IDA

Military Protective Action Distances: A Pilot Study

John M. Fregeau

Jim Heagy

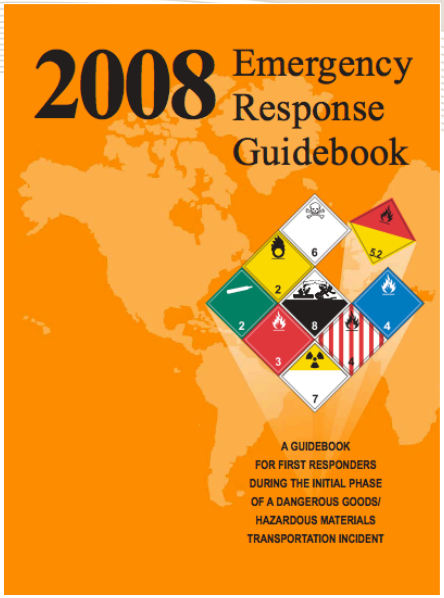
Institute for Defense Analyses

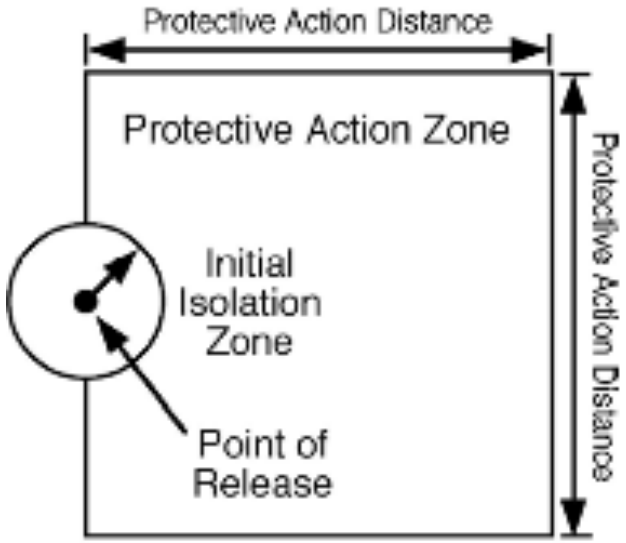
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Sponsor: Jerry Glasow, DTRA

IDA | Motivation

- Emergency Response Guidebook (ERG)
  - Developed by USDOT, and carried by all US, Canadian, and Mexican first responders.
  - Provides protective action distances (PADs) for hundreds of hazardous materials (HAZMATs).
  - PADs are based on extensive Monte Carlo analysis conducted by Argonne National Laboratory (ANL).
  - The PAD is defined as the 90th percentile distance at which concentration falls below a specific toxicity threshold, known as *AEGL-2.*
  - The protective action area is a square whose side length is the PAD distance.





http://www.phmsa.dot.gov/staticfiles/PHMSA/DownloadableFiles/Files/erg2008_eng.pdf

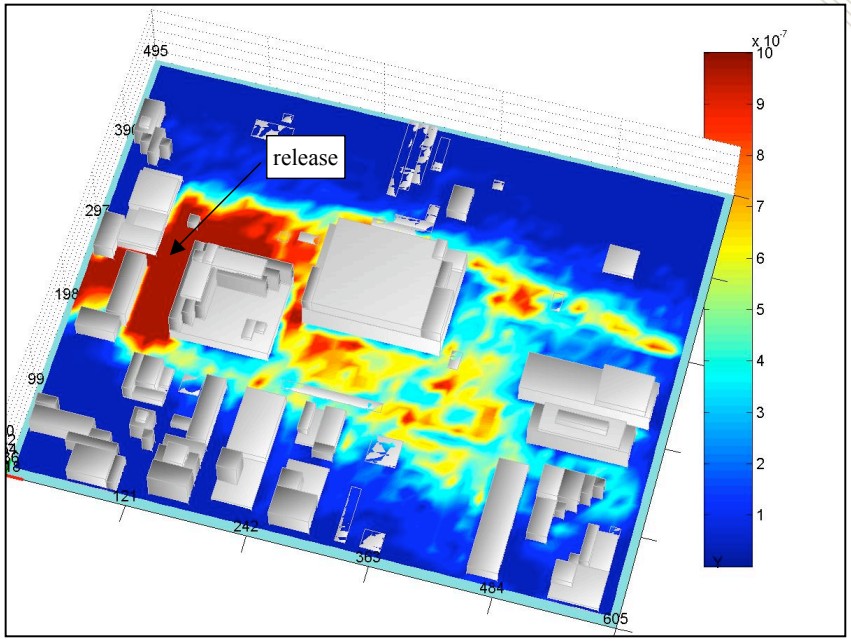
A flexible framework for calculating protective action distances

- Want to create something similar for military use.
- Methodology
  - Perform ensemble of T&D calculations, Monte Carlo-ing over a range of input parameters (such as boundary layer height, atmospheric stability, wind speed, surface roughness).
  - For each run, calculate the quantity of interest (dosage, concentration, F_{AEGL}, etc.) at each point in space at the times of interest.
  - Group runs into a logical set (e.g., daytime large release, nighttime small release) and, at each point in space, calculate desired percentile of quantity of interest.
  - Report results based on resulting single data set.

IDA | T&D Model: QUIC

- QUIC = Quick Urban and Industrial Complex
  - Particle-based method that runs on a laptop (Windows, Linux, Mac OSX).
  - Developed by Los Alamos National Lab (LANL).
  - Designed for Urban T&D, but can easily do T&D in non-urban settings
  - Fairly easy to run in batch mode.

Tracer Release in Boston



- We've written a simple Python interface for QUIC.

```
qpp = QUIC.InputFile(innerdir+'/QP_params.inp', QUIC.QPParamsDefs)
qpp.setval('z0', 0.01)
qpp.setval('Npart', 100000)
qpp.setval('duration', 1800.0)
qpp.write()
```

IDA | Acute Exposure Guideline Levels

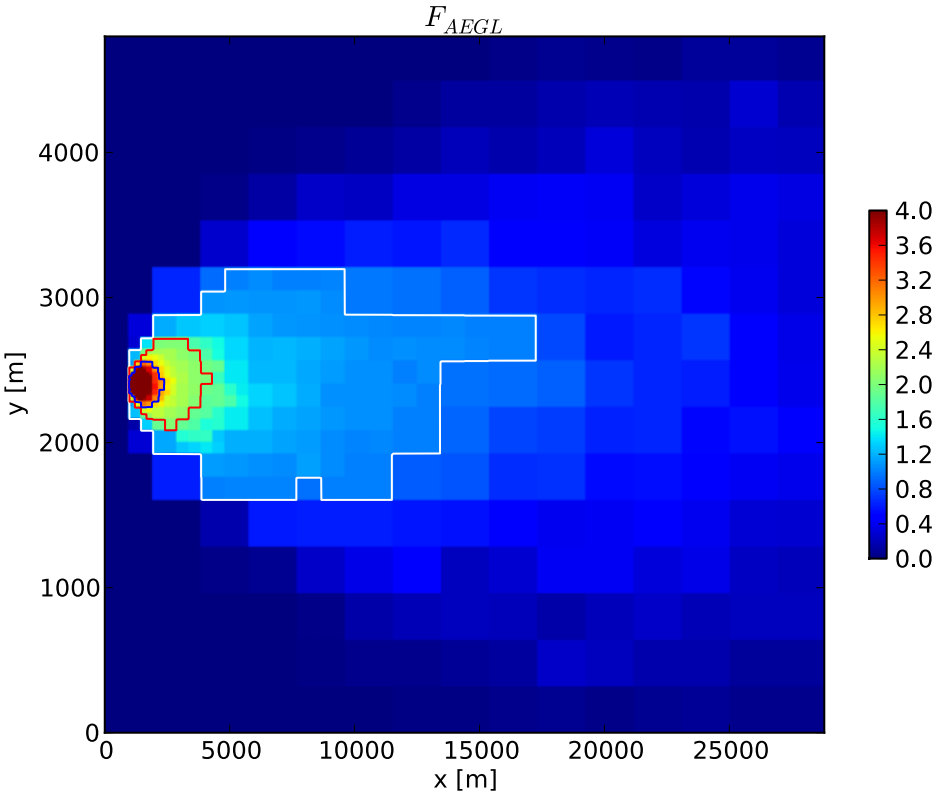
- AEGLs
  - Worldwide effort to establish exposure levels corresponding to levels of toxic effects in humans
  - Data come from studies on animals (dogs, mice, etc.) and non-lethal studies on humans
  - Include toxic load effects
- An AEGL has two components:
  - A threshold *concentration*
  - An exposure time
- 3 AEGL severities
  - AEGL 1: Discomfort, irritation, or other reversible non-disabling effect
  - AEGL 2: Irreversible, long-lasting adverse health effect
  - AEGL 3: Life-threatening health effects or death

IDA | Calculating AEGL values from T&D codes

- AEGL threshold concentrations are defined for discrete exposure times (10, 30, 60 min, …).
- However, the output of a T&D code is a concentration time series.
- A method for estimating from the concentration time series the exposure time and the corresponding AEGL threshold dosage is described in S. Stage, *Determination of AEGLs in a Dispersion Model*, J. Air and Waste Mngmt. Assoc., **54**, 49-59, 2004.
- This paper also defines a continuous AEGL function, F_{AEGL}, as a function of dosage and exposure time, which equals 1, 2, and 3, for AEGL-1, 2, and 3.

IDA | Calculating AEGL values from T&D codes

- An additional difficulty is that since we use a particle-based method, we suffer from statistical noise at low dosages.
- To overcome this we use an adaptive spatial mesh that grows volume cells until they contain a specified number of particles (typically 64, time-integrated).



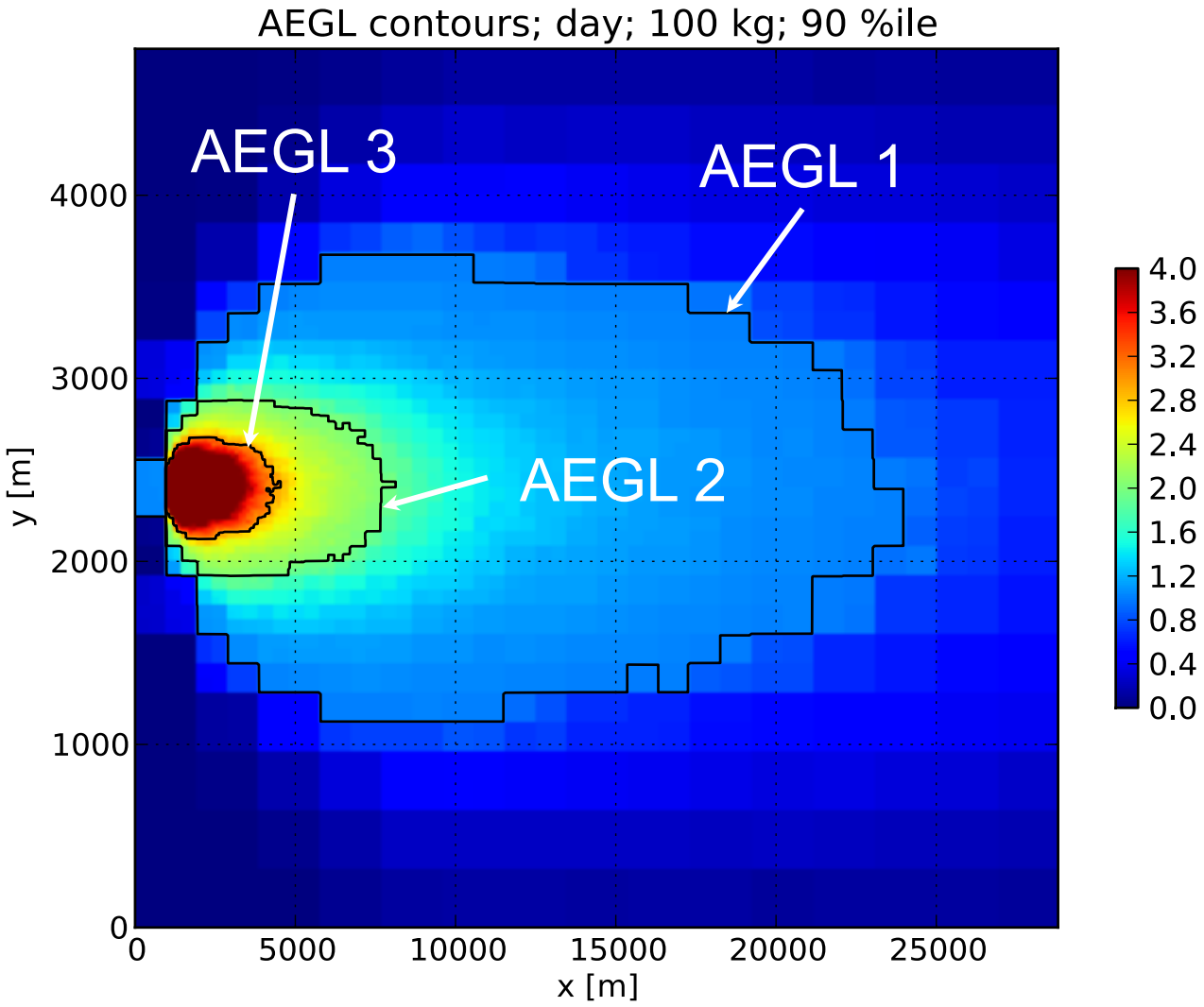
IDA | Input parameters (for sarin runs)

- Release Size
  - "Small": 100 kg instantaneous release of sarin at ground level
  - "Large": 1000 kg instantaneous release of sarin at ground level
- Wind speed (1 hour averages); fixed direction for now
  - Day releases: Weibull draw with k=1.637 and λ=4.387
  - Night releases: Weibull draw with k=1.842 and λ=2.383
- Atmospheric Stability
  - Day: Choose PGT stability class randomly on {1, 2, 3}
  - Night: Choose PGT stability class randomly on {5, 6, 7}
- Surface Roughness
  - For all releases choose surface roughness uniformly on 2 values: 0.001 m (nearly barren) and 0.05 m (grassland)
- T&D calculation duration is 1 hr for all runs.

