Combining Incompatible Spatial Data

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Acknowledgements

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Combining incompatible spatial data. *Journal of the American Statistical Association,* 2002.

Linking spatial data from different sources: The effects of change of support. *Stochastic Environmental Research and Risk Assessment*, 2006.

A geostatistical approach to linking geographically-aggregated data from different sources *Journal of Computational and Graphical Statistics*, 2007.

Very Low Birth Weight Study

Assess the association between:

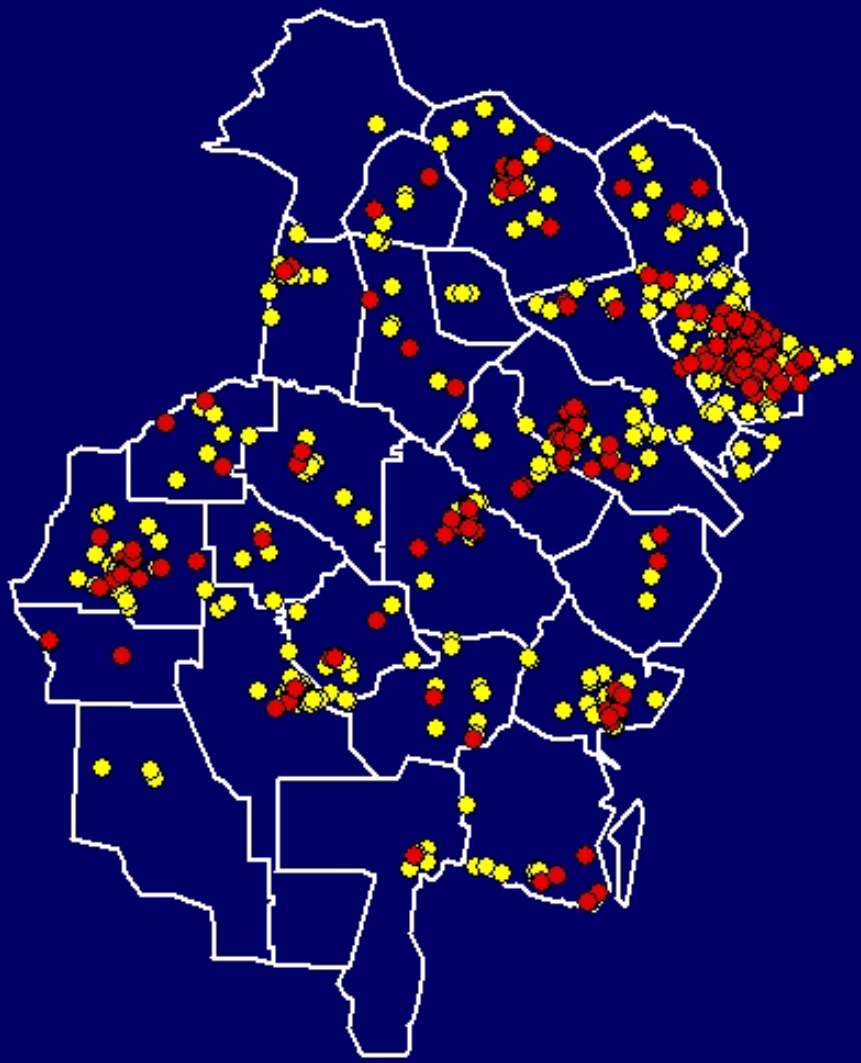
maternal exposure to air pollution
(here Total Suspended Particulates (TSP))

