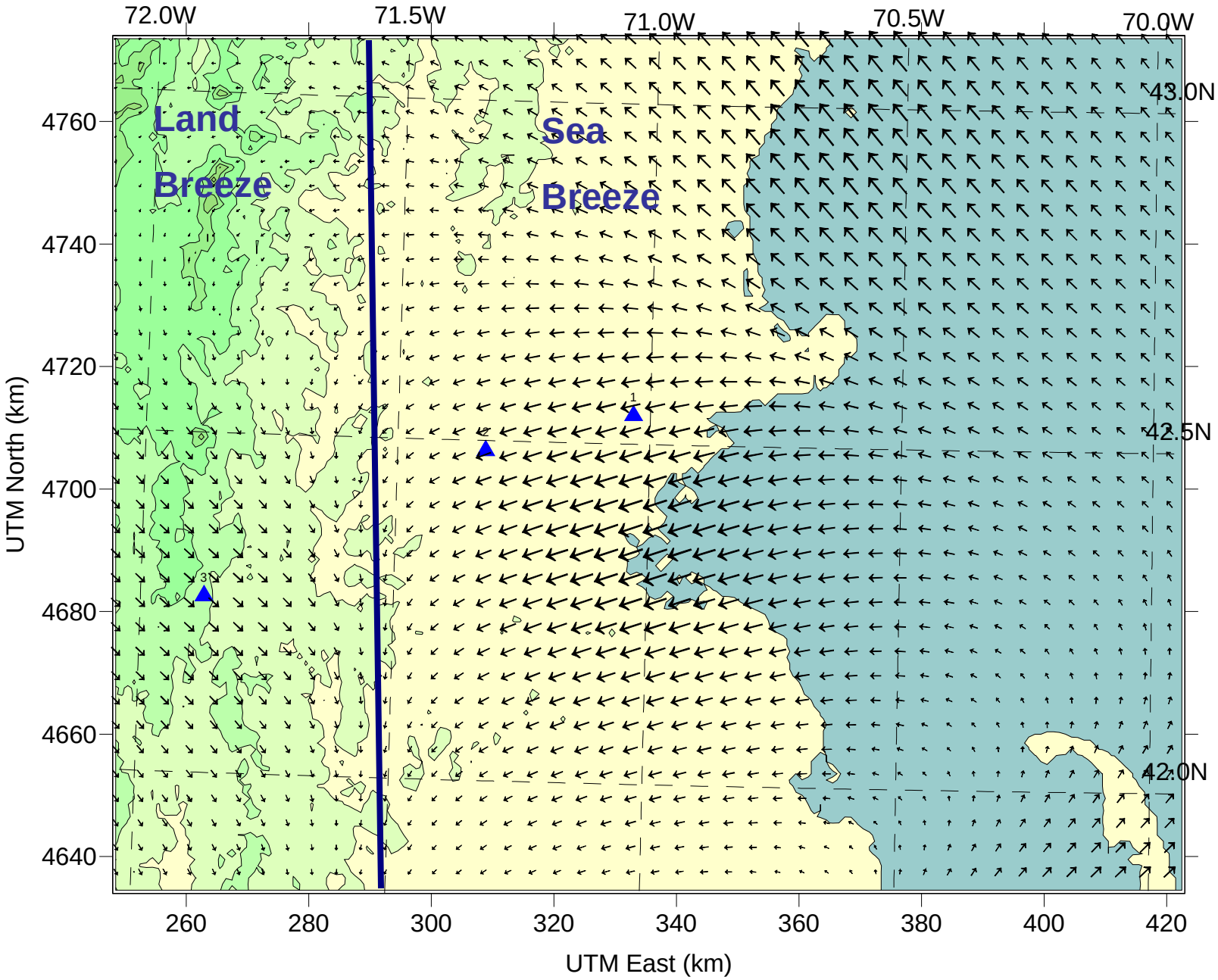
UTM Zone: 12
Hemisphere: N
Datum: WGS-84

AERMOD produces incorrect cross-valley and down valley impacts for HOSP and FMC sources. Note lack of plume interaction in AERMOD cumulative impacts.

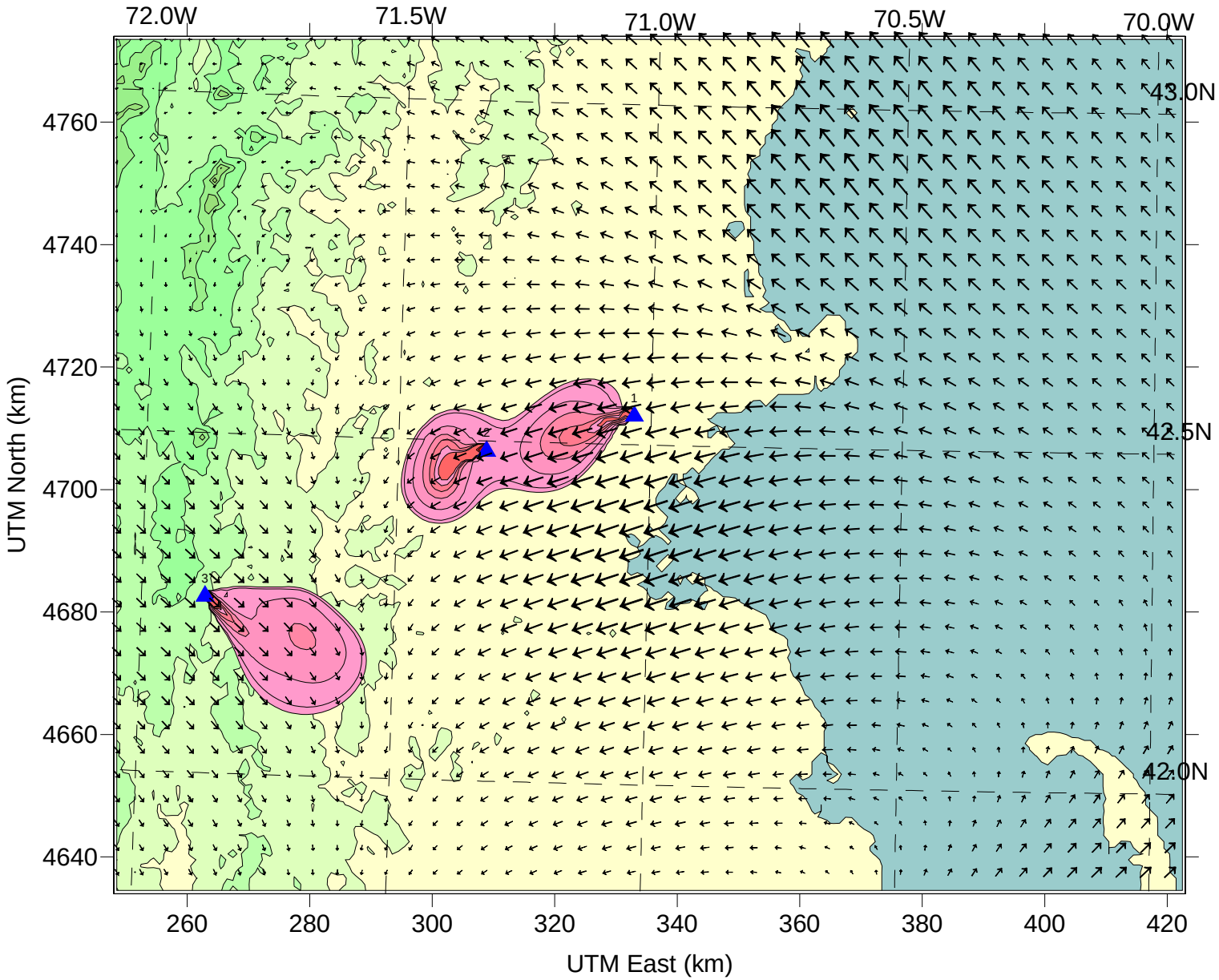
Model Applicability

- Coastal case
  - Sea breeze penetration over portion of domain
  - Relatively simple terrain
  - 3 sources
  - Most inland source considered as main "facility" source (met data based on it)
- Demonstrates even in simple terrain, spatial variability can be important