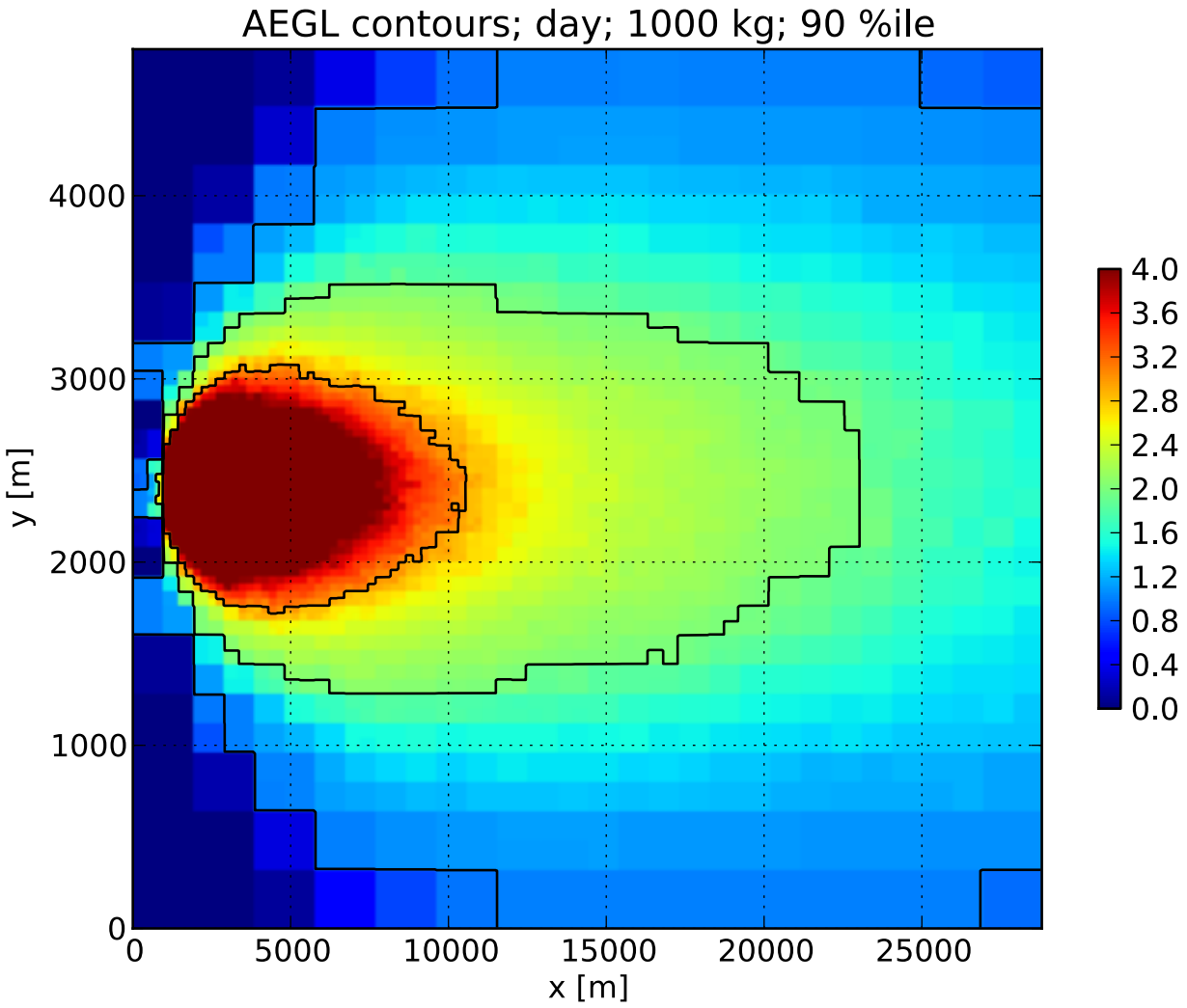
IDA | Methodology (detail)

- Perform ~1000 runs, Monte Carlo-ing over input parameters.
- For each run, calculate F_{AEGL} at each point in space.
- Group runs into logical sets: large/small release, day/night, z0=0.1,5cm, etc.
- For each logical set, take 90^{th} percentile of F_{AEGL} at each point in space and draw F_{AEGL}=1,2,3 contours on resulting field.

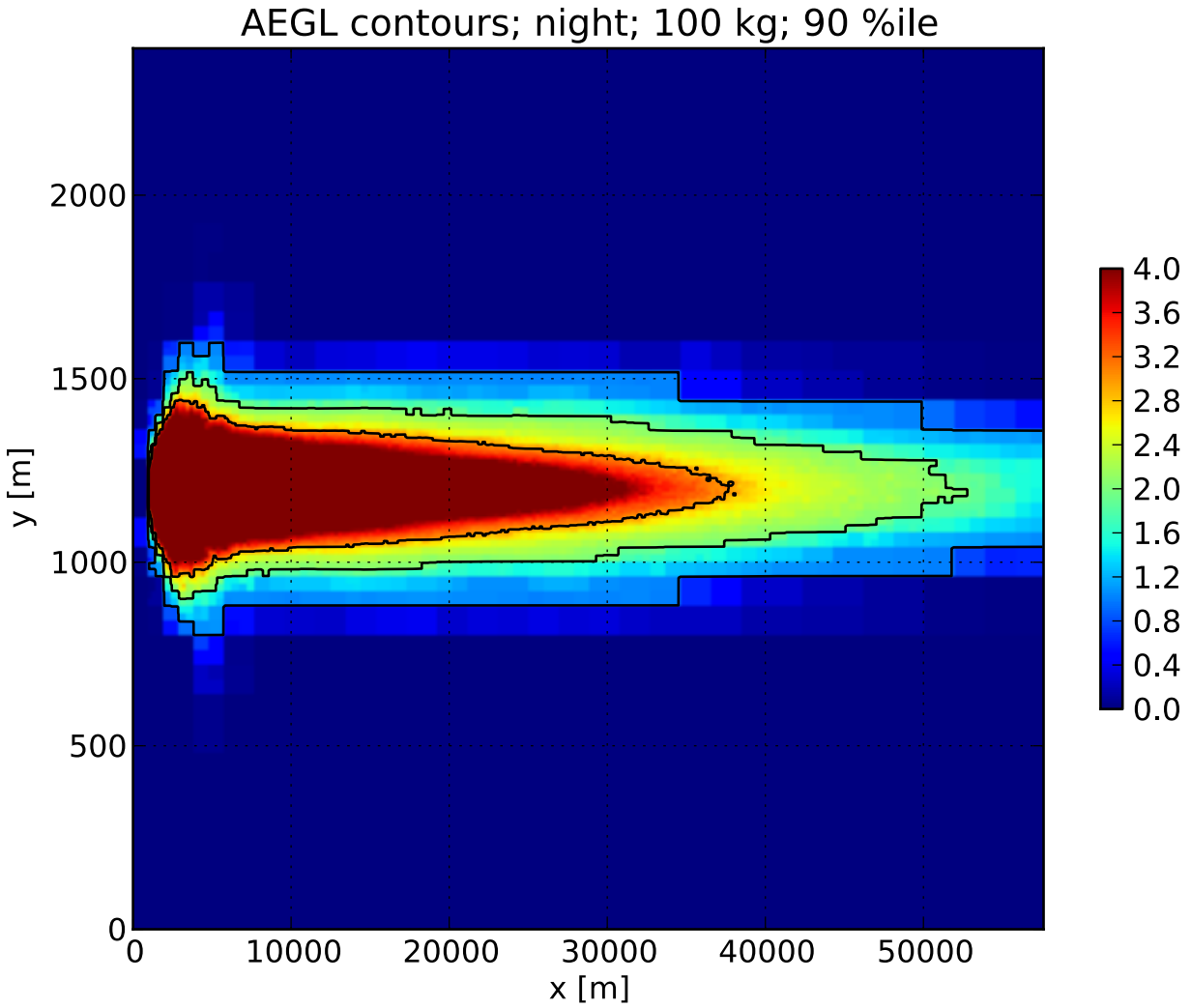
IDA | 90th percentile F_{AEGL}: small/day



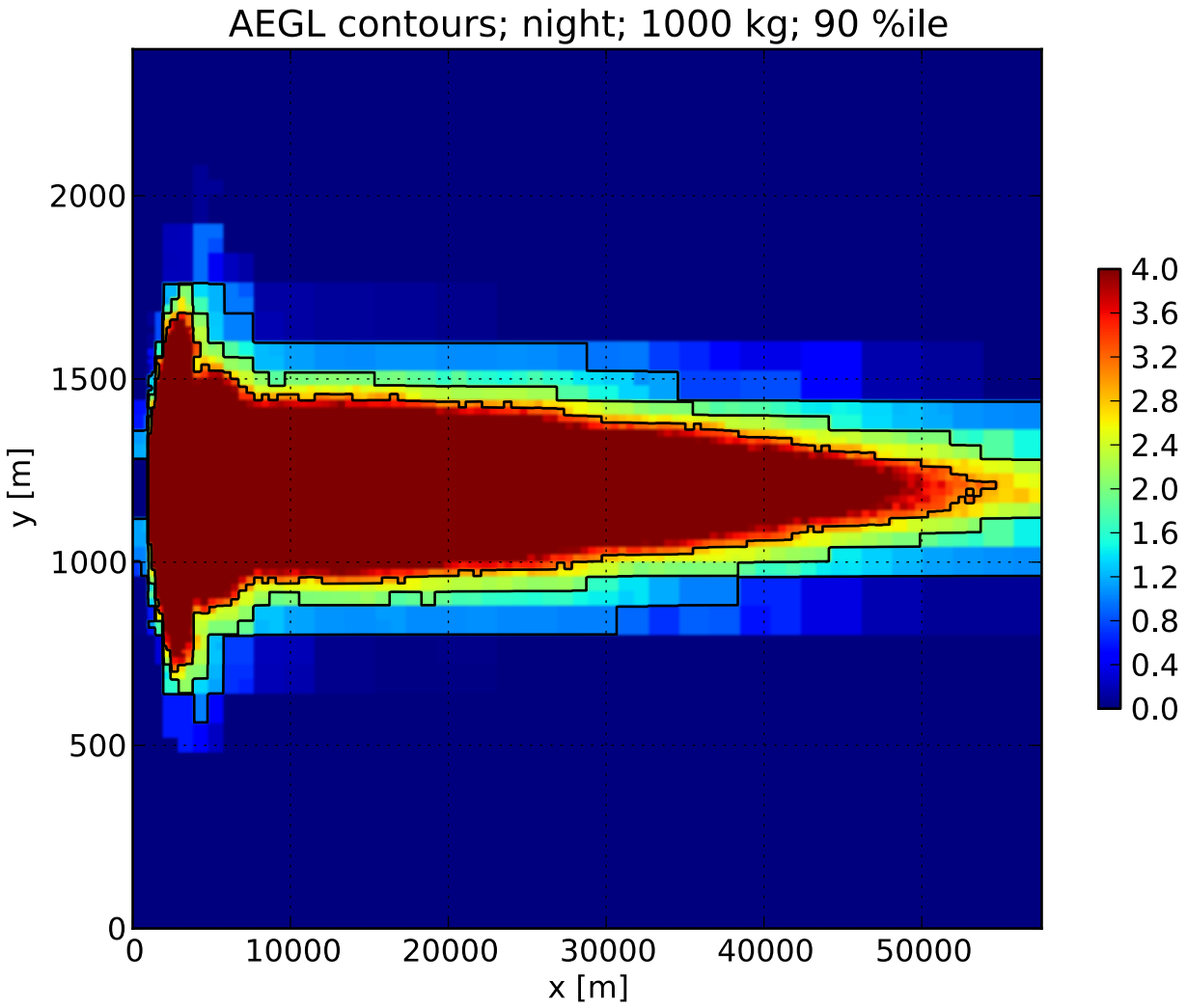
IDA | 90th percentile F_{AEGL}: large/day



