SAND2007-6979C

NUMERICAL INVESTIGATION ON THE ABILITY TO PREDICT NON-FICKIAN DISPERSION FROM AQUIFER PROPERTIES

GSA Annual Meeting
Denver, Colorado

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Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94-AL-85000

MOTIVATION

How well do random fields capture complex solute transport through real heterogeneous media?

Under what conditions do heavy-tailed non-Fickian dispersion arise?

What are the differences in the velocity fields?

Can the nature of dispersion be predicted from the these differences?

OUTLINE

Investigate these questions using high-resolution terrestrial lidar to identify and model realistic heterogeneity at the outcrop scale.

Compare 2-D particle tracking simulations using “real” lidar based heterogeneity to simulations using heterogeneity created using SGSIM.

Analyze differences in velocity distributions.

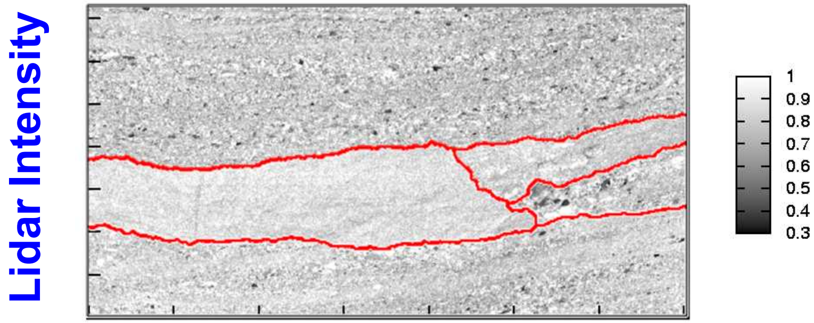
LIDAR DATA

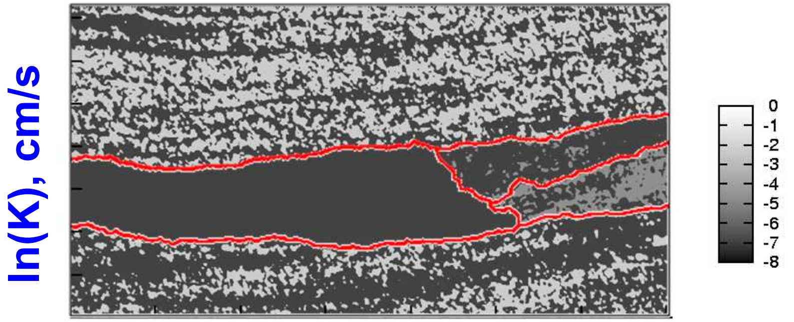
Lidar scan of sand and gravel deposit

Lidar intensity values range between 0 and 1
No relationship between intensity and K

Segmentation of intensity data into geologic units and sand and gravel facies
Assign reasonable hydraulic conductivity values
- K sand = 0.001 cm/s
- K gravel = 0.01 to 0.1 cm/s

Lidar scan = 70.3 by 36.4 cm (~ 2 by 1 ft)
Resolution = 0.5mm





More information on Lidar imagery and segmentation at the afternoon poster session:

INVESTIGATION OF NON-FICKIAN DISPERSION USING LIDAR IMAGERY ON OUTCROPS

Gary Weissmann, Jedediah Frechette, Timothy Wawrzyniec, University of New Mexico

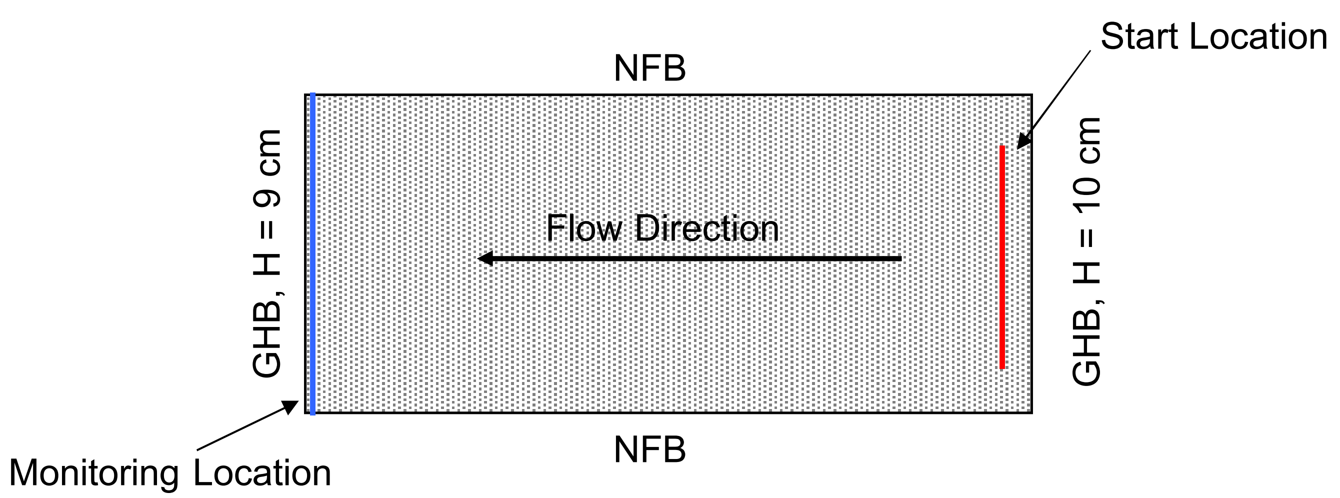
PARTICLE TRACKING SIMULATIONS

2-D Particle Tracking simulations using RWHet

70.35cm by 36.4 cm domain (~2 by 1 ft)
Cell size = 0.5mm by 0.5mm (equal to resolution of Lidar data)
1407 by 7287 grid cells

Gradient = -0.014 (dh/dl = 1cm/70.35 cm)
Porosity = 0.3 (homogeneous)
Diffusion = $1*10^{-5}$ cm^2/s ($1*10^{-9}$ m^2/s)
No Dispersion Added

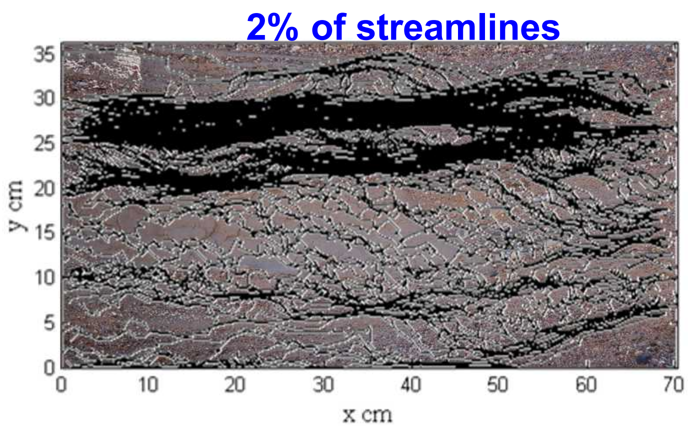
10,000 particles, flux weighted start location
Instantaneous injection
Start location = 26.5 cm line located 0.25 cm from boundary
Particle breakthrough monitored at the end of the domain