Sea Breeze Case – July 7, 1988 – 1:00pm LST

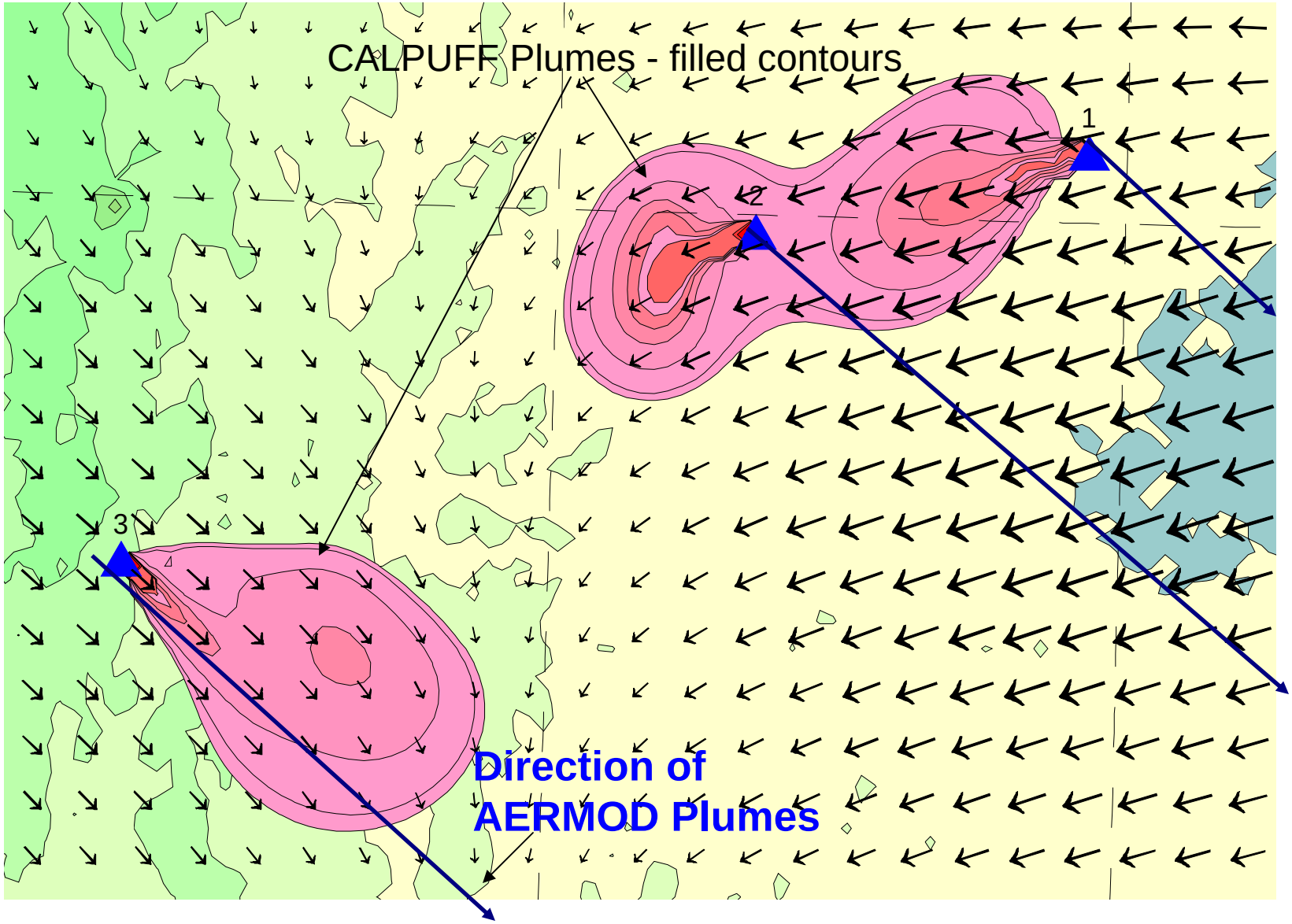


Sea Breeze Case – July 7, 1988 – 1:00pm LST



Comparison of AERMOD Plume Trajectories (Blue Arrows)

with CALPUFF Trajectories (Filled Contours)

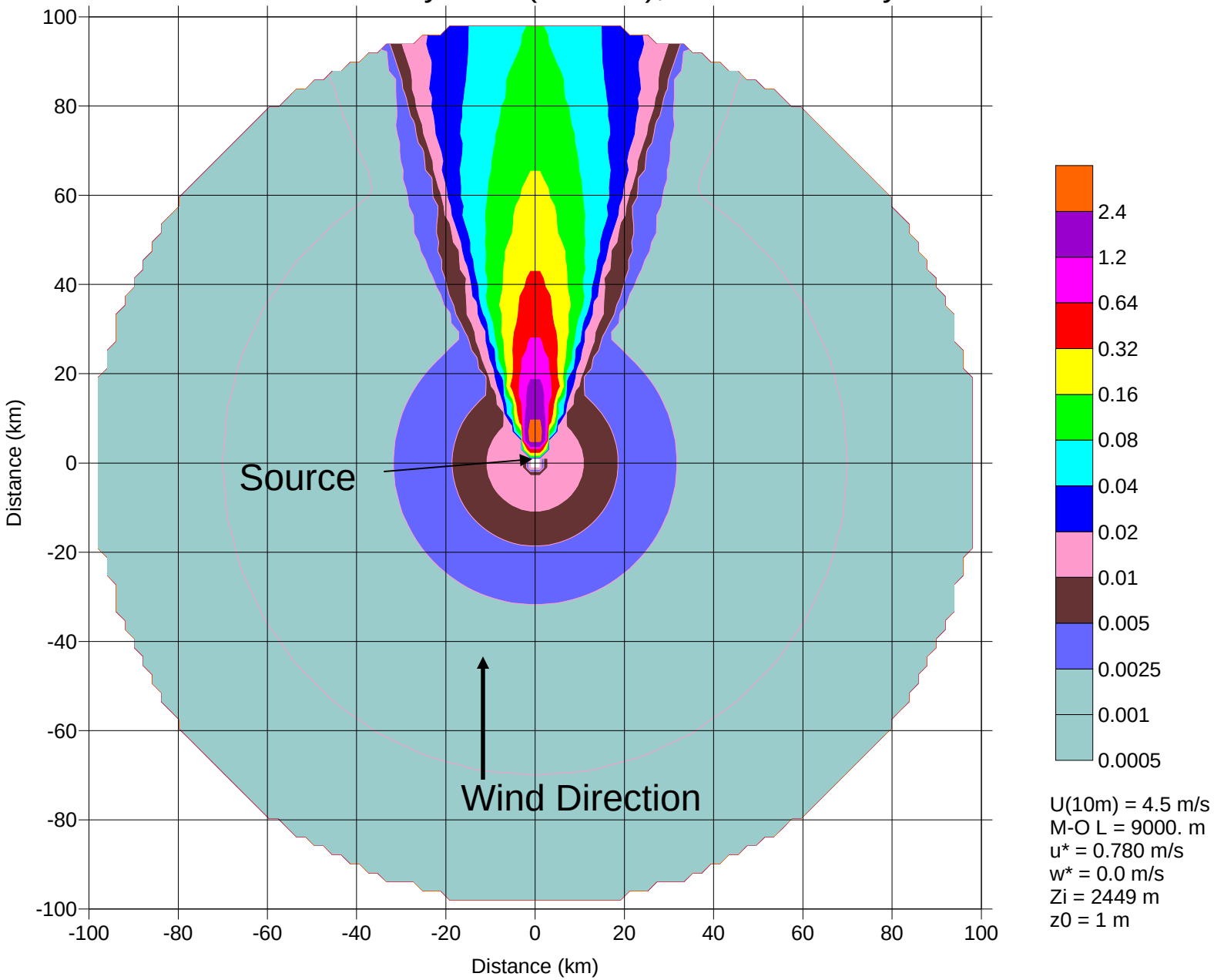


Model Applicability

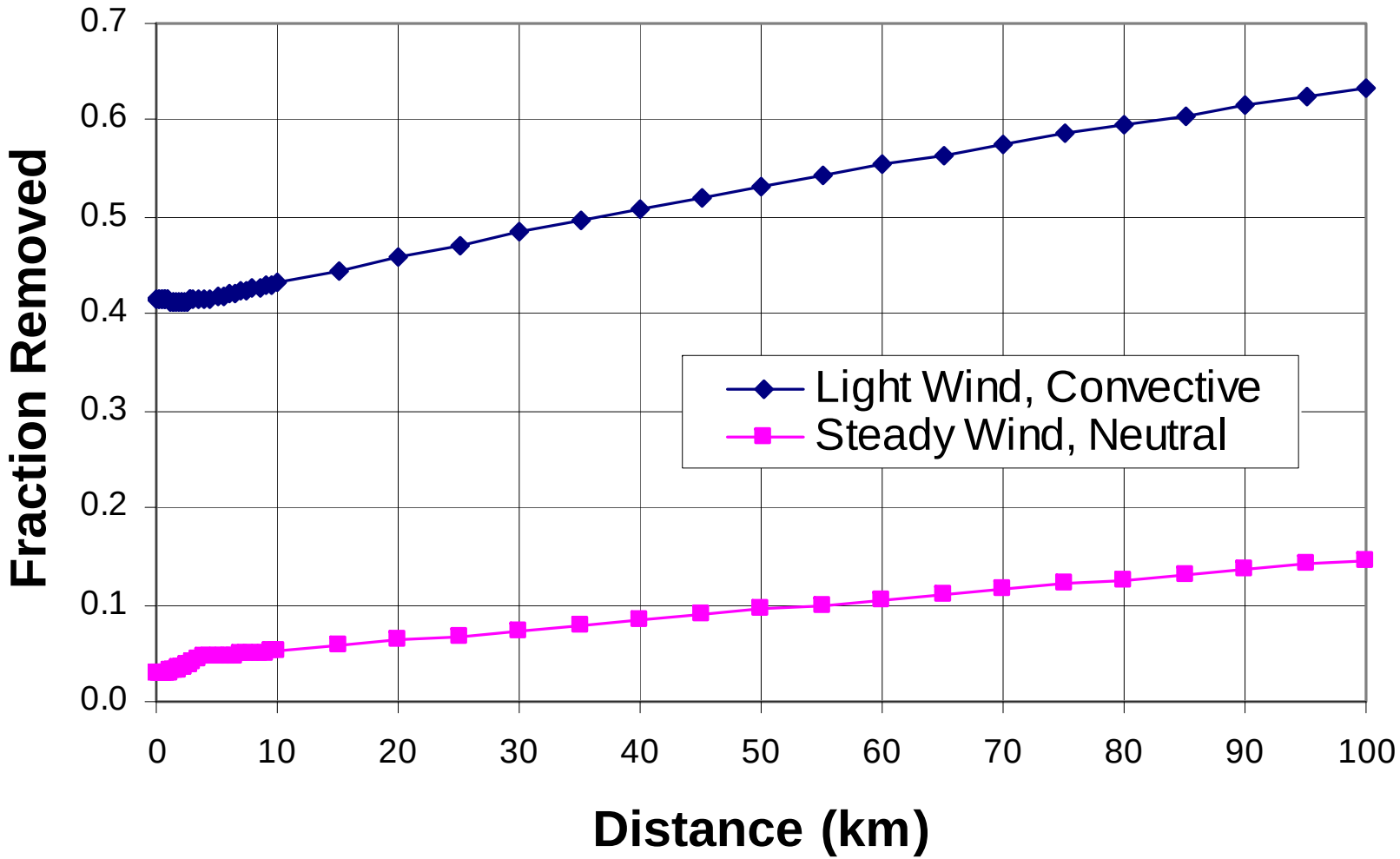
- Random plume in AERMOD creates an upwind halo around every source that results in concentrations being predicted upwind
- Can be problematic for ***cumulative impact assessments*** and assessing significant contributions to violations
- Upwind concentrations can even exceed downwind concentrations and SILs in AERMOD

