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Sandia National Laboratories

Geostatistical Density Mapping

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Outline

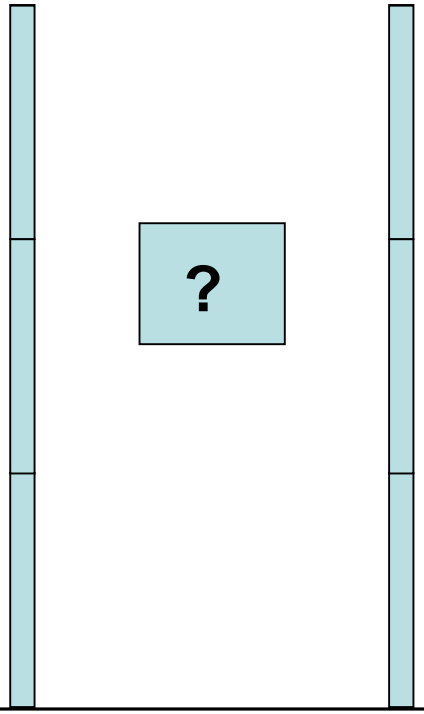
- Problem Statement
  - Anomaly Density Mapping
  - Boundary delineation
- Spatial Statistics
  - Data processing
  - Spatial variation (variogram)
  - Spatial estimation (kriging)
- Application to UXO site characterization
  - Example 1: Pueblo Colorado
  - Example 2: Toussaint River
- Mechanics of doing this in VSP
  - Simple approach (hands off)
  - Advanced approach (tinkering under the hood)
  - Exporting results out of VSP
- Summary

Problem Statement

- From limited transect data (perhaps less than 1% site coverage) answer the questions:
  - How much stuff is out there? (anomaly density mapping)
    - Provides basis for removal cost estimation
  - Where is it? (boundary delineation)
    - Separate the target areas from the background
- *How do we answer these problems in a defensible manner?*

Spatial Statistics

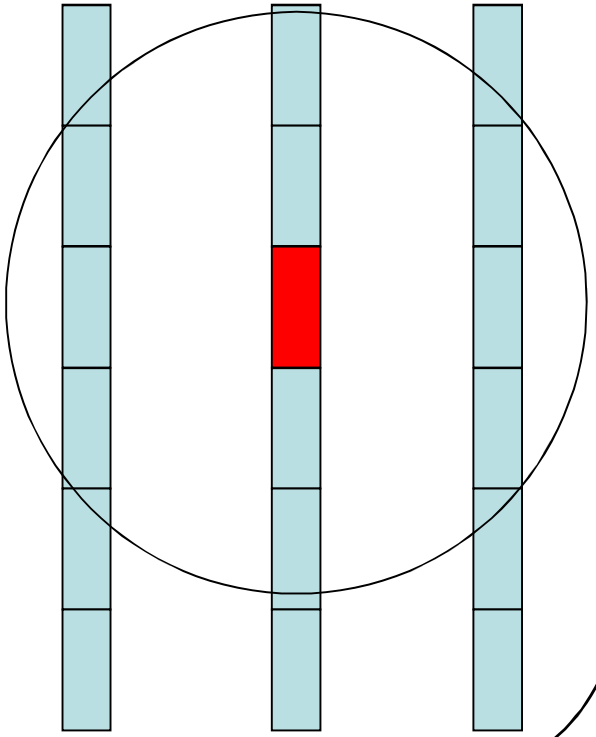
- If I measure something here, what can I say about the same thing over there where I don't have a measurement?



Geostatistics: Developed in mining industry beginning in 1950's. Now has wide application in the mining, petroleum and environmental areas for estimation of spatially varying properties

Data Processing

- Moving window approach provides average anomaly density at each averaging location and spatial coordinates of that measurement (center of circle)



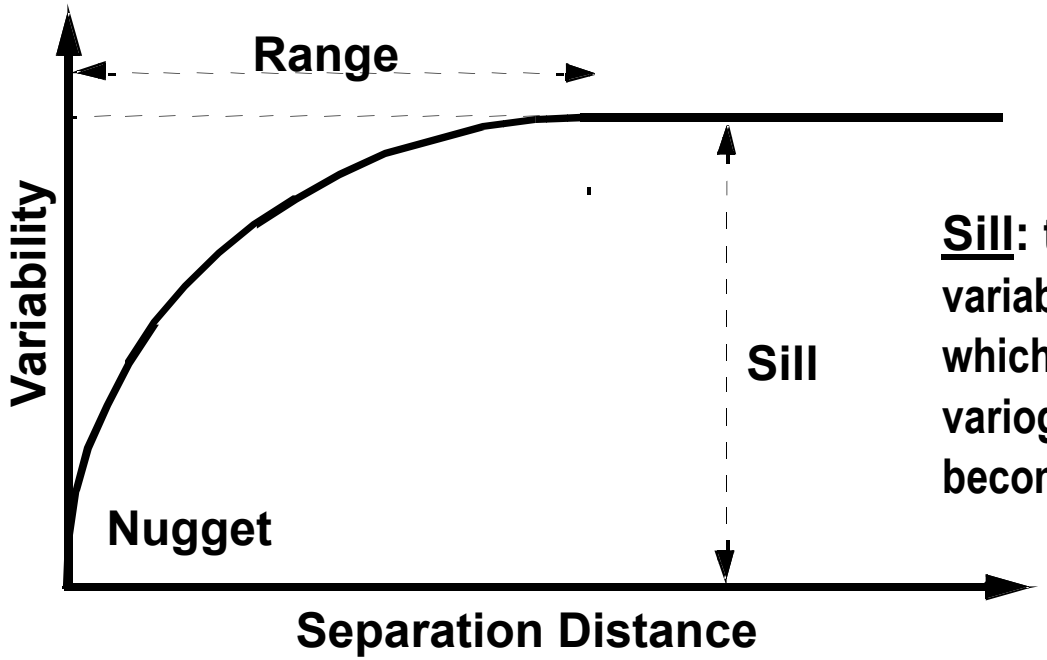
Spatial Variation

- Two measurements at locations close together tend to be more similar (less variable) than two things that are farther apart from each other.
- The way the earth works:
  - Contamination in soils
  - Porosity and permeability in aquifers
  - Dow Jones Average
  - Anomaly density at UXO sites

Variogram: Measure of Spatial Variation

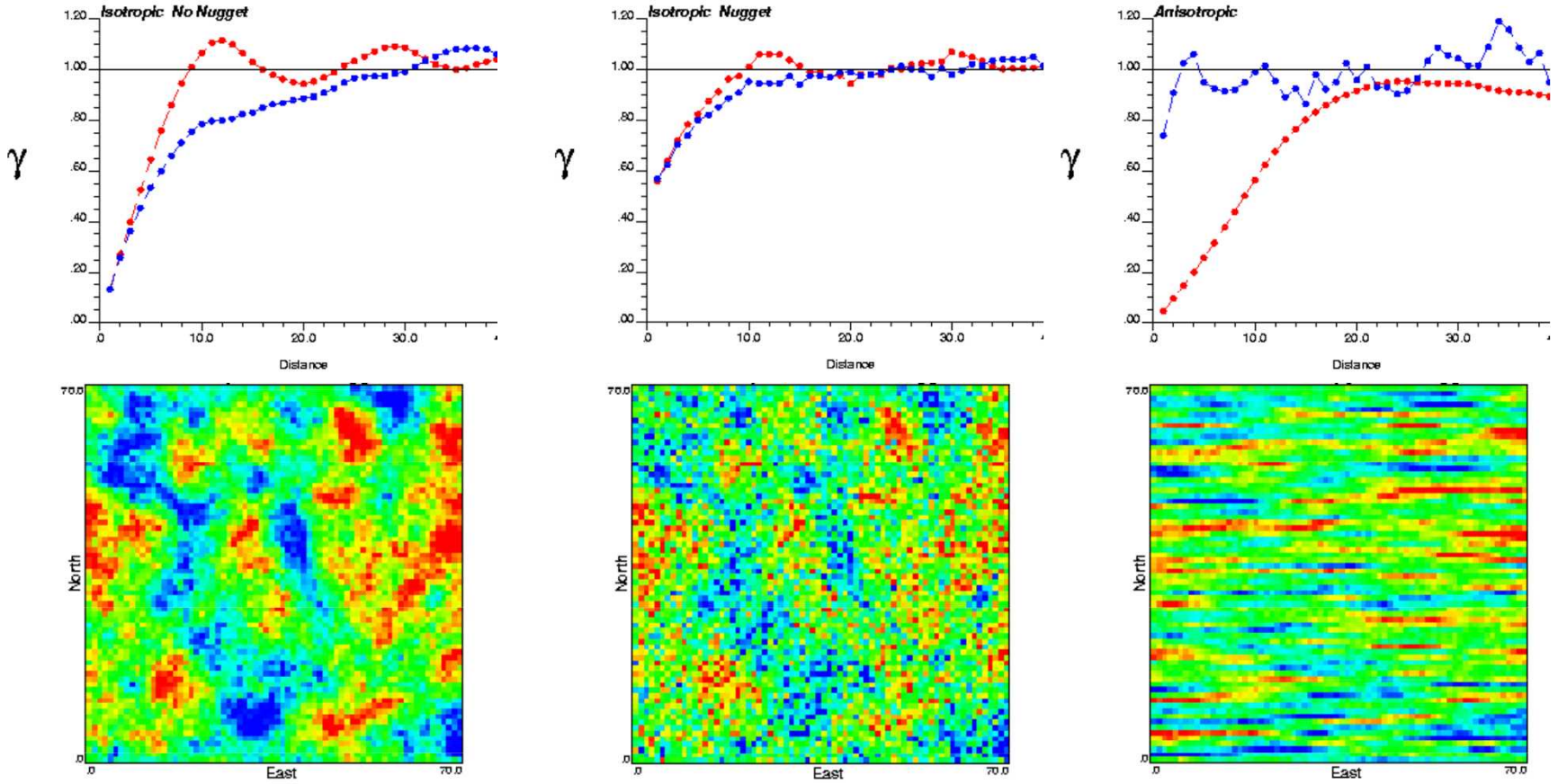
Nugget: some amount of variability at zero separation: a representation of measurement error or variability at separations smaller than the sample distance.

Range: distance at which we reach the total amount of variability



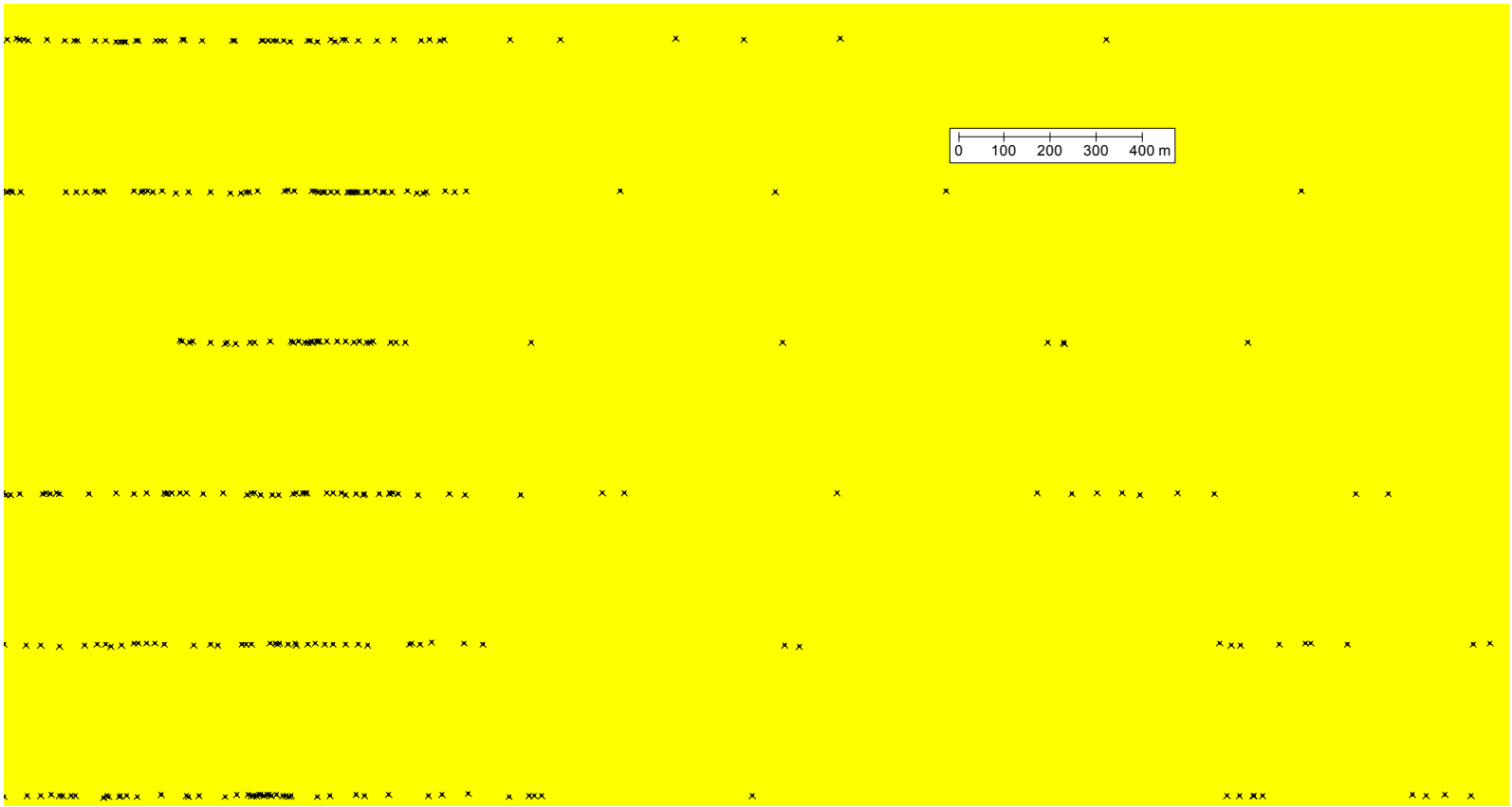
Sill: the total variability level at which the variogram value becomes constant