and

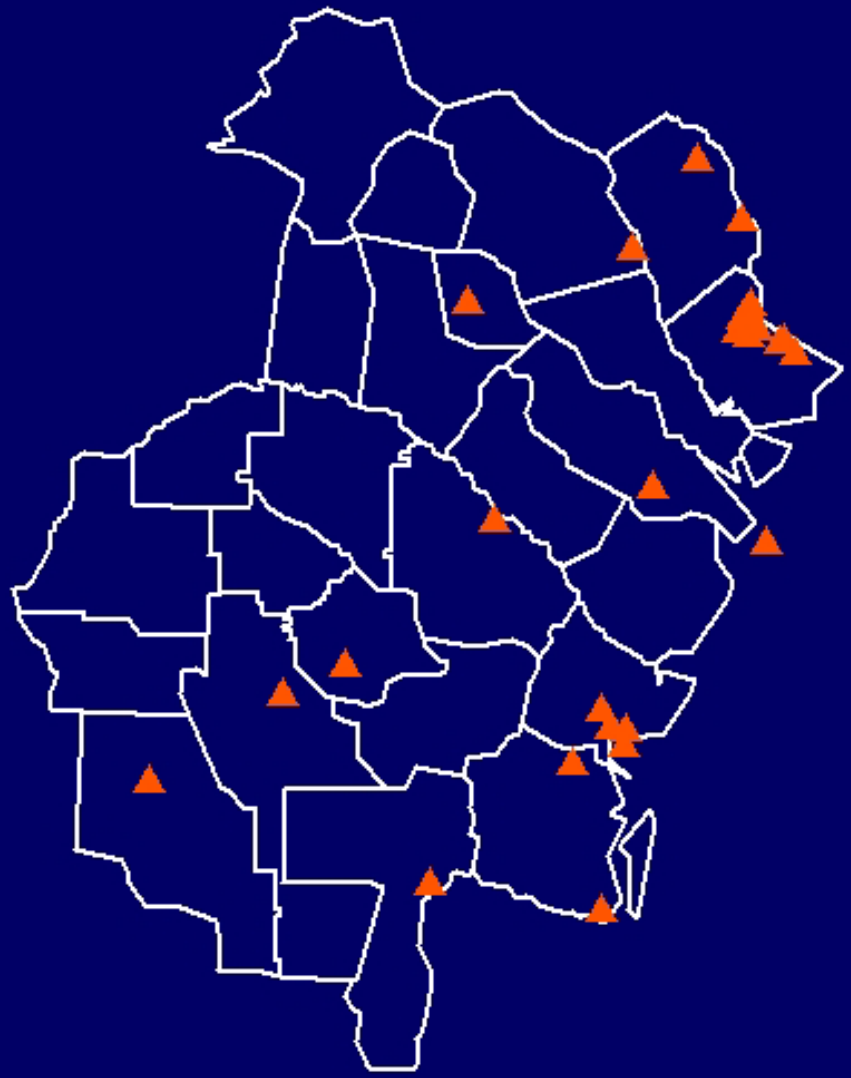
the risk of a very low birth weight baby
(weighs less than 1500 grams at birth)