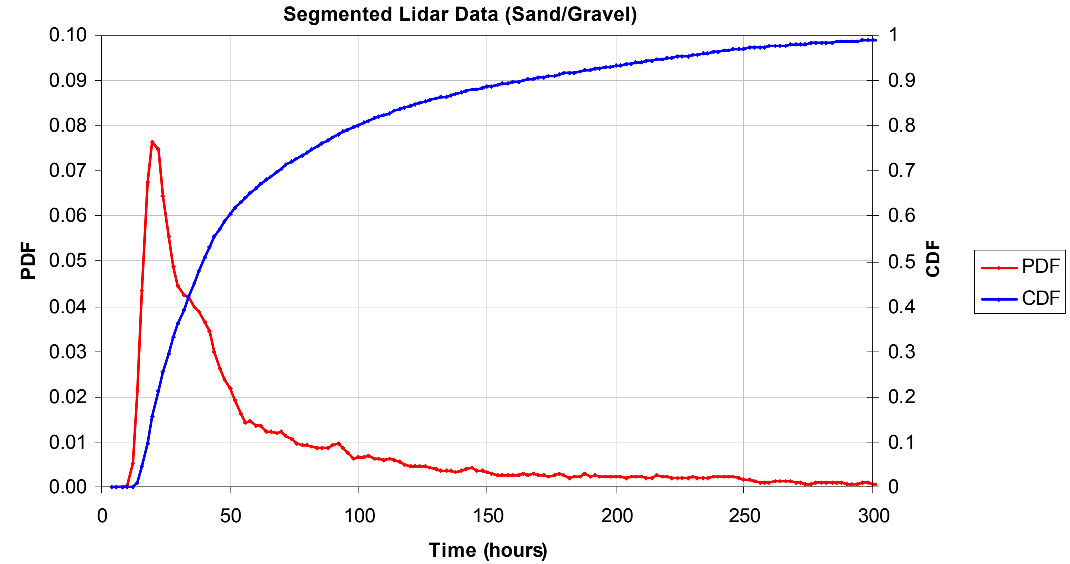


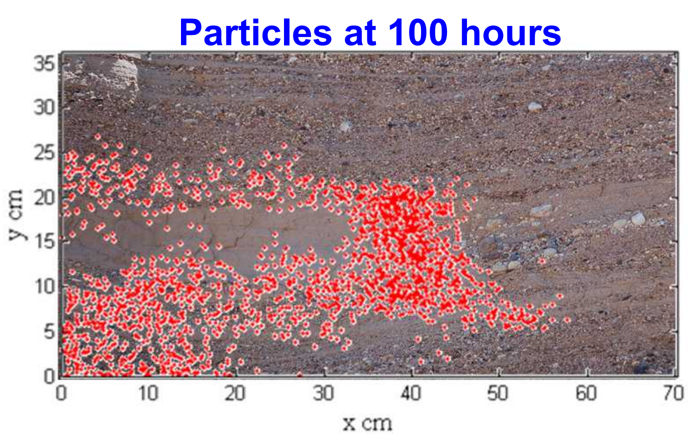
SEGMENTED LIDAR BREAKTHROUGH CURVES

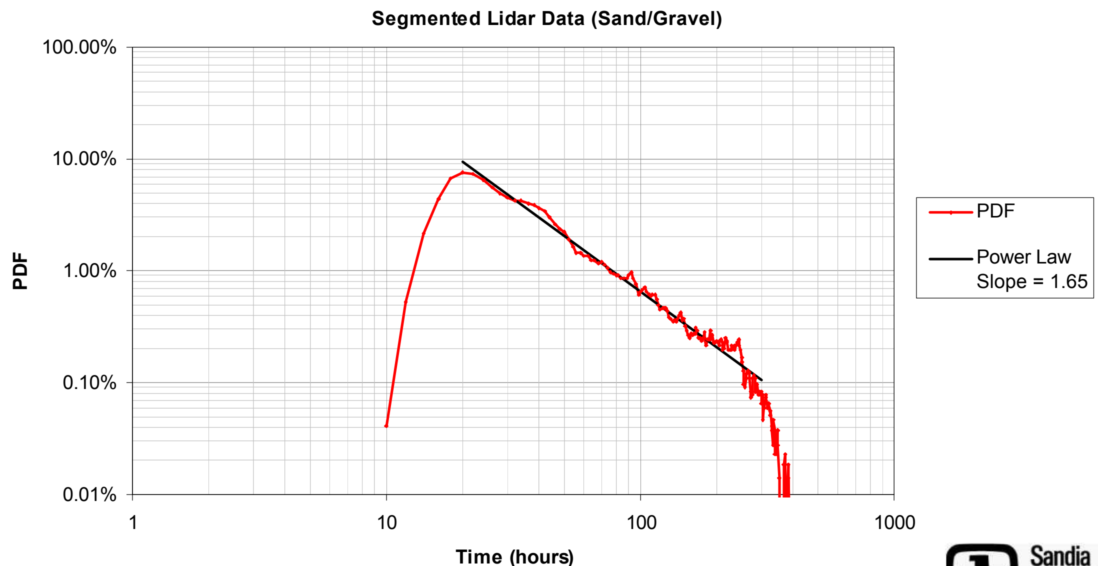
RHWet simulations using segmented lidar K field

Best fit power law slope = 1.65
Power law relationship is truncated after 0.1%









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SGSIM HYDRULIC CONDUCTIVITY

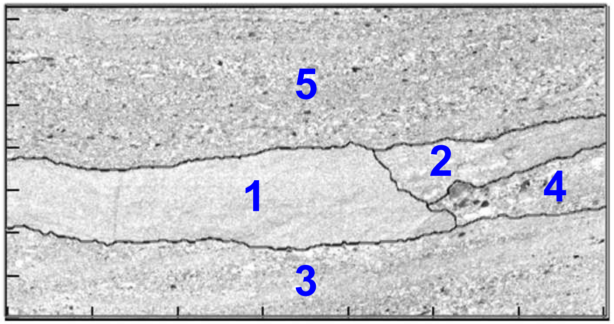
SGSIM K fields field based on variogram analysis of the segmented lidar K field. Two types of SGSIM fields are created:

1. Assign a single mean K

Geometric mean of lidar segmented K field = 0.0042 cm/s

2. Assign mean K according to the 5 geologic units

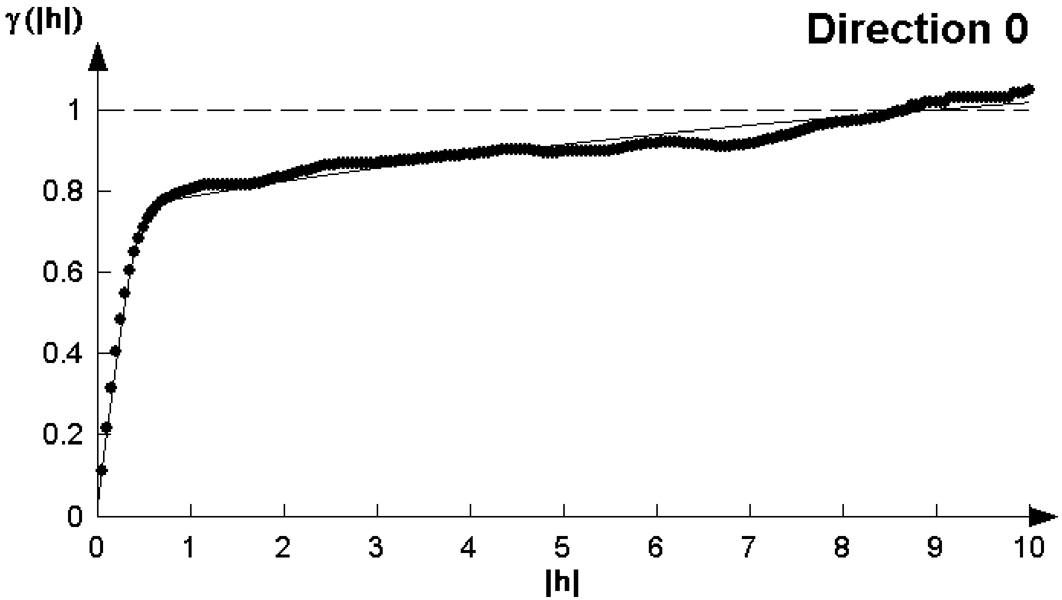
Geometric mean of unit 1 = 0.0010 cm/s
Geometric mean of unit 2 = 0.0013 cm/s
Geometric mean of unit 3 = 0.0036 cm/s
Geometric mean of unit 4 = 0.0036 cm/s
Geometric mean of unit 5 = 0.0096 cm/s