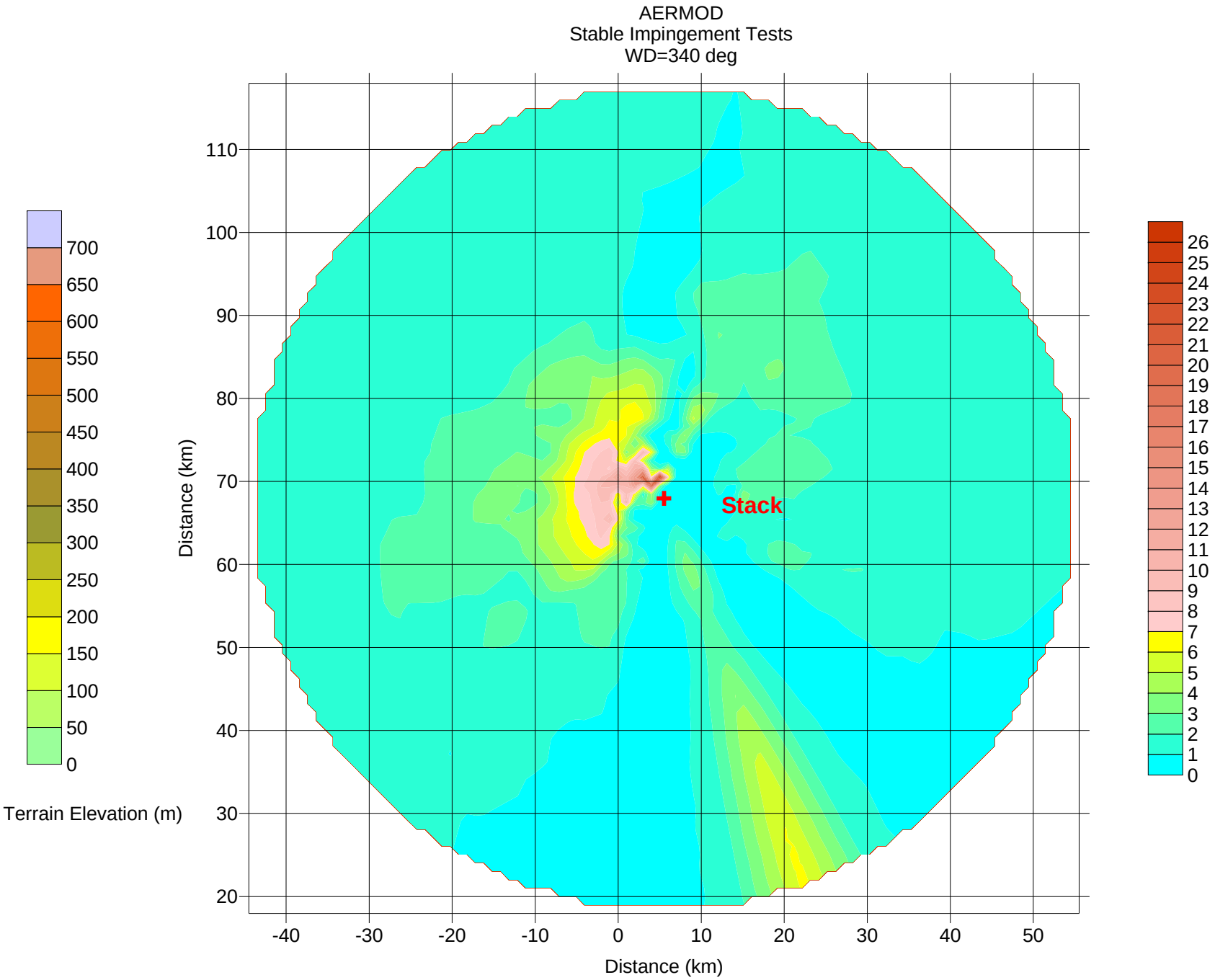
AERMOD Predicted Concentrations

Steady wind (4.5 m/s), Neutral stability

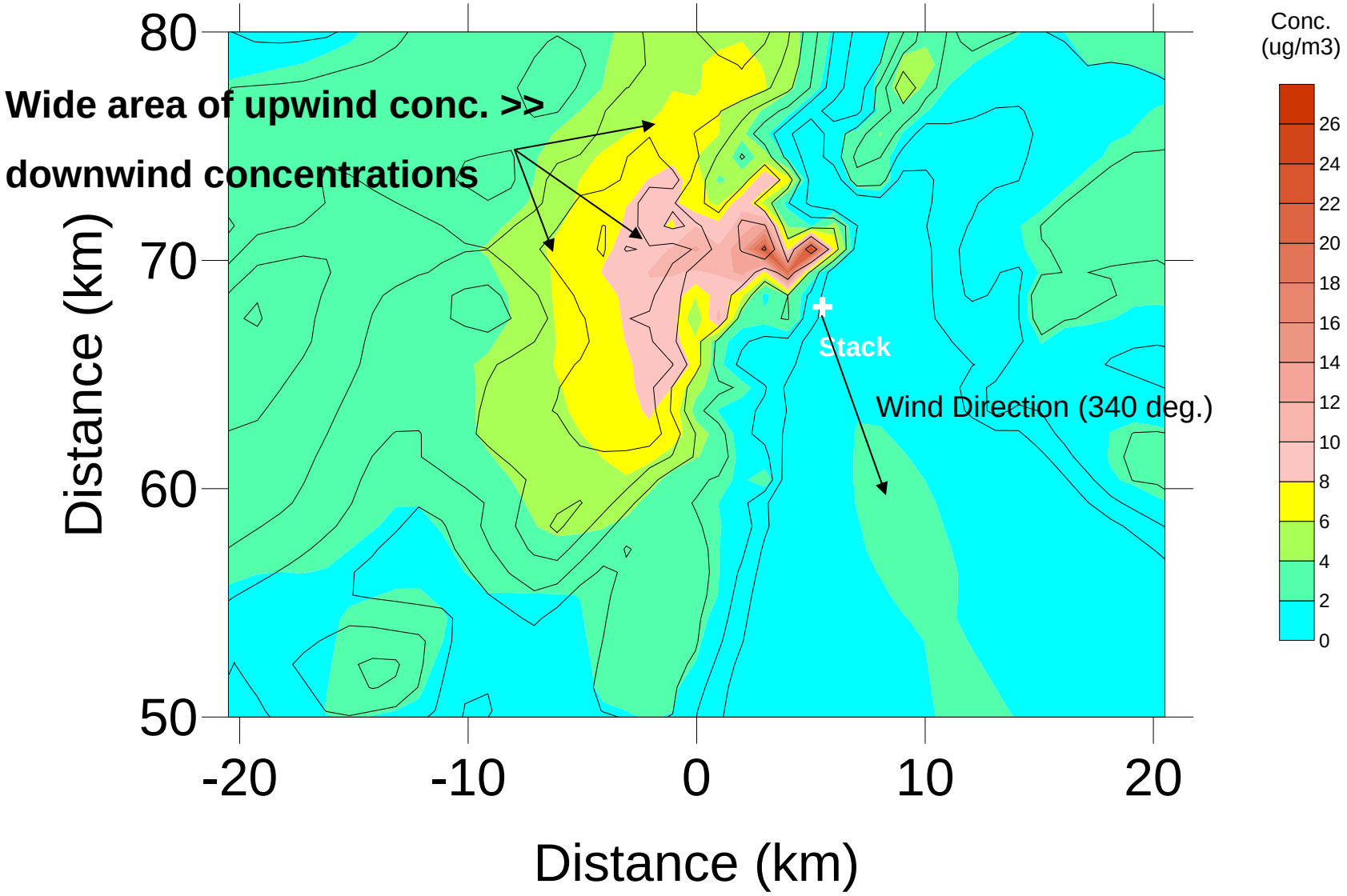


AERMOD Mass Fraction Removed From Coherent Plume to Random Plume




AERMOD
Stable Impingement Tests
WD=340 deg
Stack
Distance (km)
Distance (km)
Terrain Elevation (m)
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
110
100
90
80
70
60
50
40
30
20
-40
-30
-20
-10
0
10
20
30
40
50

AERMOD – Problem: upwind concentrations larger than downwind concentrations



Spatial Land Use Variability

AERSURFACE Users Guide:

- "Determining effective surface characteristics for the purpose of processing meteorological data for use with the AERMOD model presents many challenges."

- **"AERMOD is a steady-state plume model which assumes spatially uniform meteorological conditions across the modeling domain for each hour of meteorology, while land cover across the domain is typically very heterogeneous."**

- "A sound understanding of the important physical processes represented in the AERMOD model algorithms ... and the sensitivity of those algorithms to surface characteristics is needed in order to properly interpret the available data and make an appropriate determination."

