ArcGIS™ Geostatistical Analyst: Powerful Exploration and Data Interpolation Solutions

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J-8647

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Contents **Page**

J-8647

Contents **Page**

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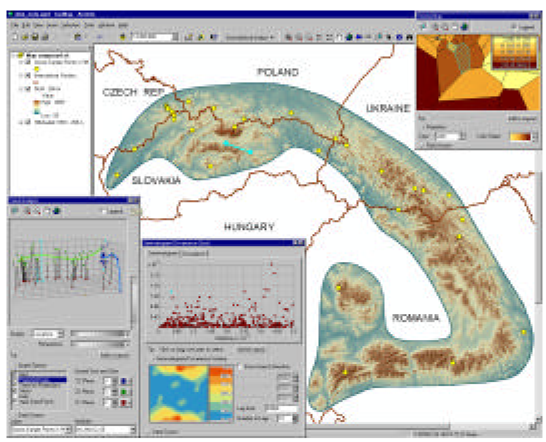
Overview

ESRI® ArcGIS™ Geostatistical Analyst is a new extension to ArcGIS 8.1 (ArcInfo™, ArcEditor™, and ArcView®) that provides a dynamic environment with a wide variety of tools for spatial data exploration, identification of data anomalies, evaluation of error in prediction surface models, statistical estimation, and optimal surface creation. From determining areas of decline to assessing possible environmental risks, Geostatistical Analyst gives anyone with spatial data the freedom to investigate, visualize, and create surfaces in a revolutionary fashion.



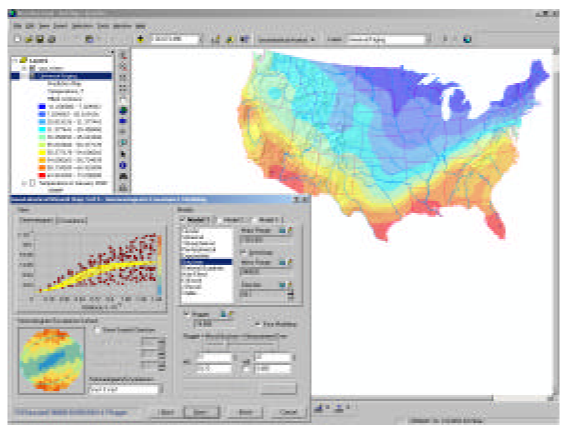
Using a variety of exploratory spatial data analysis tools, we can investigate the properties of ozone measurements taken at monitoring stations in the Carpathian Mountains.

By exploring the data, assessing the best interpolation method, and by utilizing diagnostic techniques, one can successfully and easily create optimal surfaces. From analyzing severity of ozone air pollution to identifying soil contamination, Geostatistical Analyst can be used to create predictive surfaces for many different types of data. Geostatistical Analyst can also create prediction standard error, probability, quantile, and standard error of indicator surfaces.

"In the ArcView 3.x Spatial Analyst, there really weren't many choices for spatial interpolative methods, just spline and inverse distance weighting (which didn't always produce the best outputs). When interpolating natural processes, such as geologic surfaces or groundwater flow, kriging is really the preferred method. The inclusion of more spatial interpolative methods in ArcGIS is a huge feature. Now, to do powerful interpolations of data trends, ArcGIS users no longer have to deal with the preprocessing of data for export to another application…"

Daniel M. Petrecca
Senior Staff Hydrogeologist/GIS Specialist
Langan Engineering and Environmental Services, Inc.

Geostatistical Analyst contains a variety of spatial data analysis tools to assess the optimal interpolation method for the data. Essentially, Geostatistical Analyst combines the freedom of a stand-alone statistics package and the power of geostatistical interpolation processes into one dynamic GIS software for developing quantitative answers to specific questions.



The semivariogram/covariance dialog was used to fit a geostatistical prediction model to winter temperature data for the USA. This model was then used to create the temperature distribution map.

What Does Geostatistical Analyst Do?

Geostatistical Analyst determines the probability of certain variables occurring over an area where identifying every possible location would be impossible. For example, in California, air quality monitoring stations are set up around the State. These measure the amount of particulates in the air and how harmful they are to surrounding areas. Geostatistical Analyst can determine the approximate amount of particulates in the area of interest and can also determine where these particulates may be moving by creating an interpolated surface. Geostatistical Analyst introduces a powerful exploration environment and a multitude of interpolation methods with advanced analytical tools for optimal surface creation.

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Who Uses Geostatistical Analyst?

Geostatistical Analyst is a flexible software package that allows any user with geostatistical data to analyze peculiarities, explore data, and interpolate surfaces. Geostatistical data is essentially data that is spatially continuous. Some of the various fields that utilize Geostatistical Analyst include environmental, agriculture, exploration, geology, meteorology, hydrology, archaeology, forestry, health care, mining, and real estate.