Spatial Variation: Examples



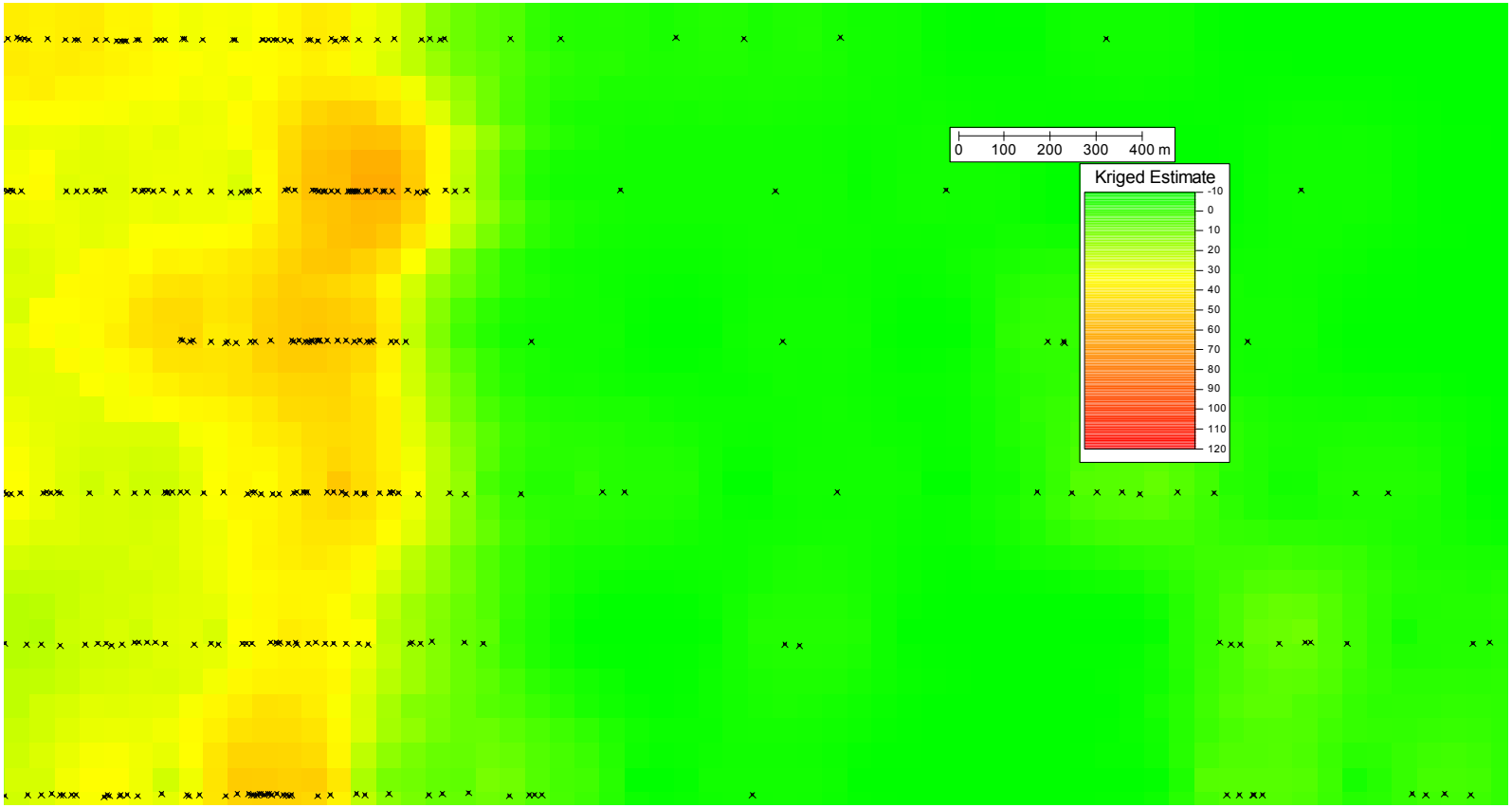
Estimation

From the anomaly locations along the transects, create a continuous estimate of anomaly density on the underlying grid

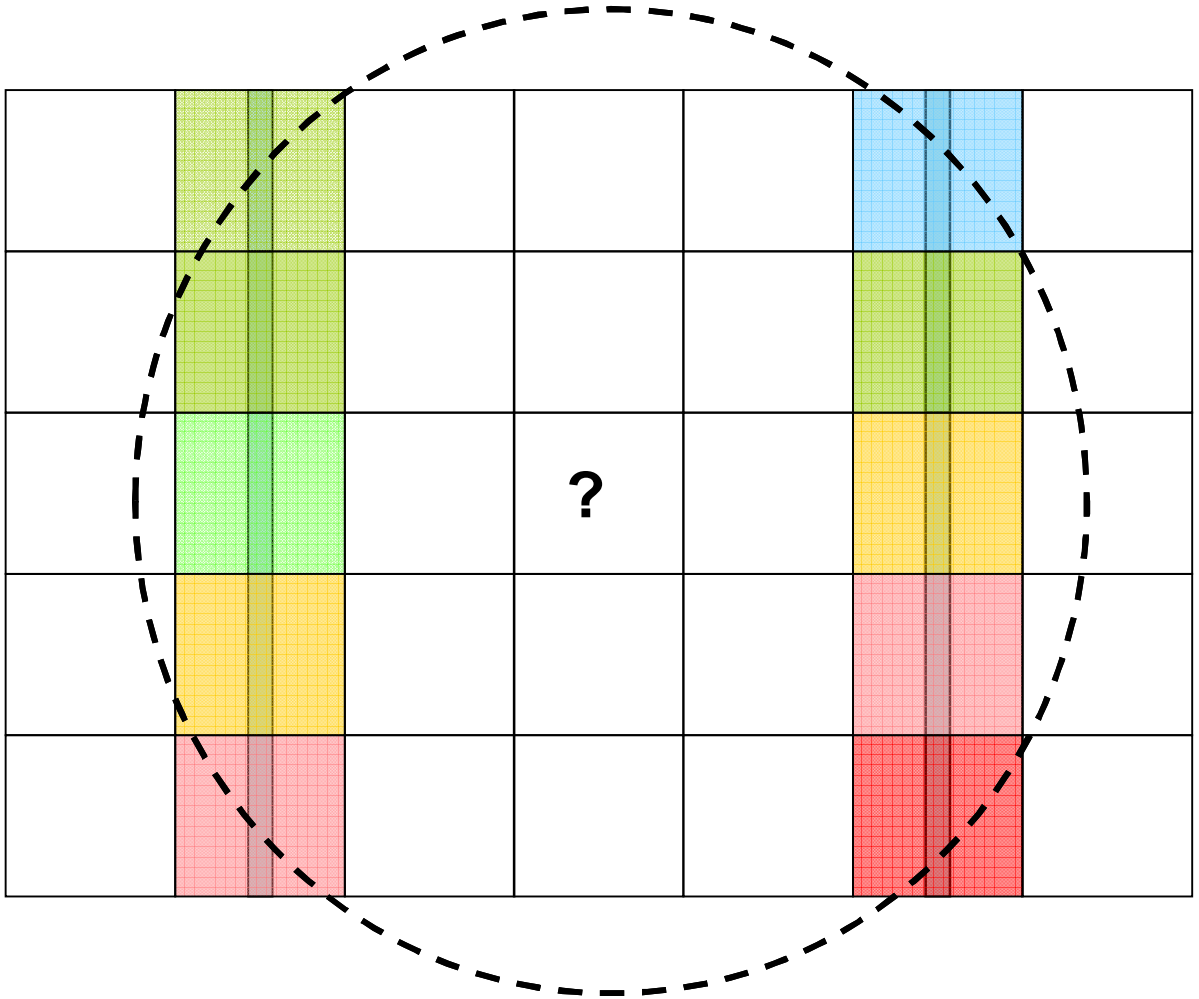


Estimation

Anomaly estimates (per acre) for each 50x50m grid cell



Kriging



Transect data have been scaled up to represent anomaly density at the scale of the estimation grid.

Each estimate is a weighted linear average of the surrounding transect data and provides the anomaly density estimate for that unknown cell

Kriging provides the estimate and the estimation variance

Kriging is B.L.U.E.

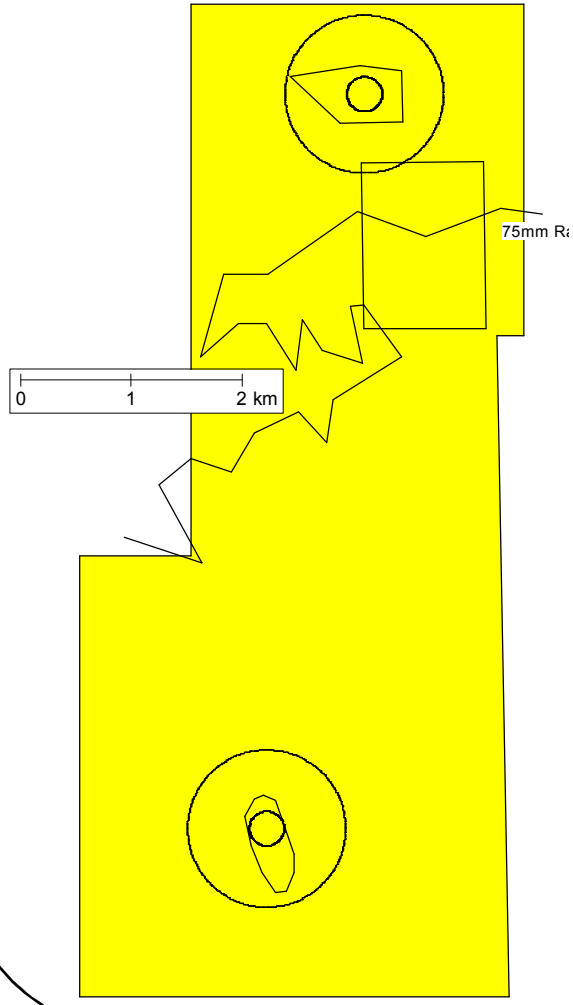
- Best
  - Distribution of residuals between estimates and true values is tight (minimum variance)
- Linear
  - Each estimate is a linear weighted average of surrounding data values
- Unbiased
  - Average residual about true values is zero
- Estimator

Example Application: Pueblo

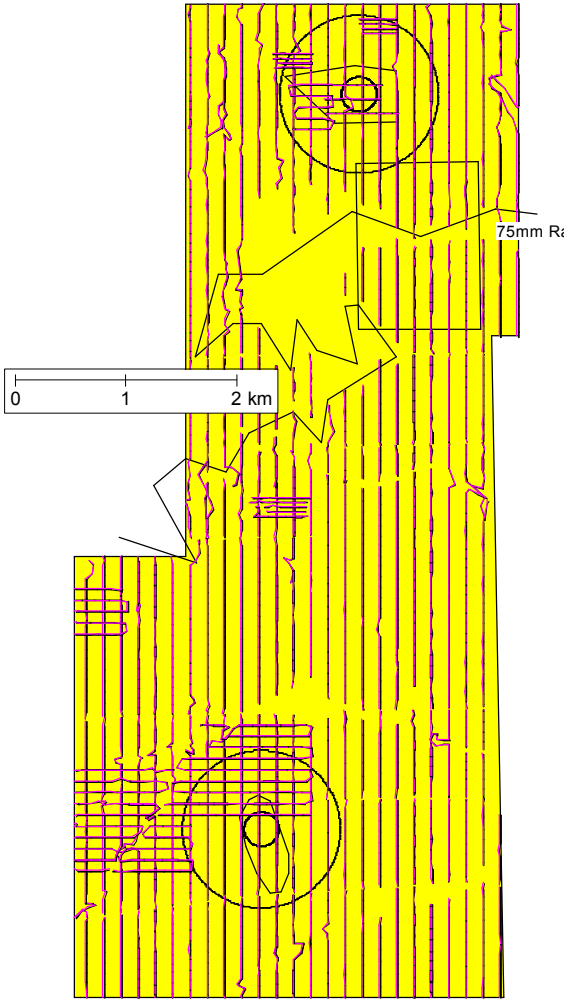
- Pueblo WAA site:
  - 7500 acres in Otero County, Colorado
  - Part of Pueblo Precision Bombing and Pattern Gunnery Range #2
  - Area contains two precision aerial bombing targets and a suspected 75mm air-ground target area
    - 100lb and 4lb incendiary bombs
    - 75mm armor piercing rounds
  - Transect Design
    - 2m width at155m spacing, 99% chance of intersecting a 500ft diameter target area (1.3% of site is sampled)