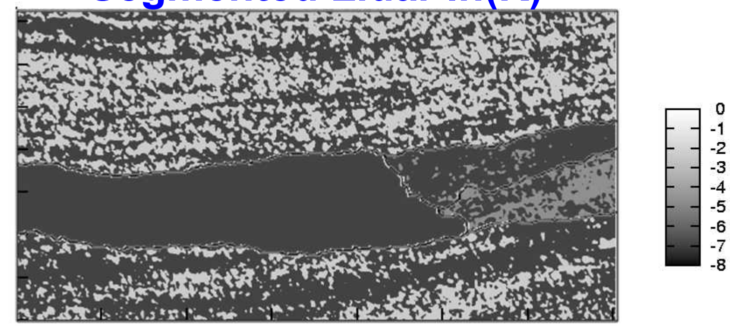
In both cases, a range of variance and anisotropy are applied

Variance of lnK = 2, 4, 6
Anisotropy = 1, 5, 10, 50, 100

VARIOGRAM MODEL



Segmented Lidar ln(K)

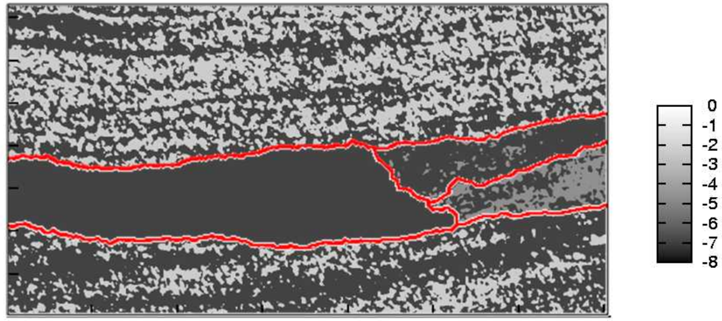


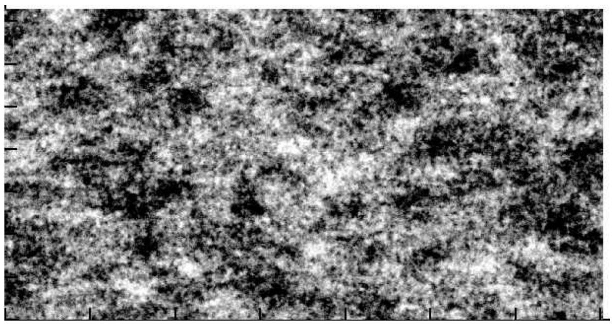
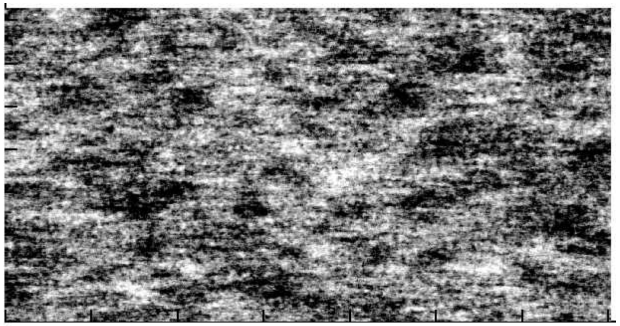
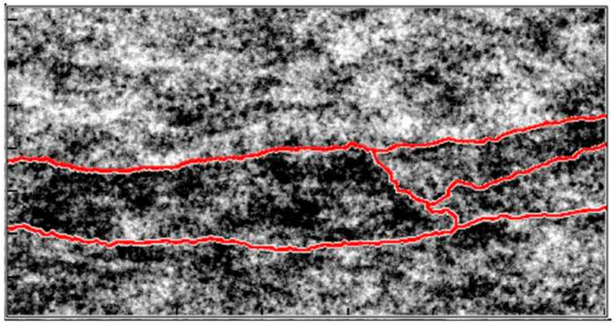
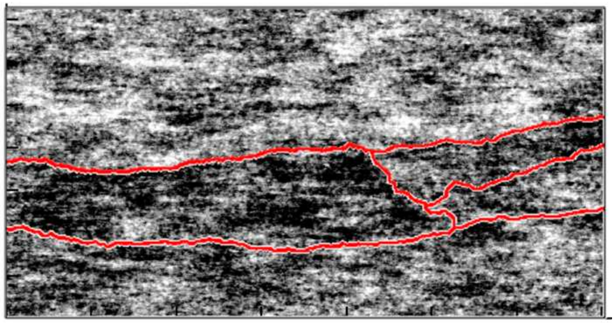
Nested structure:

Nugget = 0.03
Structure #1: Spherical Model, Range = 0.6 cm, Sill = 0.72
Structure #2: Exponential Model, Range = 30 cm, Sill = 0.43

Individual geologic units not modeled
Anisotropy not modeled
Dip direction not modeled