"I work in the environmental side where our services include hydrogeologic, geologic, and geochemical characterizations and remedial investigations of contaminated or potentially contaminated properties. Our clients include utilities, chemical companies, petroleum companies, and basically anyone that has been fortunate enough to have toxic substances on their site. So, we use the Geostatistical Analyst to interpolate many things:

- Site stratigraphy and geologic surfaces from borehole logs
- Groundwater surfaces and flow from water elevation data
- Extent of contamination from chemical analysis of soil and water samples
- Topography from spot elevations
- Trends in other field data measurements (e.g., ground penetrating radar and electromagnetic metal detector data)"

Daniel M. Petrecca
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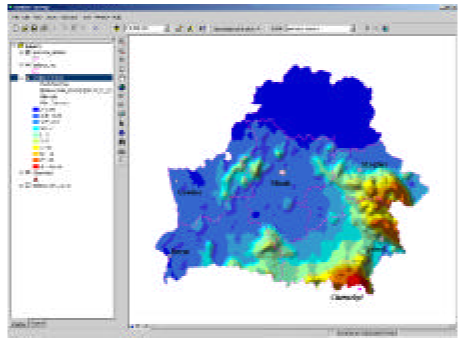
Why Use Geostatistical Analyst?

Geostatistical Analyst creates accurate continuous surfaces from measured samples. This allows prediction of where a certain phenomenon may occur by utilizing sample data. From analyzing real estate decline to assessing the movement of biohazard materials through a meandering stream, Geostatistical Analyst provides unique interpolation tools for the user's predictive needs. Not only are interpolated surfaces created, but also a wide range of analytical and exploratory tools are incorporated to extract useful information from the data. This allows users to solve complex problems over areas where it is not economically feasible to accumulate real data. Geostatistical Analyst provides a cost-effective, logical solution for analyzing a variety of data sets that would otherwise cost an enormous amount of time and money to accomplish.

Saves Lives

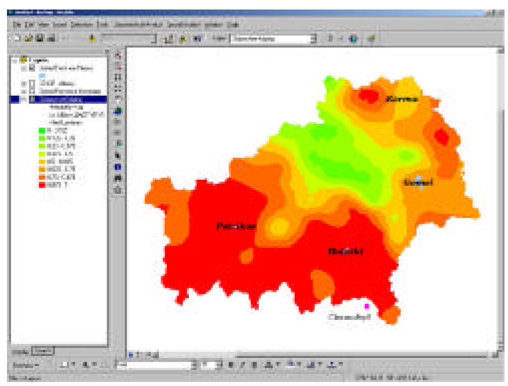
Geostatistical Analyst can assess potential environmental hazards by interpolating the possible flow and direction of radiation, air pollution, biohazard releases, aquifer contamination, and any potentially harmful waste that may be introduced into areas of human habitation.

For example, Geostatistical Analyst was used to interpolate the intensity and direction of the hazardous radiation that resulted from the Chernobyl accident. Cases of thyroid cancer, soil radionuclides, and food contamination were a few of the variables used to estimate the severity of the Chernobyl accident on the surrounding areas.



This map illustrates predicted radioceasium soil contamination levels in the country of Belarus after the Chernobyl nuclear accident in 1994.

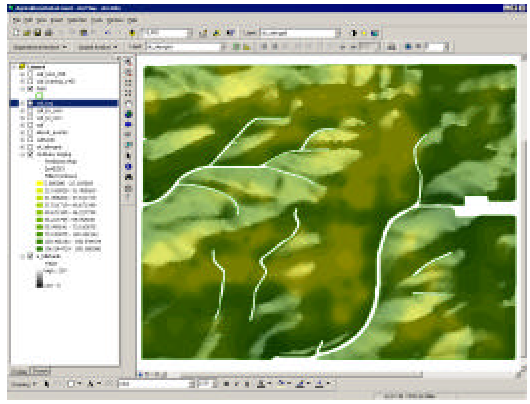
By utilizing Geostatistical Analyst, areas that have received environmental contamination can be indicated to ultimately prevent exposure to health risks.



In this example, locations shown in dark orange and red indicate a probability greater than 62 percent that radioceasium contamination exceeds the upper permissible threshold in forest berries in the southern part of Belarus in 1993.

Increases Efficiency

Geostatistical Analyst provides users with the capability to predict optimal conditions for lucrative and more reliable production. For example, a corn farmer can utilize Geostatistical Analyst to determine why crop yields in a certain area of his farm are below potential. Then crop rotations, extra fertilizer, enhanced irrigation techniques, and so forth, can be applied to the declining area. Profits can be enhanced by igniting growth in these defined stagnant areas. Geostatistical Analyst provides efficient interpolation methods for predicting and calculating areas of potential growth and or areas of decline.



By interpolating the amount of phosphorous in the soil throughout this farm in Illinois, we can effectively allocate fertilization for future crops.

Multiple Tools for Data Representation

Geostatistical Analyst is integrated into ArcMap™, and the user can take advantage of the multitude of tools to dynamically represent numerous data types. With the display tools, the user can create fine cartographic outputs and explore or analyze data to gain greater insights in order to make more effective decisions. Visualization is particularly important when using Geostatistical Analyst because, through these insights, better models are built and more accurate surfaces are created.

Exploratory Environment for Data Investigations

The more the user understands about the phenomenon being investigated the better the surface produced from the sample points will be. Geostatistical Analyst provides a full suite of Exploratory Spatial Data Analysis (ESDA) tools to explore the data. Each tool provides a view of the data in a separate window, and each tool is linked to each other and with the map. The ESDA tools allow the user to explore the distribution of the data, identify local and global outliers, look for global trends in the data, and understand the spatial structure in the data.

Wizard-Driven Interface for Fast Efficient Interpolation Processes

Geostatistical Analyst provides a friendly wizard-driven environment that guides the user through the interpolation process. By selecting the input data and the interpolation method and following the wizard instructions, a surface is instantly created for the data. It is recommended that the user analyze the data with the ESDA tools provided first to accurately assess which interpolation model is best for the data.