Pueblo Site

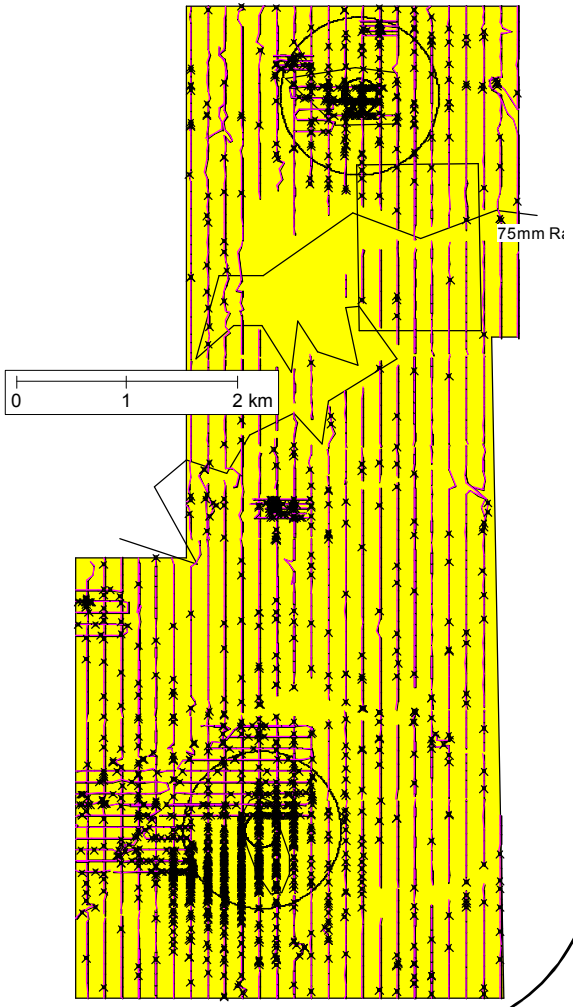
Site Layout



Transects

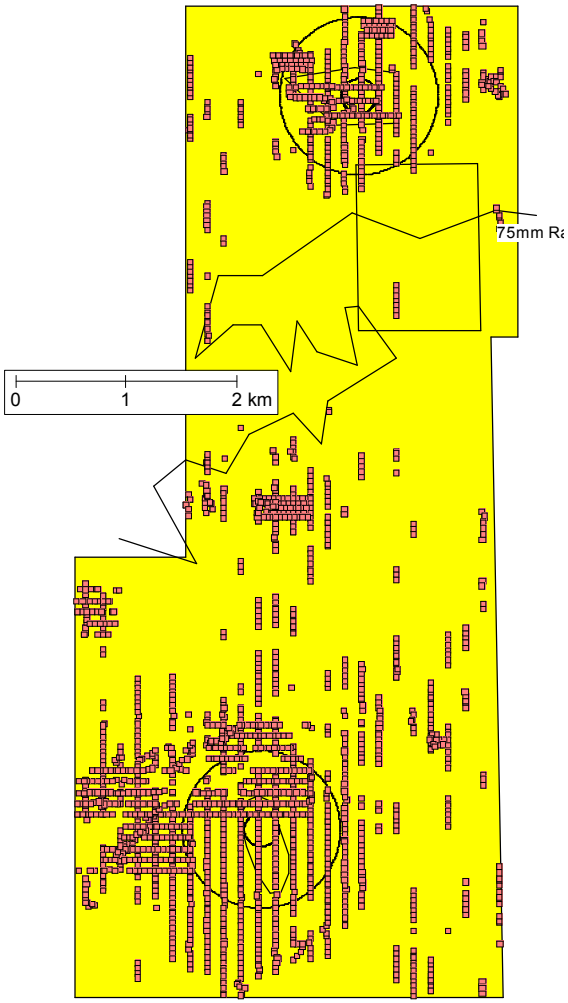


Anomalies



Pueblo Site

Flagged Areas



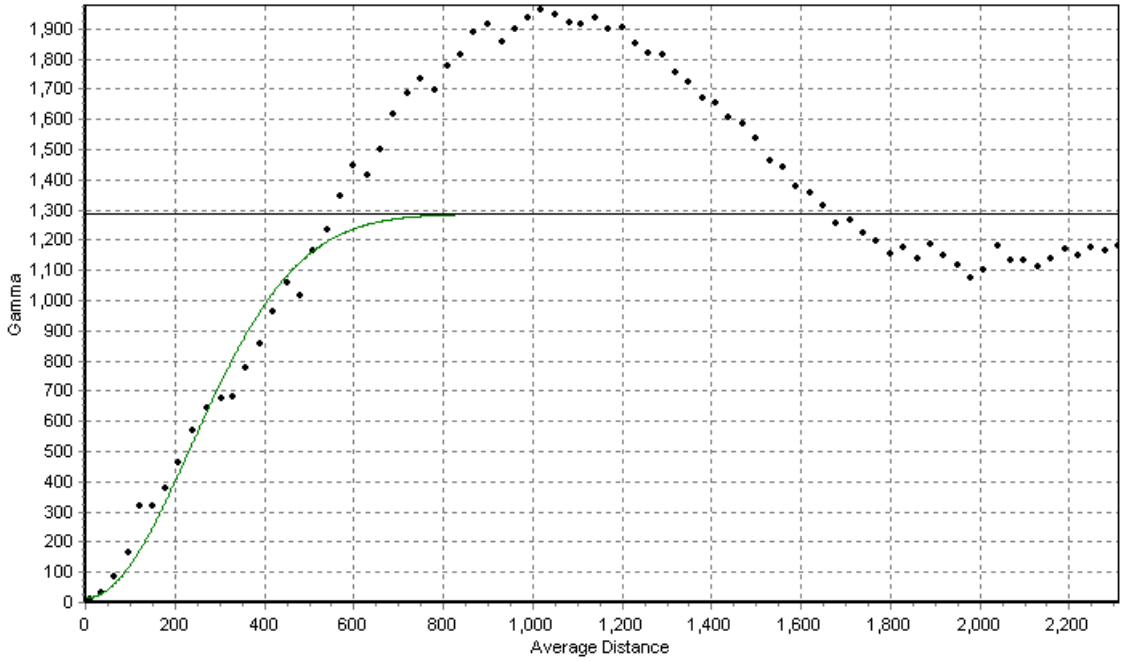
Flagging provides a “yes/no” indication of the transect being within a target area (density > target_threshold)

Flagging does not say anything about the actual density value

Estimate density values at all locations for target area boundary delineation and for estimate of total number of anomalies in each area

Pueblo Density Variogram

- First step
  - Estimate the spatial variation from the data and fit a variogram model to it