Rogers, JF et al. (2000). *American Journal of Epidemiology*

VLBW Data Locations
Cases and **Controls**

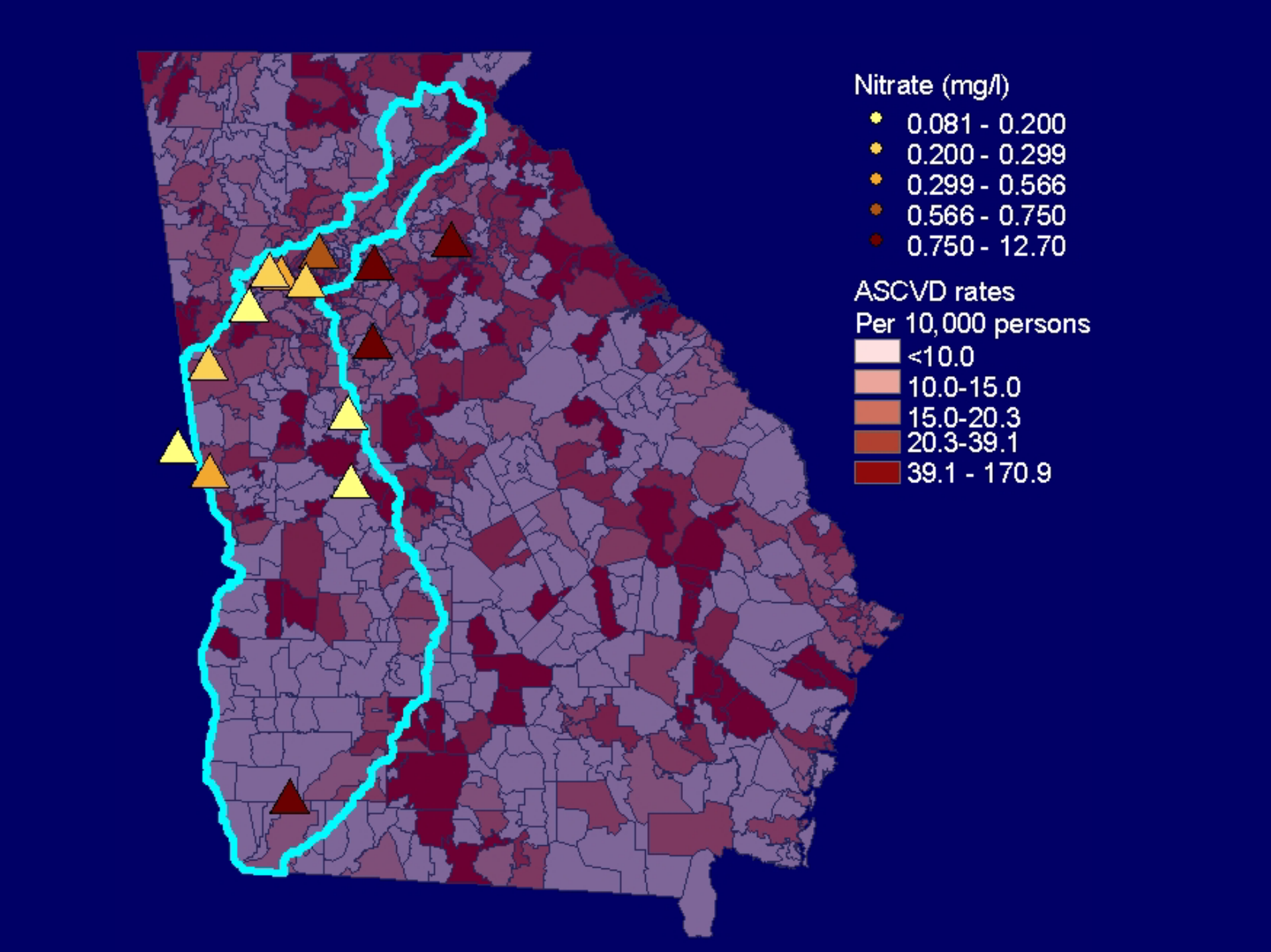


Emissions Data Locations

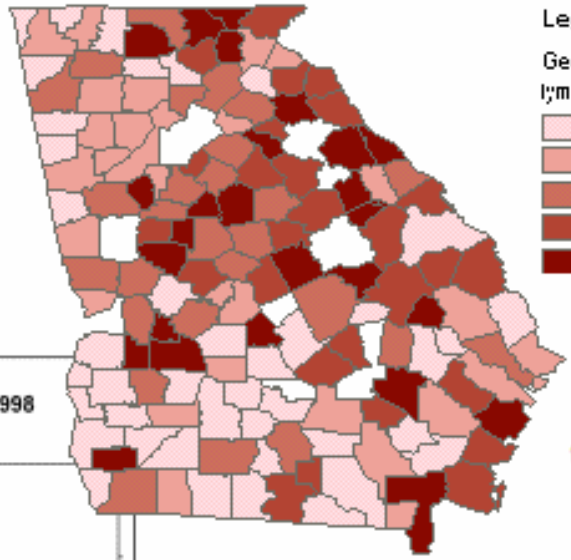


Linking Hospital Discharge and Water Quality Data

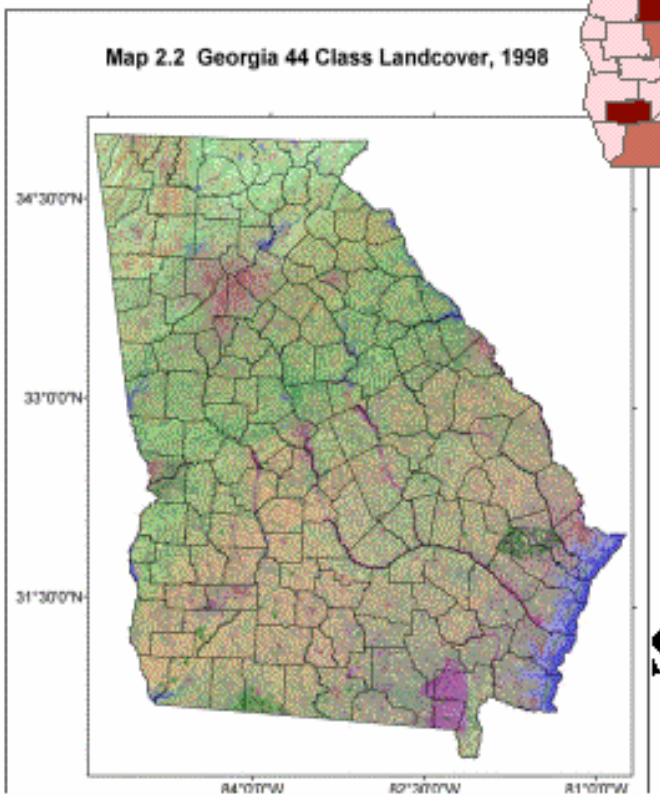
- Hospital discharge data: 1999-2003, GA, ZIP codes
- Environmental data from NAWQA
- Is there an association between **atherosclerotic cardiovascular disease** and **surface water nitrate concentration** in the Apalachicola-Chattahoochee-Flint river basin?