SGSIM HYDROLOGIC CONDUCTIVITY

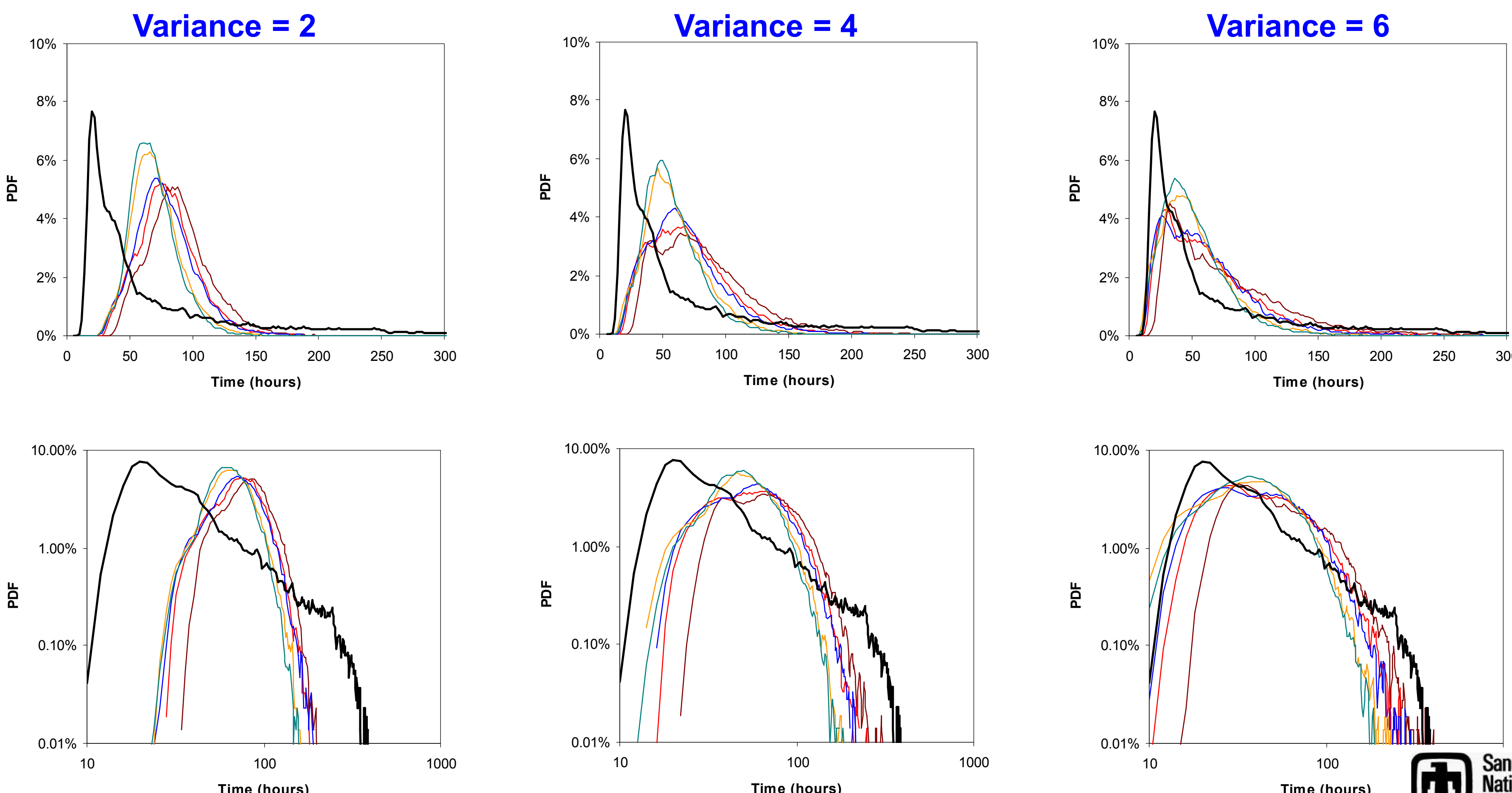


	Variance 4, Anisotropy = 5	Variance = 4, Anisotropy = 50
SGSIM		
SGSIM with Geologic Units		

SGSIM BREAKTHROUGH CURVES

SGSIM fields using a single mean K

Particle tracking simulations using SGSIM K fields with range of variance and anisotropy do not replicate heavy tailed solute transport.



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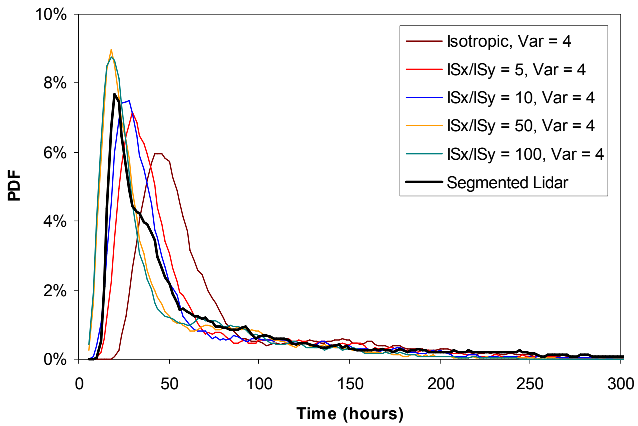
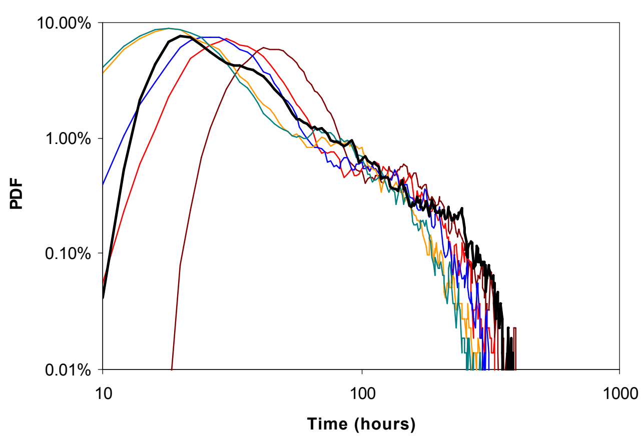
SGSIM BREAKTHROUGH CURVES

SGSIM fields using mean K from geologic units

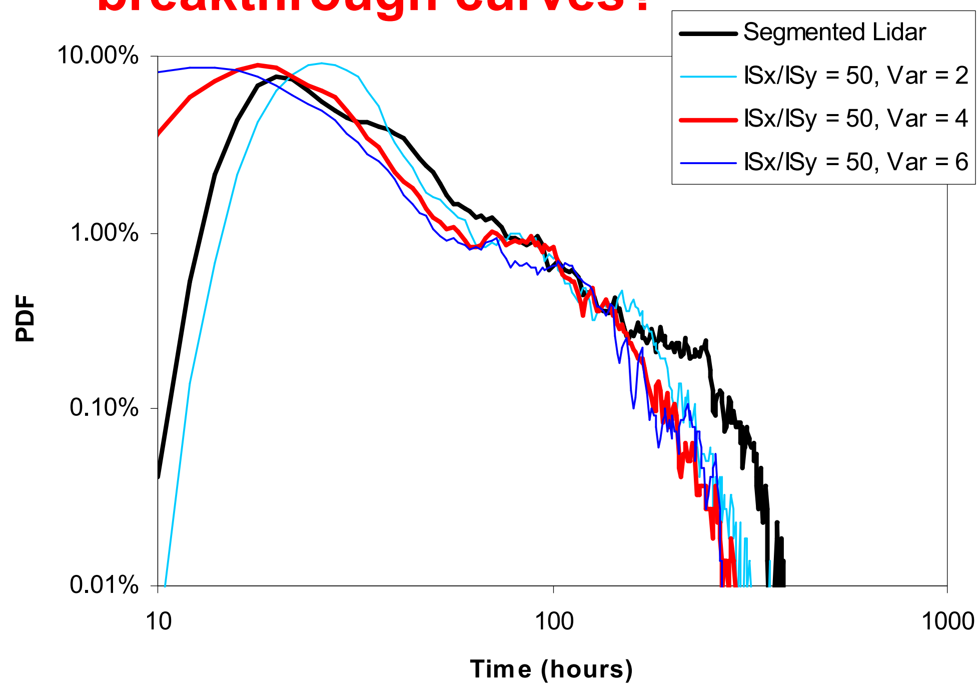
The addition of geologic units increases tailing in the breakthrough curve, however, this tailing does not follow a power law trend, as seen in the Segmented Lidar simulation.

SGSIM with geologic units
Variance = 4





DAVE: how would you describe the differences in these breakthrough curves?



