National Assessment of the Existing Criteria Pollutant Monitoring Networks

O_3, CO, NO_2, SO_2, Pb, PM_{10}, $PM_{2.5}$

Part 1 – July 25, 2001

Background on AQ Network Assessment

- Monitoring ambient concentrations provide the necessary **sensory input** to various aspects of AQ management.

- EPA/States/local agencies and Tribes have initiated a program to make the existing AQ monitoring networks more **responsive to the needs** of AQ management and public.

- Efforts are under way to implement **new monitoring** systems (**PM2.5 continuous mass, PM2.5 composition, air toxics)**. At the same time the performance of the **existing** ozone, PAMS, PM and other criteria pollutant monitoring sites are **re-assessed** for possible re-location or elimination to assist in implementing new monitoring systems.

- The National Monitoring Strategy Committee (NMSC) requested this national network assessment to provide broad direction to changes in the monitoring networks and to catalyze more refined regional/local assessments.

- Regional and local based assessments are necessary to bring together more stakeholders and closely scrutinize value of existing monitoring sites and defines particular region’s priority for investments.

Monitoring Network Evaluation: Multiple Criteria

- AQ Monitoring networks need to support **multiple aspects** of air quality management including population exposure/AQI reporting, compliance monitoring and tracking the effectiveness of control measures.

- Multiple purposes may require very **different network designs.** For example, health risk characterization requires sampling of the most harmful species over populated areas during episodes; tracking of emission-concentration changes requires broad regional sampling for establishing pollutant budgets.

- In general, an AQ monitoring network is characterized by the **spatial** distribution of sampling stations, **temporal** sampling pattern and the **species** measured.

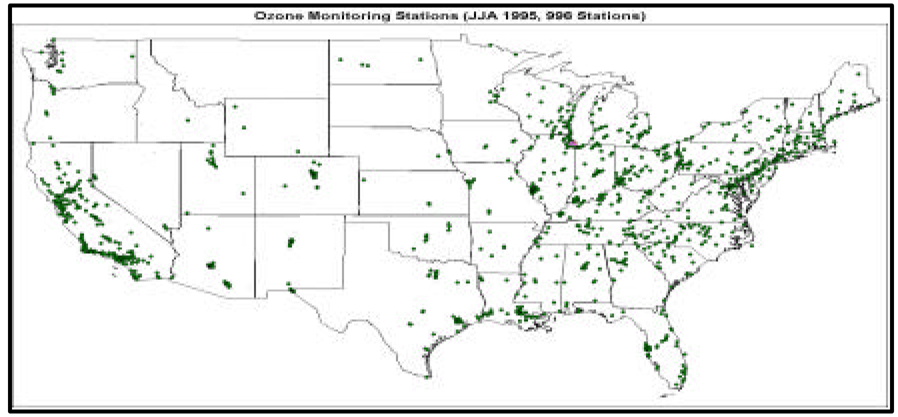
- The current methodology is focused on evaluating the **geographic features** of the network for each pollutant. The consideration of the temporal and species aspects of network evaluation is left for future considerations. The results across individual networks will be aggregated to provide an integrated national assessment.

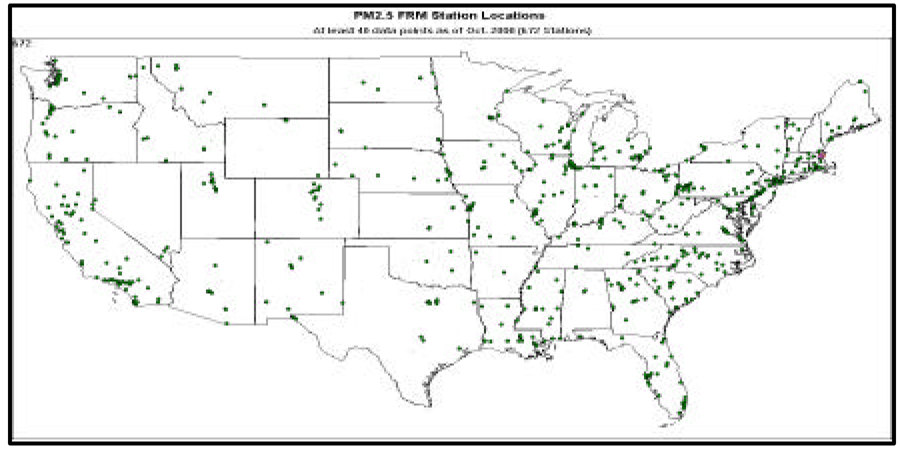
- This methodology is based on **multiple relative rankings** of individual existing stations.