IDA | 90th percentile F_{AEGL}: small/night

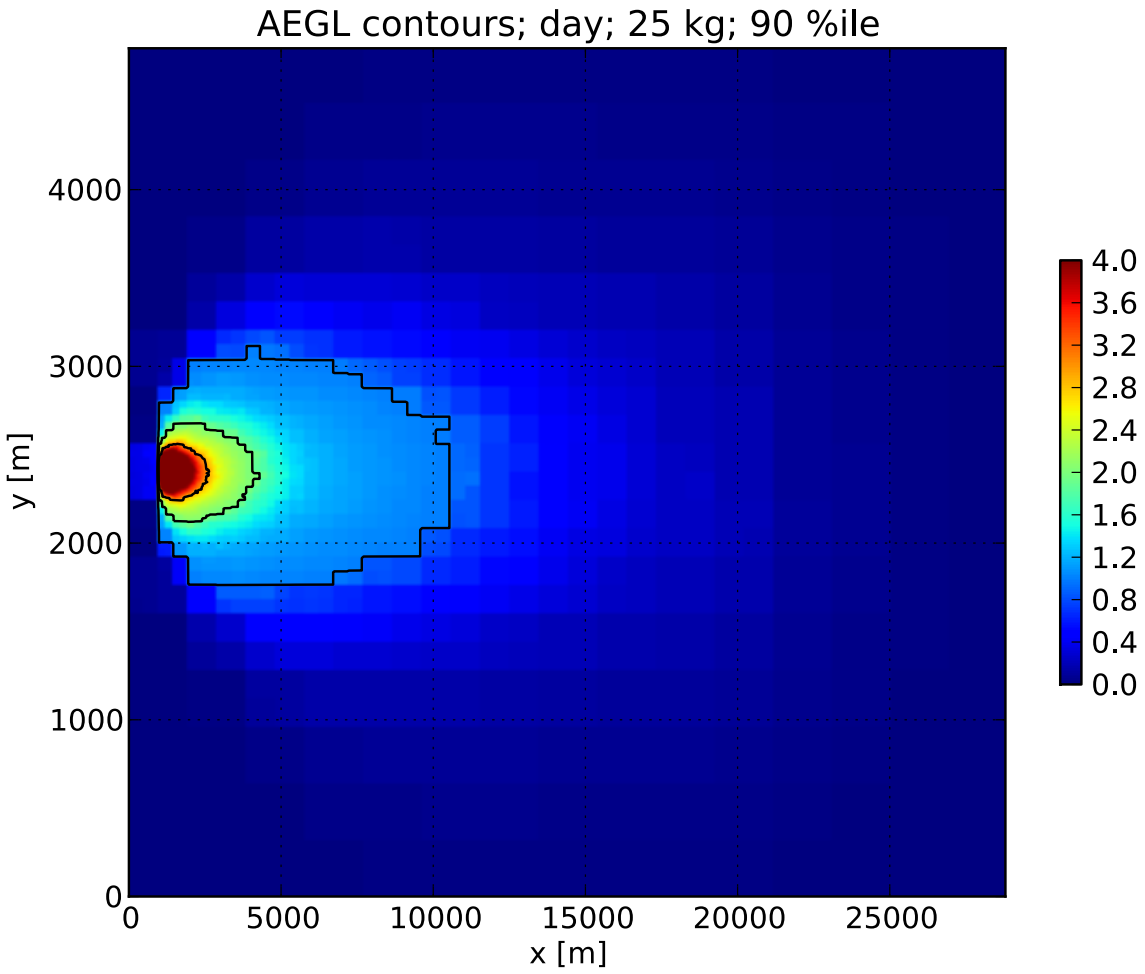


IDA | 90th percentile F_{AEGL}: large/night



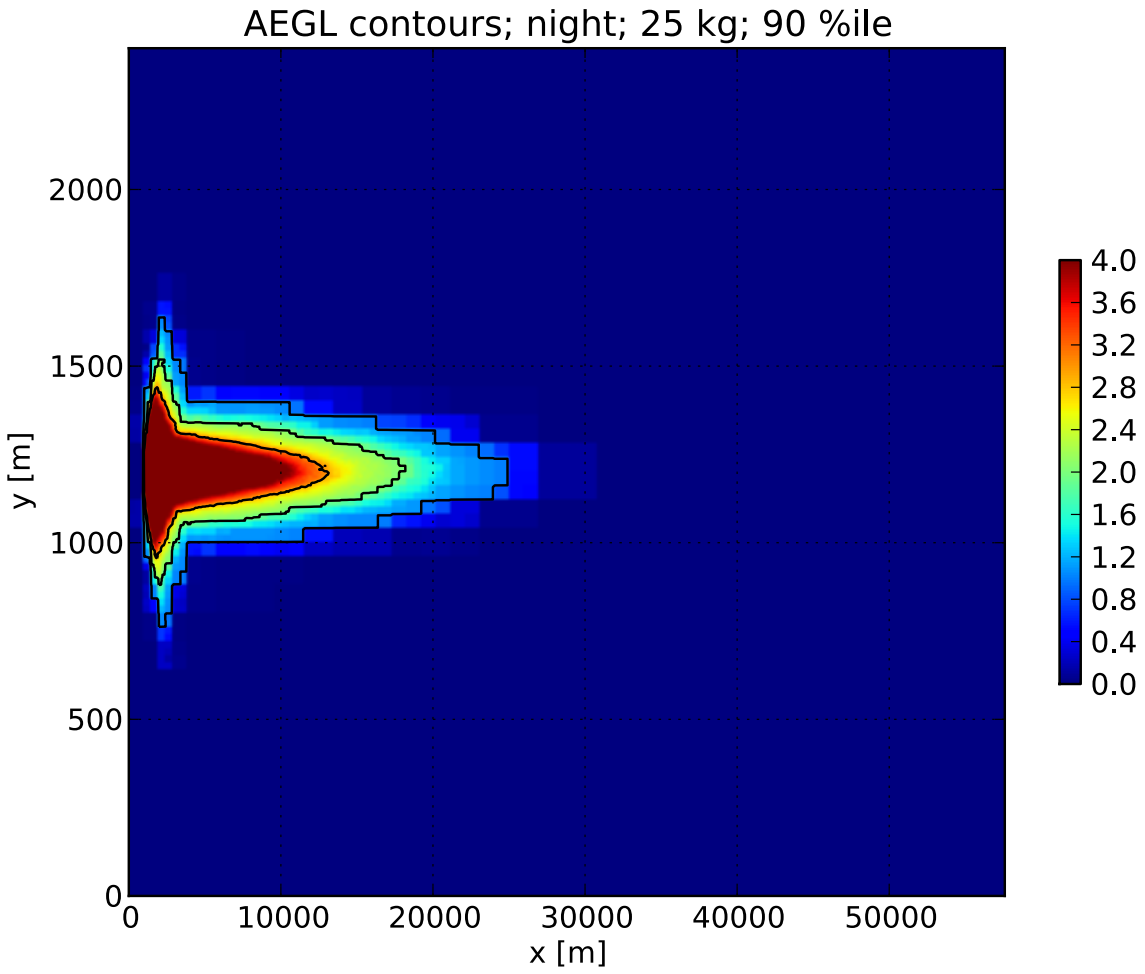
ERG direct comparison: 25 kg sarin release: day, contours at 30 min

- ERG gives 2.3 km PAD
- We find 3.3 km PAD



ERG direct comparison: 25 kg sarin release: night, contours at 30 min

- ERG gives 4.5 km PAD
- We find 17.2 km PAD!



IDA | Summary

- PAD methodology established.
  - Relevant inputs identified.
  - Flexible computational framework established.
- PADs for sarin computed, but not yet operationally useful.
  - Crosswind distances seem reasonable.
  - Downwind distances very long, especially at night; raises questions on met inputs.
- Since F_{AEGL} is computed and saved at each point in space, method yields protective action *regions*, not just distances, for any desired level of confidence (percentile).
  - For large scale releases in heavily populated areas, the detailed protective action regions may reveal safe pockets, reducing the scale of protective action responses.
  - They may also reveal unsafe areas outside the canonical protective action areas.
- Use of QUIC allows inclusion of more complex terrain, if desired.

Appendix

QUIC "Validation"/Cross-Comparisons

QUIC vs. Select Prairie Grass Releases

- NOTE: Short range comparison (≤ 800 m)

QUIC vs. ALOHA

- Continuous release
- Concentration comparison (ALOHA AEGL implementation is wrong)

QUIC vs. HPAC

- Several instantaneous release comparisons
- AEGL and dosage comparisons

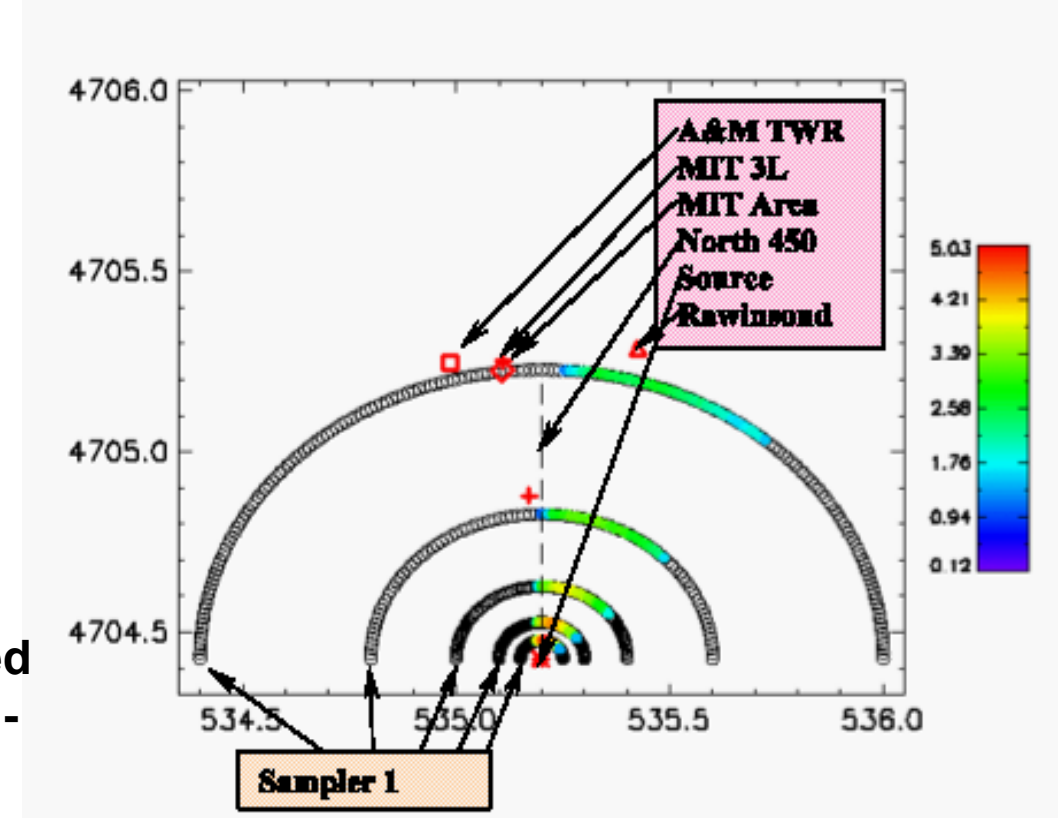
Prairie Grass Review

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Prairie Grass Project: large collaborative effort to study the transport and dispersion of a tracer gas (SO_2) in a large open field in Nebraska in 1956. Copious data and detailed reports are available.

Sensors placed at height 1.5m in arcs out to 800m.

Wealth of weather data collected with ground instruments, rawin-sonde, and aircraft.

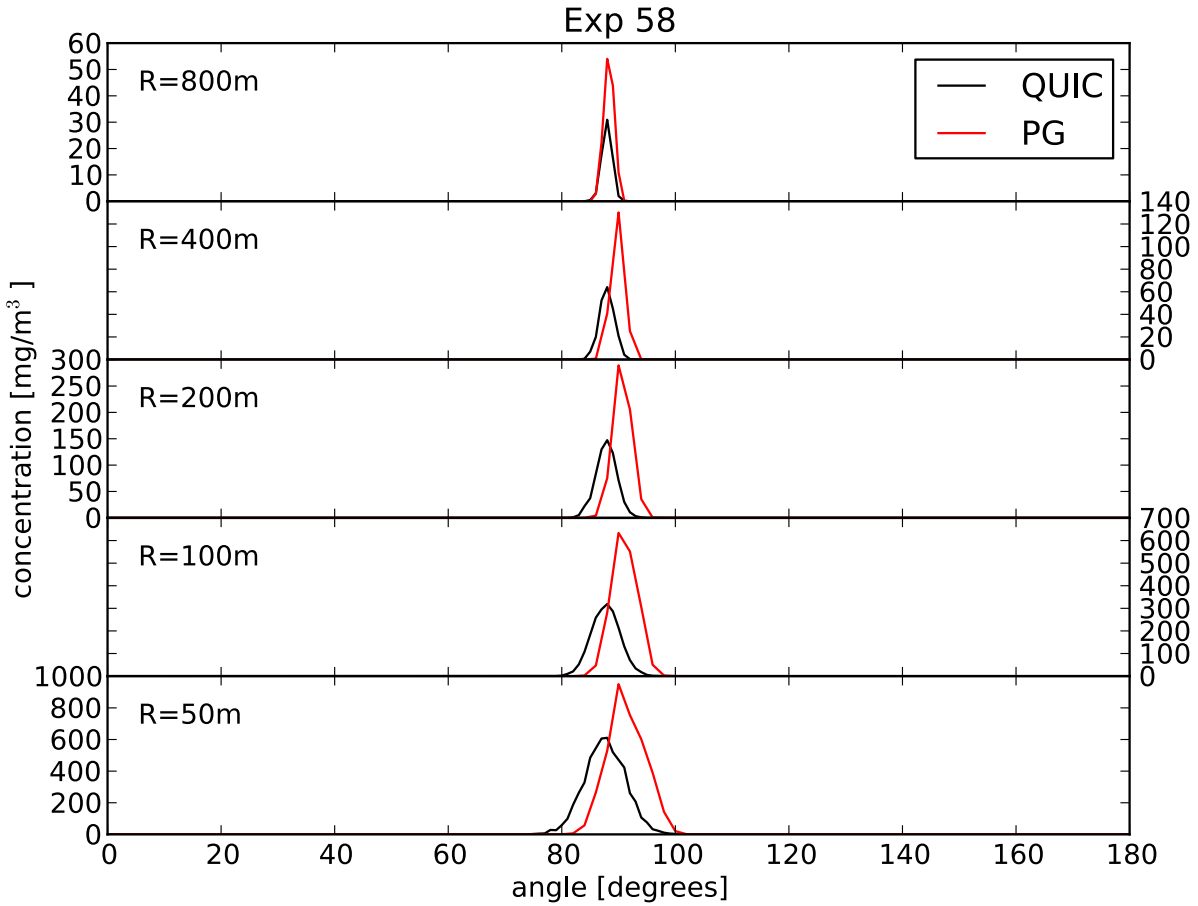


QUIC Inputs for Prairie Grass Runs

- **Site info**
  - Topography, vegetation, etc.
  - Surface roughness
- **Weather**
  - Wind speed and direction as a function of position and altitude
  - Temperature profile
  - Relative humidity
  - Boundary layer height
  - Stability parameter (Monin-Obukhov length)
- **Simulation parameters**
  - Source type (basic, dense gas, explosive, etc.)
  - Source strength
  - Particle splitting
  - Wall roughness