"With Geostatistical Analyst, you get to adjust the interpolation methods and parameters and see a preview of the surface in real time as the changes are made in the wizard. So, once the final methods and parameters are determined, the surface is created once as a layer."

Daniel M. Petrecca
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Perform Diagnostics

After creating a prediction surface, it is important to identify how scientifically sound the model is. Geostatistical Analyst provides cross-validation and validation tools that allow the user to evaluate the model and predictions. The tools quantify the statistical significance of the model and the model can be changed by refining the parameters.

Geostatistical Analyst also provides the user with comparative tools for choosing the best interpolated surface for the data. These tools are provided so that the user can quantify the predictions based on one model relative to another. By visually analyzing the prediction errors of the different models, the optimal model can be utilized.

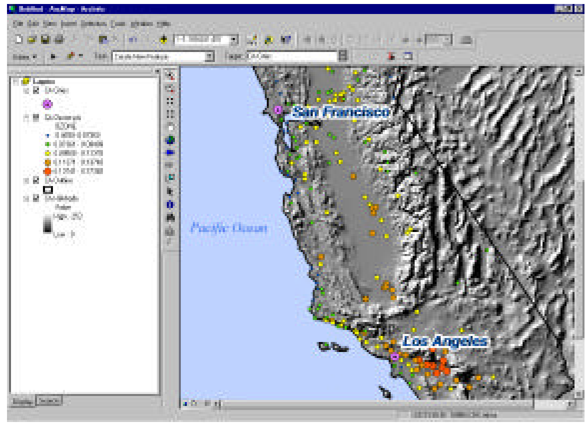
Working with Your Data

There are four basic steps to creating an optimal interpolated surface.

- Represent the data.
- Explore the data.
- Fit a model.
- Perform diagnostics.

Represent the Data

There are many different tools for visualizing the data, which provides a great deal of information before creating a surface. By visualizing the data, useful information such as inferences from oceans, elevation, roads, and polygon edges can be acquired. Representing the data is a vital first step in assessing the validity of the data and identifying external factors that may ultimately play a role in the distribution of data.

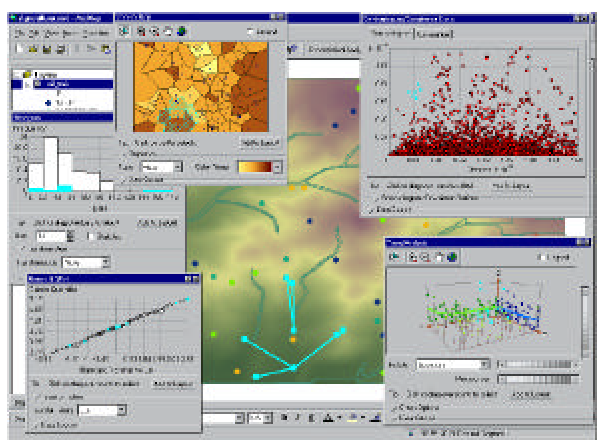


In this display we can notice that elevation and coastal influences play a role in the severity of air pollution in California.

Explore the Data: Exploratory Spatial Data Analysis

The ESDA environment is designed to explore. There are certain tasks that are useful in most explorations. Exploring the distribution of the data, looking for global and local outliers, looking for global trends, examining spatial autocorrelation, and understanding the covariation among multiple data sets are all useful tasks to perform on the data. The ESDA tools can assist the user with these tasks as well as many others. ESDA is a powerful set of exploratory tools for determining which geostatistical interpolation method is appropriate for the data.

The views in ESDA are selectively interactive with ArcMap. Data selected or highlighted with these tools will also be selected or highlighted in ArcMap. This provides the user with a unique capability to visually explore the data.



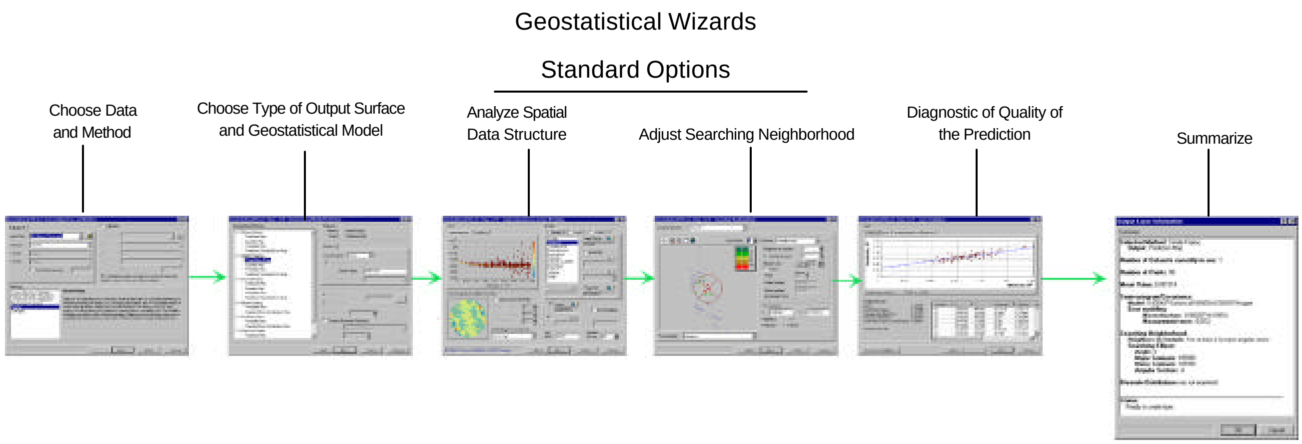
With brushing, all data points that are selected in the ESDA tools are also selected in the display for analysis.