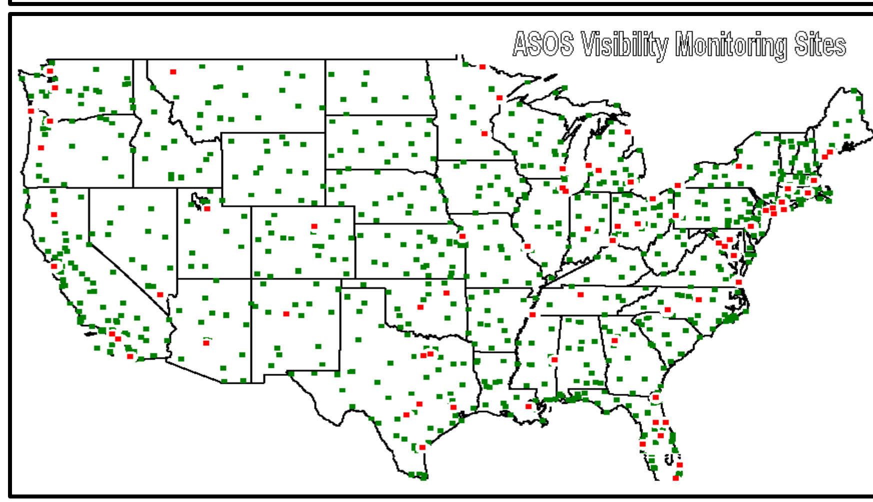
Network Layout: Uniform or Clustered?

- The existing monitoring networks for O3, PM2.5 and weather parameters show very different strategies:
- The monitoring **ozone network is highly clustered** in around populated areas (top). Evidently, O3 regulatory network is laid out with to focus on areas 'where the people are'.
- The recently established FRM **PM2.5 network is less clustered** (center).
- On the other hand, the automated surface weather observing system, **ASOS is uniformly distributed in space** for broad spatial coverage (bottom).
- Clearly, the layout of these networks is tailored for different purposes.

Click on images for full resolution







Network Evaluation
Combining Subjective and Objective Steps

- The proposed network evaluation methodology combines subjective and objective methods for network evaluation. Below is the outline of the hybrid procedure.

1. **First, select multiple evaluation criteria** i.e. risk assessment, compliance monitoring, trend tracking etc. *This is a subjective procedure driven by the network objectives*.

2. **Decide on specific measures** that can represent each criterion, i.e. number of persons in the sampling zone of each station; concentration etc. *The selection of the suitable measures is also somewhat subjective.*

3. **Calculate the numeric value of each measure** for each station in the network. *This can be performed objectively using well defined, transparent algorithmic procedures.*

4. **Rank the stations** according the each measure. This yields a separate rank value for each measure. For example, a station may be ranked 5 by day-max O3 and ranked 255 by persons in the sampling zone. *This step can also be performed objectively*.

5. **Weigh the rankings**, i.e. set the relative importance of various measures. *This involves comparing 'apples and oranges' and it is clearly subjective.*

6. **Add the weighed rankings** to derive the overall importance of the station and rank the stations by this aggregate measure. Use the aggregate ranking to guide decisions on network modifications.

Network Evaluation Using Five Independent Measures

- The approach is illustrated with the criteria pollutant network using five independent measures.
- The **five different measures** represent the information need for (1) population exposure/AQI, (2) compliance monitoring and (3) tracking/model evaluation. The methodology allows easy incorporation of additional measures.
- These are all measures of the network benefits. Other benefits measures (temporal, species) should also be incorporated.
- For cost-benefit analysis, the cost of the network operation should also be incorporated.

AQ Management Activity	**Geographic Info. Need**	**Station Measure**
Risk assessment	Pollutant concentration	Varies by pollutant
Risk Assessment	Persons/Station	Persons in sampling zone
Compliance evaluation	Conc. vicinity to NAAQS	Deviation from NAAQS
Reg./local source attribution, tracking and model evaluation	Spatial coverage	Area of Sampling Zone
All above	Estimation uncertainty	Meas. & estimate difference

Five Independent Measures

- In this assessment, five independent measures were used to evaluate the AQ monitoring network performance.
  - **Pollutant Concentration** is a measure of the health risk. The concentration metrics used for each pollutant correspond to the associated NAAQS'. [See next slide.] The stations with the highest concentration values are ranked 1.
  - **Estimation Uncertainty** measures the ability to estimate the concentration at a station location using data from all other stations. The station with the highest deviation between the actual and the estimated values (i.e. estimation uncertainty) is ranked #1. In other words, the stations who's values can be estimated accurately from other data are ranked (valued) low.
  - **Deviation from NAAQS** measures the station's value for compliance evaluation. The station ranking is according to the absolute difference between the station value and the NAAQS. The highest ranking is for the station whose concentration is closest to the standard (smallest deviation). Stations well above or below the standard concentration are ranked low.
  - **Spatial Coverage** measures the geographic surface are each station covers. The highest ranking is for the station with the largest area in it's sampling zone. This measure assigns high relative value to remote regional sites and low value to clustered urban sites with small sampling zones.
  - **Persons/Station** measures the number of people in the 'sampling zone' of each station. Using this measure the station with the largest population in it's zone is ranked #1. Note: Estimating the health risk requires both the population and the concentration in the sampling zone. No population data was available for Puerto Rico or Virgin Islands.