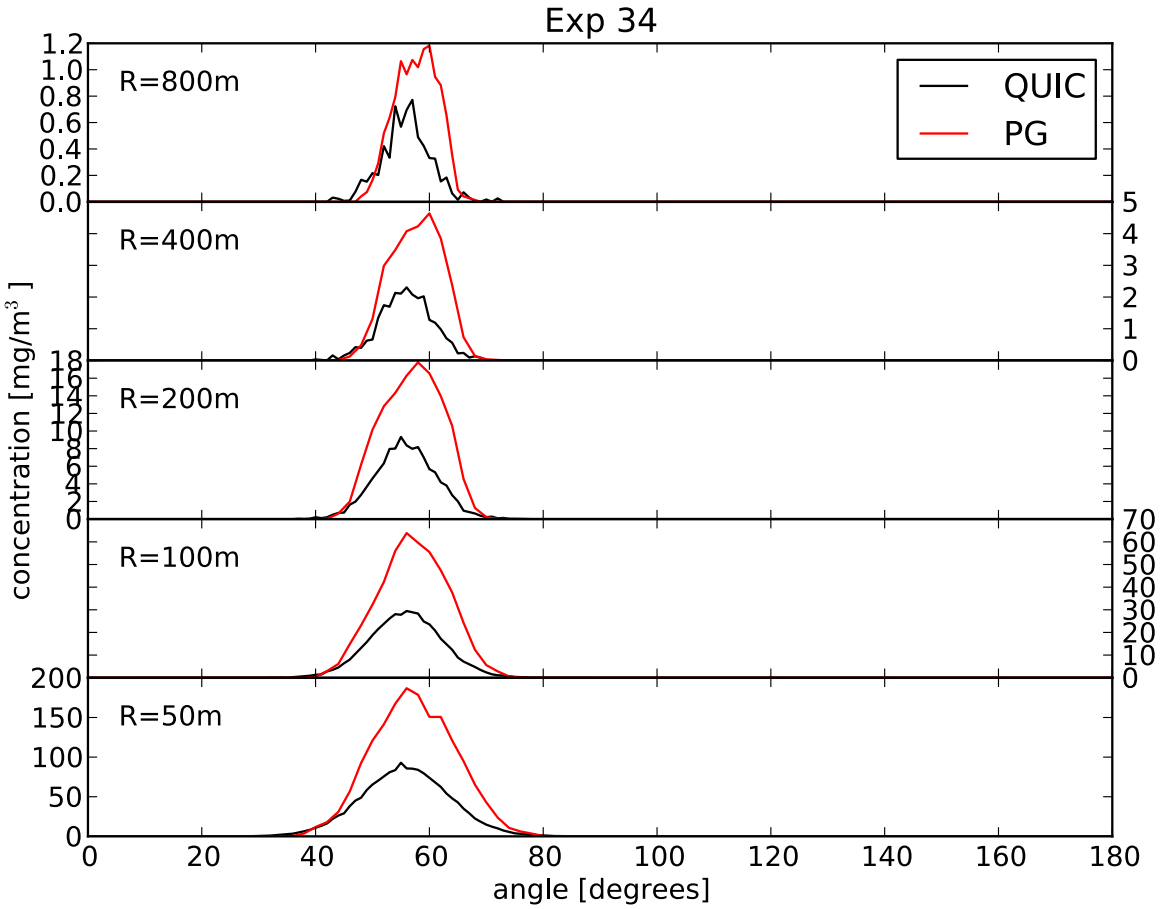
QUIC vs. PG: Stable Case (Nighttime)

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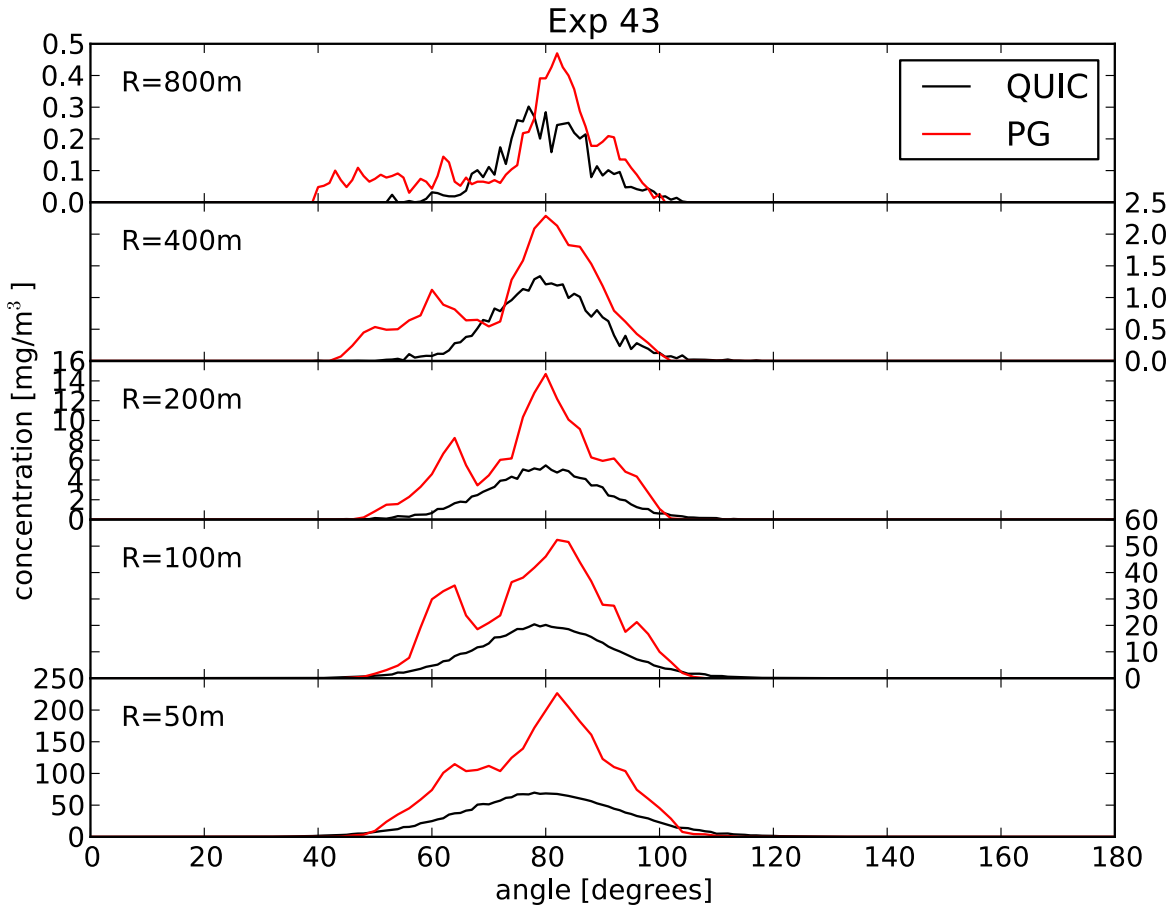
QUIC underpredicts PG

QUIC vs. PG: Neutral Case



QUIC underpredicts PG

QUIC vs. PG: Unstable Case (Daytime)



QUIC underpredicts PG

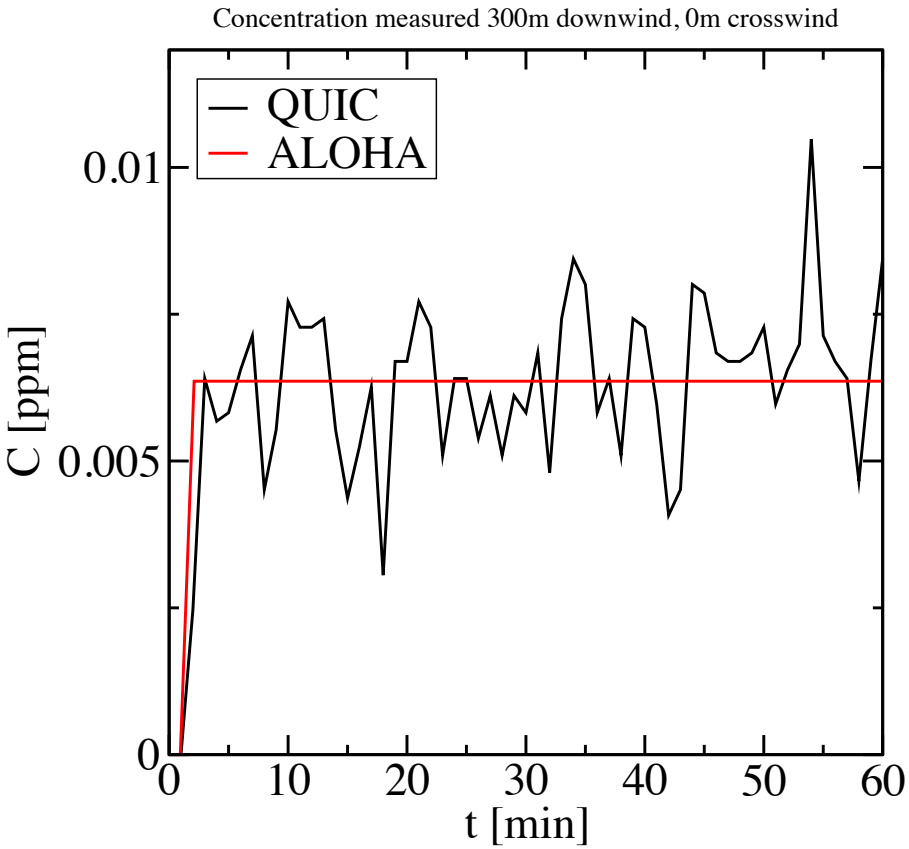
QUIC/ALOHA Comparison (1)

ALOHA uses a simple Gaussian plume model.

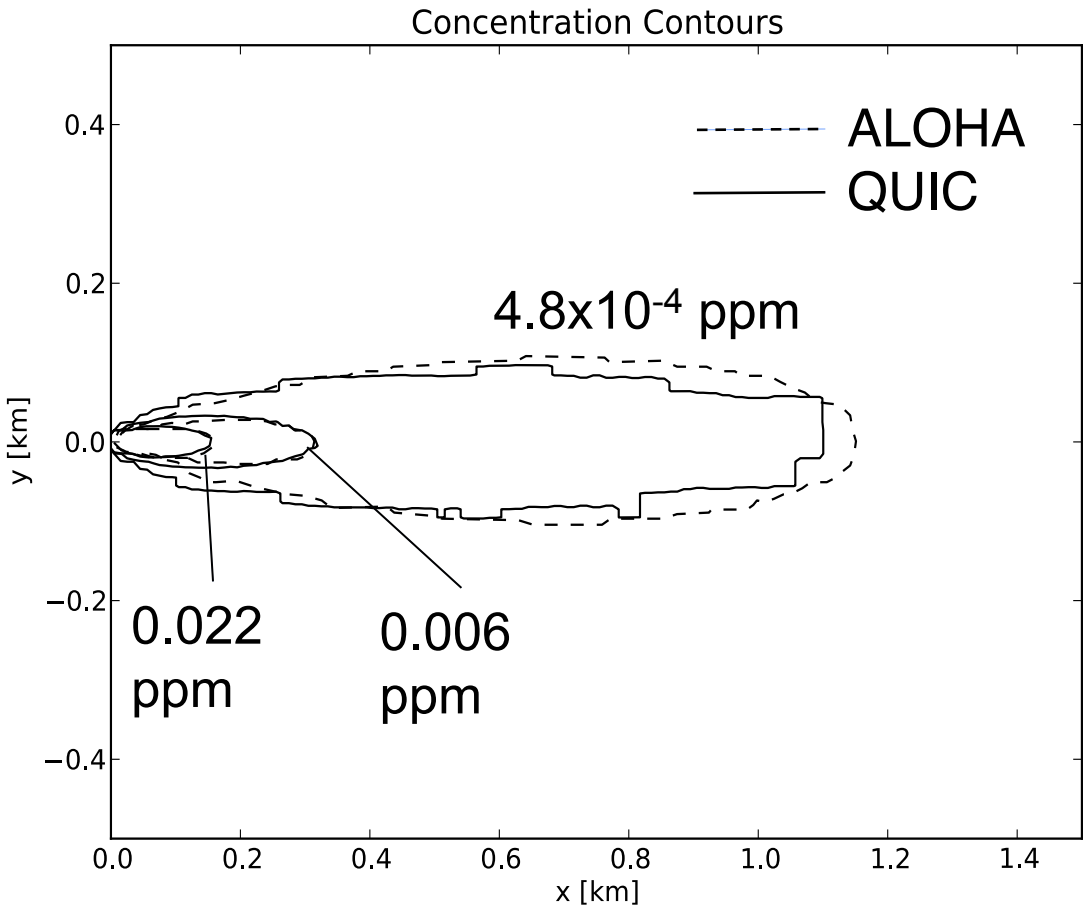
ALOHA uses an incorrect interpretation of AEGLS, so we compared *concentration* (steady-state and time varying) with QUIC for a continuous release of 1kg of sarin over 1 hr.

Parameters: u=3m/s at 2m AGL, z_0=1.2cm, stability class C.

Time series agrees well. Note that fluctuations are due to particle nature of the QUIC T&D method.