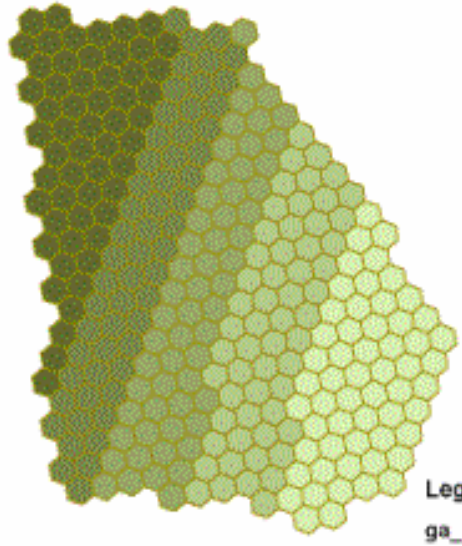

Nitrate (mg/l)
0.081 - 0.200
0.200 - 0.299
0.299 - 0.566
0.566 - 0.750
0.750 - 12.70
ASCVD rates
Per 10,000 persons
<10.0
10.0-15.0
15.0-20.3
20.3-39.1
39.1 - 170.9

Lyme disease rates by county



Landcover 30m





Species Diversity by hexagon

Key Features

- Data collected for different purposes
- Rarely recorded at the same time and place
- Many different spatial units involved:

Health Data:

- Census Units:
  - Tracts, counties, states
- ZIP code units
- Geocoded addresses

Environmental Data:

- Monitors
- Satellites
- Sampling Units

The Common Goal

- Use all the data to make inference about an outcome associated with one particular set of spatial units (e.g., health of individuals)
- Must involve upscaling (aggregation), downscaling (disaggregation), or side scaling (overlapping units or points)
- Statistically, this means making **predictions** of data associated with one set of spatial units from data associated with other sets of spatial units

The Modifiable Areal Unit Problem

- Results from any statistical analysis depend on how the data are aggregated geographically.

- Openshaw and Taylor (1979):
  - Different geographical aggregations of the same data can produce ``**a million or so**'' correlation coefficients.
  - Could produce correlations ranging from -0.97 to +0.99!

- **The Ecological Fallacy:**
  - Analyses based on grouped data often lead to conclusions different from those based on individual data.

Two Aspects of the MAUP

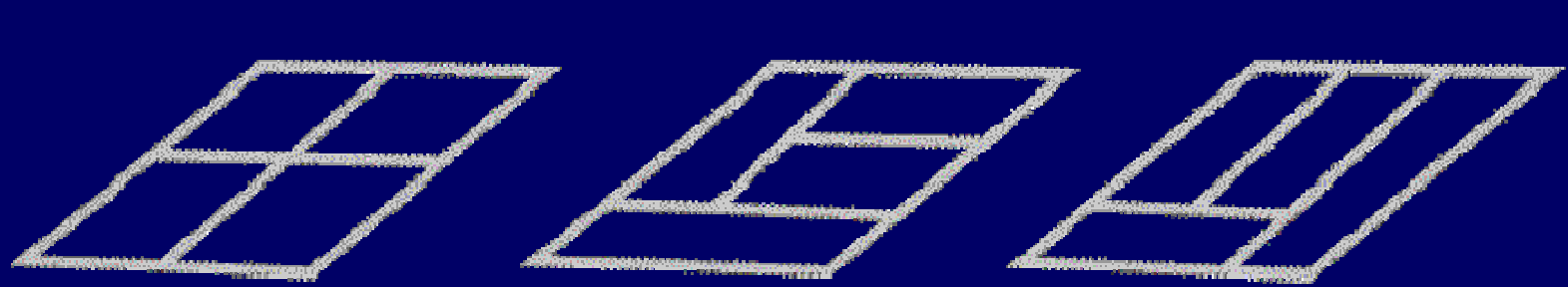
"Scale Effect" or the "Aggregation Effect":

Different results and inferences are obtained when the same set of data is grouped into increasingly larger areal units.

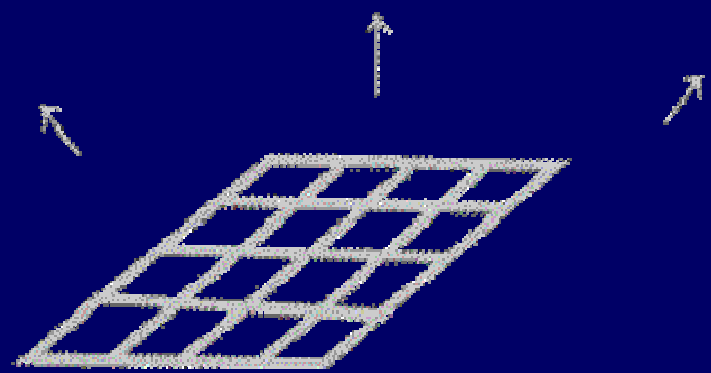
"Zoning Effect" or the "Grouping Effect":

The variability in results and inference due to alternative formations of the areal units.