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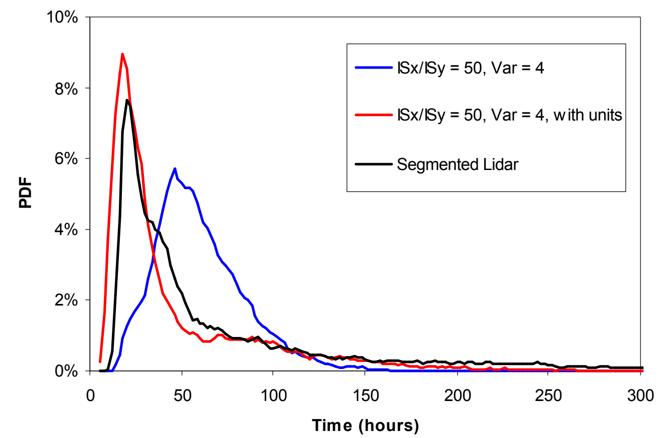
SGSIM BREAKTHROUGH CURVES

How is the difference in solute tailing related to the velocity field?

The following analysis focus on the three particle tracking simulations below:

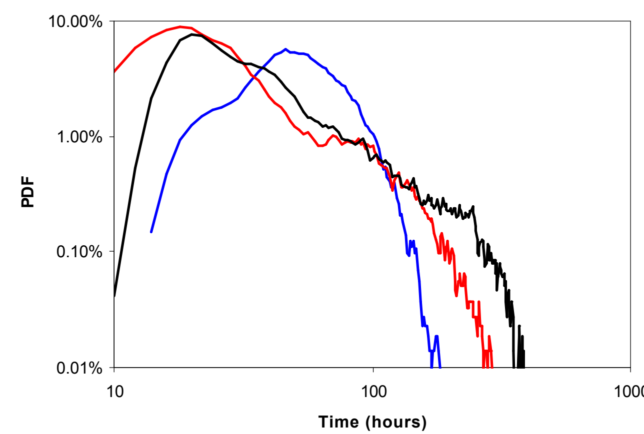
Segmented Lidar = Black
SGSIM = Blue
SGSIM with geologic units = Red

SGSIM K fields have a variance of 4 and anisotropy of 50



% of particles remaining at 200 hours

Segmented Lidar = 6.72%
SGSIM = 0.03%
SGSIM with geologic units = 1.24%



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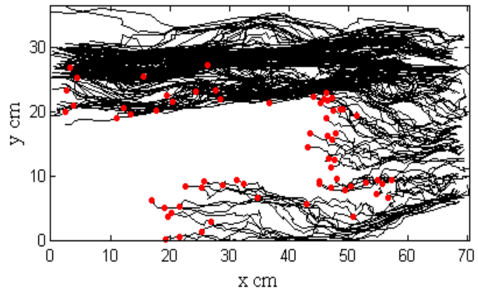
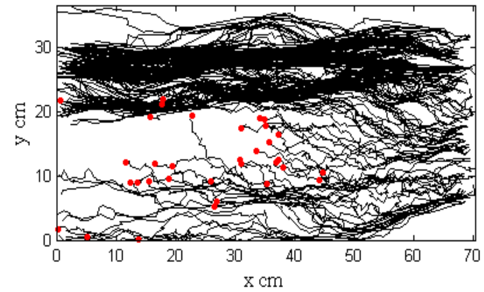
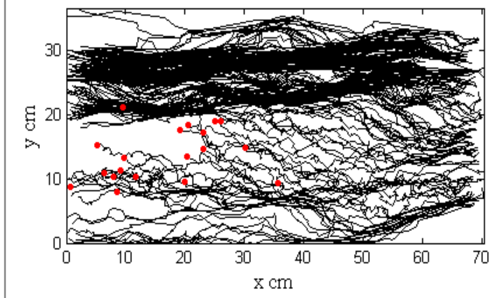
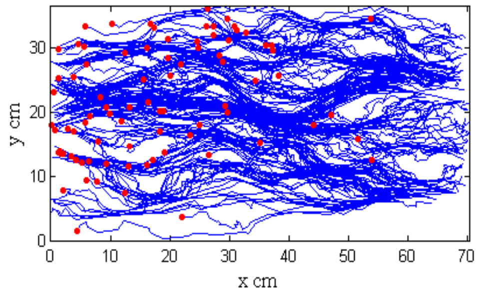
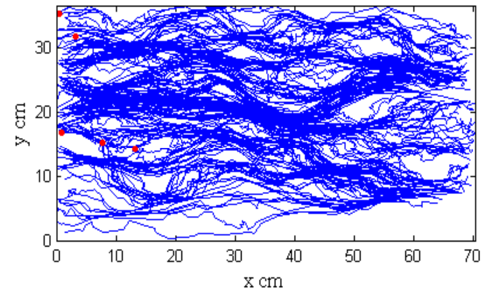
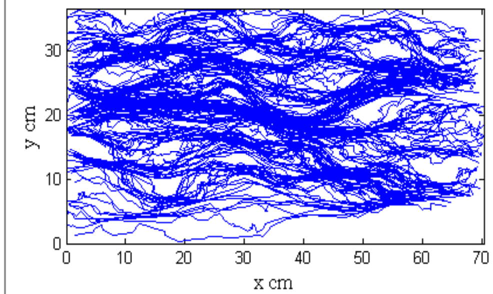
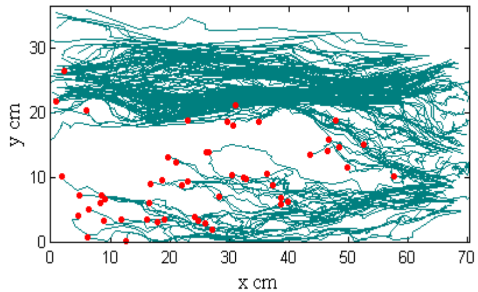
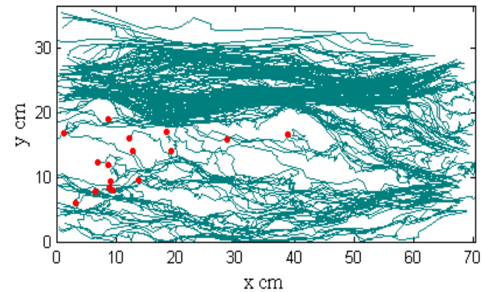
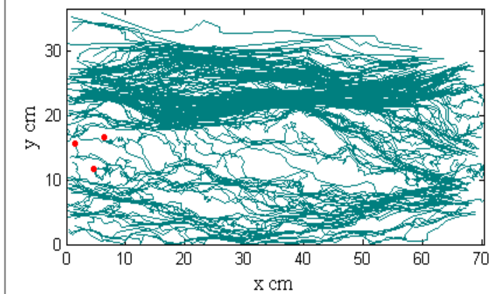
STREAMLINES

	15 hours	30 hours	45 hours
Segmented Lidar			
SGSIM			
SGSIM with Geologic Units			

200 of the 10000 stream lines (2%)

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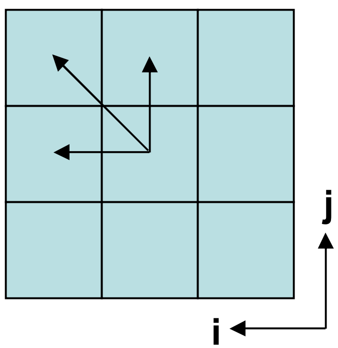
VELOCITY CALCULATION