QUIC/ALOHA Comparison (2)



Concentration contours agree well

HPAC Settings for QUIC Comparison

Analytic Incident model with a 100kg instantaneous release

Fixed wind profile with zero meteorological uncertainty

Large-scale meteorological variability is turned off, since QUIC does not treat it (Want to compare apples to apples)

Conditional averaging is turned off, since QUIC does not treat the effects of weather uncertainty

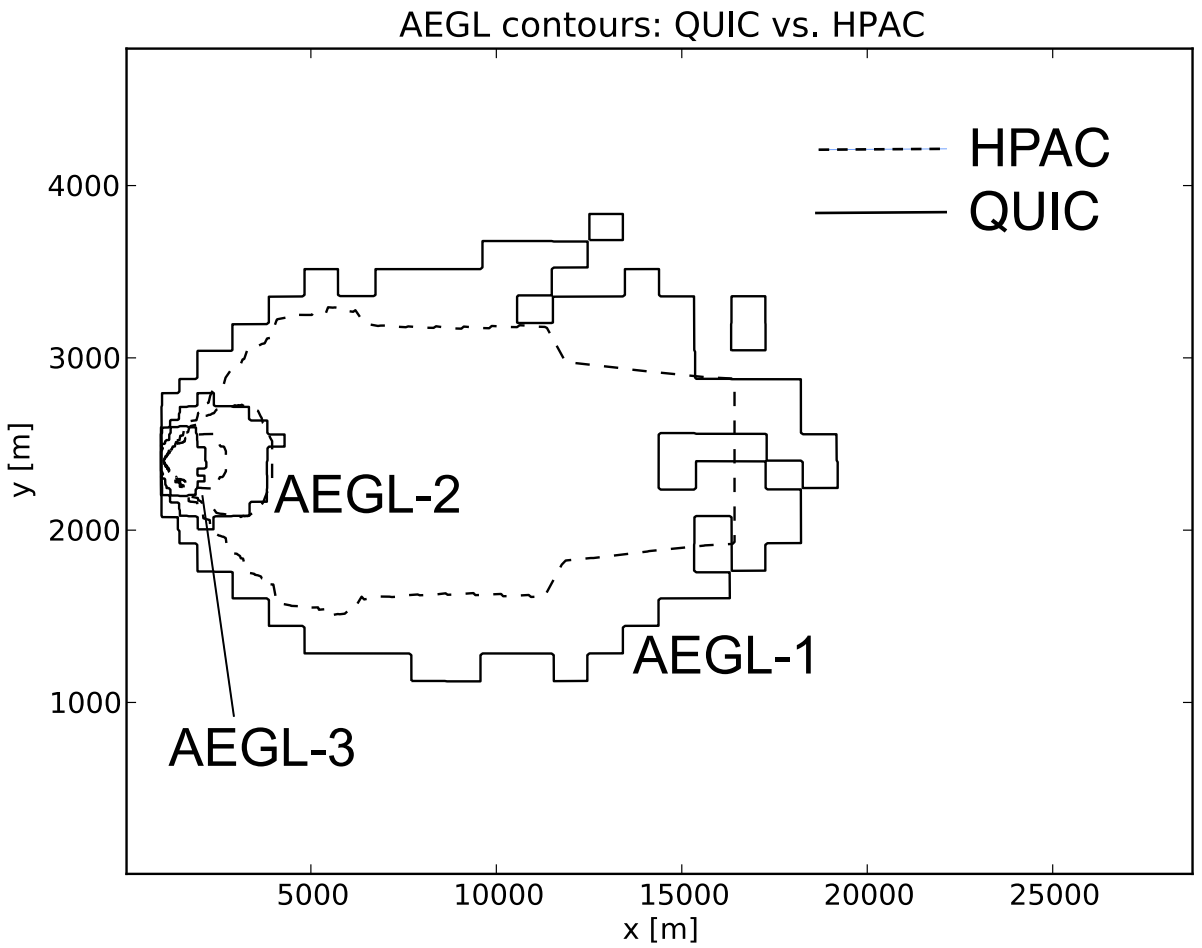
The DEGRADE module is also turned off

QUIC vs. HPAC: Day, AEGL Contours

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Comparable downwind distances for AEGL-1 and 2.

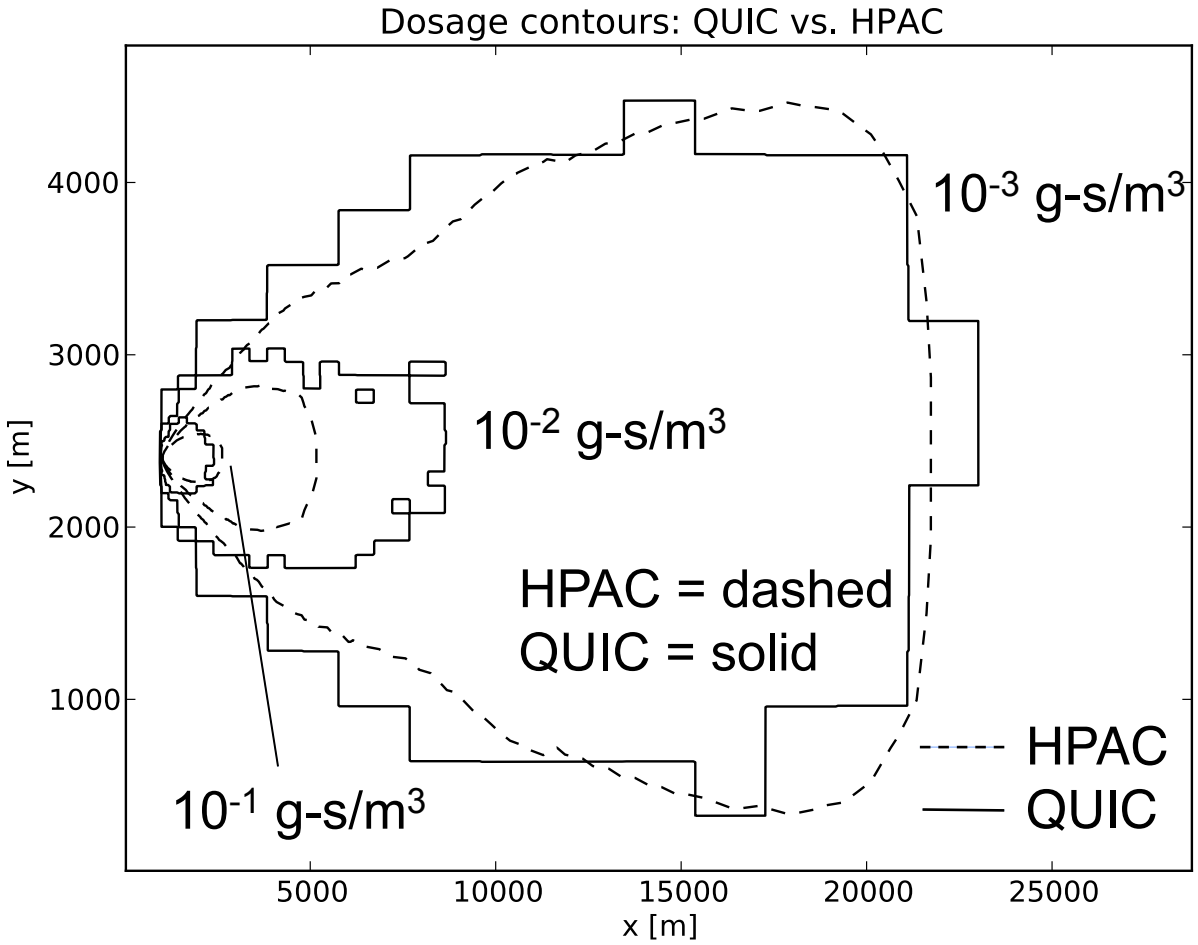
AEGL-3 downwind distance is noticeably larger in HPAC, but the enclosed area is comparable. (Upwind transport is the likely culprit.)



QUIC vs. HPAC: Day, Dosage Contours

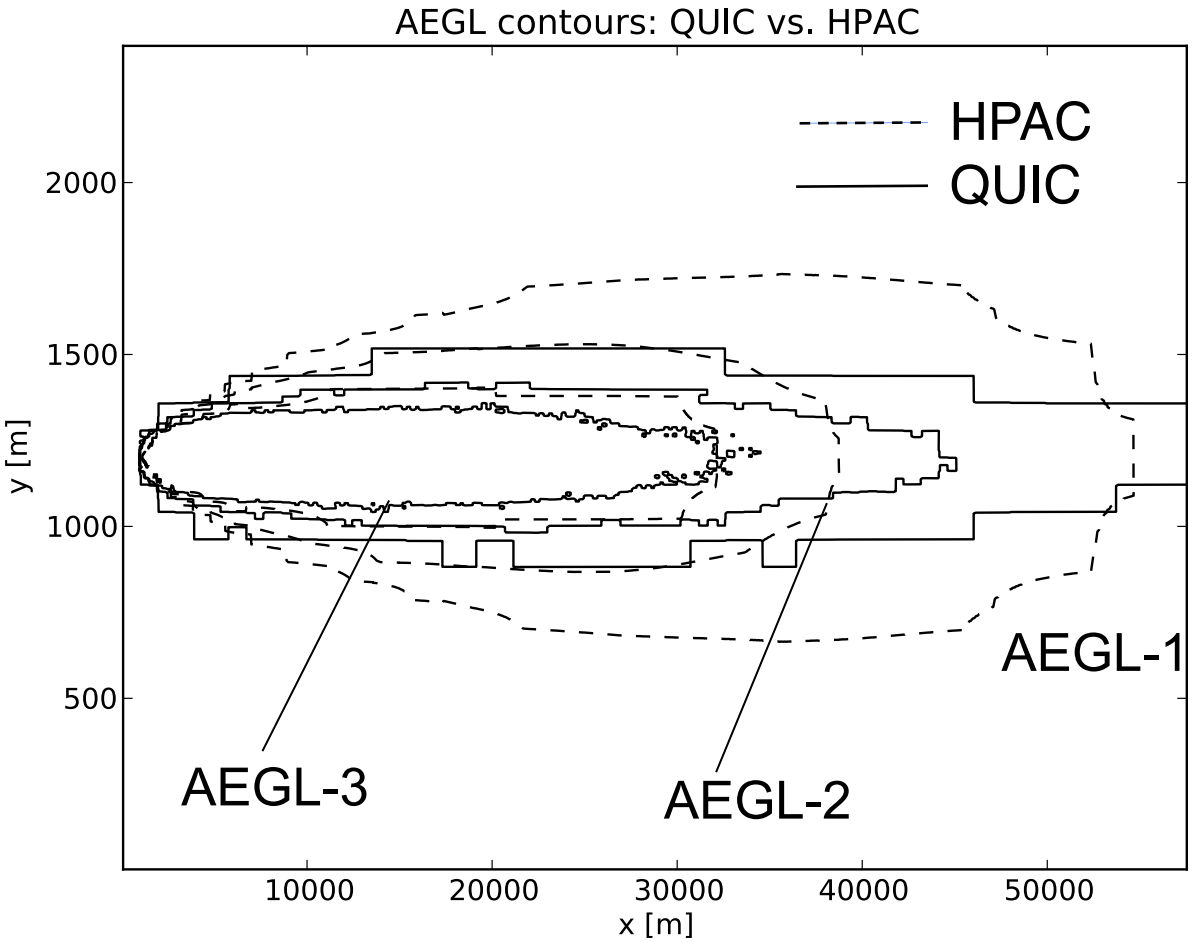
Outermost and innermost contours agree nicely.

Surprisingly, intermediate contours (10^{-2} g-s/m^3) differ by factor of almost 2 in downwind distance



QUIC vs. HPAC: Night, AEGL Contours

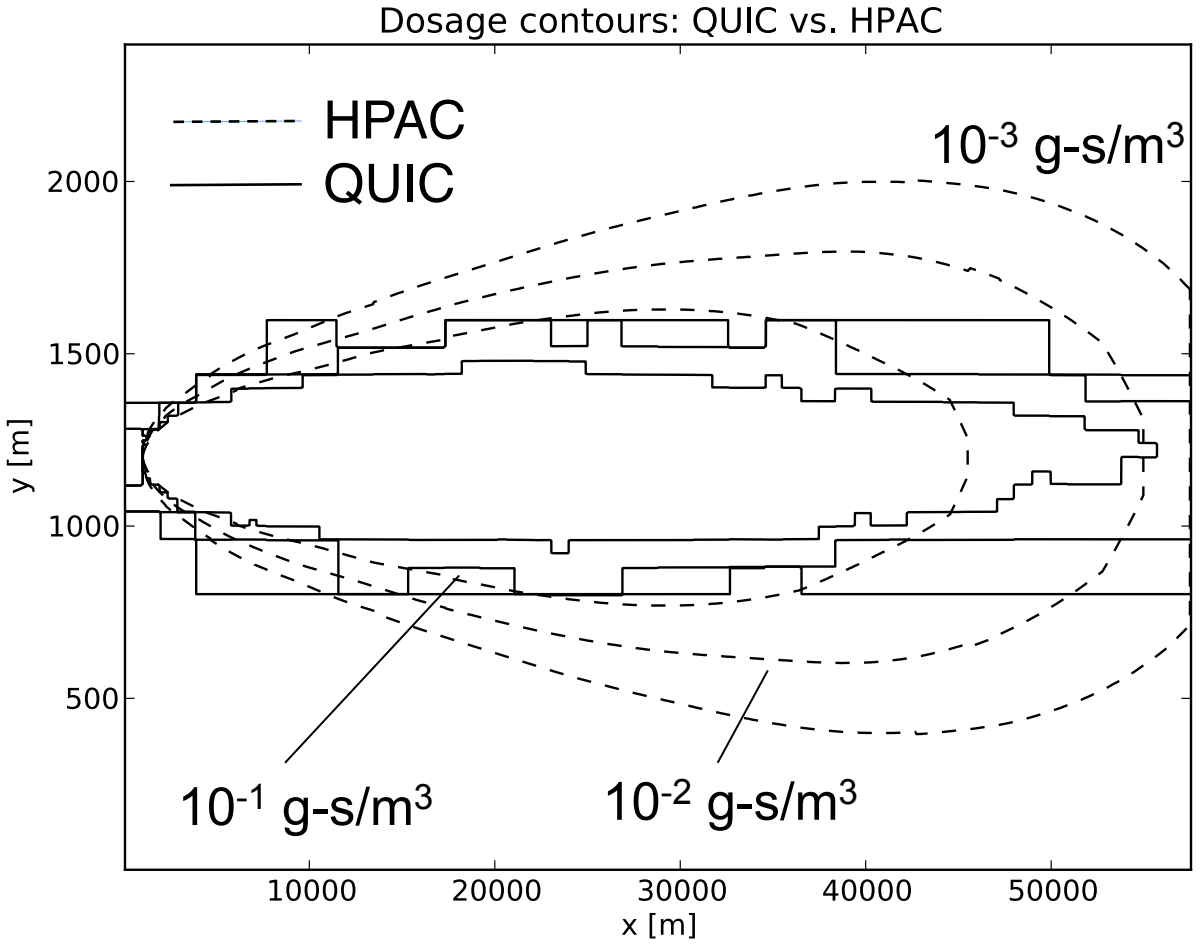
Very nice agreement in downwind distances, but crosswind distances differ by up to a factor of 2.