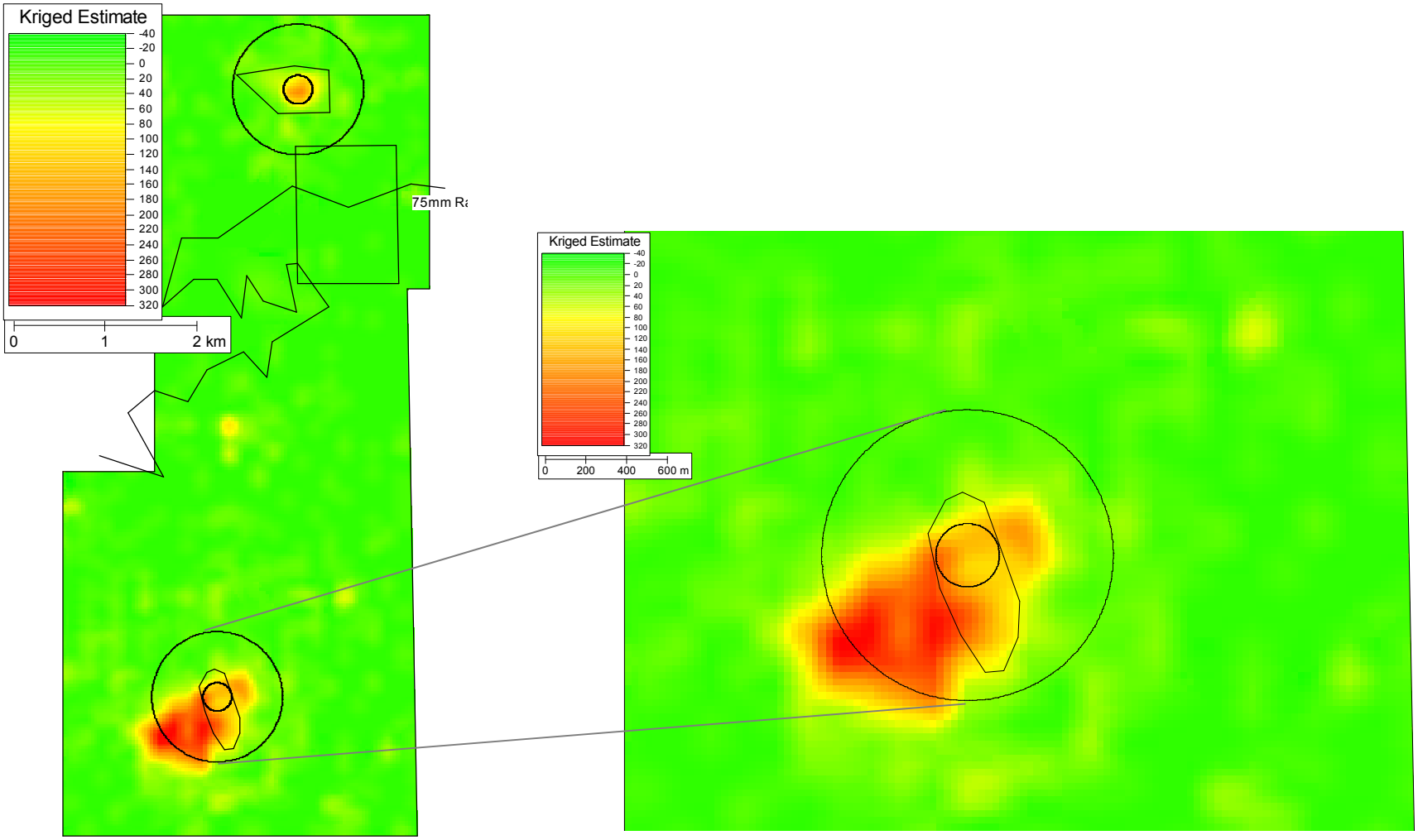
Pueblo anomaly density data

Strong spatial continuity out to a range of 600m

No nugget effect

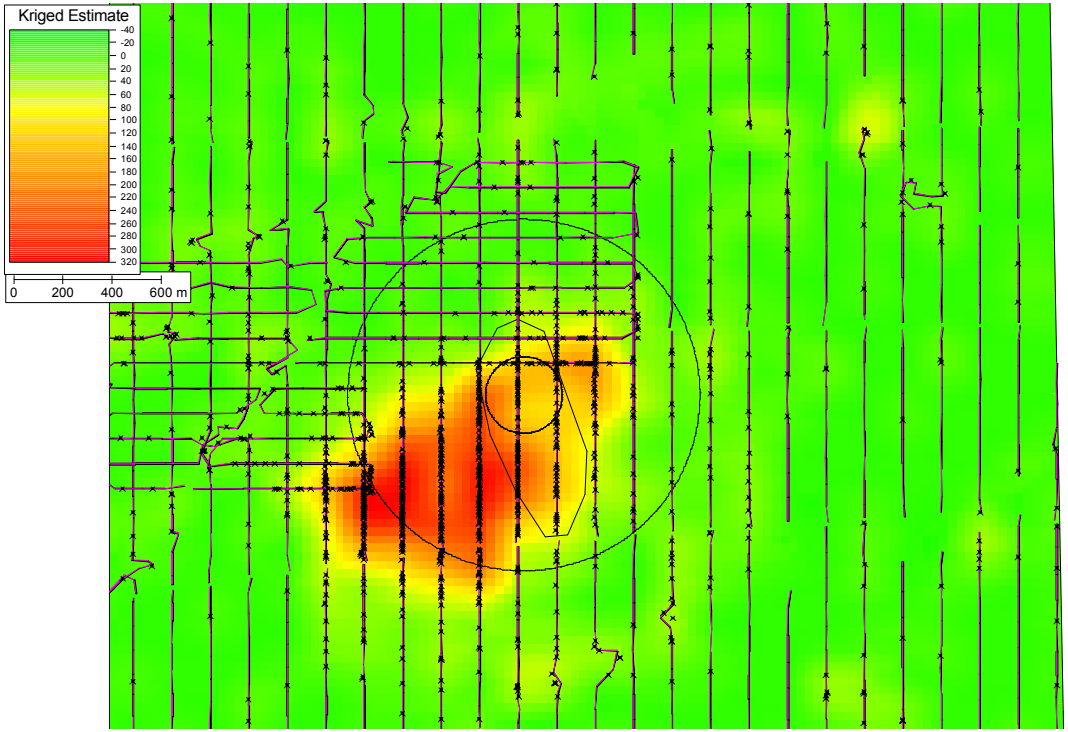
Variogram fit to the sill value

Pueblo Kriged Density Estimates

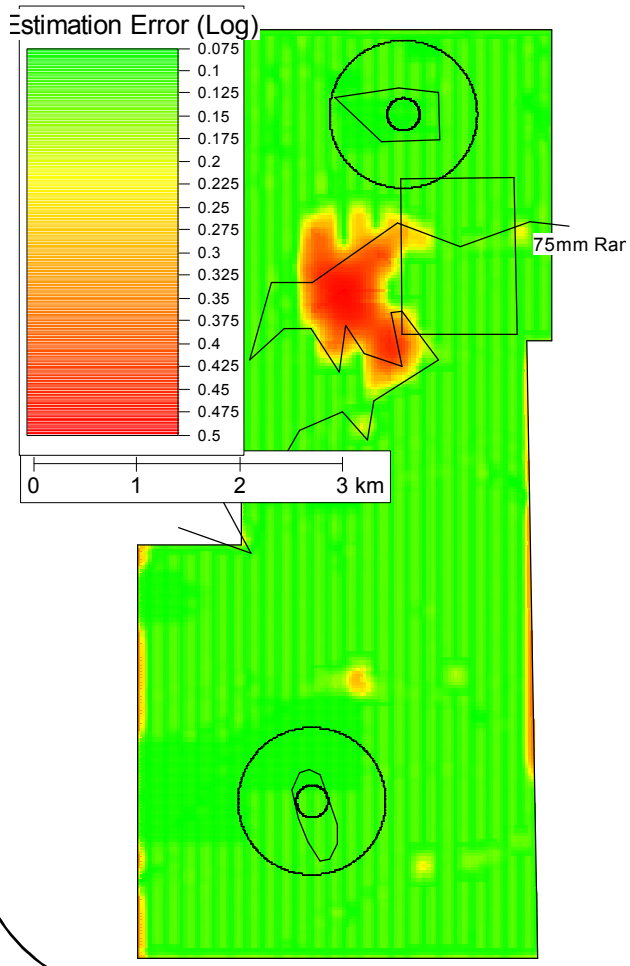


Pueblo Southern Target

Kriging fills in details of the southern target including density variation across the target area



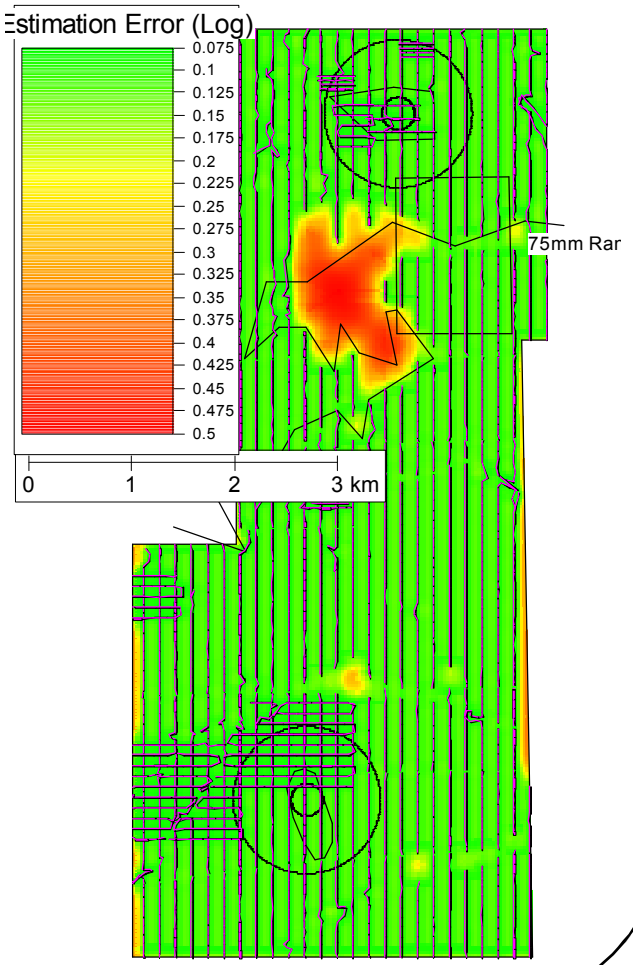
Kriging Variance



Kriging variance provides a map of the uncertainty in the estimated density

Areas “far” from a transect are highly uncertain. “Far” is defined by variogram (note holes in transect coverage)

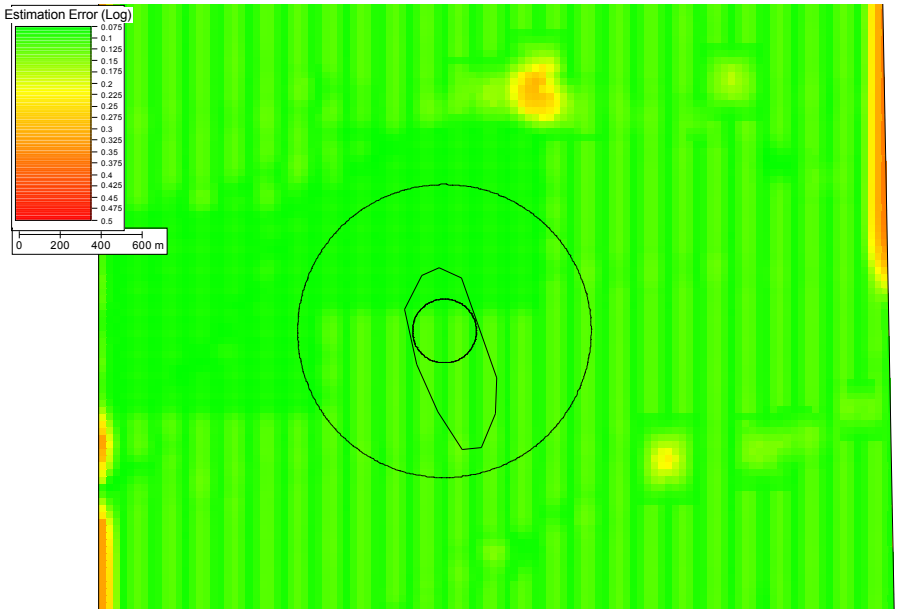
Is distance between transects too far for accurate estimation?

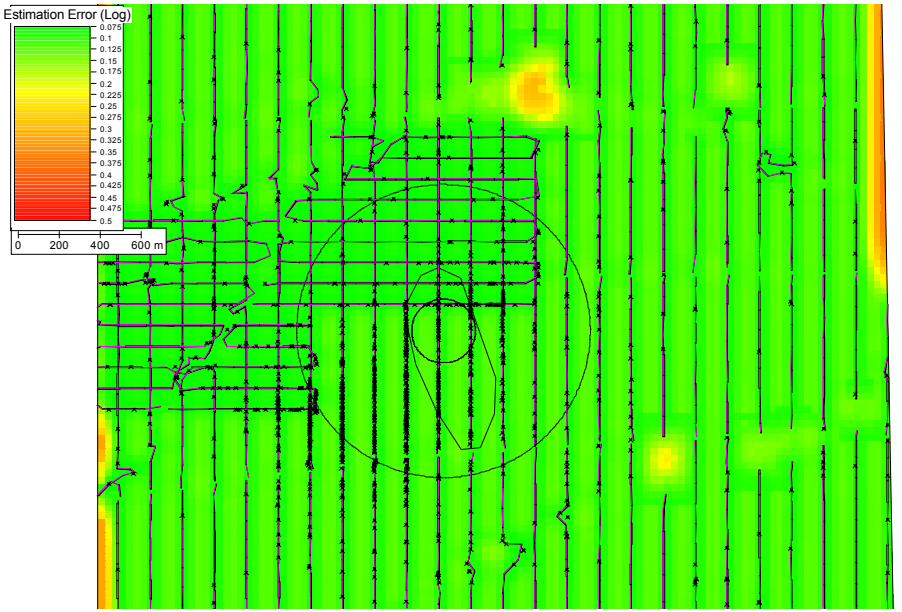


Kriging Variance

Expanded view of several small areas of relatively high variance

These areas caused by breaks in transect coverage due to topographic features





Toussaint River Site (Lake Erie)

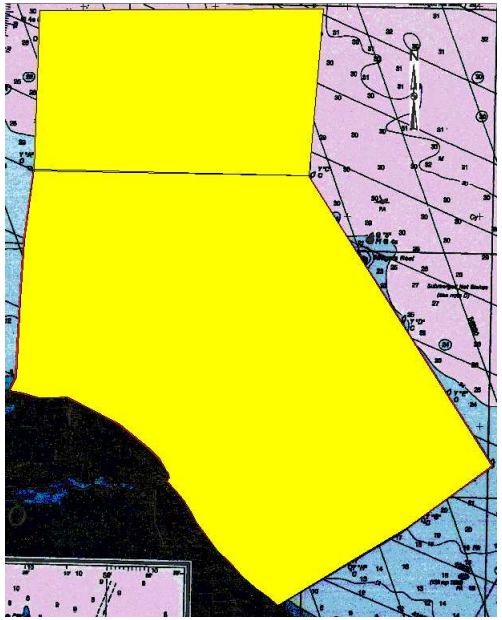
- Erie Army Depot and Toussaint River
  - Testing and proof firing or artillery and ordnance storage facility
  - Active for nearly 50 years (1918-1966)
  - Firing fan locations on the shore pointing into the lake (underwater site)
  - Little information on expected target sizes
  - Transect design of 5m width with 165m spacing, changed to 330m spacing during survey

Toussaint River Site

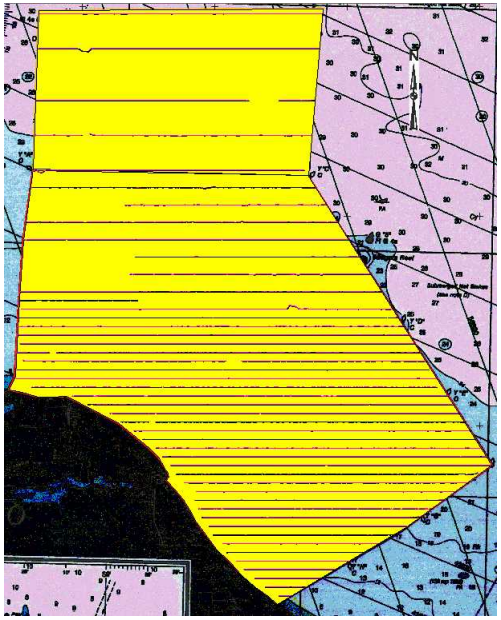
Underwater towed magnetometer array (AETC/SAIC)