Data Representativeness

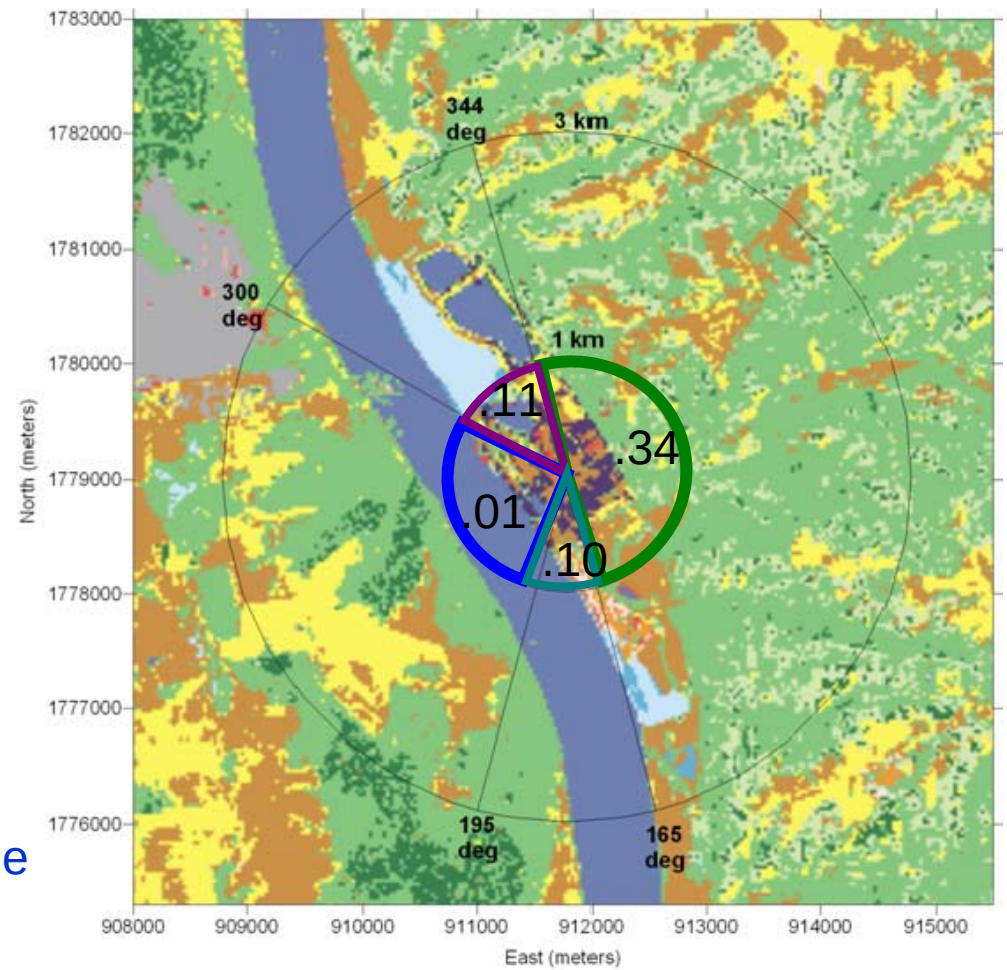
AERMOD Implementation Guide (January 9, 2008)

- "... data representativeness can be thought of in terms of constructing realistic planetary boundary layer (PBL) similarity profiles and adequately characterizing the dispersive capacity of the atmosphere."

- "... the determination of representativeness of site-specific data for AERMOD applications should also include an assessment of surface characteristics of the measurement and source locations and cannot be based solely on proximity."

AERSURFACE Results (1km)

AERSURFACE Roughness Lengths (m) for June by Wind Direction Sector

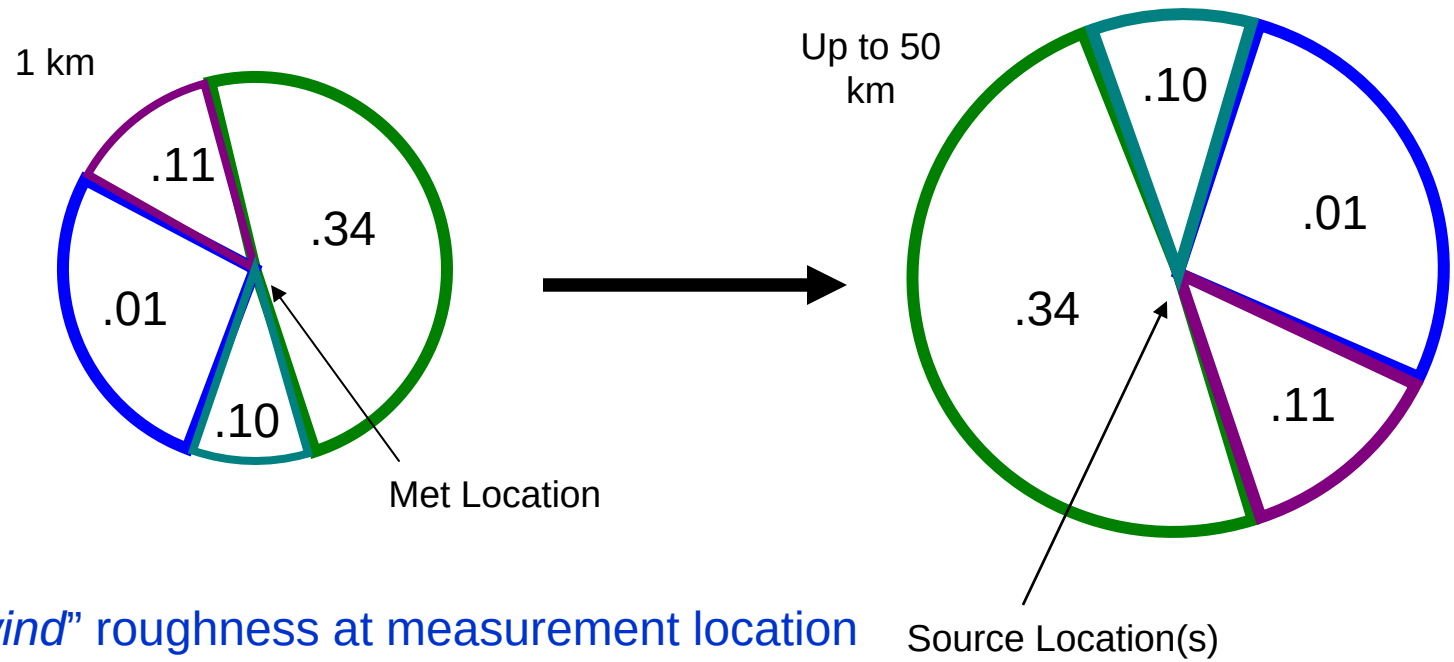


Roughness lengths upwind of measurement location characterize local boundary layer

(Move location 1km East and smooth water disappears from characterization)

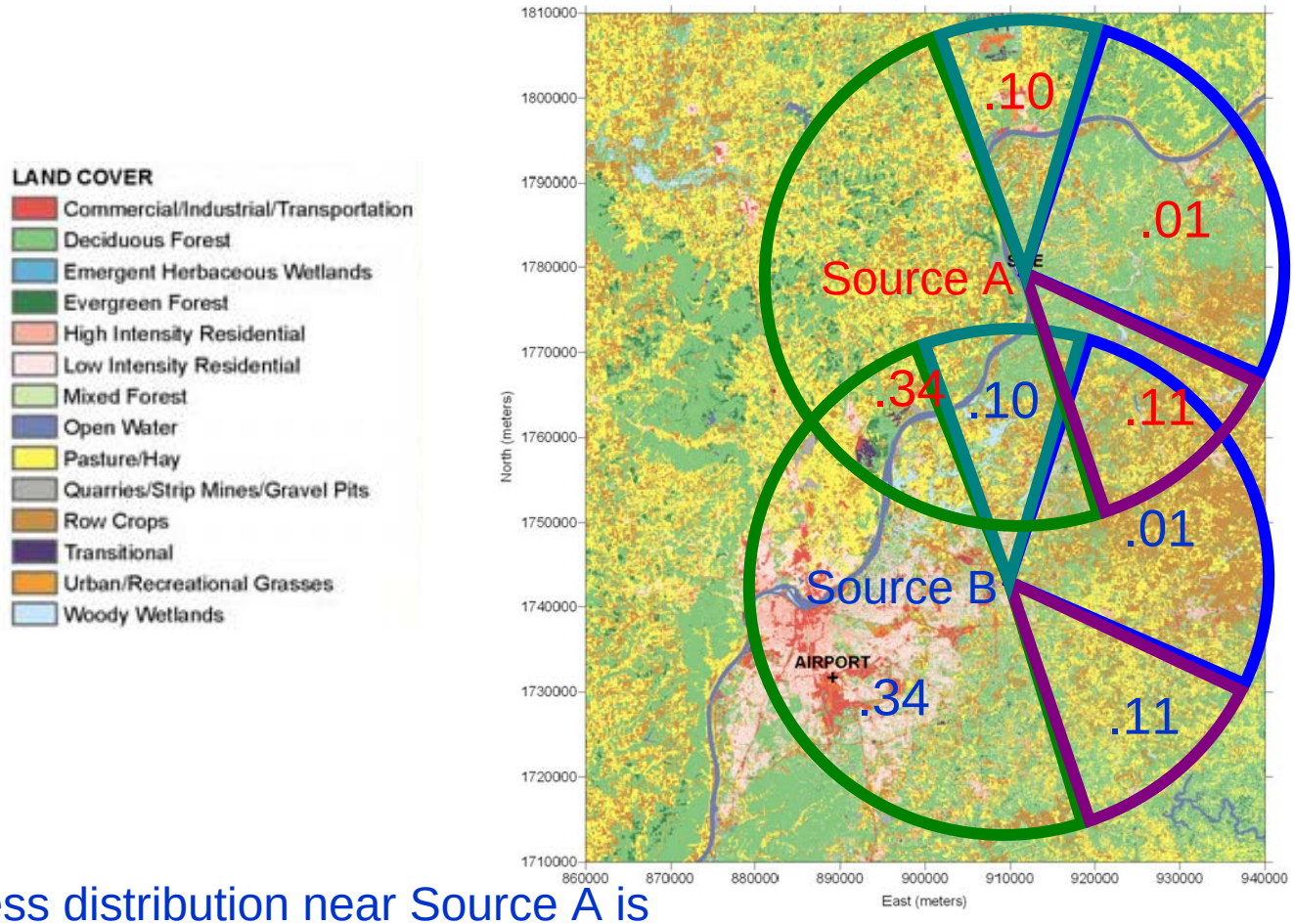
AERMOD Dispersion

- Averaged Surface Roughness Upwind of Met. Measurements
- Surface Roughness for Dispersion Downwind of Each Source