QUIC vs. HPAC: Night, Dosage Contours

Grid was not large enough to resolve QUIC downwind distance, even for the intermediate dosage contour.

Surprisingly, the crosswind distance disagreement is even larger with dosages than with AEGLs.



Are Fixed Winds the Culprit?

Test by comparing fixed and varying winds using real measured data from the FFT07 data set

- Day: average speed = 3.5 m/s
- Night: average speed = 2 m/s

Results presented in the following slides are for one simulation, not a Monte Carlo average

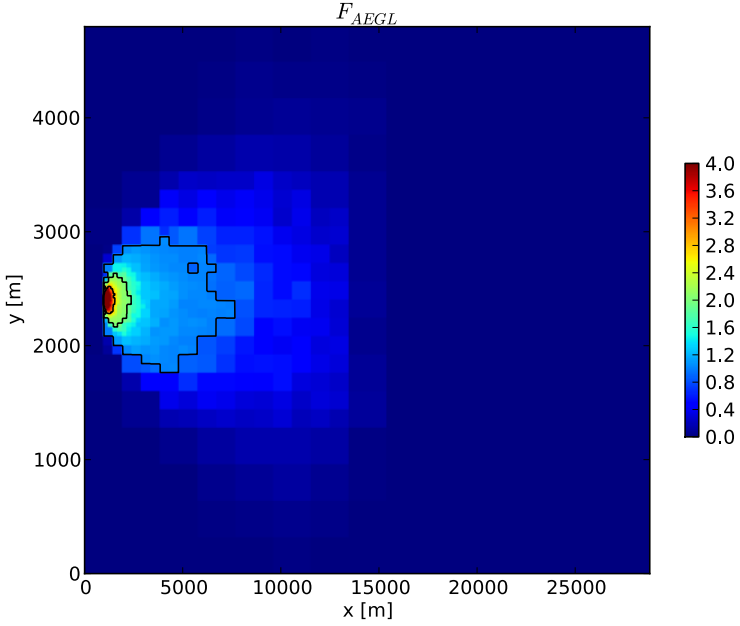
Preliminary results show that varying wind direction does not appreciably affect downwind hazard distance during the day, but does at night.

Need to perform more simulations to get an understanding of the resulting F_{AEGL} distributions

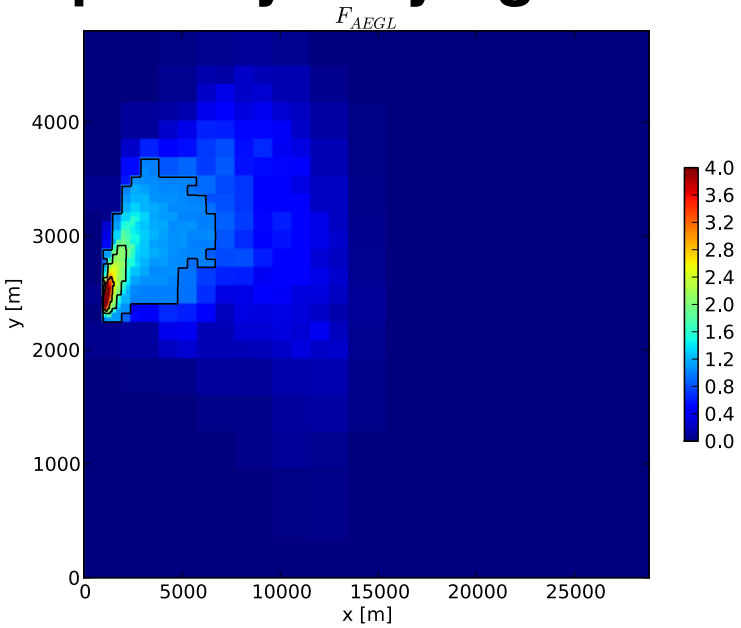
Varying Winds: Day

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Fixed Winds



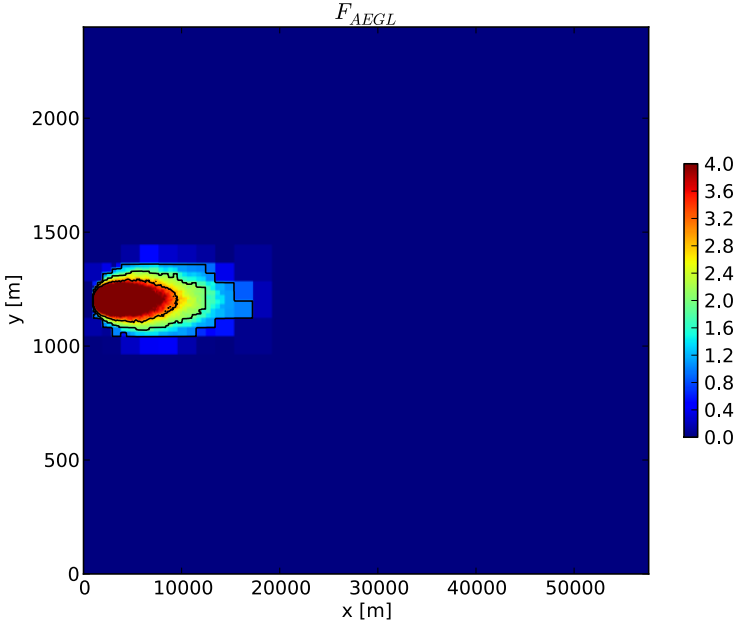
Spatially Varying Winds



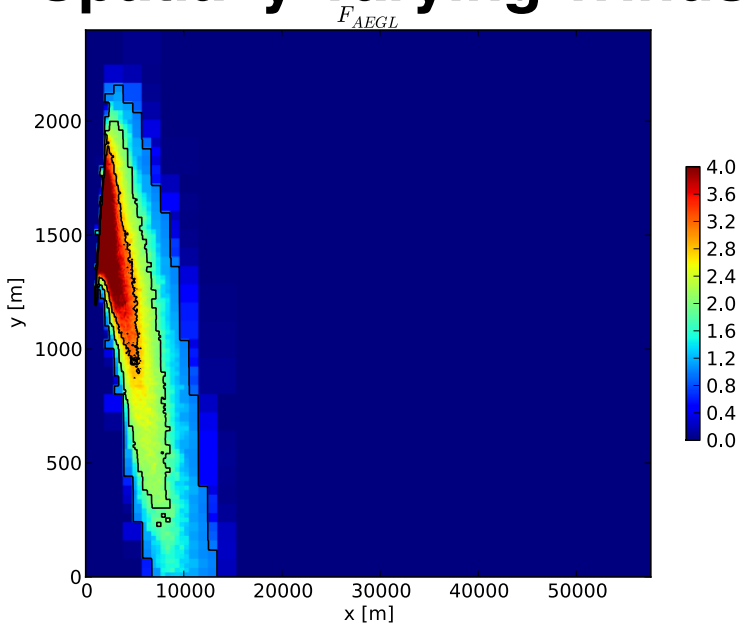
Comparable Downwind PADs
Comparable Crosswind PADs