Zoning Effect



Aggegation Effect

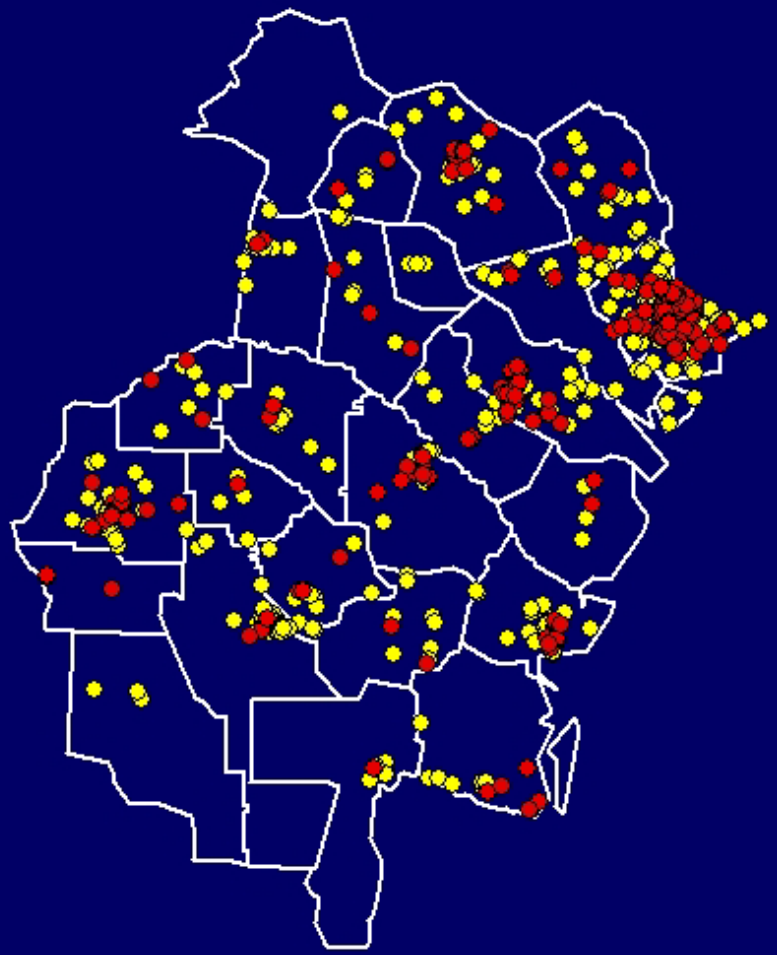


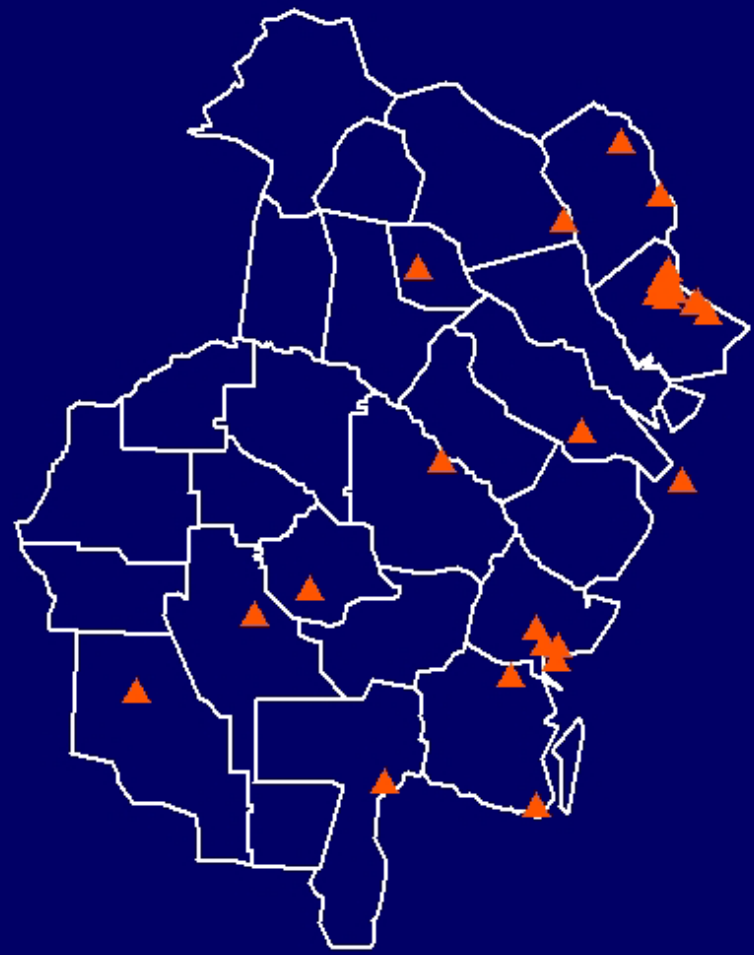
Spatial Support

- The size, shape and orientation of the spatial units.
- Measurements associated with areal units are inherently aggregates (totals, averages).
- The statistical and spatial properties of averages are different from those of the individual measurements (**Change of Support Problem**).
- Predicting at a point in the center of an areal unit is not the same as predicting an average value over that unit.