Grid based velocity

Based on steady state head and hydraulic conductivity

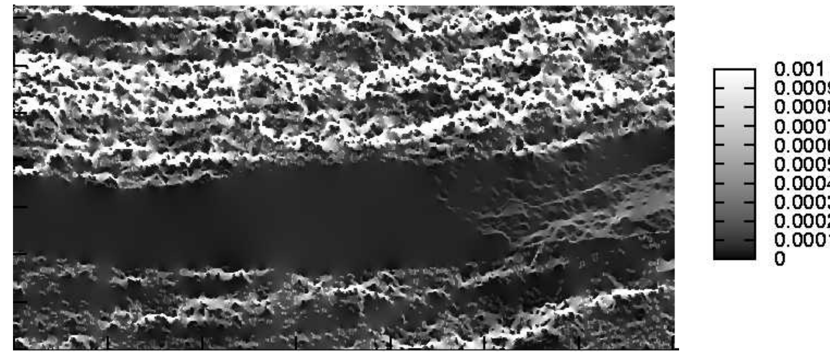


$$V_x^{i,j} = -\frac{1}{2n\Delta x}\left[\begin{array}{l}\sqrt{K_{i,j}K_{i-1,j}}\left(h_{i,j}-h_{i-1,j}\right) \\ +\sqrt{K_{i+1,j}K_{i,j}}\left(h_{i+1,j}-h_{i,j}\right)\end{array}\right]$$

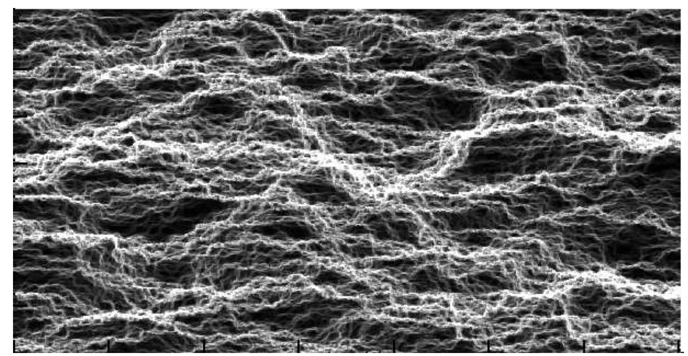
$$V_y^{i,j} = -\frac{1}{2n\Delta y}\left[\begin{array}{l}\sqrt{K_{i,j}K_{i,j-1}}\left(h_{i,j}-h_{i,j-1}\right) \\ +\sqrt{K_{i,j+1}K_{i,j}}\left(h_{i,j+1}-h_{i,j}\right)\end{array}\right]$$

$$V^{i,j} = \sqrt{V_x^{i,j^2} + V_y^{i,j^2}}$$

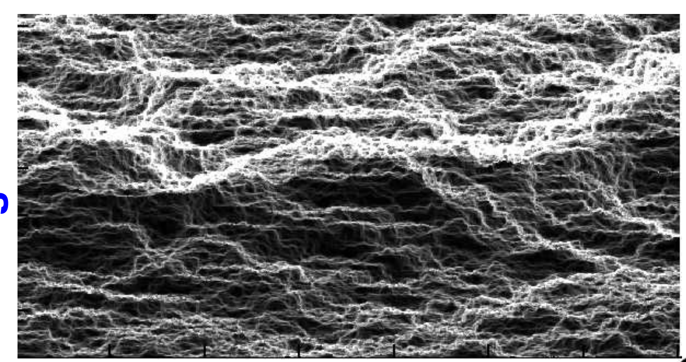
Segmented Lidar



SGSIM



SGSIM with Geologic Units



VELOCITY ANALYSIS

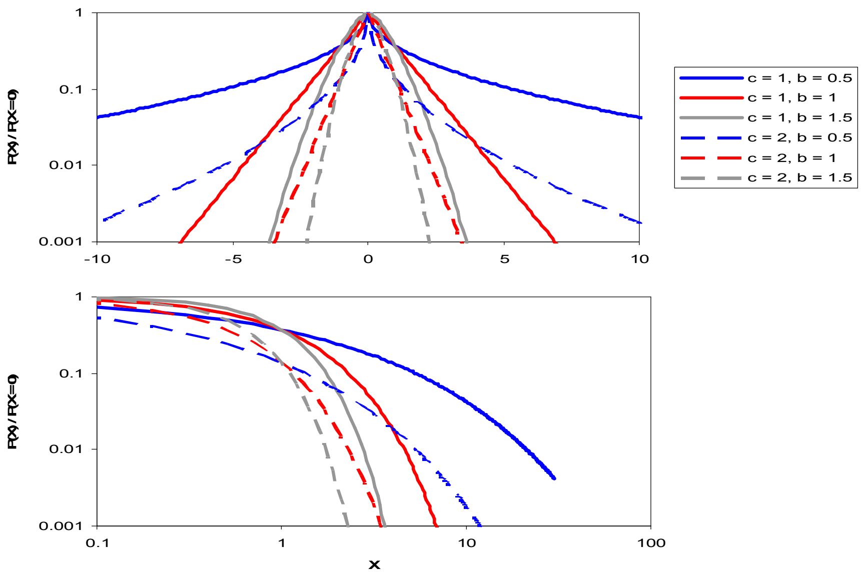
1. Calculate distribution in velocity increments using the following 3 velocity fields:

Segmented Lidar
SGSIM (variance = 4, anisotropy = 50)
SGSIM with geologic units (variance = 4, anisotropy = 50)

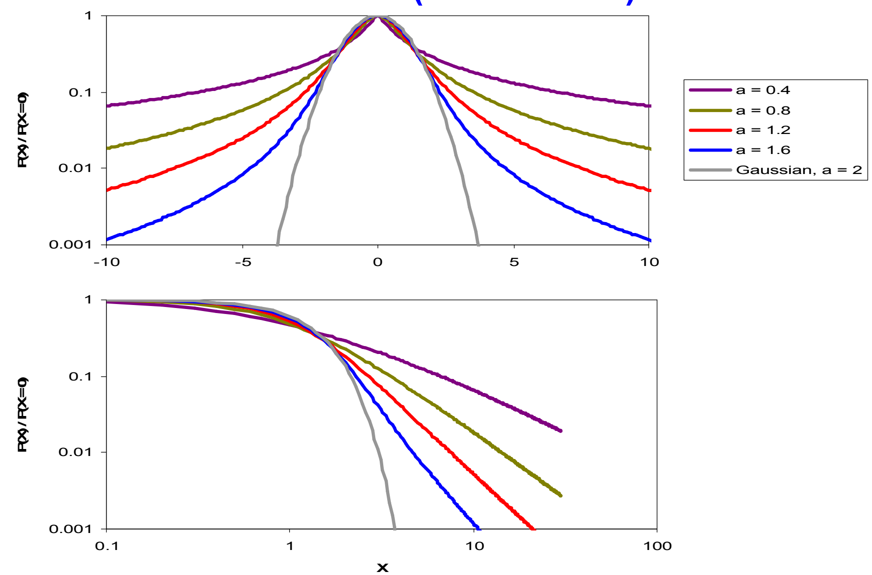
Increment data in the X and Y direction, adjacent grid cells
Increment data are used to eliminate non-stationary effects within the velocity field