Varying Winds: Night

Fixed Winds



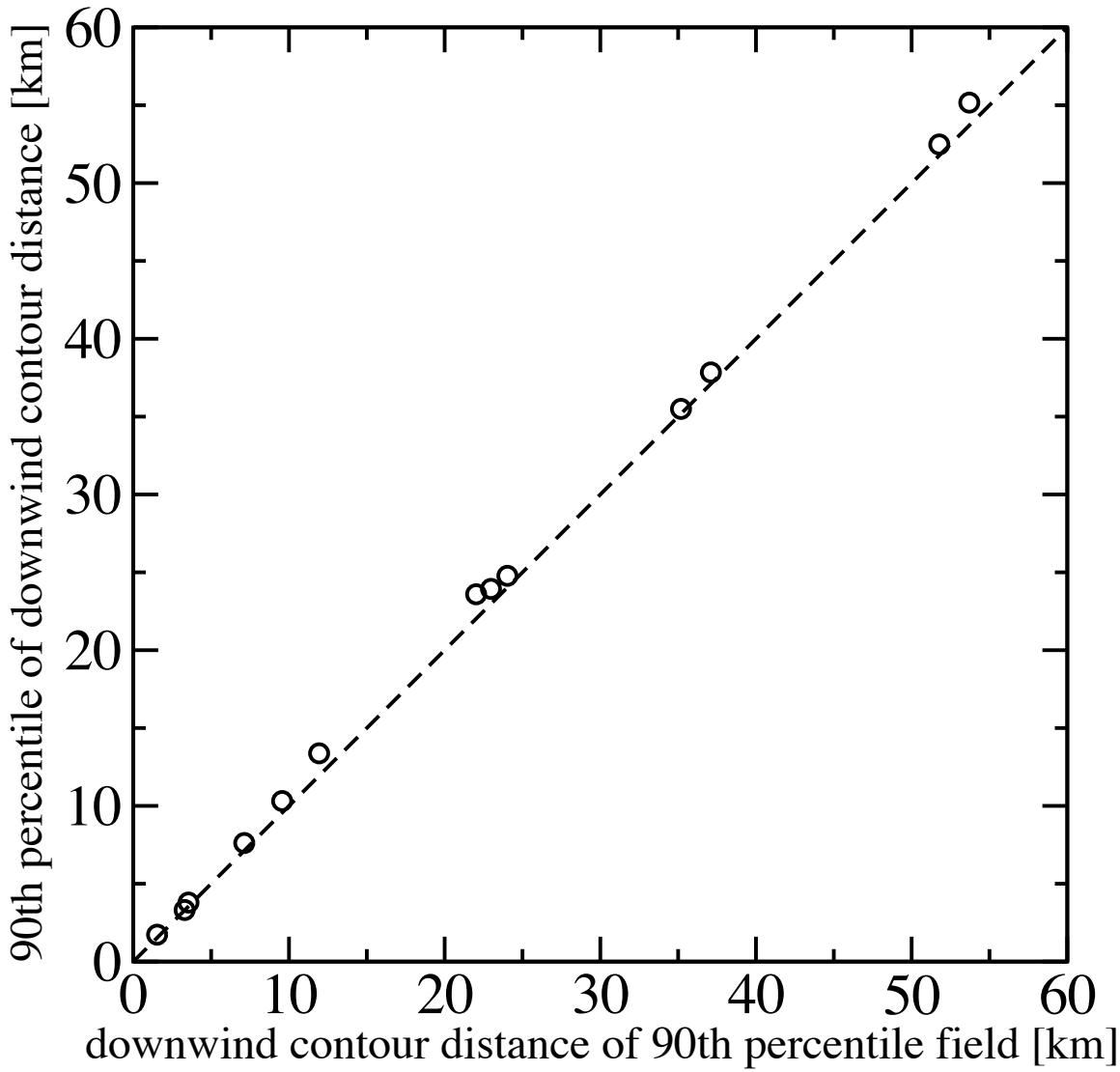
Spatially Varying Winds



Comparable Downwind PADs
Crosswind PAD Significantly Larger for Varying Winds

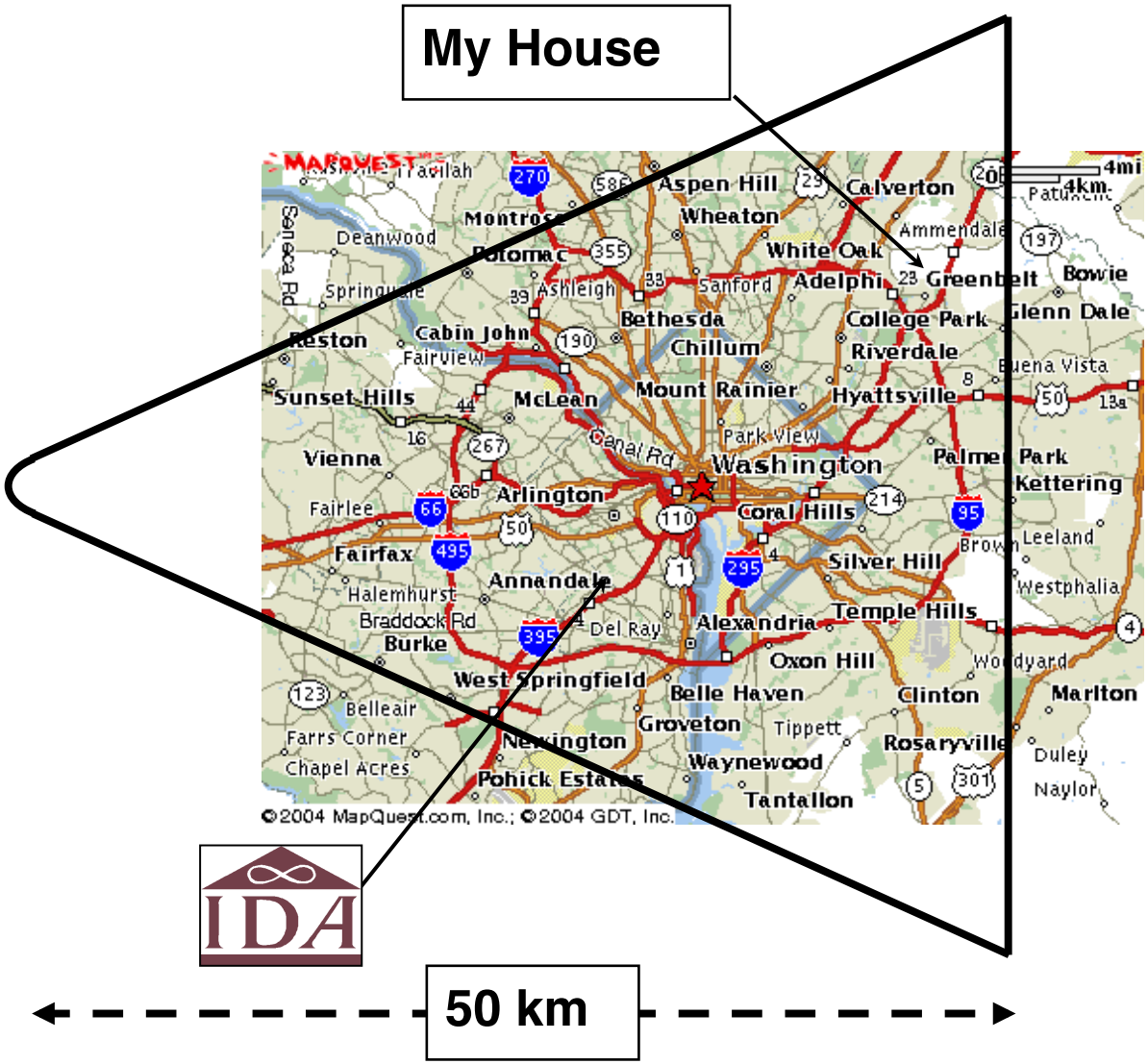
Downwind Distances on 90th Percentile Field

Is taking the downwind distance on the 90th percentile AEGL field equivalent to taking the 90th percentile of the downwind distance?



Largest ATP-45 Chemical Template Encloses DC Beltway

Science and Technology Division



Template area: 1560 km^2

Area of Rhode Island: 2706 km^2

Population of Wash. DC alone: 572059 (2000 Census)

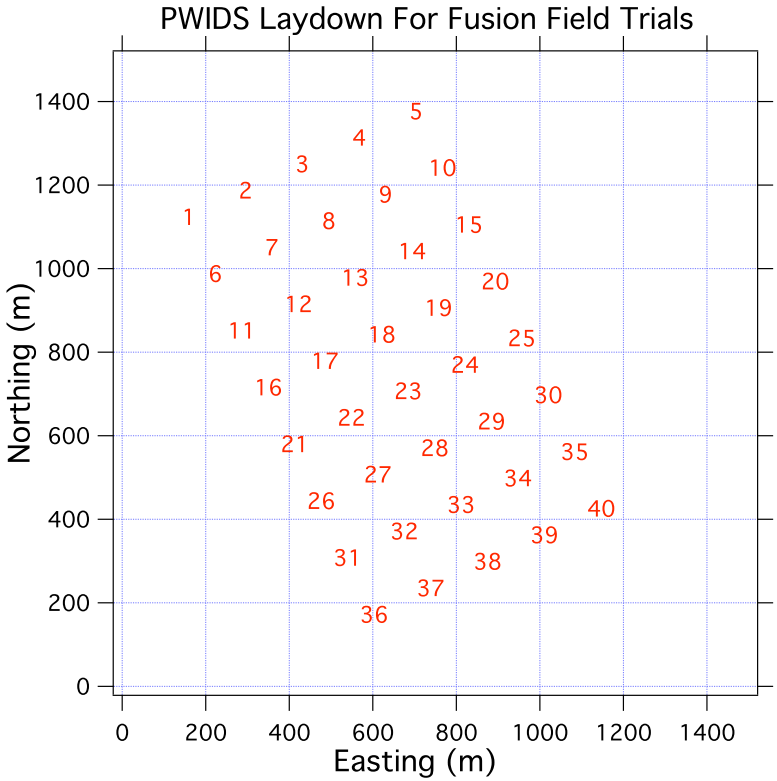
Land area of Wash. DC: 159 km^2

Wind Inputs

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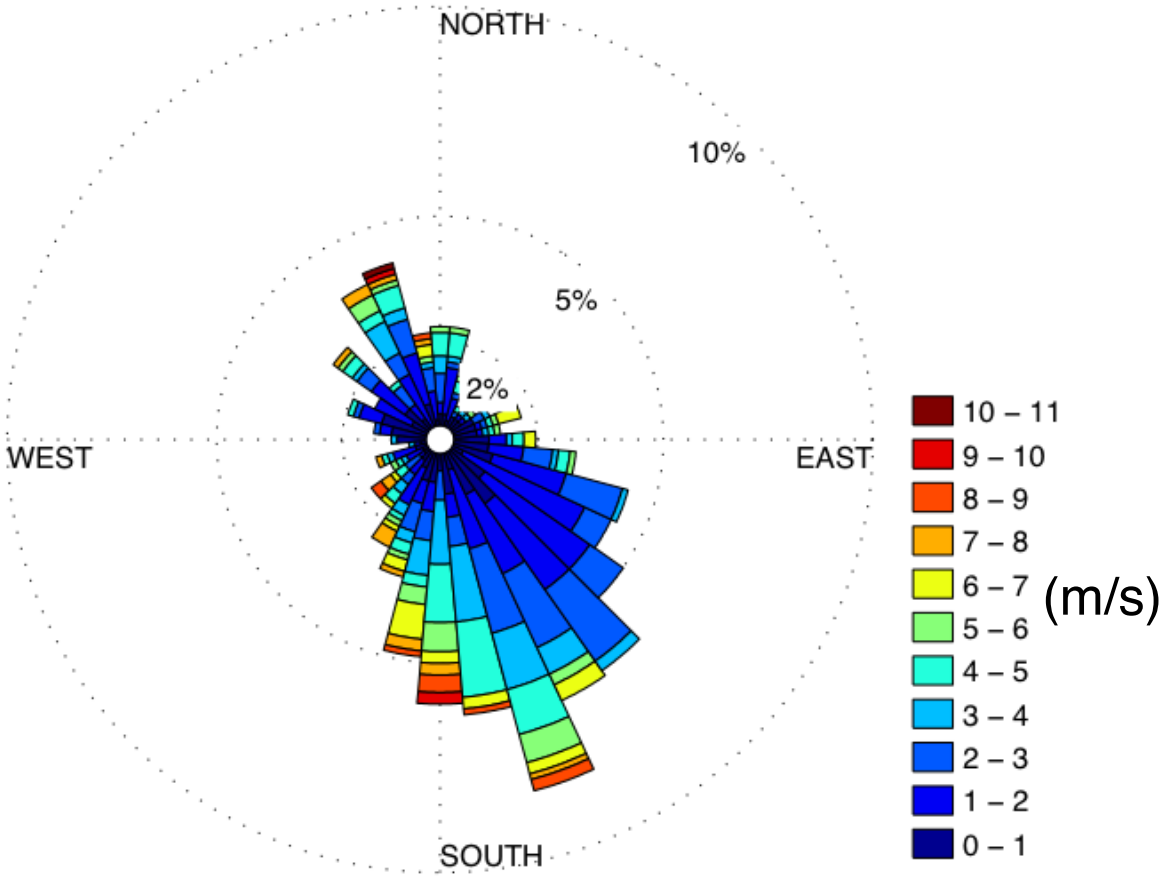
Wind speed distributions extracted from 1 month of wind data collected from array of 40 Portable Weather Instrument Display Systems (PWIDS) during DTRA-sponsored Fusion Field Trial Tests (Dugway Proving Ground, Sept. 2007)





1 Hour Average Wind Rose

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Winds are predominately from SSE, explaining the orientation of the PWIDS array

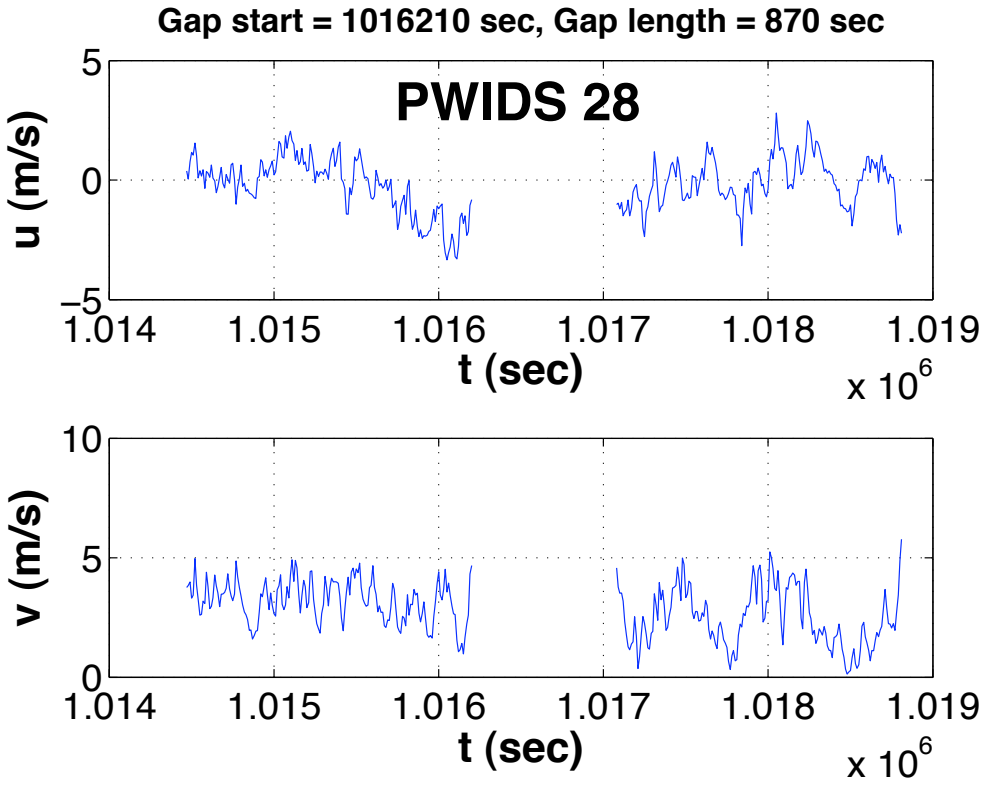
Wind Processing: Raw Data

Raw wind data

- Wind speed components (U and V) measured at each PWIDS at 10 second sampling interval for ~ 30 days: 259170 points per time series
- Elevation: 2m AGL

Data Dropouts

- No single PWIDS time series spans entire month
- Dropout rates range from ~ 1% - 32% across the array



Common Wind Speed Distributions

Rician Distribution

If *x* and *y* are uncorrelated zero mean Gaussian random variables with standard deviation σ, then

$$r = \sqrt{(A + x)^2 + y^2}$$

with $A>0$, is a Rician random variable

$$\rho(r) = \frac{r}{\sigma^2} \exp\left(\frac{-(r^2 + A^2)}{2\sigma^2} \right) I_0\left(\frac{rA}{\sigma^2} \right)$$