Toussaint River Site

Site Layout

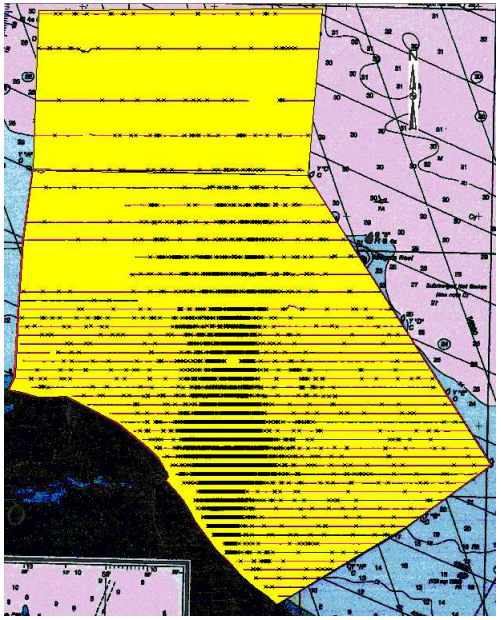


Transects

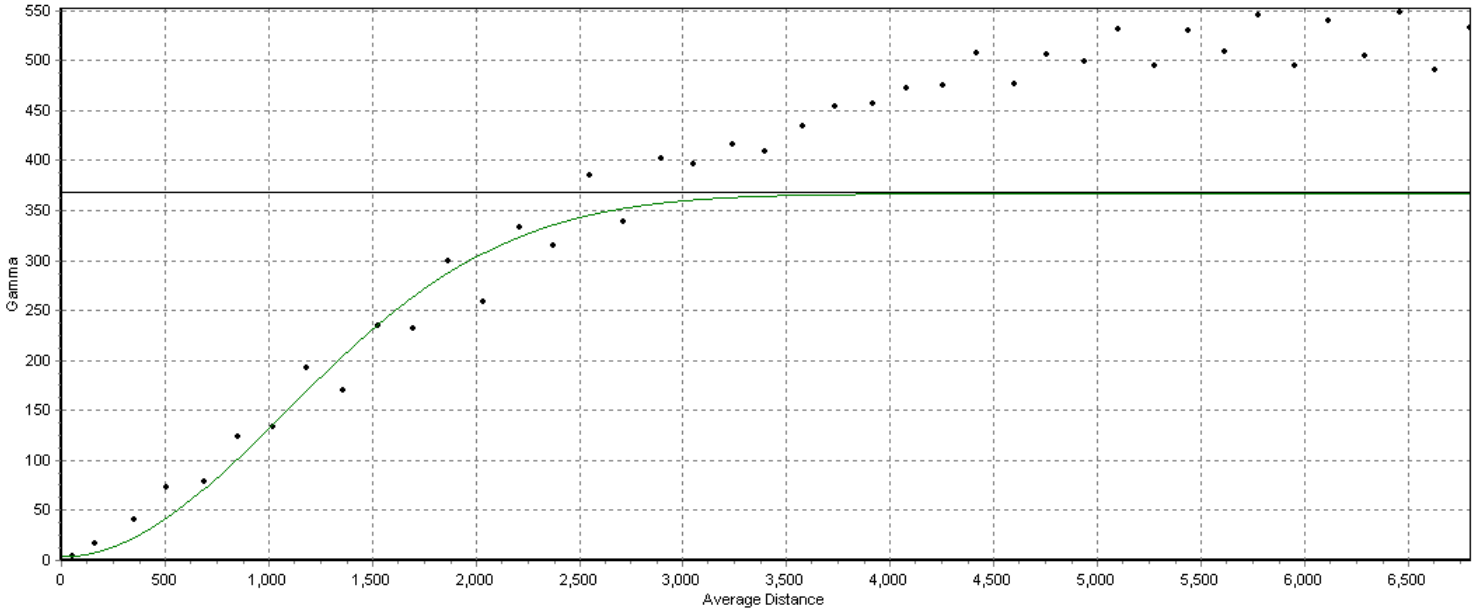


18 km

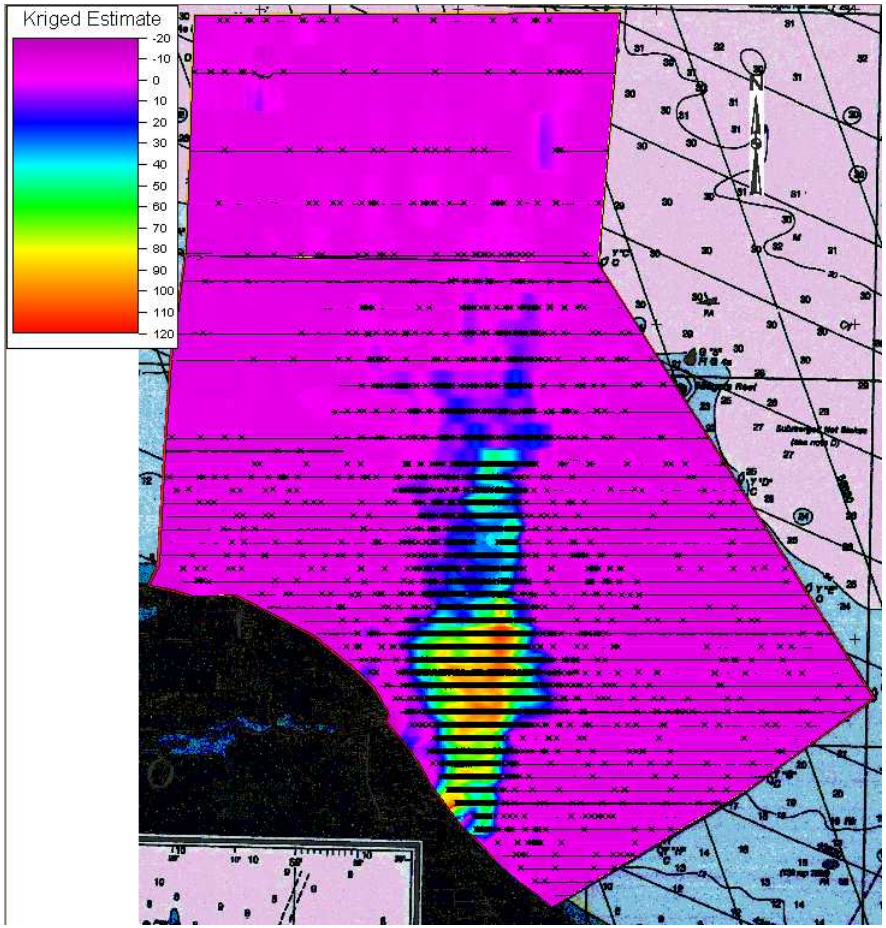
Anomalies

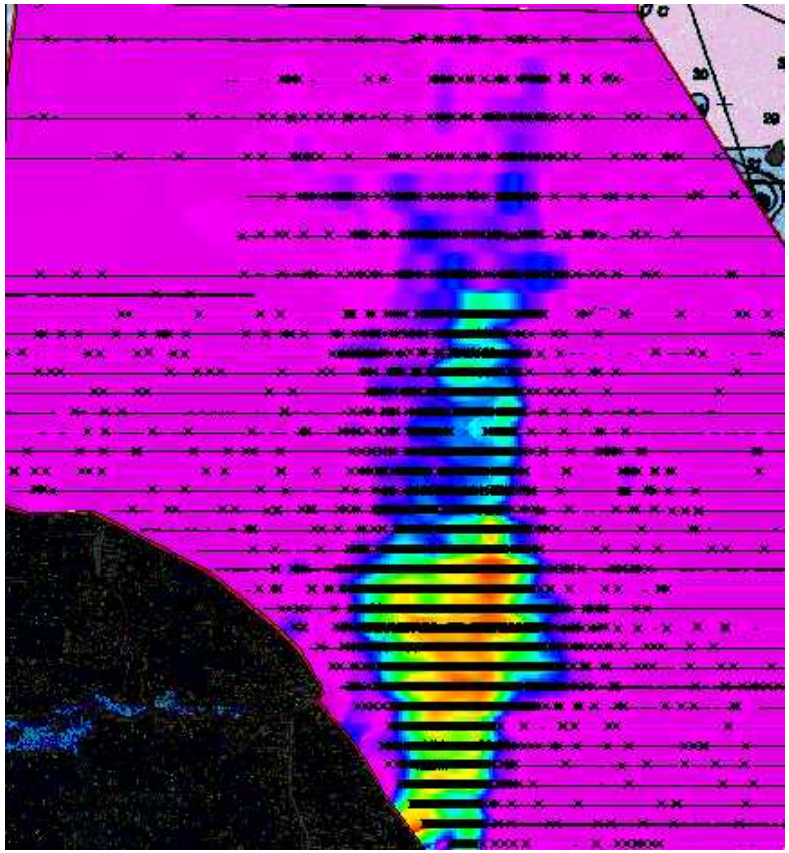


TR Variogram

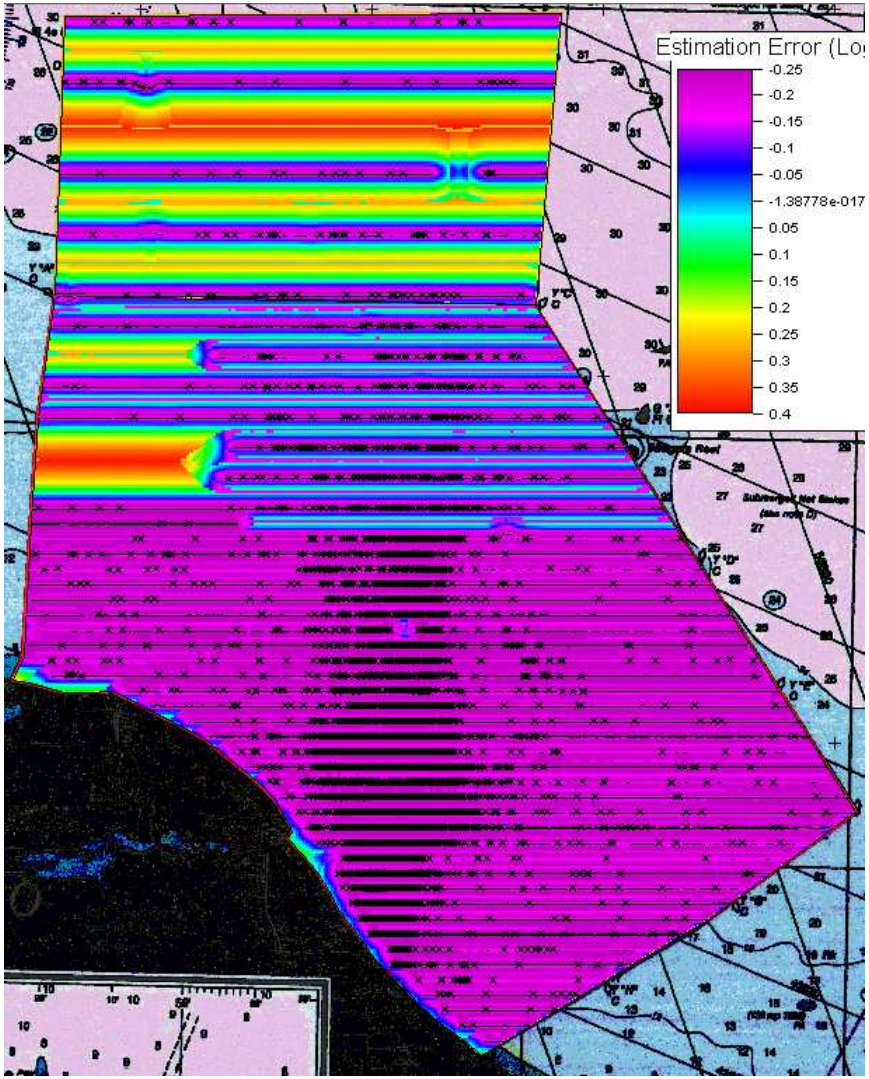


TR Kriging Results





TR Kriging Variance



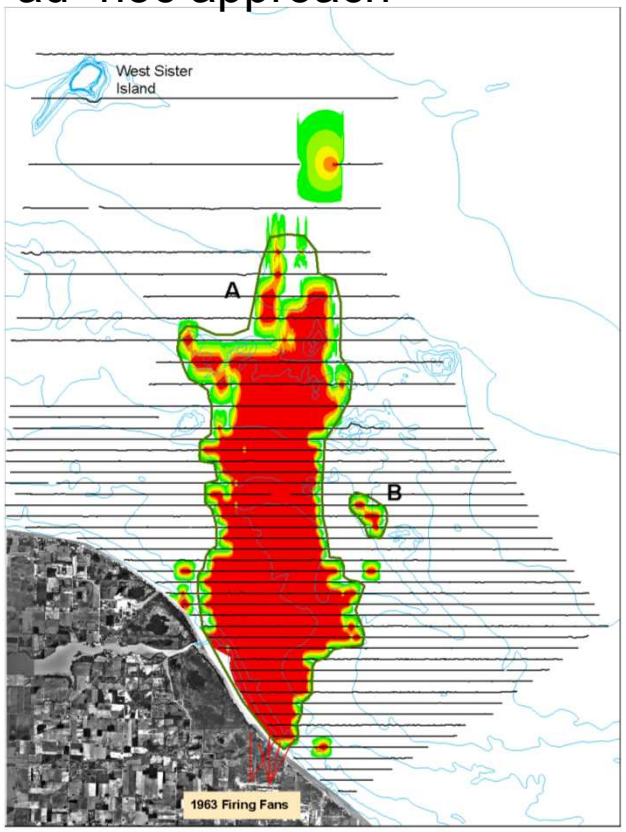
TR: Boundary Delineation

- Four approaches to boundary delineation have been used
  - 1) Ad hoc hand contouring of a map to get features of interest and generally include areas of *high* density
  - 2) Estimate the anomaly density and draw the contour at the anomaly threshold for the target areas
  - 3) Estimate the probability of being within the target areas at all locations and draw select the acceptable (X% chance of false negative decision) probability contour
  - 4) Examine the anomaly count in all the estimated cells and include the cells that encompass X% of all anomalies above background

Choice of delineation approach is generally site-specific depending on regulator and stakeholder input