"*Upwind*" roughness at measurement location determines *downwind* dispersion at source location in AERMOD

Downwind Roughness (m) for AERMOD Sources



Roughness distribution near Source A is not appropriate for modeling interacting Source B, nor is it appropriate for much of the 50km region around Source A

AERMOD Sensitivity to Surface Property Processing

- Current Guidance: 1 km search radius for surface roughness, with upwind sectors determined by the user. Albedo and Bowen ratio determined for a 10km square centered at location.
- Previous Guidance: 3 km search radius for surface roughness, albedo, and Bowen ratio with upwind sectors determined by the user.
- Significance of change characterized for actual permitting application
  - 4 stacks (2 at 231 m, 3 m and 27 m stack heights)
  - Nearly 3500 receptors
  - One full year of surface meteorological data (Louisville International Airport - SDF)

AERMOD Sensitivity to Surface Property Processing

% Change in Peak Concentrations				
Averaging Time	**1-hr**	**8-hr**	**24-hr**	**Annual**
AERSURFACE 1-km method – previous 3- km method at Airport location	89%	123%	103%	-0.3%
AERSURFACE 1-km Method (airport – onsite location)	-34%	-43%	-39%	-3%

- Switch to AERSURACE with 1-km radius for z0 increased maximum short term concentration predictions from AERMOD by more than a factor of 2
- Using airport roughness instead of onsite roughness changes reduces AERMOD predicted short term concentrations by up to 43%

AERMOD Sensitivity to AERMAP DATUM Error

- EPA comment: Magnitude of changes in concentrations due to CALPUFF v5.8 were larger than expected
- All models will be sensitive to changes in the input parameters, including changes due to errors.
- Example: coordinate transformation corrected in AERMAP
- Significance of AERMAP changes characterized for an actual permitting application
  - 2 tall stacks (231 m stack height)
  - 2 short stacks (3 m and 27 m stack height)
  - Nearly 3500 receptors

AERMOD Sensitivity to AERMAP DATUM Error

% Change in Peak Concentrations [(bad-corrected)/corrected]					
Averaging Time	1-hr	3-hr	8-hr	24-hr	Annual
Overall Maximum	48 %	7 %	52 %	43 %	27 %
Paired (bad location)	7307 %	10980 %	10246 %	1784 %	30 %
Paired (correct location)	-99 %	-97 %	-99 %	-96 %	27 %

- Large differences frequently result from code changes
- Differences at specific locations (paired in space) can be especially sensitive

TRC

Model Sensitivity

- All dispersion models are sensitive to changes in model inputs
- Skill that an experienced, competent and objective modeler brings is ability to make appropriate decisions on how a model should be run
- Regulatory guidance has a role in model applications, but cookbook formulas do not work well in many cases

CALPUFF Model Evaluation

- Long-range transport
  - CAPTEX field data for long-range transport distances
  - Inel field data for intermediate transport distances
  - Wyoming dataset (long and short range – cumulative impacts)

- Short-intermediate distances
  - Kincaid SF_6: tracer releases from 187m stack in flat terrain
  - Lovett SO_2: ambient monitoring on ridge near 145m stack in Hudson river valley
  - PRIME datasets (building downwash)
  - Arkadelphia SF_6 : tracer releases from line source vents (potrooms)
  - Tennessee SO_2: 2 years of monitoring of emissions from potrooms and stacks
  - Overwater and coastal datasets (5)
    - Ventura, Carpinteria, Pismo Beach, Cameron (0.5 – 8 km)
    - Oresund (22 - 42 km)

AERMOD Model Evaluation

17 AERMOD Evaluation Datasets			
Developmental		Independent	
Alaska	(PRIME)	AGA	(PRIME)
Bowline (subset)	(PRIME)	Bowline	(PRIME)
DAEC	(PRIME)	Baldwin	
Indianapolis		Clifty Creek	
Kincaid SF6		EOCR	(PRIME)
Kincaid SO2		Lee (wind tunnel)	(PRIME)
Lovett		Martin's Creek	
Millstone	(PRIME)	Tracy	
Prairie Grass		Westvaco	
9 used in developing/tuning model algorithms 7 used to develop/test PRIME downwash module common to ISC-PRIME, AERMOD, and CALPUFF			

Model Evaluation

AERMOD (non-PRIME) Developmental Datasets

Site	Land Use	Terrain	Source Type(s)	Multiple Source Facilities	Onsite Sigma-Theta	Onsite Sigma-W	Modeled/ Observed RHC (EPA)
Indianapolis (SF6)	Urban	Flat	84 m Stack	None	Yes	Yes	1.11 (1hr)
Kincaid (SF6)	Rural	Flat	187 m Stack	None	Yes	Yes	0.77 (1hr)
Kincaid (SO2)	Rural	Flat	187 m Stack	None	Yes	Yes	0.98 (3hr) 0.94 (24hr) 0.30 (annual)
Lovett (SO2)	Rural	Complex	145 m Stack	None	Yes	Yes	1.03 (3hr) 1.01 (24hr) 0.85 (annual)
Prairie Grass (SO2)	Rural	Flat	0.46 m release	None	Yes	Yes	0.89 (1hr)

Model Evaluation

AERMOD (non-PRIME) Independent Evaluation Datasets

Site	Land Use	Terrain	Source Type(s)	Multiple Source Facilities	Onsite Sigma -Theta	Onsite Sigma -W	Modeled/ Observed RHC (EPA)
Baldwin (SO2)	Rural	Flat	Three 184 m Stacks	None	No	No	1.24 (3hr) 0.97 (24hr) 0.97 (annual)
Clifty Creek (SO2)	Rural	Half of Stack Ht.	Three 208 m Stacks	None	No	No	1.05 (3hr) 0.67 (24hr) 0.54 (annual)
Martin's Creek (SO2)	Rural	Complex	122 m to 183 m Stacks	None	Yes	No	1.12 (3hr) 1.78 (24hr) 0.78 (annual)
Tracy (SF6)	Rural	Complex	91 m Stack	None	Yes	Yes	1.04 (1hr)
Westvaco (SO2)	Rural	Complex	183 m Stack	None	Yes	Yes	1.06 (3hr) 1.07 (24hr) 1.59 (annual)

TRC

Model Evaluation

AERMOD (PRIME) Datasets

Site	Land Use	Terrain	Source Type(s)	Multiple Source Facilities	Onsite Sigma-Theta	Onsite Sigma-W	Modeled/ Observed RHC (EPA)
AGA (SF6)	Rural	Flat	10-25 m Stack	None	No	No	0.92 (1hr)
Alaska (SF6)	Rural	Flat	39 m Stack	None	Yes	Yes	1.06(1hr)
Bowline Point (SO2)	Rural	Flat	Two 87 m Stacks	None	No	No	1.14 (1hr) 1.43 (24hr)
DAEC (SF6)	Rural	Flat	1 m, 24m & 46m rooftops	None	Yes	No	0.69 (46 m) 0.25 (24 m) 0.51 (1m)
EOCR (SF6)	Rural	Flat	Rooftop?	None	Yes	No	1.72 (1hr)
Lee (wind tunnel)	“Rural”	Flat	64.8 m stack	None			0.51 (neutral) 2.50 (stable)
Millstone (SF6)	Coastal	Flat	48m and 29m stacks	None	No	No	0.44 (46 m) 1.32 (29 m)

Model Evaluation

17 AERMOD Evaluation Datasets	
0	Number involving cumulative impact assessments
0	Number in complex terrain involving multi-facility impacts
1	Number in coastal locations, but not a fumigation scenario due to downwash (PRIME building downwash dataset)
0	Number of building downwash studies with very long buildings

- AERMOD has not been evaluated for use in assessing design concentration limits arising from interacting facilities, especially those in complex geographic areas
- Evaluation datasets include evidence of underprediction

Model Evaluation

AERMOD Results for Kincaid SF6 Tracer Dataset

- Arc-maximum results (best if samplers capture maximum)
- Kincaid SF6 distributed in Model Validation Kit (MVK) used in "Harmonisation of Atmospheric Dispersion Modelling for Regulatory Purposes" workshops
- MVK includes Quality Index (QI) values established for subset of the data
  - QI=0: disregard value
  - QI=1: most probably not the maximum value
  - QI=2: identified value may be near a local maximum
  - QI=3: identified value is a well-defined maximum

Kincaid SF6 Dataset	Modeled/ Observed RHC
EPA (all data?)	0.77 (underprediction)
MVK Subset for QI=2 or 3	0.68 (underprediction)
MVK Subset for QI=3	0.64 (underprediction)