Fit a Model

Once the user has thoroughly explored the data to assess the proper interpolation method, Geostatistical Analyst provides a wizard that makes the interpolation process easy. A wide variety of interpolation methods for creating surfaces are available.

There are two main groupings of interpolation techniques, deterministic and geostatistical. The deterministic interpolation technique is used for creating surfaces from measured points based on either the extent of similarity (e.g., inverse distance weighted [IDW]) or the degree of smoothing (e.g., radial basis functions). The geostatistical interpolation technique is based on statistics and is used for more advanced prediction surface modeling that also includes errors or uncertainty of predictions.

Depending on the method, the following output surfaces can be produced: the prediction, prediction standard error (uncertainty), quantile, probability, or standard error of indicators. Geostatistical Analyst gives the user full control over the parameters of the associated models and reliable defaults are provided.



The geostatistical wizard guides the user through the interpolation process. Standard options are shown and a wide variety of analytical tools, such as detrending, declustering, and transformations, are also included.

Deterministic Methods

- Inverse Distance Weighted
- Global Polynomial
- Local Polynomial
- Radial Basis Functions

Deterministic interpolation techniques can be divided into two groups: global and local. Global techniques calculate predictions using the entire data set. Local techniques calculate predictions from the measured points within specified neighborhoods, which are smaller spatial areas within the larger study area. Geostatistical Analyst provides the global polynomial as a global interpolator and the IDW, local polynomials, and radial basis functions as local interpolators.

An interpolation can either force the resulting surface to pass through the data values or not. An interpolation technique that predicts a value identical to the measured value at a sampled location is known as an exact interpolator. An inexact interpolator predicts a value at a sampled location that is different from the measured value. The latter can be used to avoid sharp peaks or troughs in the output surface. IDW and radial basis functions are exact interpolators, while global and local polynomial are inexact.

Geostatistical Methods

- Kriging and Cokriging
  - Algorithm
    - Ordinary
    - Simple
    - Universal
    - Indicator
    - Probability
    - Disjunctive
- Output Surfaces
  - Prediction and prediction standard error
  - Quantile
  - Probability and standard error of indicators

Geostatistical techniques create surfaces incorporating the statistical properties of the measured data. Because geostatistics is based on statistics, these techniques produce not only prediction surfaces but also error or uncertainty surfaces, giving the user an indication of how good the predictions are.

Kriging is divided into two distinct tasks: quantifying the spatial structure of the data and producing a prediction. Quantifying the spatial data structure, known as variography, is where the user fits a spatial-dependence model to the data. To make a prediction for an unknown value for a specific location, kriging will use the fitted model from variography, the spatial data configuration, and the values of the measured sample points around the prediction location. Geostatistical Analyst provides many tools to help determine which parameters to use, and defaults are also provided so that a surface can be created quickly.

Many methods are associated with geostatistics but they are all in the kriging family. Ordinary, simple, universal, probability, indicator, and disjunctive kriging along with the multivariate versions in cokriging are available in Geostatistical Analyst.

Kriging

Kriging is a moderately quick interpolater that can be exact or smoothed depending on the measurement error model. It is very flexible and allows the user to investigate graphs of spatial autocorrelation. Kriging uses statistical models that allow a variety of map outputs including predictions, prediction standard errors, standard error of indicators, and probability. The flexibility of kriging can require a lot of decision making. Kriging assumes the data comes from a stationary stochastic process, and some methods assume normally distributed data.

Cokriging

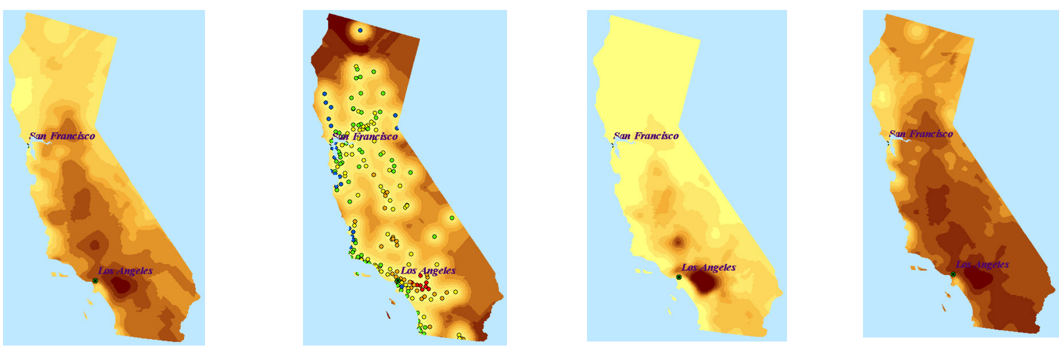
Cokriging is the multivariate equivalent to kriging. By using multiple data sets it is a very flexible interpolation method, allowing the user to investigate graphs of cross-correlation and autocorrelation. The flexibility of cokriging requires the most decision making. Cokriging can use either semivariograms or covariances. It can use transformations and remove trends, and it can allow for measurement error in the same situations as for the various kriging methods.