Weibull Distribution

$$\rho(r) = \frac{k}{\lambda}\left(\frac{r}{\lambda} \right)^{k-1} e^{-(r/\lambda)^k}$$

k is shape parameter; λ is scale parameter

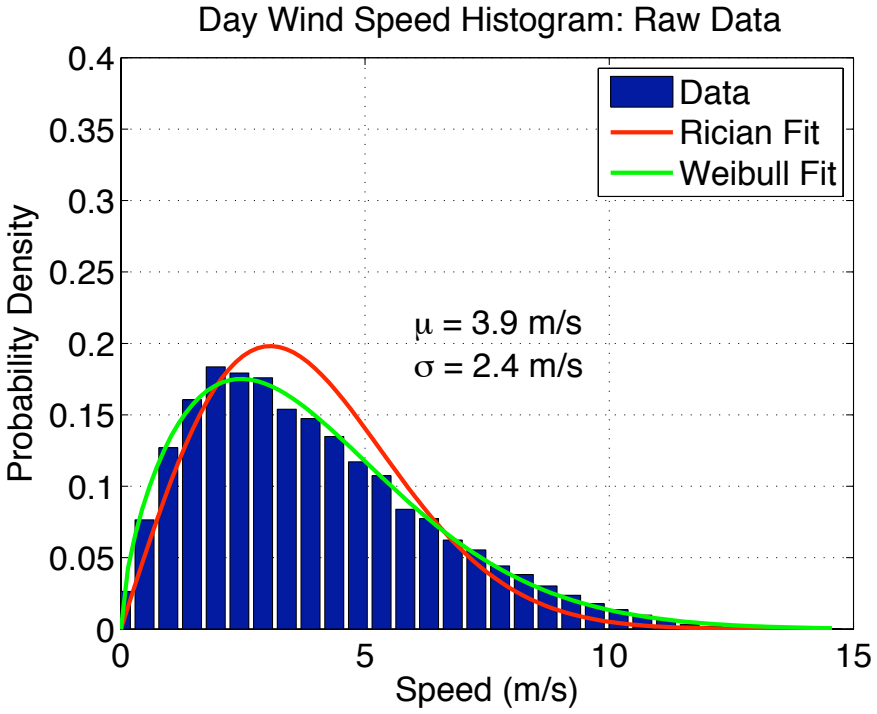
Day and Night Wind Speed Histograms

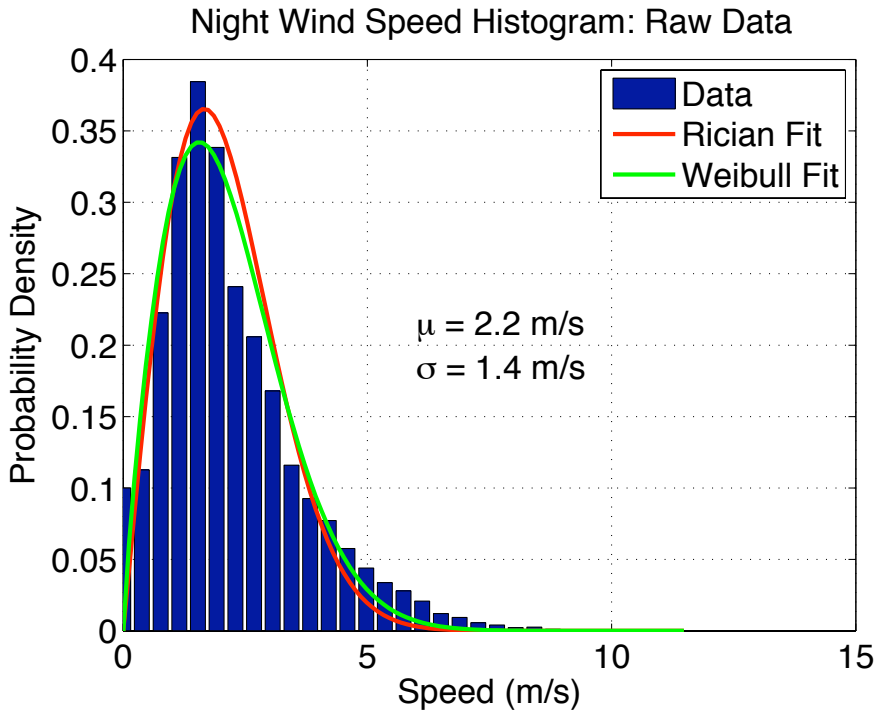
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For purposes of this study, day and night are 6 hour intervals defined as follows:

- Day: 10:00 ≤ *local time* ≤ 16:00
- Night: 22:00 ≤ *local time* ≤ 04:00 (NOTE: Times are *not* DST)

Histograms for 10 sec ("raw") sampling rate



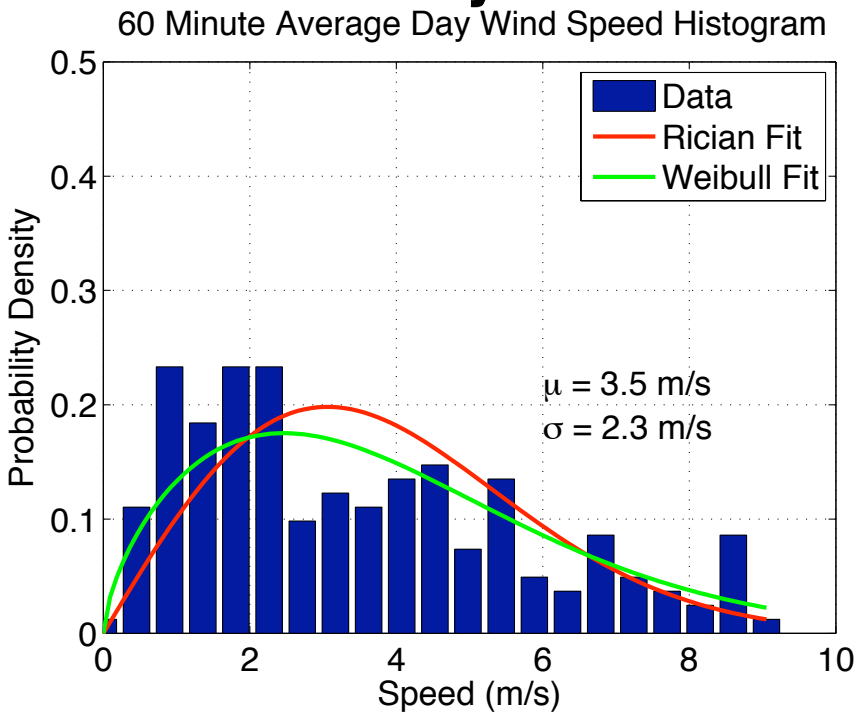


Day and night histograms well-modeled by Weibull distribution

1 Hour Average Wind Speed Histograms

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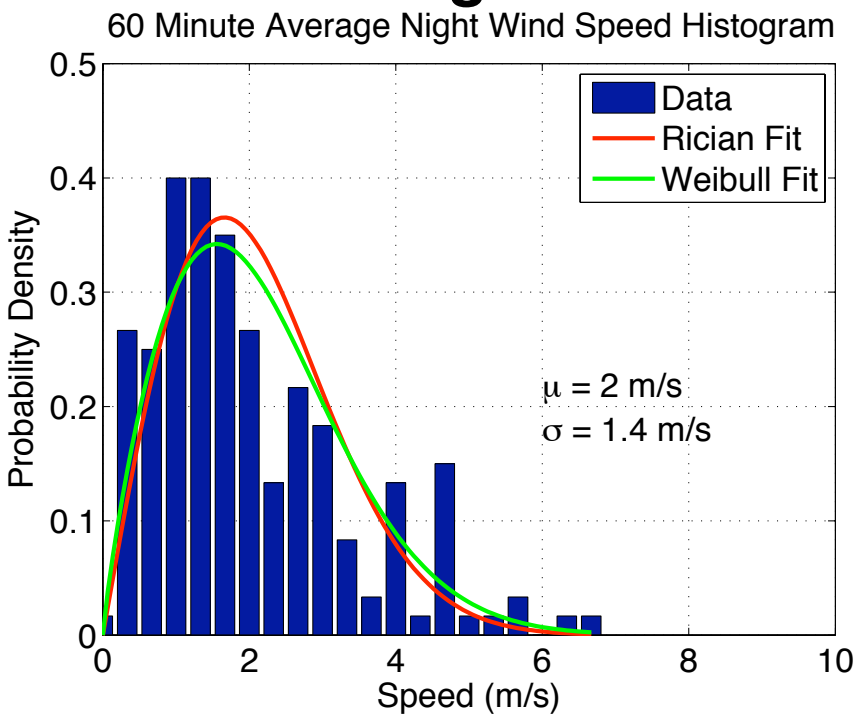
Day



$\chi^2_{\text{Rician}} = 0.07,$ $\chi^2_{\text{Weibull}} = 0.04$

k= 1.637; λ =4.387

Night



$\chi^2_{\text{Rician}} = 0.1,$ $\chi^2_{\text{Weibull}} = 0.09$

k= 1.842; λ =2.383

Wind Processing: Filling Gaps

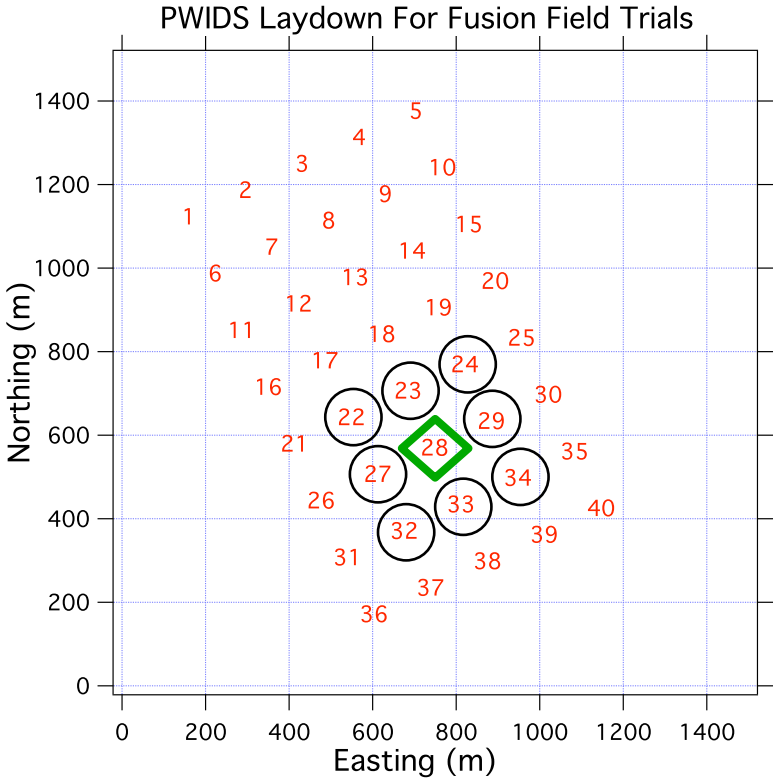
Goal: Construct continuous time series for U and V that span entire month

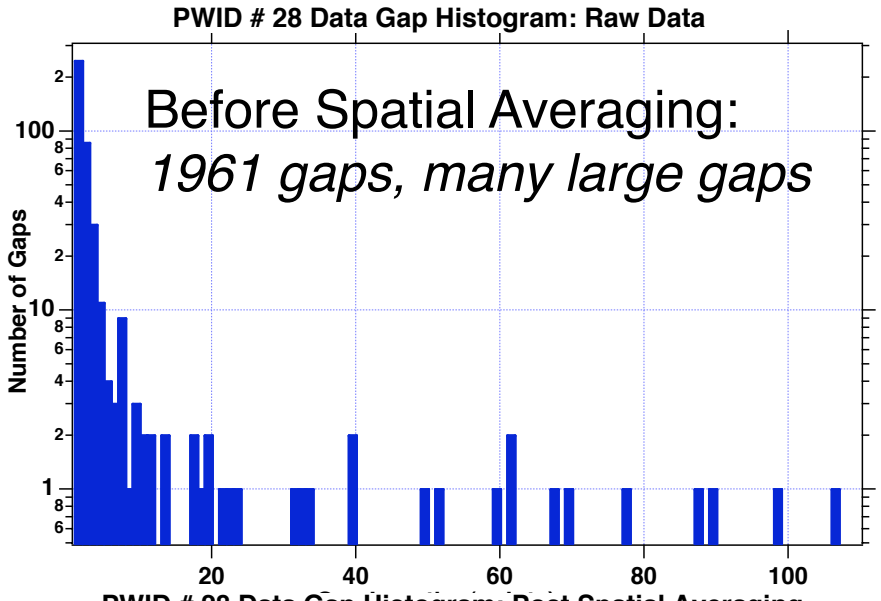
1. Find PWIDS detector with a low dropout rate and whose longest gap is among the shortest
2. Where possible, replace gaps with spatial average of nearest neighbors
3. Replace remaining single point gaps with time average of two immediate neighbors in time
4. Replace remaining multiple point gaps with points generated from Autoregressive (AR-1) model (see backup slides)

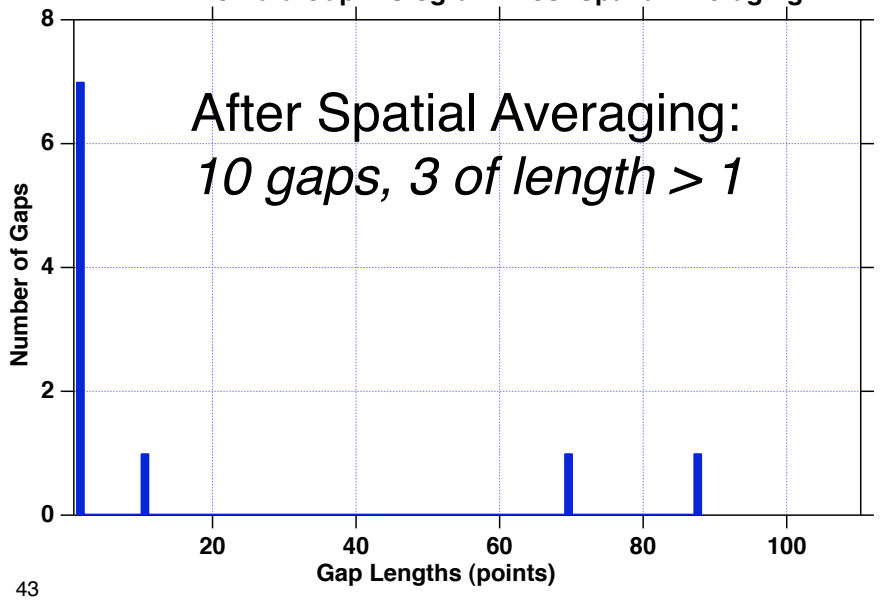
PWIDS #	# of Gaps	Longest Gap	Dropout rate (%)
14	1948	114	0.752
28	**1961**	**106**	**0.757**
18	1978	113	0.763
10	2096	141	0.809
38	2172	119	0.838

Wind Processing: Spatial Averaging

Science and Technology Division







Wind Processing: Filling Large Gaps

Gaps are filled with AR-1 statistical model

$$x_{n+1} = c + \phi x_n + \varepsilon_n$$

Zero mean Gaussian random noise, with variance σ_ε

Parameters c, ϕ, and σ_ε are determined by mean, variance, and autocorrelation of surrounding data