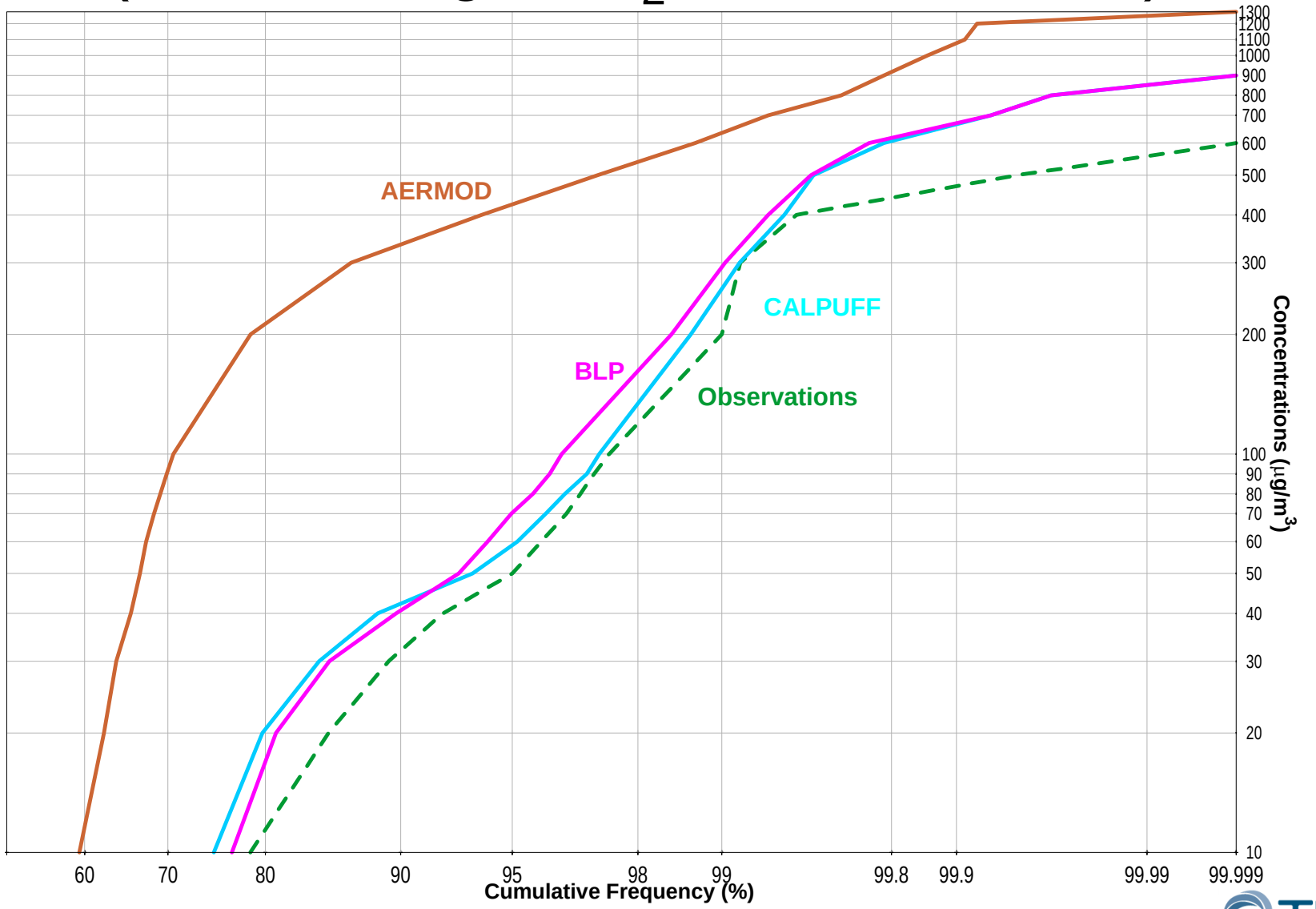
Model Evaluation

SO_2 Evaluation – Tennessee Smelter

- SO_2 measured upwind and 300m downwind of facility
- Primary sources: 4 potrooms (line sources), 4 banks of scrubber stacks (point sources)
- Two years of data evaluated as part of 1981 BLP evaluation which resulted in BLP acceptance as a *Guideline Model*
- Simulations with BLP, AERMOD and CALPUFF

Units: ($\mu g/m^3$)	**1976**	**1977**
Observed	8	13
CALPUFF	15.8	18.5
BLP	17.1	19.6
AERMOD	116.2	114.2

Observed vs Predicted Q-Q Plots – 1977 (1-hr Average SO_2 Concentrations)



Overwater Evaluation Datasets

- OCD datasets (4 datasets)
  - Ventura, Carpinteria, Pismo Beach, Cameron
  - Test of overwater dispersion over 4-8 km range except for Carpinteria and Gaviota (<1km)
  - Both stable and unstable conditions
- Oresund Experiment
  - Tracer experiments across 20 km-wide strait of Oresund between Denmark and Sweden
  - Tracer released at height of 95m or 115m
  - Transport distances to monitors: 22-44 km

Cameron, Carpinteria, Pismo Beach, Ventura
All CALMET Configurations with CALPUFF Configuration A

CALPUFF Configuration

(Modeled Sigma-v ≥ 0.37 m/s)

A -- Modeled Iy, CALPUFF Turbs, Draxler Fy

B -- Observed Iy, CALPUFF Turbs, Draxler Fy

E -- Modeled Iy, AERMOD Turbs, Draxler Fy

F -- Observed Iy, AERMOD Turbs, Draxler Fy

C -- Modeled Iy, CALPUFF Turbs, Variable TLy

D -- Observed Iy, CALPUFF Turbs, Variable TLy

G -- Modeled Iy, AERMOD Turbs, Variable TLy

H -- Observed Iy, AERMOD Turbs, Variable Tly

CALMET Configuration

c0 – OCD overwater BL parameter module

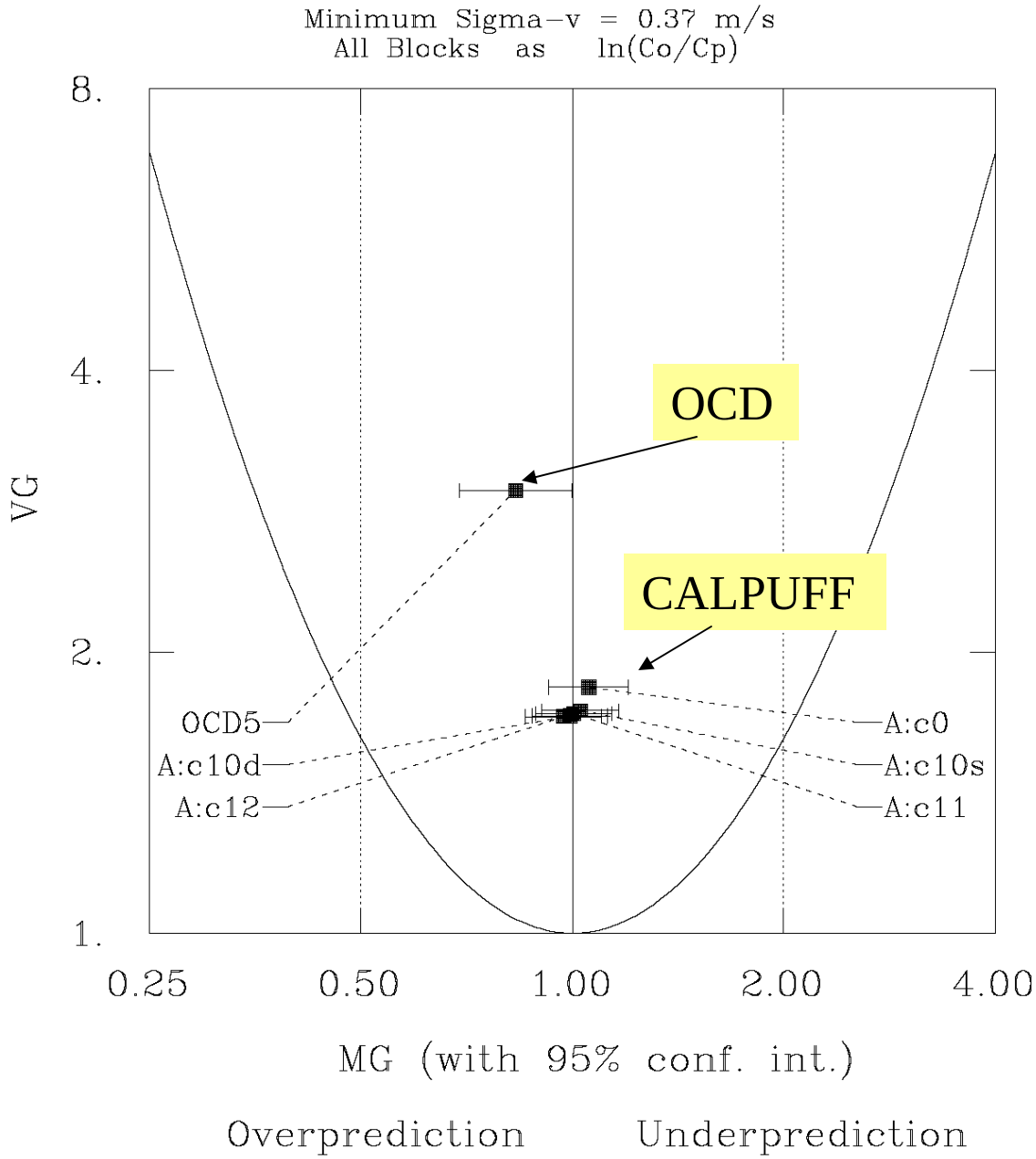
c10d – COARE module (standard "deep water")

c10s – COARE module with shallow water adj.