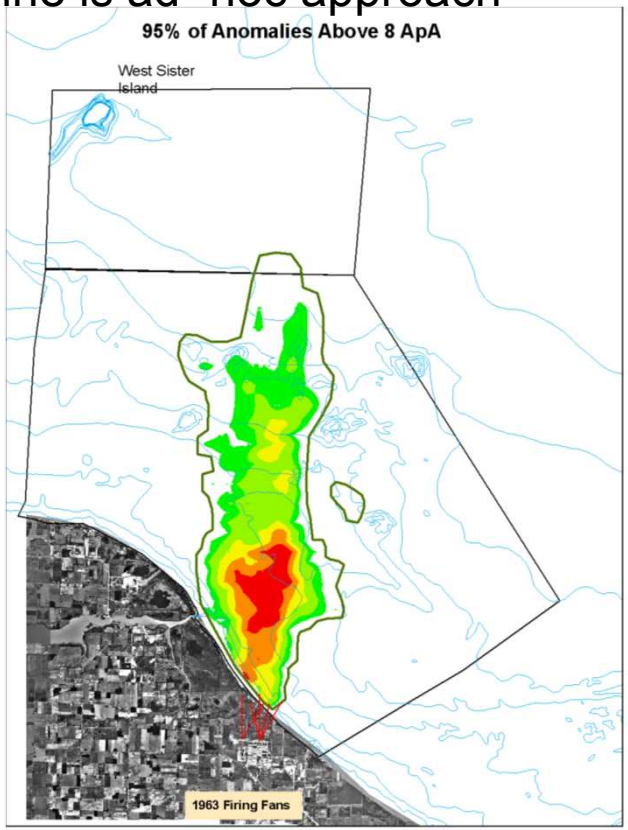
Boundary Delineation Examples

If *Prob(target)* is 5% or greater, the area is colored. Dark line is ad- hoc approach



Background/target threshold is 8 ApA

Colored areas encompass 95% of all estimated anomalies above background. Dark line is ad- hoc approach



Estimated Anomaly Count

Results from boundary delineation using ad-hoc approach

Counts are for the area delineated as a target

	AOI A	AOI B	Total
Area (acres)	12,571	236	12,807
Transect Detected Anomalies	4,683	30	4,713
Kriging Estimated Anomalies	332,447	1,568	334,015
Area > 80 ApA (acres)	755	0	755

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  - Example 1: Pueblo Colorado
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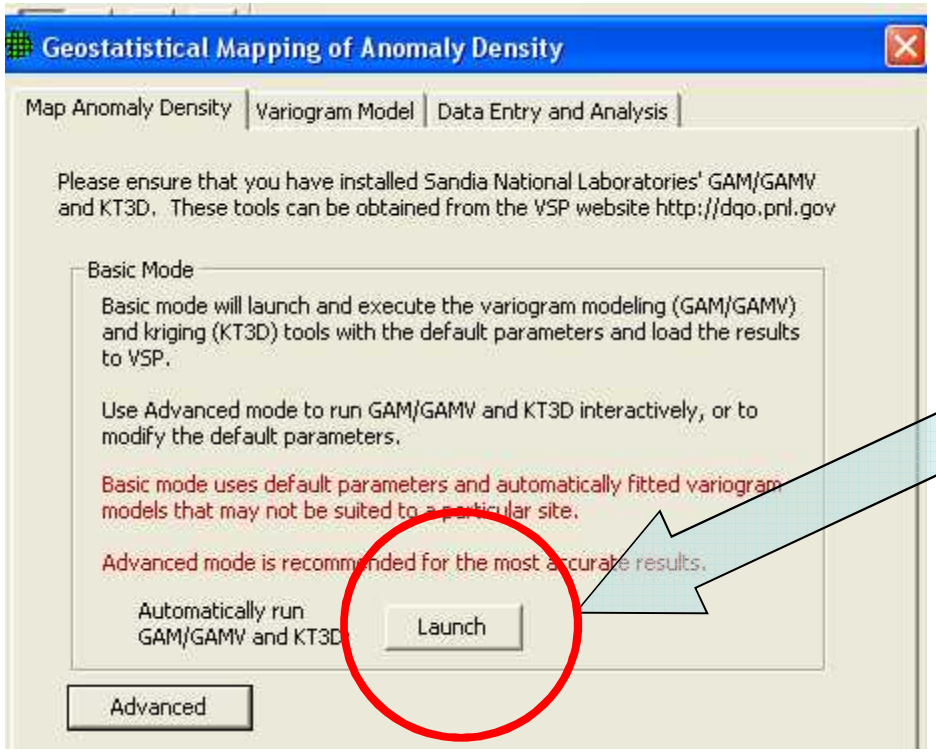
Simple Approach

Sampling Goals

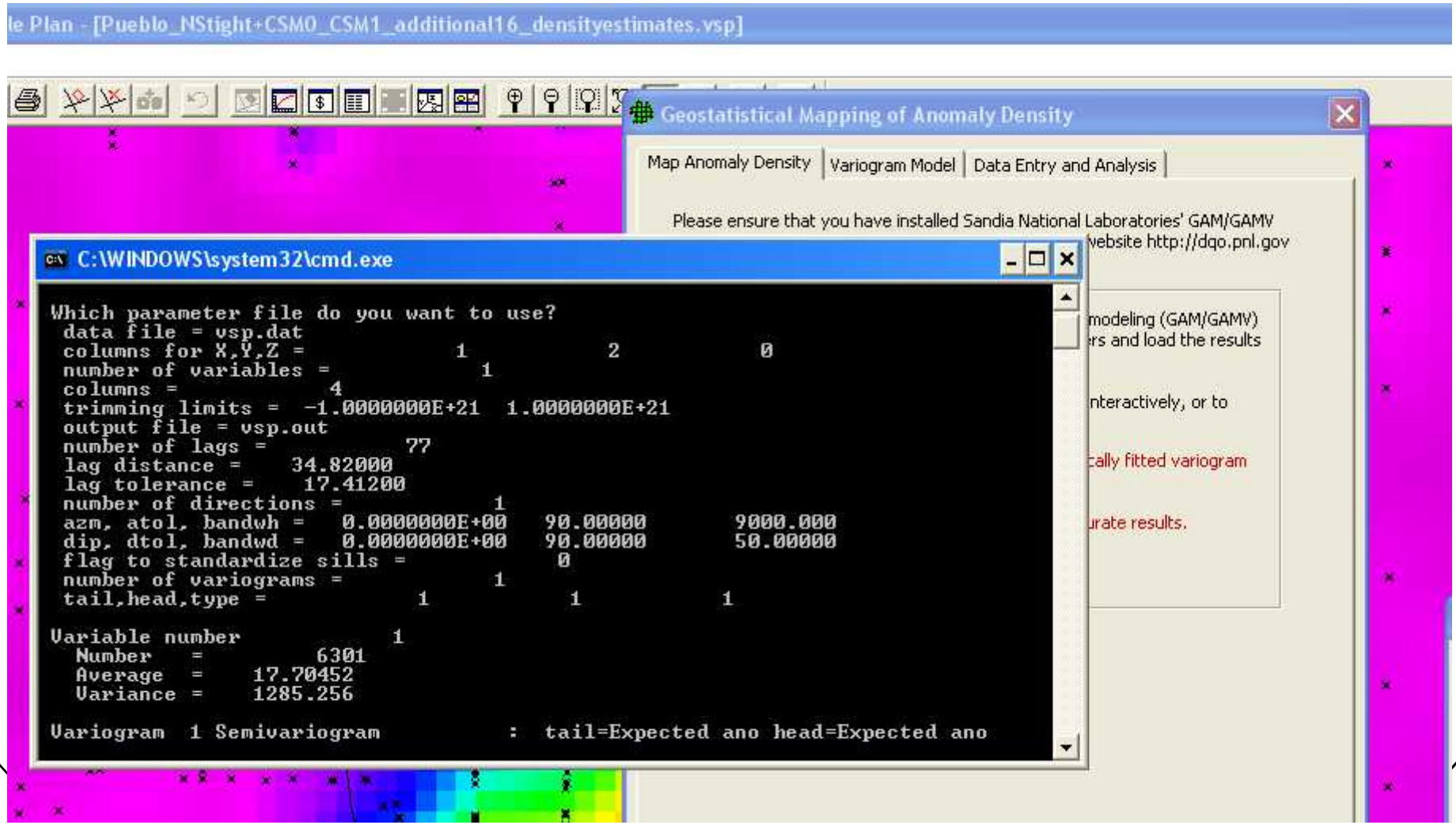
Find UXO Target Areas

Geostatistical Mapping of Anomaly Density . . .