2. Compare Velocity distributions to Laplace and α-stable distributions

Laplace
PDF(x) = exp(-cxb)

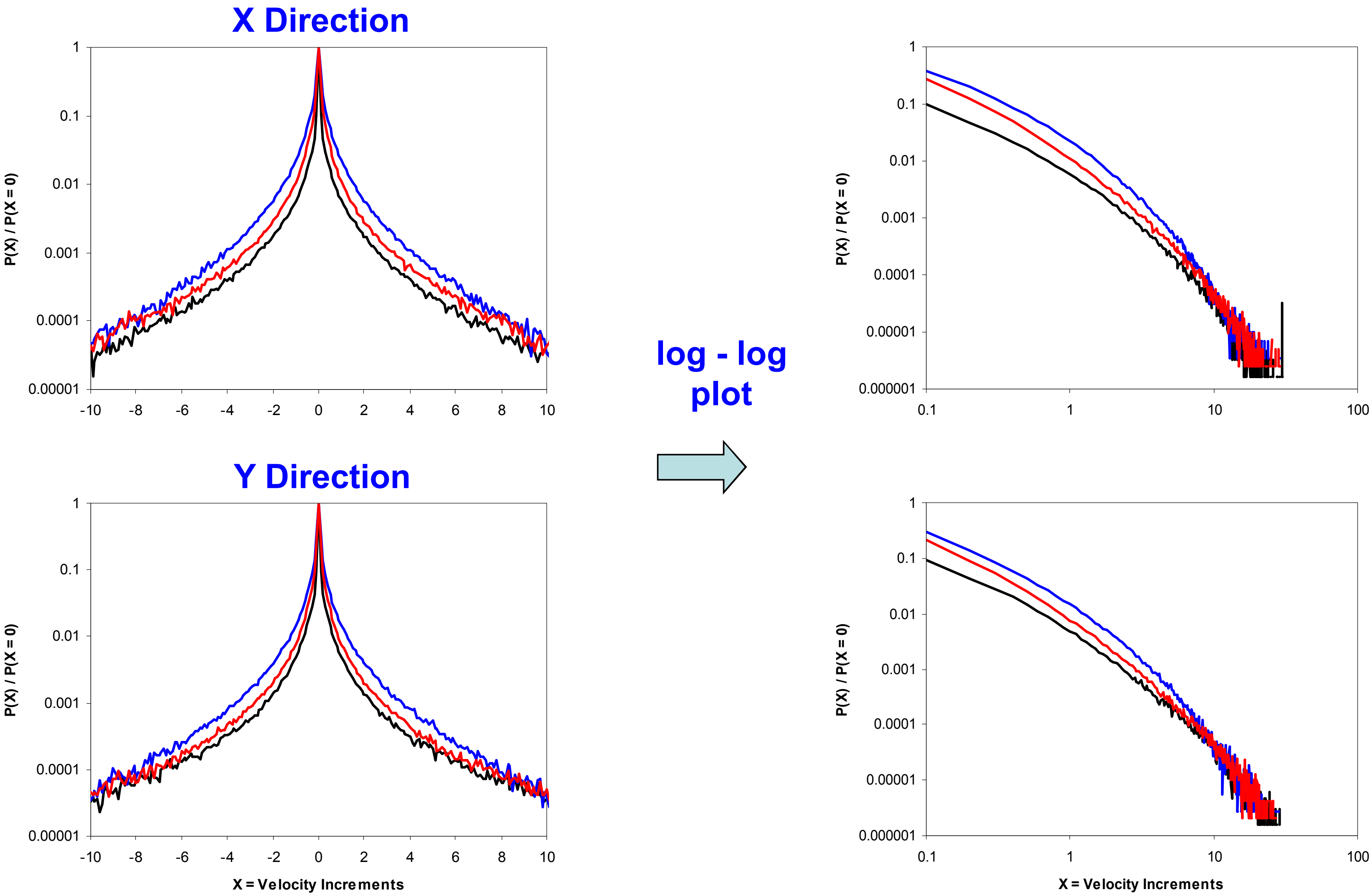


α-stable
PDF(x) calculated using stable software (John Nolan)



VELOCITY ANALYSIS

Black = Segmented Lidar
Blue = SGSIM
Red = SGSIM with Geologic Units



Tails decay exponentially. Fit distributions to a Laplace

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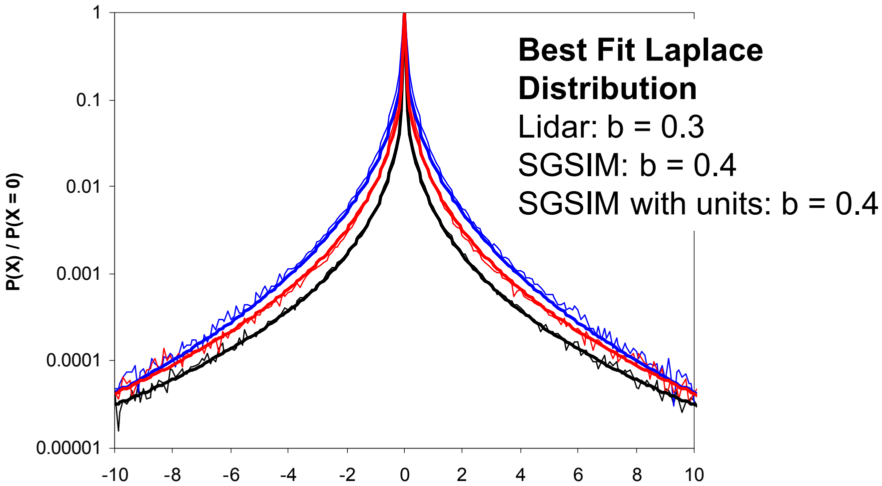
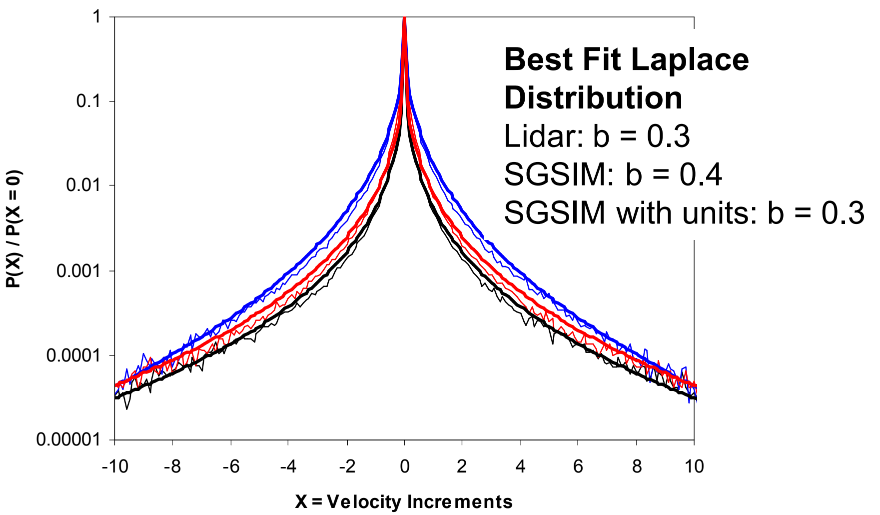
VELOCITY ANALYSIS