Output Surfaces

There are four interpolation surfaces available with Geostatistical Analyst. These are prediction, quantile, probability of exceeding thresholds, and errors of predictions. These allow the user to analyze the data in a variety of ways.

- **Prediction map:** Produced from the interpolated values.
- **Error of predictions map:** Produced from the standard errors of interpolated values or the standard error of interpolated indicator values.
- **Quantile map:** Produced when you specify a probability and you want a map of the values where predictions exceed (or do not exceed) the values at the specified probability.
- **Probability map:** Produced when you specify a threshold and you want a map of probabilities that the values exceed (or do not exceed) the specified threshold.

Prediction | **Error of Predictions** | **Probability** | **Quantile**



Various Surfaces Produced Using Ordinary Kriging

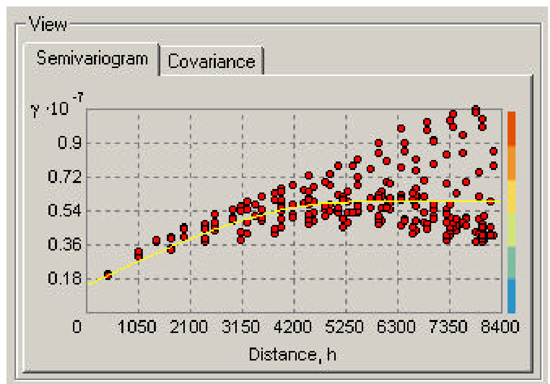
Analytical Tools for Creating Surfaces

Geostatistical Analyst provides a series of dialog boxes containing analytical tools to assist you in determining the values for the parameters specified. Some of these dialog boxes and tools are applicable to almost all interpolation methods such as specifying the search neighborhood, cross-validation, and validation. Others are specific to the geostatistical methods (kriging and cokriging) such as modeling semivariograms, transformations, detrending, declustering, and checking for bivariate normal distributions.

Investigation of Spatial Data Structure: Variography

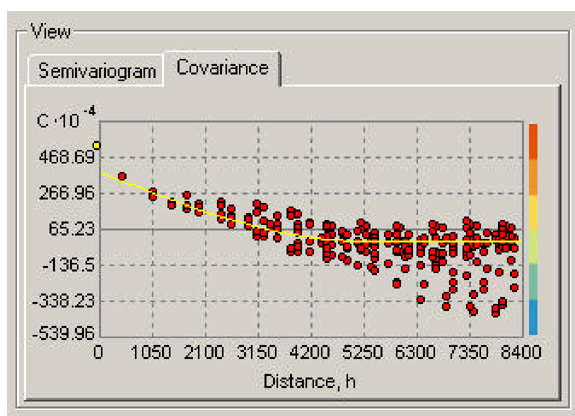
The semivariogram and covariance functions measure the strength of statistical correlation as a function of distance. Geostatistical Analyst provides you with a semivariogram/covariance preview. This makes adjusting the parameters of the model, including anisotropy and modeling measurement errors, friendly and more efficient.

- The semivariogram displays the statistical correlation of nearby data points. As the distance increases, the likelihood of these data points being related becomes smaller.



The variance of the difference increases with distance, so the semivariogram can be thought of as a dissimilarity function.

- When two locations are close to each other, then we expect them to be similar and so their covariance will be large. As the locations get farther apart, they become less similar and so their covariance becomes zero.



The autocorrelation decreases with distance, so the covariance can be thought of as a similarity function.

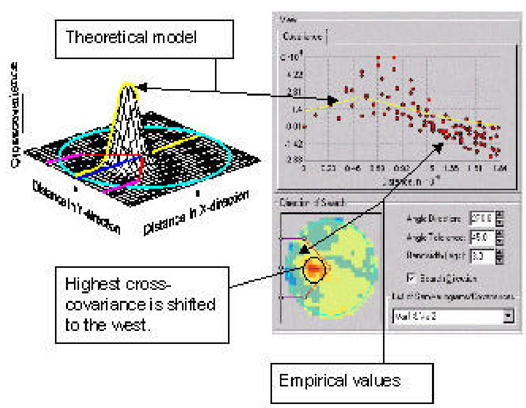
- Error Modeling.

Regardless of the interpolation method there will always be some error in the analysis. This error can be influenced by many factors such as data contamination, variation in physical properties of data samples, human error, and temporal changes between measurements. All of these factors play a role in the severity of the measurement errors. Error modeling is used to minimize the effect of these measurement errors. When measurement error is specified, kriging is an inexact interpolation technique. Therefore, predictions in the measurement locations are different from the actual measurements. Geostatistical Analyst allows you to adjust the measurement error to optimize the error model. For coincidental data (multiple measurements at one location) Geostatistical Analyst can estimate measured variation for the user. Three of the kriging methods—ordinary, simple, and universal—allow the use of the measurement error model.

- Cross-Covariance.

Cross-covariance is the statistical tendency of variables of different types to vary in ways that are related to each other. Positive cross-covariance occurs when both variables tend to be above their respective means together, and negative cross-covariance occurs if one variable tends to be above its mean when the other variable is below its mean.

When you have multiple data sets and you want to use cokriging, then you need to develop models for cross-covariance.