c11 – COARE module with wave option 1

c12 – COARE module with wave option 2

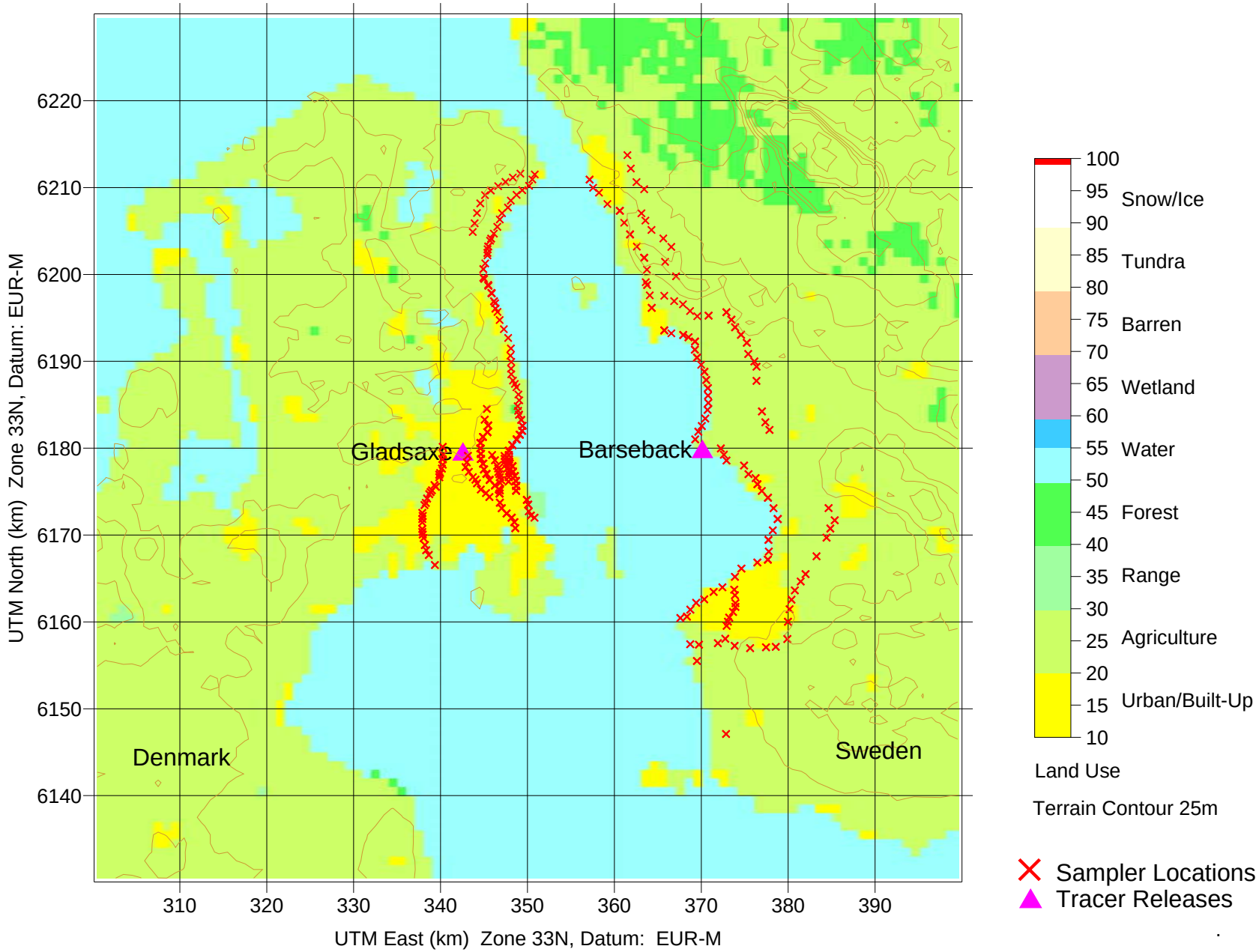
OCD5 with Modeled Iy (Sigma-v ≥ 0.37 m/s)



Factor of 2 and Correlation statistics

Modeled Iy	**Fraction within factor of 2**	**Correlation**
CALPUFF (CALPUFF Turbulence Profile)	0.66	0.84
CALPUFF (AERMOD Turbulence Profile)	0.67	0.85
OCD5	0.54	0.71
Observed Iy	**Fraction within factor of 2**	**Correlation**
CALPUFF (CALPUFF Turbulence Profile)	0.60	0.83
CALPUFF (AERMOD Turbulence Profile)	0.62	0.84
OCD5	0.54	0.66

Strait of Oresund



Oresund

CALMET - CALPUFF Configuration

-Zi1 – No Turb Advection, Maul-Carson Mixing Ht

-Zi1OW – No Turb Advection, Maul-Carson Mixing Ht , Obs Overwater

-Zi2 – No Turb Advection, Batchvarova-Gryning Mixing Ht

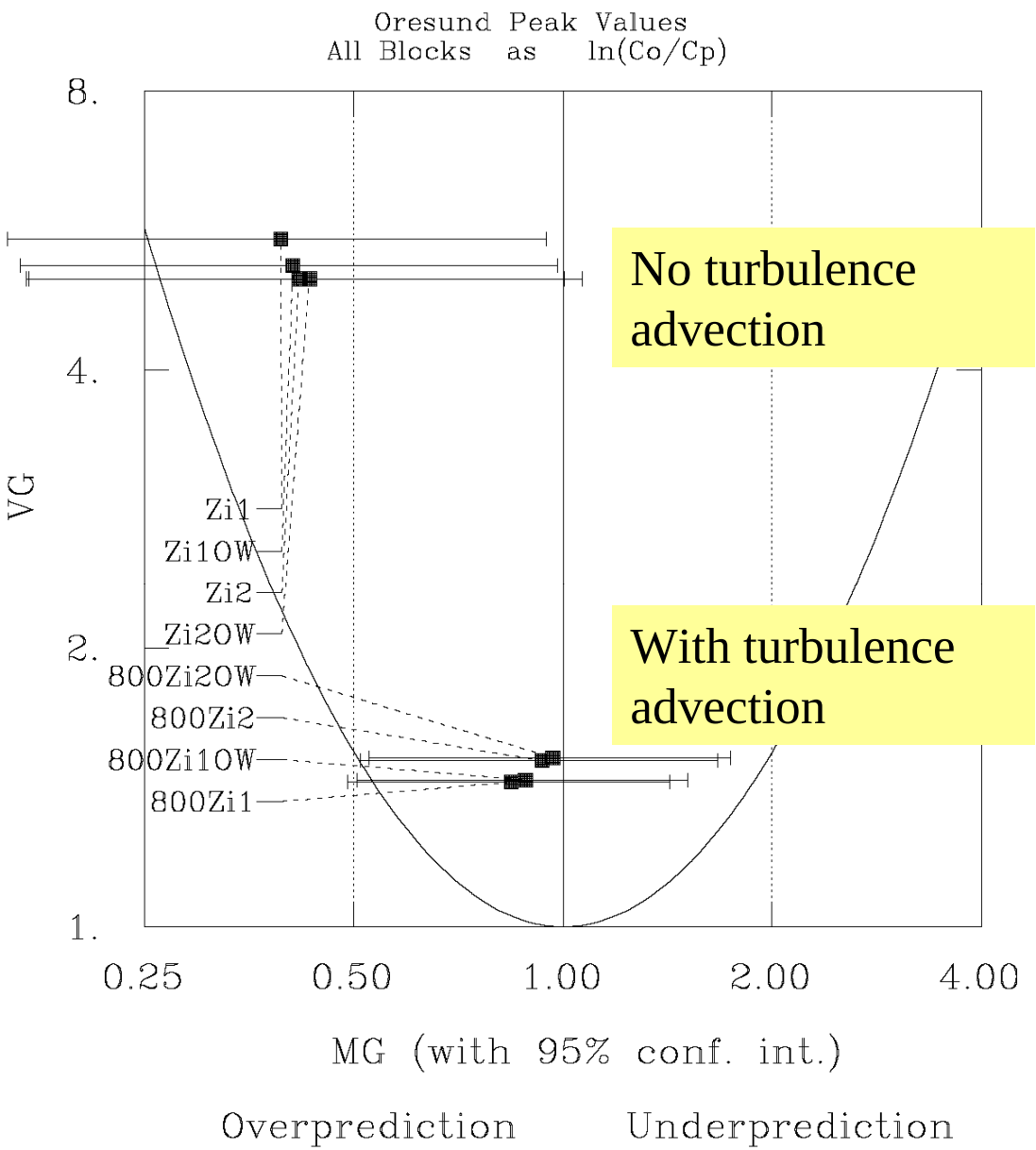
-Zi1OW – No Turb Advection, Batchvarova-Gryning Mixing Ht , Obs Overwater