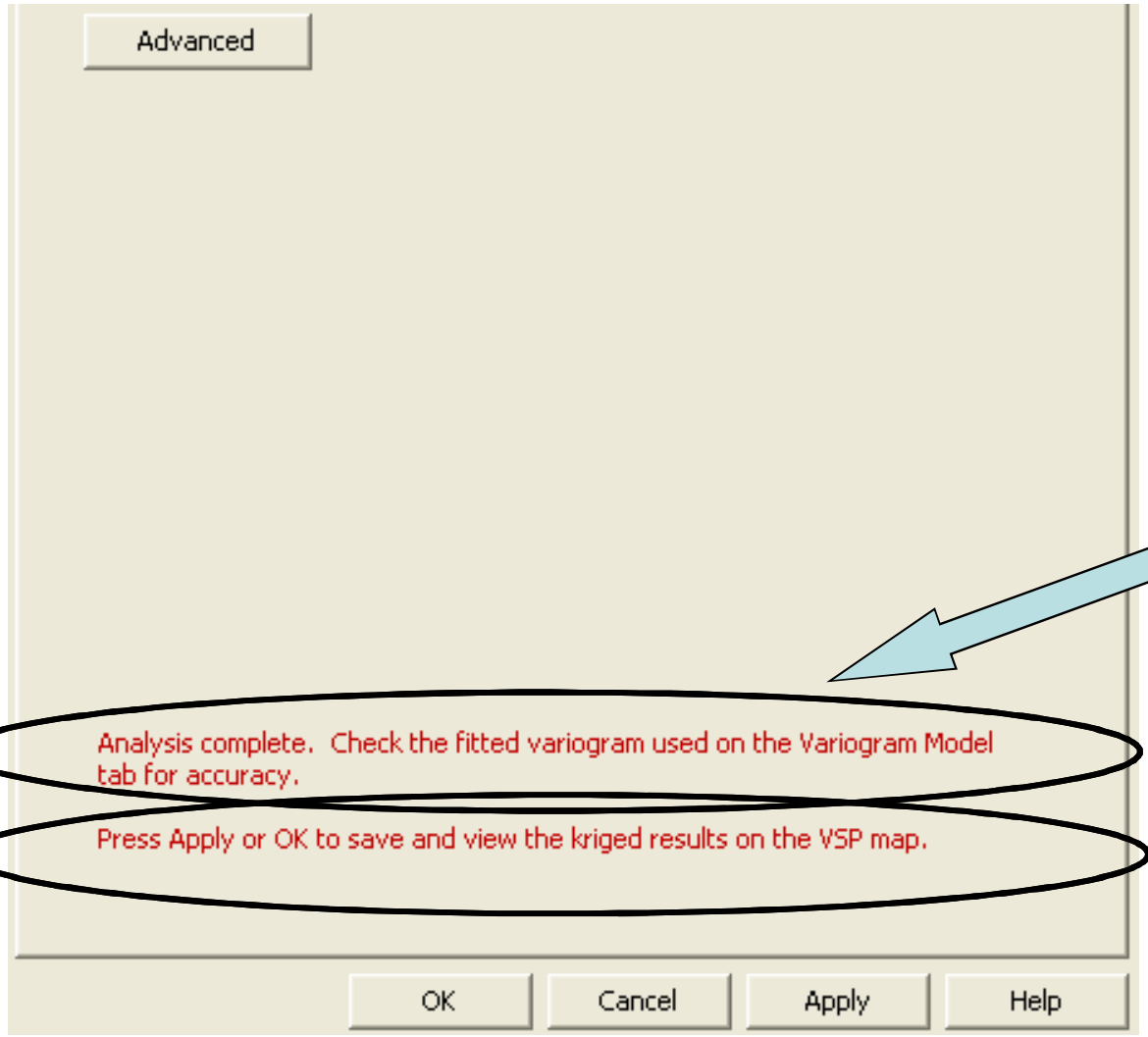


DOS Windows

Two applications are launched in DOS windows one after the other



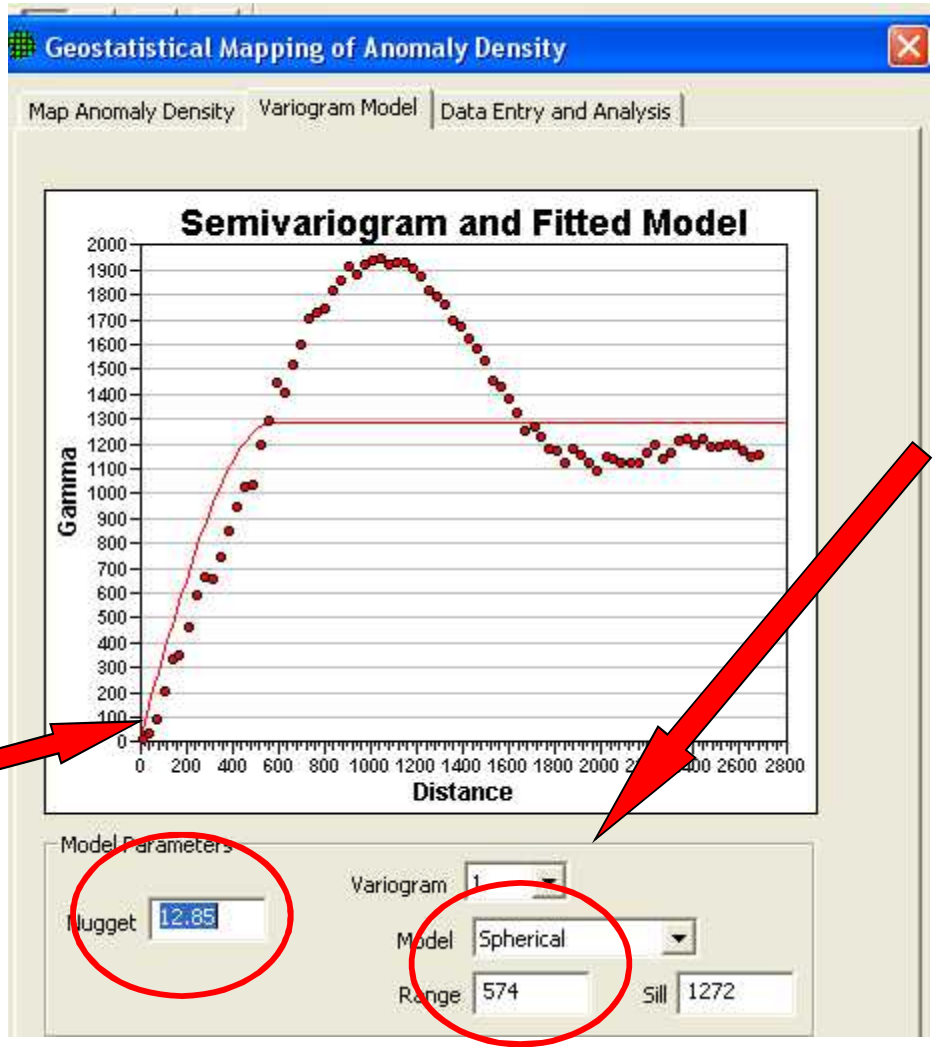
Successful Completion



One check on the automatic process is to check the fit of the variogram model

Final step is to save the results and show the estimated map

Checking Variogram Model



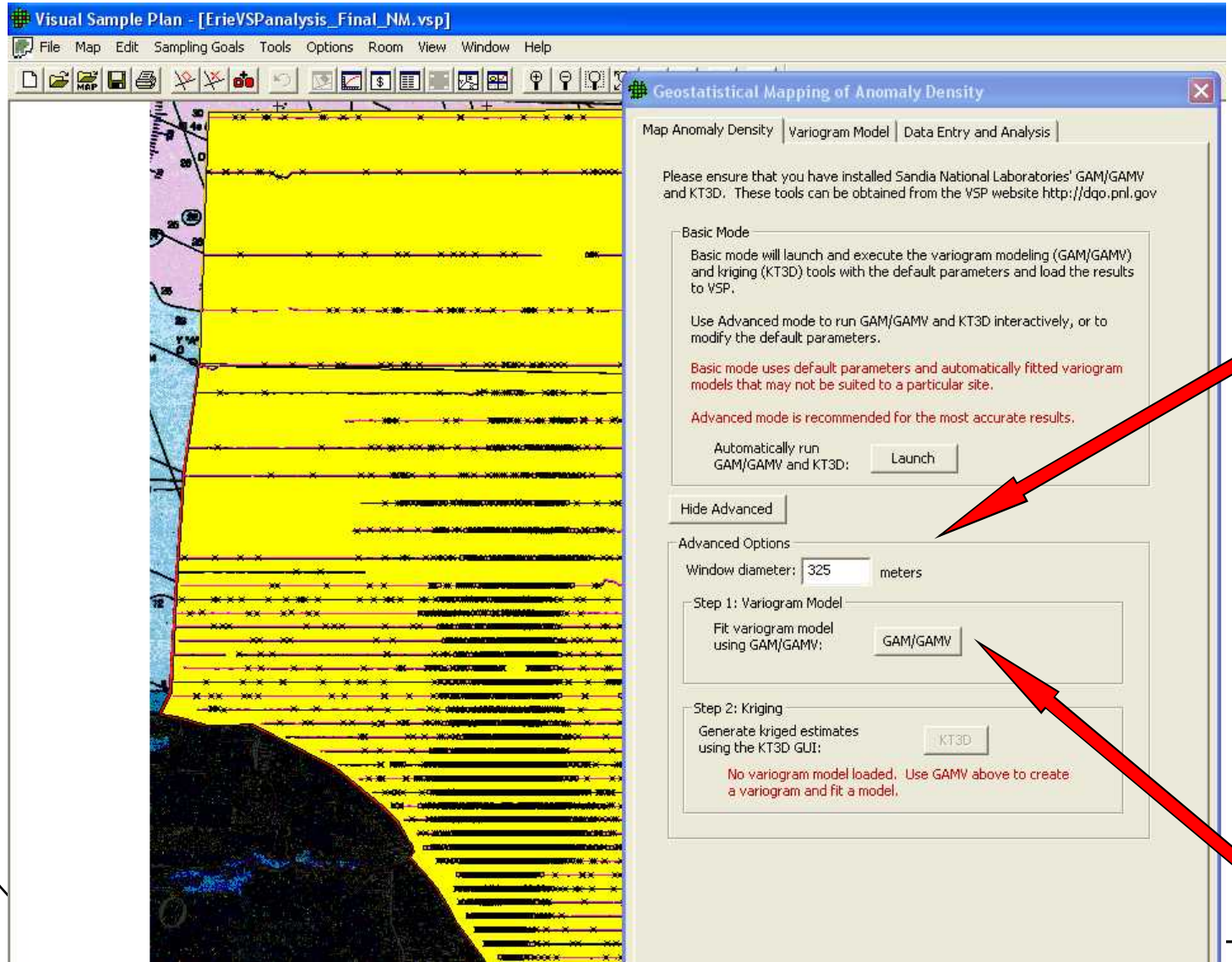
Nugget: Y intercept of variogram

Simple approach fits single model to the data

Spherical model with a range of 574m found to provide best fit

Sill + Nugget = variance of data set

Advanced Approach

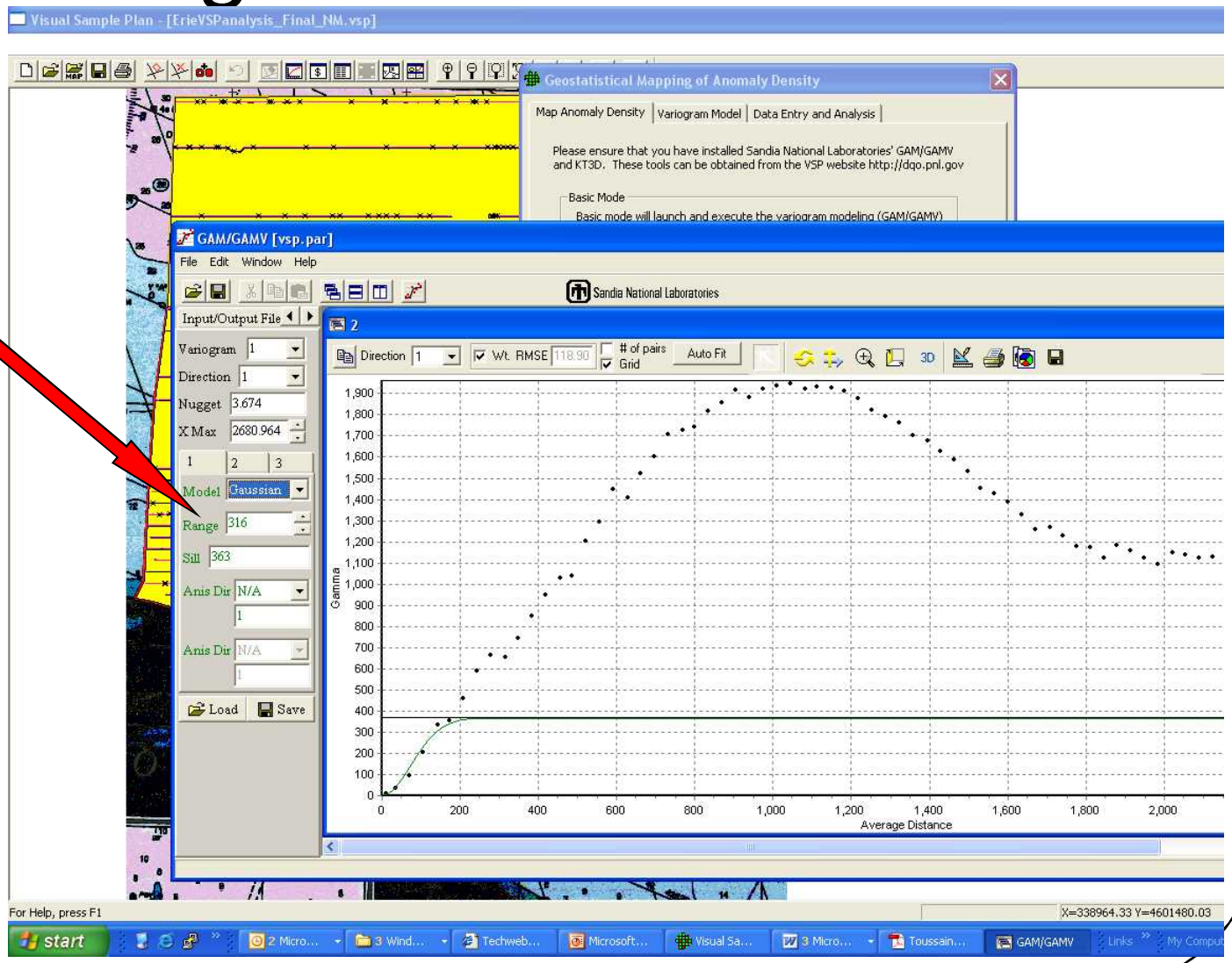


User can change the size of the window diameter for data processing

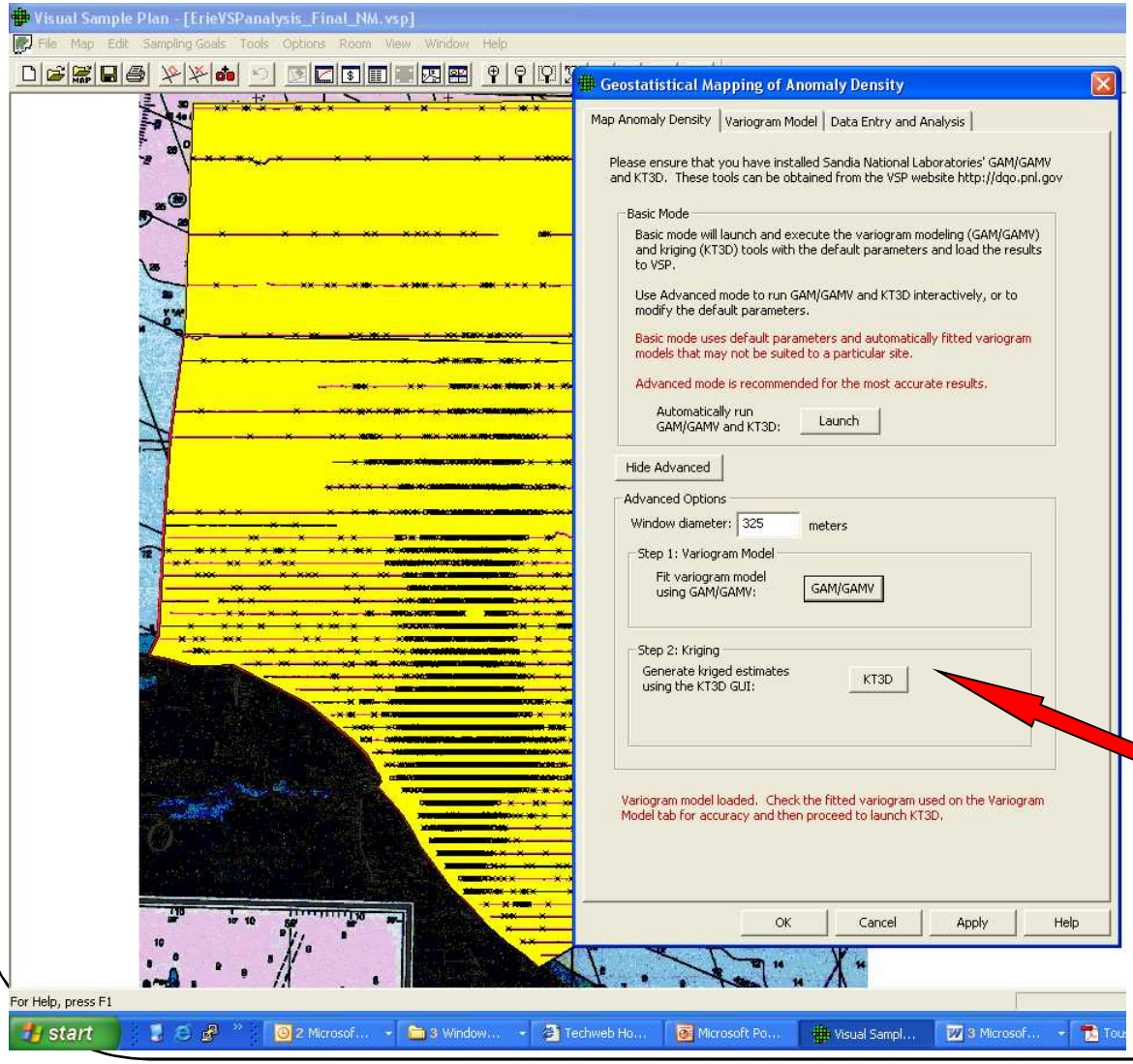
Launch variogram calculation and fitting software