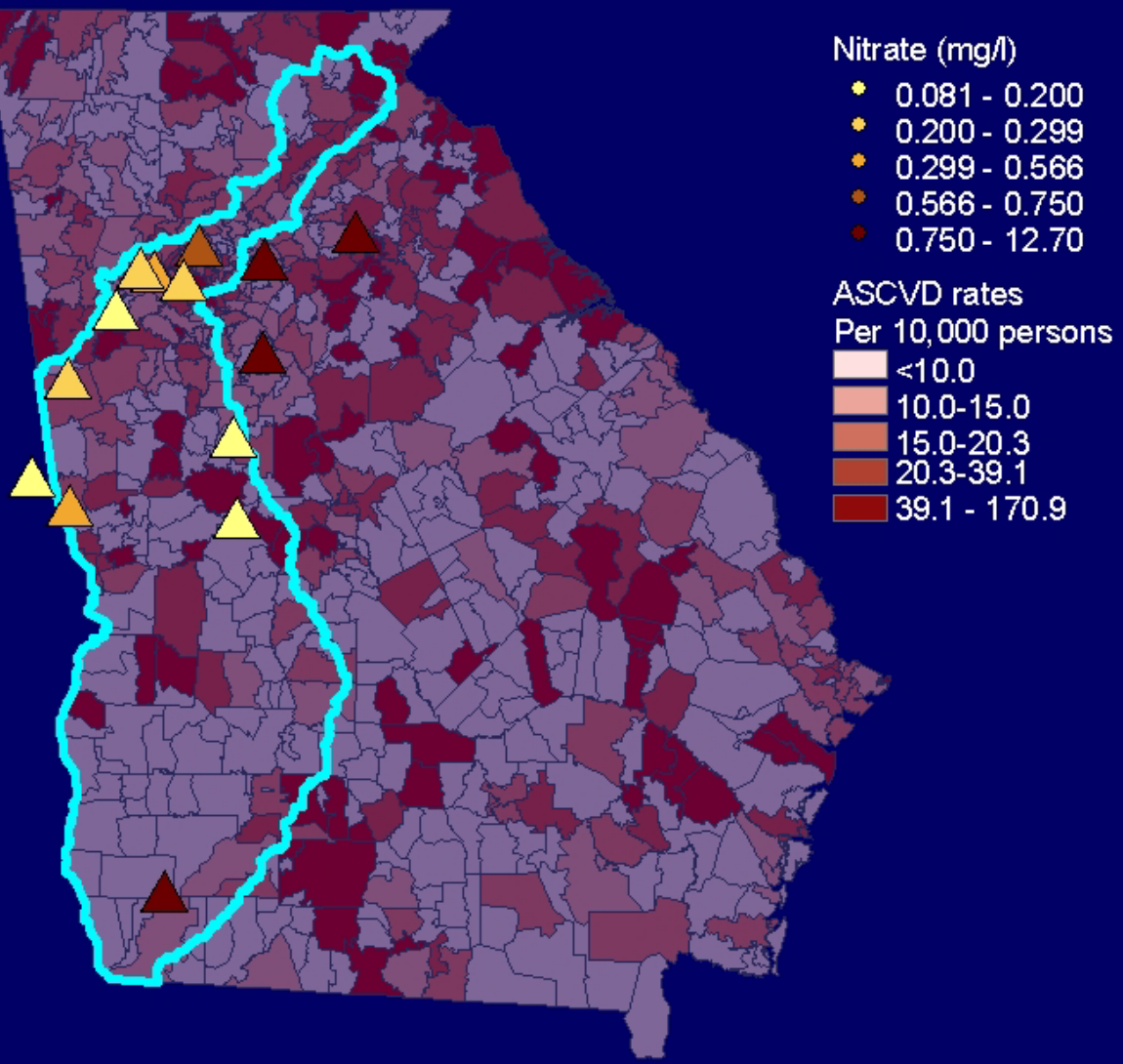
Case 1: Predict ground-level concentrations at each case and control location

Can also predict the risk of having a VLBW birth at each industrial facility. Makes post-linkage analysis more difficult (?).





Case 2: Nitrate data have point support, but health data are aggregated over ZIP code units (rates)



Options

- Predict a nitrate value at the “center” of each ZIP code unit (“traditional” approach)
- Support-adjusted prediction:
  - Predict many values in the ZIP code and then average the results
  - Need point-in-polygon codes or “zonal” analysis capabilities
  - Formal statistical technique is called “**block** kriging” and is used to get correct standard errors
- Can also “downscale” health data and predict the relative risk of ASCVD at any point.