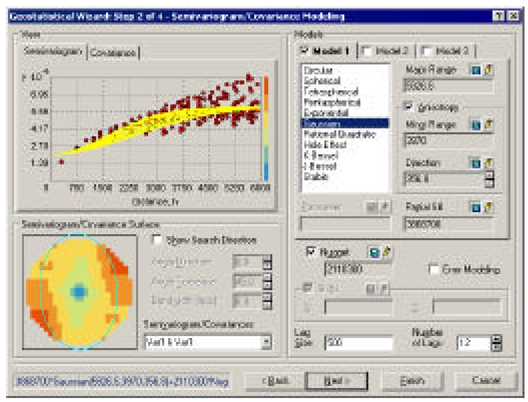


Cross-covariance modeling is used to define the local characteristics of spatial correlation between two data sets and used to look for spatial shifts in cross-correlation between two data sets. In this example, there is a strong spatial shift in the values of two data sets toward the west.

- Anisotropy: Directional semivariogram and covariance functions.

Anisotropy is similar to global directional trends except that the cause of the directional influence is not usually known and it is modeled as a random error. Anisotropy is a characteristic of a random process that shows higher autocorrelation in one direction than another. Even without knowing the cause, anisotropic influences can be quantified and accounted for.

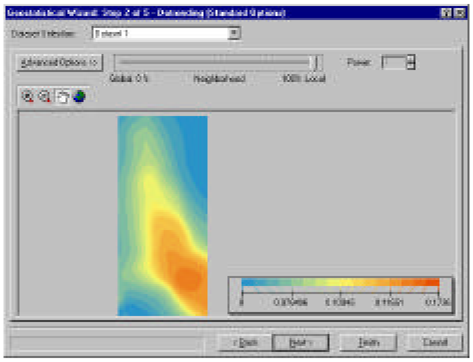
An isotropic model reaches the level at which the semivariogram levels off (sill) at the same distance all directions. However, with an anisotropic model, some directions reach the sill more rapidly than others.



The yellow lines show the semivariogram models for many different directions. The models are a theoretical "best fit" semivariogram model to the empirical semivariogram. Geostatistical Analyst automatically calculates the optimum parameters (e.g., the major range, minor range, and angle of direction) to account for the anisotropic influence.

Detrending Tools

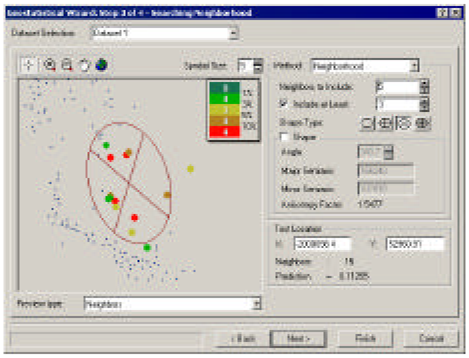
Sometimes it is useful to remove a surface trend from the data and use kriging or cokriging on the detrended (residual) data. Detrending decomposes data into a deterministic trend component and autocorrelated random component. Once the trend is removed, the user will carry out kriging on the residuals. Before the final predictions are actually calculated, the trend is added back to the output surface.



Detrending decomposes your data into a deterministic trend component and an autocorrelated random component.

Search Neighborhood Specification

As the data locations become farther away from a location where the value is unknown, they may not be as useful when predicting the value at an unmeasured location. At some distance, the points will have no correlation with the prediction location, and it is possible that they may even be located in an area much different than the unknown location. Therefore, it is common practice to specify a search neighborhood that limits the number and the configuration of the points that will be used in the predictions. There are two controlling mechanisms to limit the points used, namely, specifying the shape of the neighborhood and establishing constraints on the points within and outside the shape.

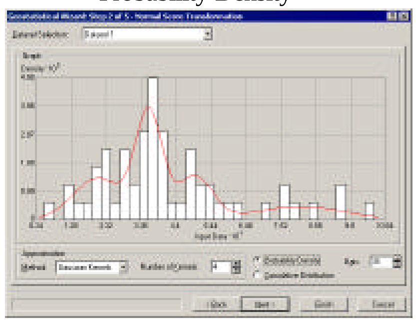


The points highlighted in the data view give an indicator of the weights (absolute value in percent) associated with each point located in the moving window. The weights are used to estimate the value at the unknown location, which is at the center of the crosshair.

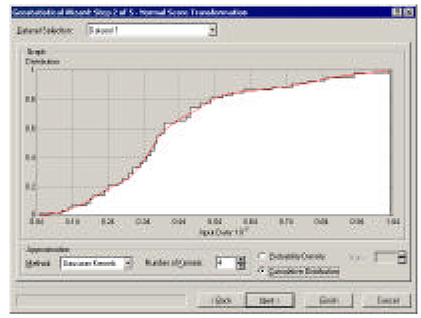
Data Transformations

Transformations can be used to make the data more normally distributed and satisfy assumptions of constant variability. Data transformations are performed before using some geostatistical methods such as disjunctive kriging and for maps that require the normality assumption. Quantile and probability maps from simple, ordinary, and universal kriging methods require the normality assumption. Geostatistical Analyst supports transformations including Box–Cox (also known as power transformations), logarithmic, arcsine, and normal score.