Advanced Mode: Variogram Calculation

Manual adjustments for the variogram model parameters

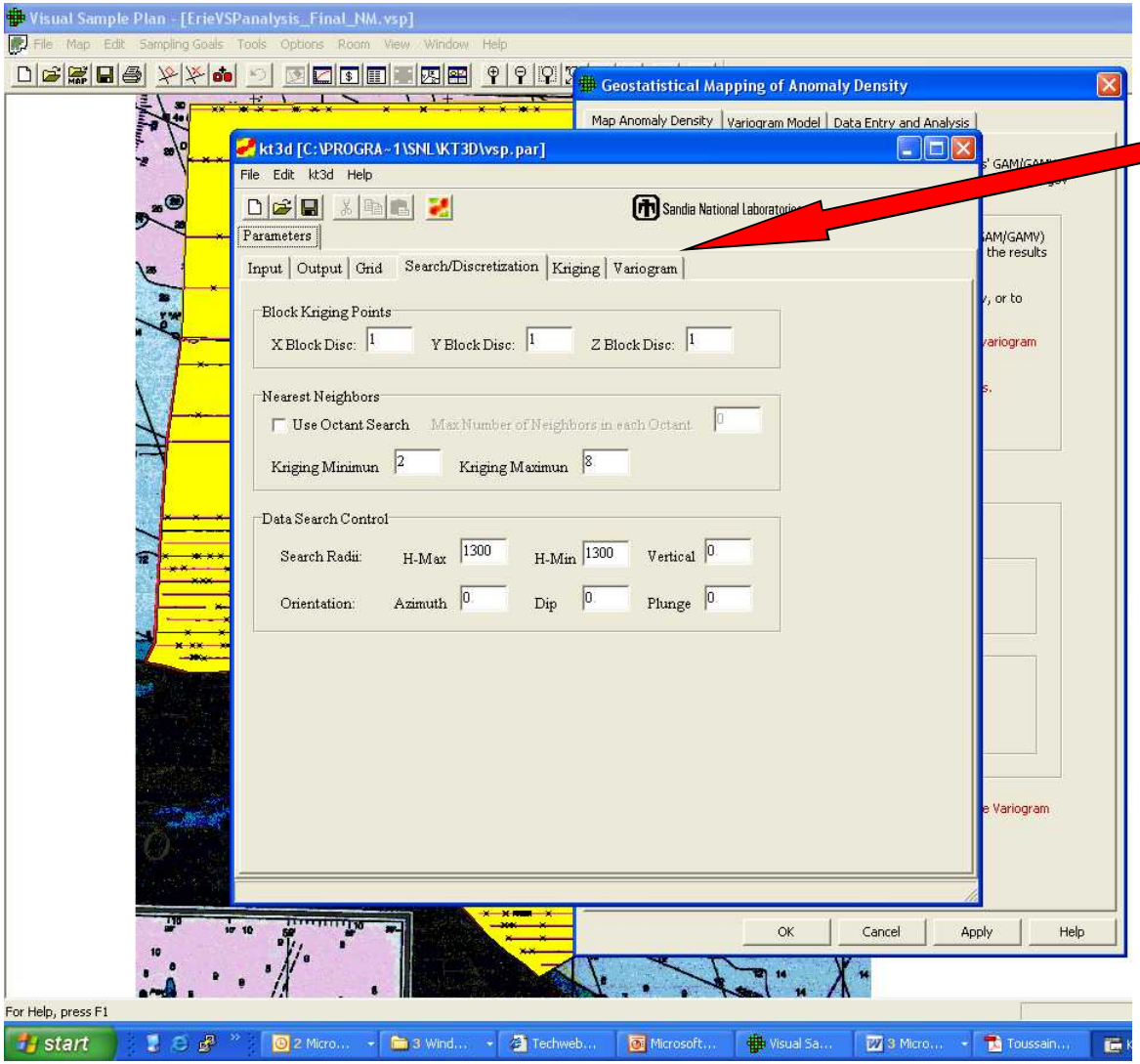


Kriging Start



Kriging button is now activated

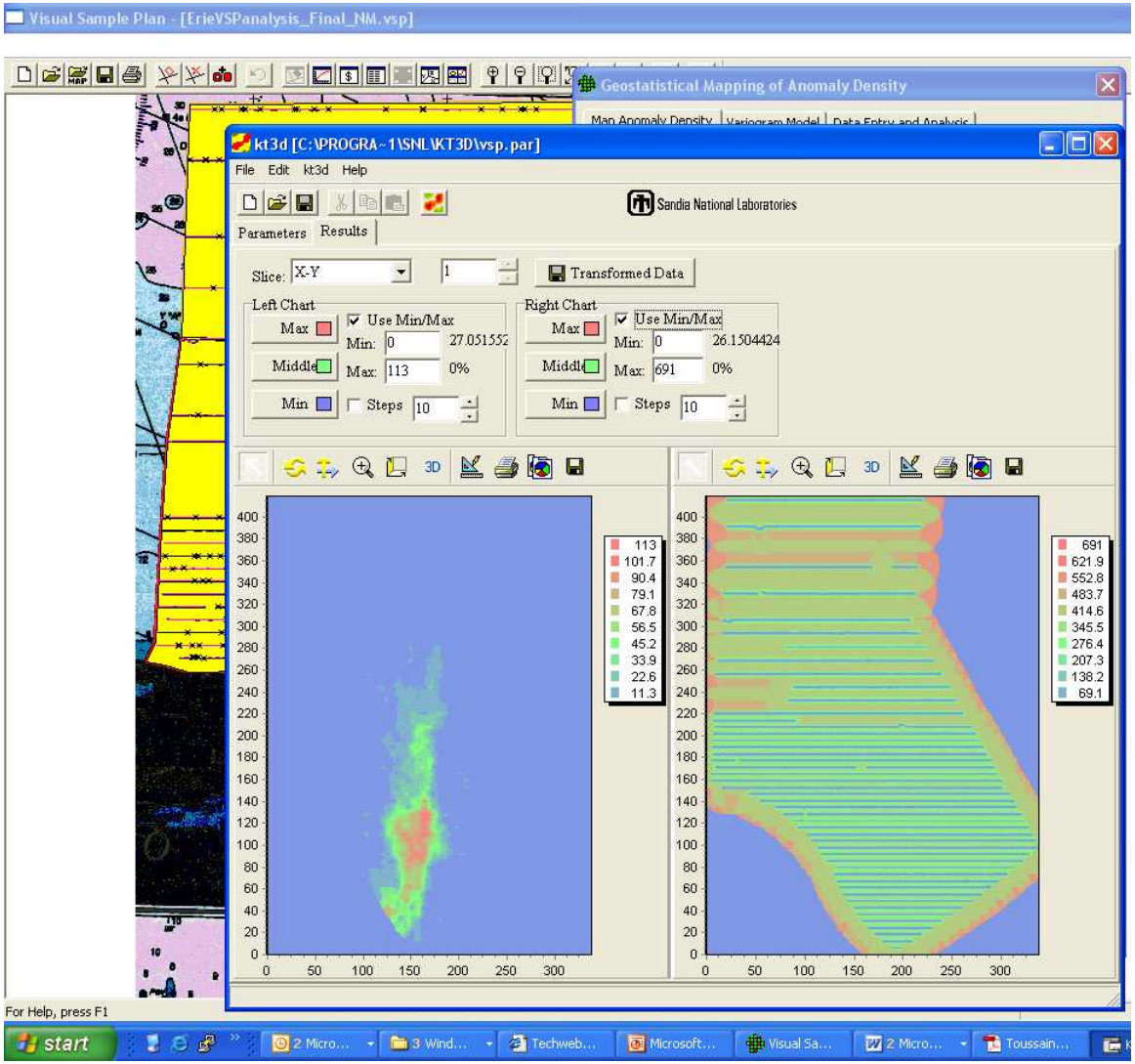
Kriging Options



Tabs allow access to full suite of parameters to control kriging process

Example of search orientation tab

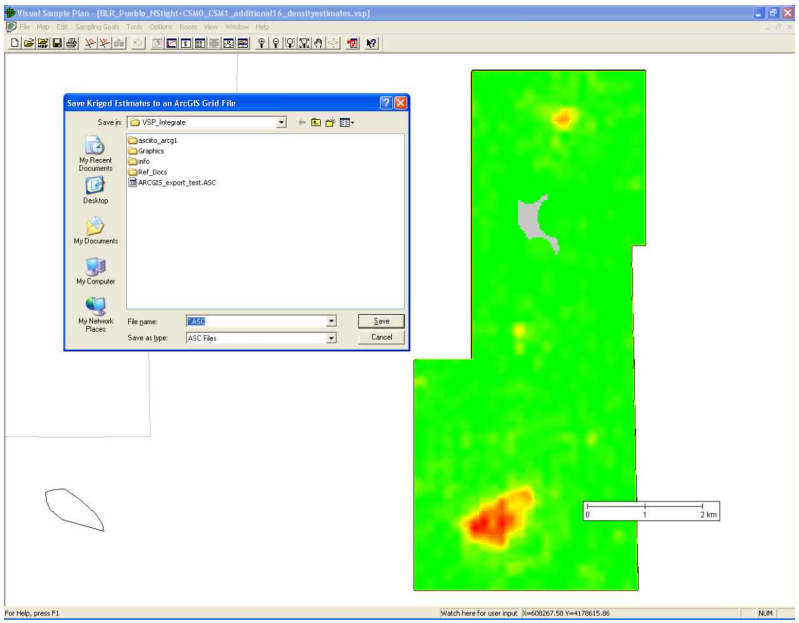
Kriging Output



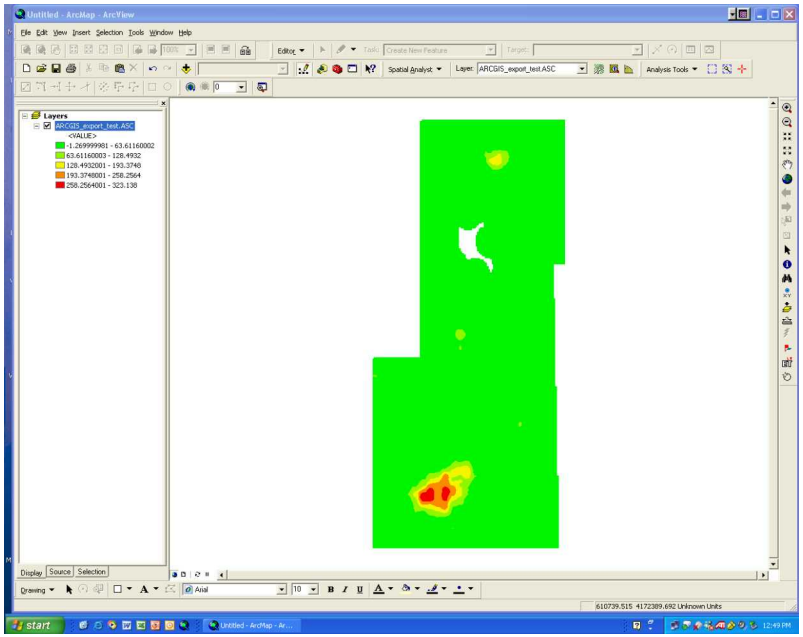
Simple graphical check of results before returning to VSP menu

Exporting From VSP

VSP



ArcGIS 9.2



Kriging results in VSP can be exported to a file directly readable by ArcGIS 9.2

Useful for enhancing graphics and additional analysis

Summary

- Geostatistical tools are used to estimate anomaly density at locations off of transects
- Demonstrated approach on two different sites
- Software tools for variogram and kriging are connected to VSP and provide both easy and advanced applications