More General Approaches

- Regression Methods
- Multi-scale tree models
- Bayesian Hierarchical Models
- Geostatistical Methods

Gotway and Young (2002) *JASA*

Regression Methods

- Data on “source units” are modeled as functions of the areas of atomic units formed by intersection with “target units.” Flowerdew and Green (1992)

Advantages:

- can include covariates
- some give measure of uncertainty

Disadvantages:

- have to build atomic model
- may not be aggregation consistent
- need GIS for atomic areas
- often ignore spatial autocorrelation

Multi-Scale Tree Models

- Each level of the tree corresponds to a different spatial scale.
- Data are observed at some of the nodes of the tree and the goal is prediction at other nodes of the tree.
- Algorithms are based on the Kalman filter.
- Basseville et al. (1992), Chou et al. (1994), Huang et al. (2002)

Multi-Scale Tree Models

Advantages:

- can be computationally efficient
- work well with large data sets
- elegant statistical theory
- can get measure of uncertainty

Disadvantages:

- often ignore spatial support
- parameter estimation can be difficult
- not suitable for use with overlapping units?

Bayesian Hierarchical Models

- Specify a model for the data, given unknown variables, and then specify prior distributions for the unknown variables.
- Unknown variables may include data to be predicted.
- Kalman filtering and state space models can be special cases.

- Mugglin and Carlin (1998), Best et al. (2000), Wikle et al. (2001), Gelfand et al. (2001).

Bayesian Hierarchical Models

Advantages:

- can easily build complex models
- many multi-scale processes are inherently hierarchical
- can incorporate parameter uncertainty
- comprehensive description of uncertainty

Disadvantages:

- most use areal weighting only
- rely too heavily on Gaussian distributions and likelihoods
- prior choice and convergence issues
- Implementation difficult with large data sets

Geostatistical Approaches

- Predictions are optimal functions of the data.
- Optimal weights obtained by minimizing prediction mean-squared error (BLUPs).
- ``Block'' kriging, isofactorial models and ``co''-kriging.
- Can be implemented using Kalman filtering.

Journel and Huijbregts (1978), Matheron (1984), Daley (1992), Cressie (1993), Gotway and Young (2007)

Geostatistical Approaches

Advantages:

- geostatistics was invented to address the COSP
- active work in mining to increase profitability
- have optimal statistical properties
- can get a measure of uncertainty
- basic calculations can be done in GIS

Disadvantages:

- parameter estimation can be challenging
- requires simplified models for use with large data sets
- most based on linear models