Probability Density



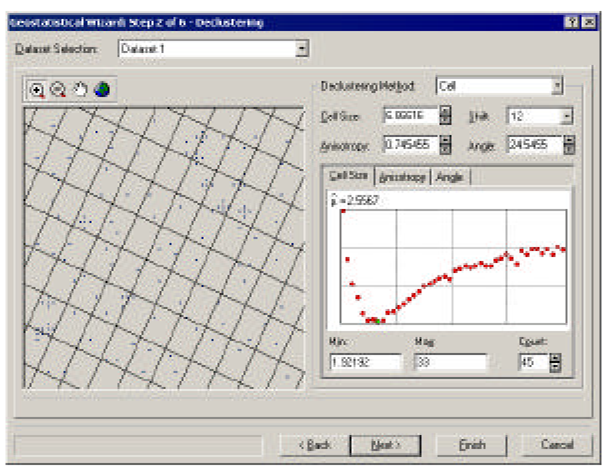
Cumulative Distribution



Using transformations makes variances constant throughout your study area and makes the data more normally distributed.

Declustering Method

Oftentimes the data may have a high density of sample points near one another. This may lead to a spatial preferentiality among your data points. If data is preferentially sampled when it is spatially autocorrelated, the resulting histogram from the sample may not reflect the histogram of the population. Therefore, the declustering method assigns higher weights to the less densely populated sample points and lower weights to the high density areas.

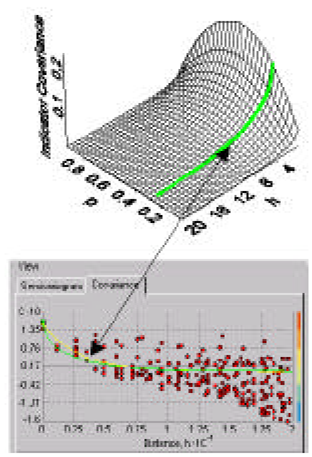


In cell declustering, rectangular cells are arranged over the data locations in a grid, and the weight attached to each data location is inversely proportional to the number of data points in its cell. By adjusting the grid size and orientation, the data points can be effectively declustered.

Bivariate Normal Distribution

Disjunctive kriging requires that the data have a bivariate normal distribution. Also, to develop probability and quantile maps using simple kriging, ordinary kriging, and universal kriging, we assume that the data comes from a full multivariate normal distribution. By checking for bivariate normality, it is reasonable to assume that the data comes from a full multivariate normal distribution.

Bivariate Normal Distribution



The green line is the theoretical curve of indicator covariance assuming the data comes from a bivariate normal distribution, and the yellow line is fitted to the observed indicator data. Thus, the green line and the yellow line should be similar if the data has a bivariate normal distribution.

Perform Diagnostics

After creating a prediction surface, it is useful to recognize if the model is optimal for the data set in question. Geostatistical Analyst provides cross-validation and validation tools that allow you to evaluate the surface. The tools quantify the "accuracy" of the model. You can either accept the model and its parameters or you can refine the parameters of the model to create a better surface.

Cross-Validation and Validation

Cross-validation and validation help you make an informed decision as to which model provides the best predictions. The calculated statistics serve as diagnostics that indicate whether the model and/or its associated parameter values are reasonable.

Cross-validation and validation use the following idea—withhold one or more data locations and then predict their associated data using the data at the rest of the locations. In this way, you can compare the predicted value to the observed value and from this, acquire useful information about some of your previous decisions on the kriging model (e.g., the semivariogram parameters, the searching neighborhood, and so on).

J-8647

- Cross-Validation

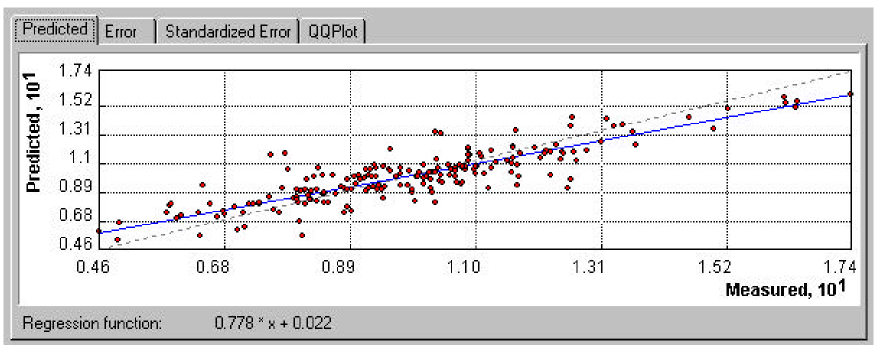
Cross-validation uses all of the data to estimate the trend and autocorrelation models. Then it removes each data location, one at a time, and predicts the associated data value. For all points, cross-validation compares the measured and predicted values. After completing cross-validation, some data locations may be set aside as unusual, requiring the trend and autocorrelation models to be refitted.

- Validation

Validation uses part of the data to develop the trend and autocorrelation models to be used for prediction. Then predictions to the known locations are compared with the measured data. Validation checks whether a "protocol" of decisions is valid (for example, choice of semivariogram model, choice of lag size, and choice of search neighborhood).

- Graphs and Summaries for Cross-Validation and Validation

Geostatistical Analyst gives several graphs and summaries of the measurement values versus the predicted values.