Black = Segmented Lidar
Blue = SGSIM
Red = SGSIM with Geologic Units

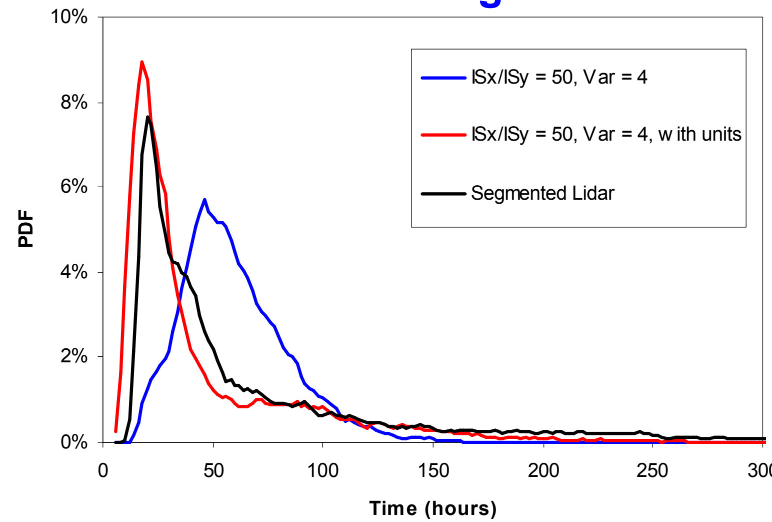
X Direction

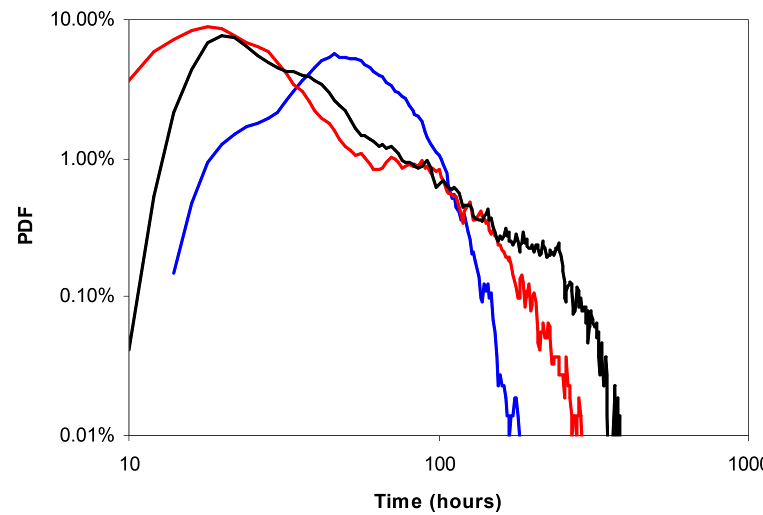


Y Direction



Breakthrough Curves





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CONCLUSIONS

SGSIM fields, even with high anisotropy and long range correlation, do not replicate solute tailing as simulated through realistic heterogeneity based on the lidar scan.

Lidar segmented K field results in a breakthrough curve with a truncated power law tail, slope = 1.65.

Adding geologic units to the SGSIM K field increases tailing, but does not propagate a power law tail.

SGSIM velocity increment distributions approximate velocity increment distributions from the segmented Lidar heterogeneity.

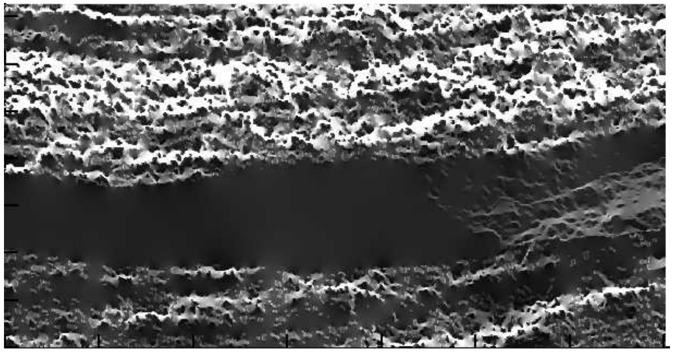
Stretched Laplace distribution, β values range between 0.3 and 0.4

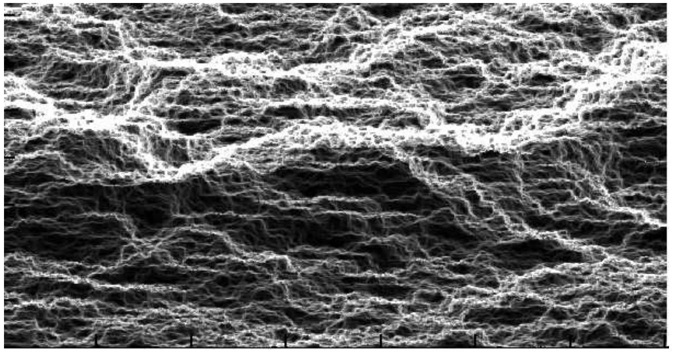
Velocity increment distributions alone are not a good indicator of heavy tailed solute transport.

What characteristics of the lidar segmented K and V field leads to power law tailing?

Lidar K field has sharp contact between sand and gravel.

Steady state velocity increments (grid based) ≠ velocities of particles (streamline based).





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FUTURE RESEARCH

Using additional Lidar scans, extract geologic units and facies information from intensity data using segmentation methods.

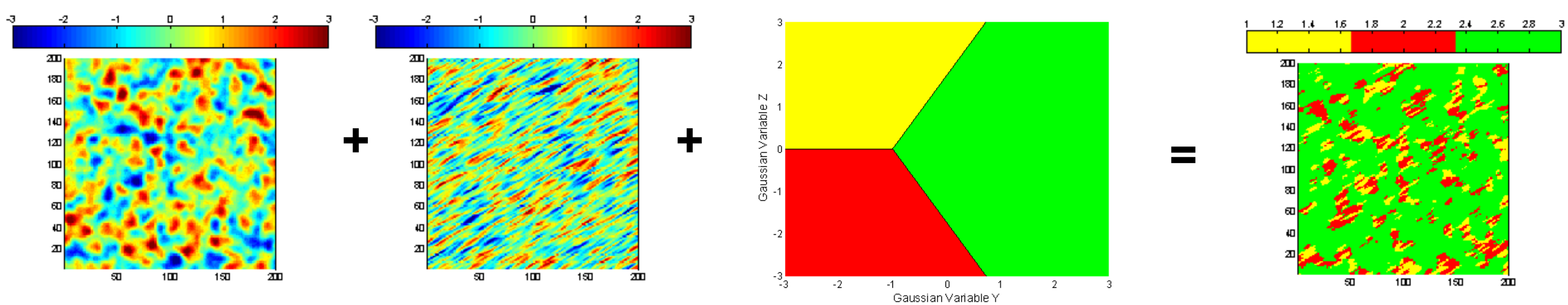
Refinement of segmentation methods to best classify outcrop heterogeneity.

Laboratory scale sand pack experiment based on lidar image. Visualize solute transport through outcrop scale heterogeneity.

How do sharp contacts influence the dispersion of particles?

Would PluriGaussian simulation better replicate sharp contacts and therefore better replicate solute transport through real heterogeneous media?

PluriGaussian simulation combines multiple Gaussian fields and a phase diagram to create a facies map.



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Dave Benson
Colorado School of Mines

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University of New Mexico

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