-800Zi1 –Turb Advection (800s), Maul-Carson Mixing Ht

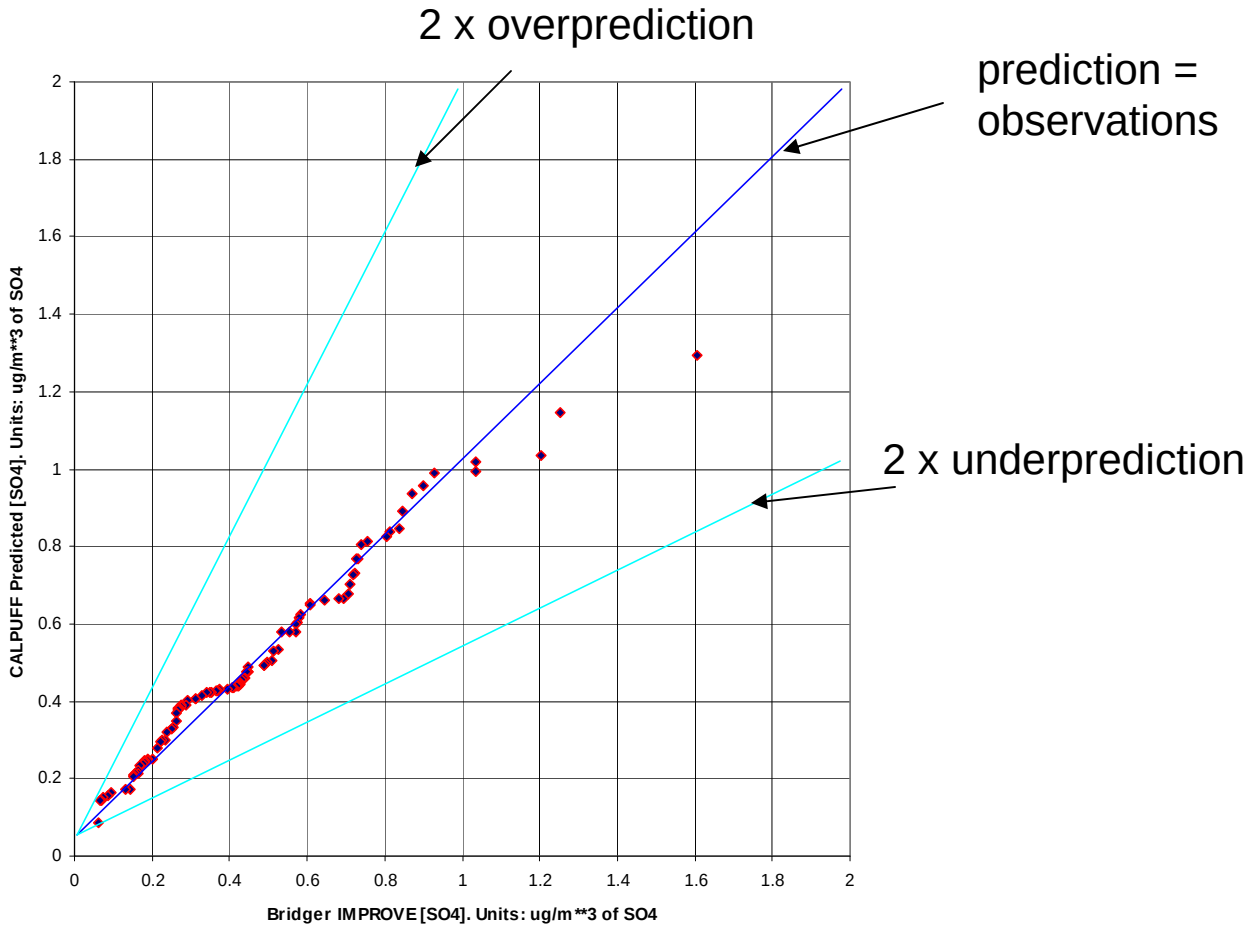
-800Zi1OW –Turb Advection (800s), Maul-Carson Mixing Ht , Obs Overwater

-800Zi2 –Turb Advection (800s), Batchvarova-Gryning Mixing Ht

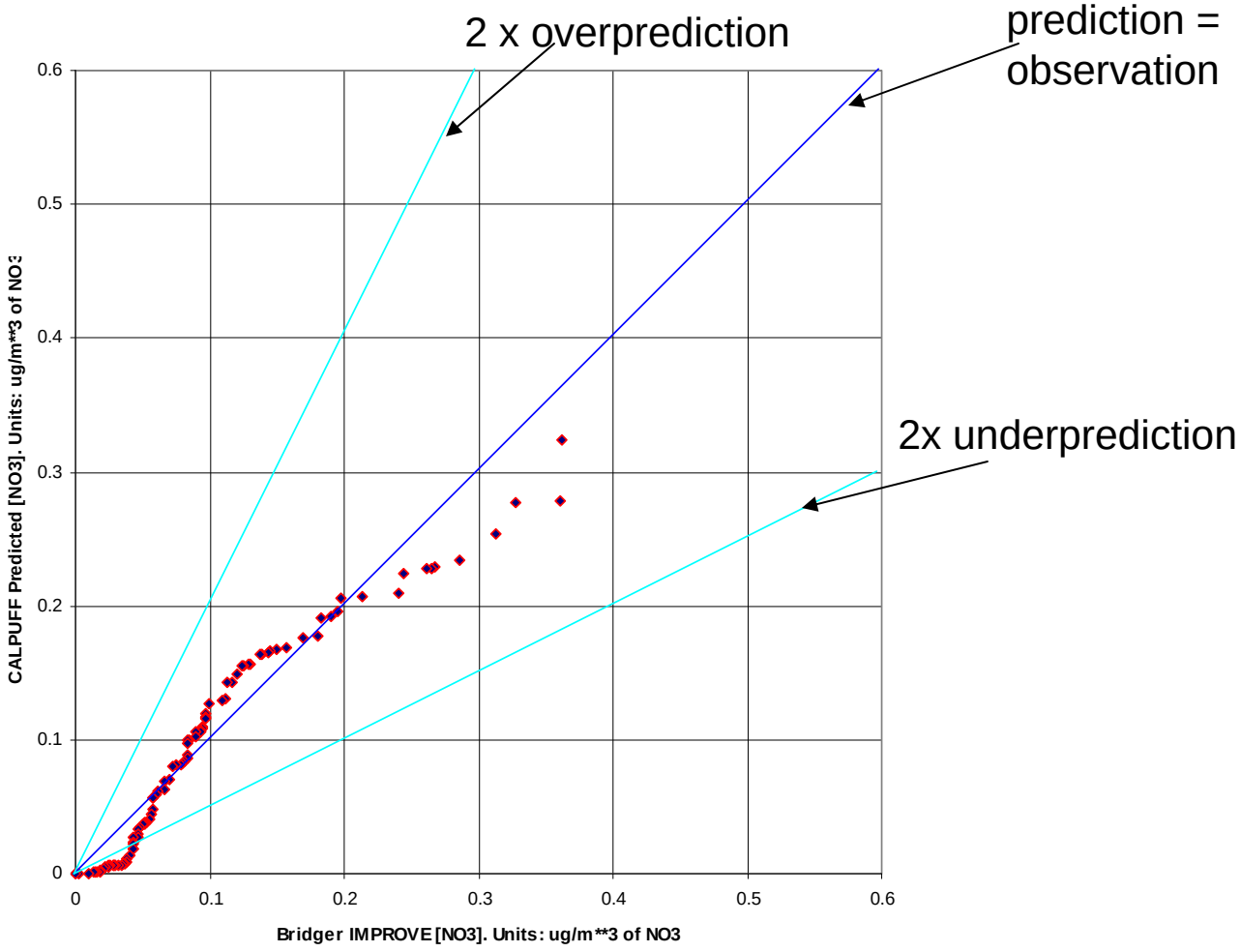
-800Zi1OW –Turb Advection (800s), Batchvarova-Gryning Mixing Ht , Obs Overwater



CALPUFF PERFORMANCE PREDICTING SO_4 W/ BCs and ALM (BRIDGER IMPROVE SITE)



CALPUFF PERFORMANCE PREDICTING NO_3 W/ BCs and ALM (BRIDGER IMPROVE SITE)



OBSERVED AND PREDICTED SO_4, NO_3 and SO_2 (ug/m^3)

Species	Obs Mean	Pred Mean	Obs SD	Pred SD	Within 2x
SO_4	.453	.492	.286	.248	94%
NO_3	.0978	.0922	.082	.081	78%
SO_2	.366	.585	.172	.207	90%

OBSERVED AND PREDICTED B_{ext} (Mm^{-1}) BRIDGER TRANSMISSOMETER SITE

Variable	CALPUFF Method 2	CALPUFF Method 6	Obs	Fractional Bias Method 2	Fractional Bias Method 6
Mean	23.2	22.5	24.7	-0.017	-0.030
Standard Deviation	4.6	5.5	7.2	-	-

OBSERVED and PREDICTED ANNUAL WET S and N DEPOSITION (kg/ha/yr) AT NADP SITES

Species	Site	Observed Wet Flux	Predicted Wet Flux
N	Pinedale	0.99	1.17
S	Pinedale	0.75	0.69
N	Sinks Canyon	1.34	1.36
S	Sinks Canyon	1.11	0.83
N	South Pass	1.43	1.28
S	South Pass	0.97	0.79
N	Gypsum	1.18	1.24
S	Gypsum	0.73	0.72

Model Evaluation Summary

- AERMOD has been shown to perform well in certain circumstances but has shown underprediction in several of the EPA datasets.
- No evaluation data presented by EPA for cumulative impacts assessments or for upwind impacts predicted by random plume, or multi-source impacts
- Most evaluations method different from typical permitting study (i.e., observed turbulence rather than predicted turbulence)
- AERMOD model formulation makes it unsuitable for many non-steady-state situations

Consistency vs. Accuracy

Paragraph 1(d) of the *Guideline*:

"The model that most accurately estimates concentrations in the area of interest is always sought. However, it is clear from the needs expressed by the States and EPA Regional Offices, by many industries and trade associations, and also by the deliberations of Congress, that **consistency in the selection and application of models and data based should be sought, even in case-by-case analyses**. Consistency ensures that air quality control agencies and the general public have a common basis for estimating pollutant concentrations, assessing control strategies and specifying emission limits. **Such consistency is not, however, promoted at the expense of model and data base accuracy**. The *Guideline* provides a consistent basis for selection of the model accurate models and data bases for use in air quality assessments."

Summary

- AERMOD should not automatically be preferred over CALPUFF in applications involving non-steady-state application
- AERMOD has significant issues with cumulative impacts
- AERMOD sensitive to specification of land use and surface properties may involve substantial error associated with its inability to vary surface properties appropriately for the facility source and especially background sources.
- The intent of the GAQM should be followed to allow CALPUFF use wherever complex flow or non-steady-state conditions are important