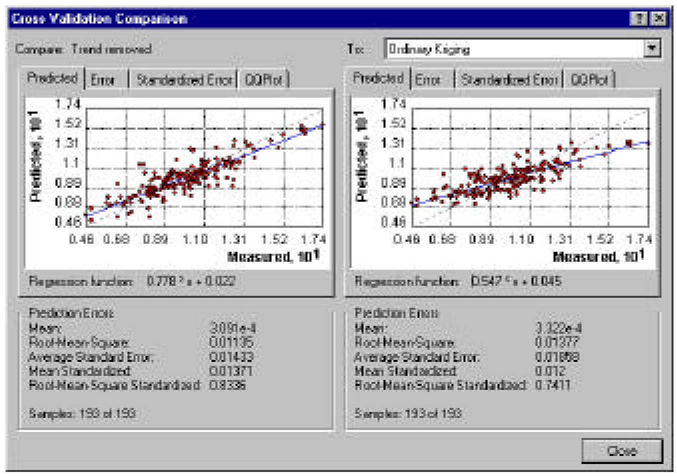


The prediction plot has a blue fitted line through the scatter of points and an equation is given just below the plot. The error plot is the same as the prediction plot, except here the true values are subtracted from the predicted values. For the standardized error plot, the true values are subtracted from the predicted values and then divided by the estimated kriging standard errors. All three of these plots help to show how well kriging is predicting. With autocorrelation and a good kriging model, the blue line should be closer to the 1:1 (black dashed) line.

The QQPlot shows the quantiles of the difference between the standardized errors and the corresponding quantiles from a standard normal distribution. If the errors of the predictions from their true values are normally distributed, the points should lie roughly along the dashed line. If the errors are normally distributed, the user can be confident of using methods that rely on normality (e.g., quantile maps in ordinary kriging).

Model Comparison

A Comparison dialog box uses the cross-validation technique and allows you to examine the statistics and the plots side by side. Generally, the best model is the one that has the standardized mean nearest to zero, the smallest root-mean-squared prediction error, the average standard error nearest the root-mean-squared prediction error, and the standardized root-mean-squared prediction error nearest to one.



The comparison dialog box allows the user to examine statistics and plots of different models side-by-side.

Display Options

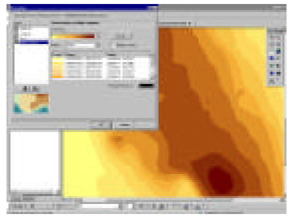
A geostatistical layer's functionality is similar to all ArcMap layers. You can add it to ArcMap, remove it, display it, and alter the symbology in countless ways. However, a geostatistical layer differs from other layers because of the way it is created and stored. A geostatistical layer can only be created by Geostatistical Analyst. Most ArcMap layer types store the reference to the data source, the symbology for displaying the layer, and other defining characteristics. A geostatistical layer stores the source of the data from which it was created (usually a point feature layer), the symbology, and other defining characteristics, but it also stores the model parameters from the interpolation, which can be refined at any time. From the Properties dialog for a geostatistical layer, you can view both the original data source and the model parameters.

Not only can you identify the source of the input points and the model parameters, but you can also retrieve general information with the general tab, see and alter the layer's map extent with the extent tab, change the symbology with the symbology tab, and set the transparency and whether to show map tips with the display tab.

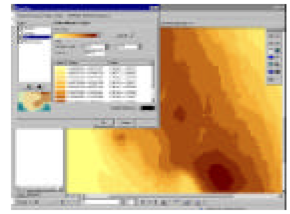
Display Formats

A geostatistical layer can be viewed in four different formats: filled contours, contours, grid, or hillshade. You can also combine multiple formats in a single display of the layer to achieve various effects. A full range of symbology and controlling parameters exists for each format.

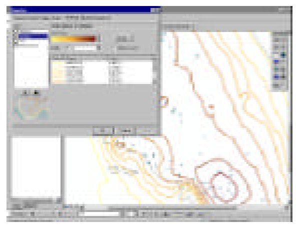
Filled Contours



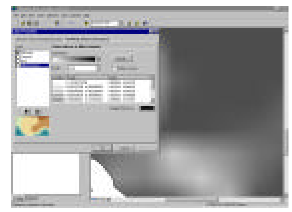
Grids



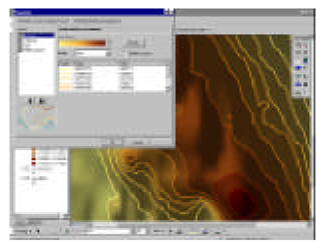
Contours



Hillshade



Combination of Contours, Filled Contours, and Hillshade



Conclusion

As you can see, Geostatistical Analyst is much more than an interpolation software package. Geostatistical Analyst is a revolutionary technology that provides a dynamic environment with a wide variety of tools and wizards to explore data, analyze peculiarities, and optimally display an interpolated surface with associated uncertainties. Geostatistical Analyst gives the user the power to fully understand the qualitative and quantitative aspects of their data. By providing the user with the freedom to statistically predict and model situations and incorporating powerful exploration and visualization tools, Geostatistical Analyst effectively bridges the gap between geostatistics and GIS.

Data Used in Screen Shots

- Agriculture data was provided by the University of Illinois.
- Radioceasium forest berry contamination data was provided by the Institute of radiation safety "BELRAD", Minsk, Belarus.
- Air quality data was provided by the California Environmental Protection Agency, Air Resource Board.
- Carpathian Mountains data was provided by the USDA Forest Service, Riverside, California.
- Radioceasium soil contamination data was provided by the International Sakharov Environmental University, Minsk, Belarus.