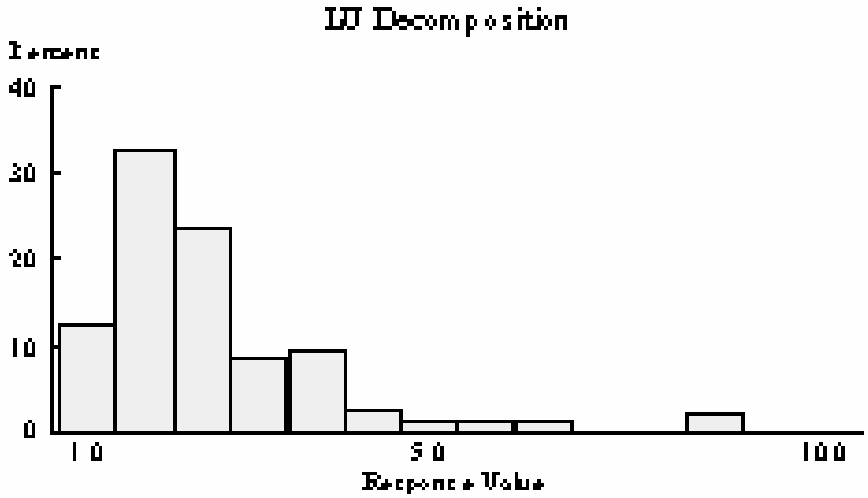
THE Most Important Issue: Uncertainty

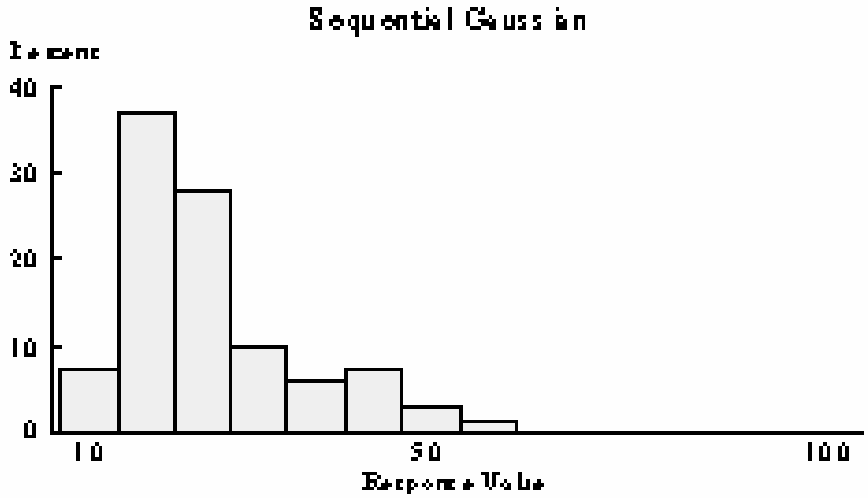
- Post-linkage analysis must account for the uncertainties that arise from prediction during linkage, as well as any uncertainties in the initial data.
- Otherwise, confidence intervals are too narrow, p-values are too small, and conclusions are probably wrong.
- Probabilistic prediction methods provide a measure of prediction uncertainty (standard errors), but these cannot be easily used in subsequent analyses.

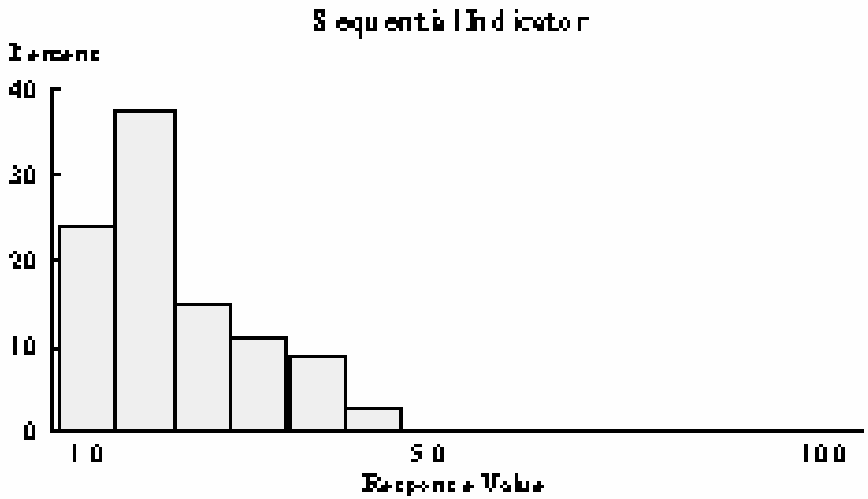
Methods for Quantifying Uncertainty

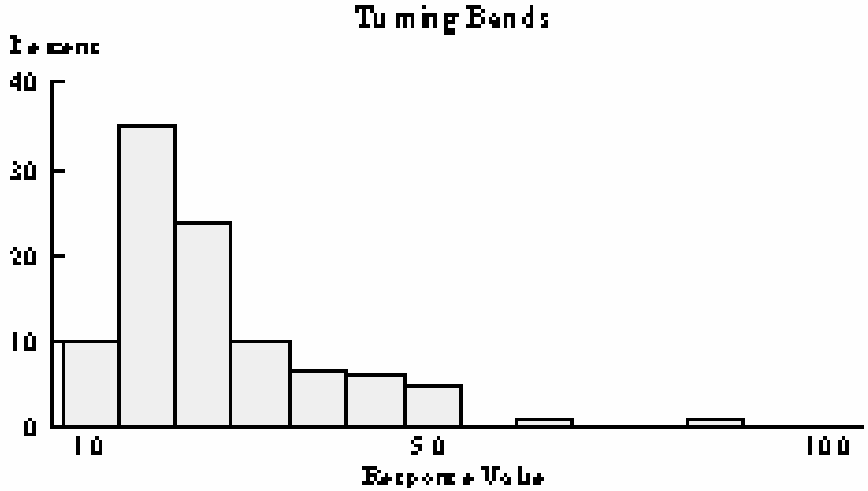
- Model the variability in the input, simulate from this model, analyze the resulting variation in output.
    - Monte Carlo/Geostatistical simulation
    - EM algorithm with maximum likelihood
    - Bayesian hierarchical models
- Computationally challenging particularly for COSPs.
- Properties of simulated data? Are uncertainty measures accurate?

Gotway and Rutherford (1994,1996).


LU Decomposition
Percent
40
30
20
10
0
10
50
100
Response Value


Sequential Gaussian
Percent
40
30
20
10
0
10
50
100
Response Value


Sequential Indicator
Percent
40
30
20
10
0
10
50
100
Response Value


Turning Bands
Percent
40
30
20
10
0
10
50
100
Response Value

Summary

- Spatial data are often more than just points in space. The support of the data is important.
- Corresponding to every spatial scale is a level of spatial aggregation that reflects a particular mixture of sub-units that comprise the larger units.
- Aggregation alters variability and impacts inference
- Quantifying uncertainty is very important. Assessing the accuracy of uncertainty measures is also important and has been largely overlooked.