Measuring Pollutant Concentration

•The metrics and years used for the three concentration-based measures were:

Pollutant	Primary National Ambient Air Quality Standard (NAAQS), from *Trends Report*		**Surrogate Metric Used in This Assessment**
	Type of Average	Standard Level Concentration	
O_3	Maximum Daily 1-hour Average[a]	0.12 ppm	**1995-1997 & 1998-2000 3-year averages of annual 2nd daily max 1-hour**
	4^{th} Maximum Daily 8-hour Average[b]	0.08 ppm	**1995-1997 & 1998-2000 3-year averages of annual 4^{th} daily max 8-hour**
CO	8-hour[a]	9 ppm	**1998-2000 3-year average of 2nd max 8-hour**
	1-hour[a]	35 ppm	**1998-2000 3-year average of 2nd max 1-hour**
NO_2	Annual Arithmetic Mean	0.053 ppm	**1998-2000 3-year average of annual means**
SO_2	Annual Arithmetic Mean	0.03 ppm	**1998-2000 3-year average of annual means**
	24-hour[c]	0.14 ppm	**1998-2000 3-year average of annual 2^{nd} max interval Z**
Pb	Maximum Quarterly Average	1.5 µg/m^3	**1998-2000 3-year average of annual max quarterly mean**
PM_{10}	Annual Arithmetic Mean	50 µg/m^3	**1998-2000 3-year average of annual means**
	24-hour[c]	150 µg/m^3	**1998-2000 3-year average of annual daily 2nd max's**
$PM_{2.5}$	Annual Arithmetic Mean[d]	15 µg/m^3	**1999-2000 2-year average of annual means**
	24-hour[e]	65 µg/m^3	**1999-2000 2-year average of annual 98th percentiles**

***Note: 1-hr and 8-hr ozone were treated as different pollutants.**

a The standard is attained when the expected number of days per calendar year with maximum hourly average concentrations above 0.12 ppm is equal to or less than one, as determined according to Appendix H of the Ozone NAAQS.

b Three-year average of the annual 4^{th} highest daily maximum 8-hour average concentration.

c Not to be exceeded more than once per year.

d Spatially averaged over designated monitors.

e The form is the 98^{th} percentile

Calculating Concentration Estimation Uncertainty

- Estimation uncertainty measures the ability to estimate the concentration at a station location using data from all other stations.

- The station with the highest deviation between the actual and the estimated values (i.e. estimation uncertainty) is ranked #1.

- The estimation uncertainty depends on the spatial extrapolation method. The spatial extrapolation method used here is a declustered, inverse distance weighed scheme developed by S. Falke (2000). Several other interpolation schemes exist.

- This measures relates to redundancy, which also can be calculated through various correlation approaches.

Error Estimation by Cross-Validation

- **Cross-validation** is applied to obtain an estimation error. This involves removing a monitor site from the data base and using the remaining sites to calculate an estimated concentration at the removed monitor location.

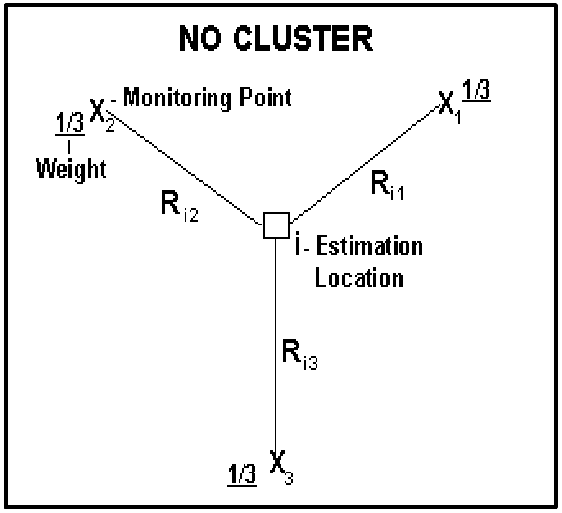
- The **estimation error** is calculated as the difference between the Estimated - Measured Concentration.

- The **nearest 5 sites** within a 750 kilometer radius of the estimation location are used in the estimation calculation.

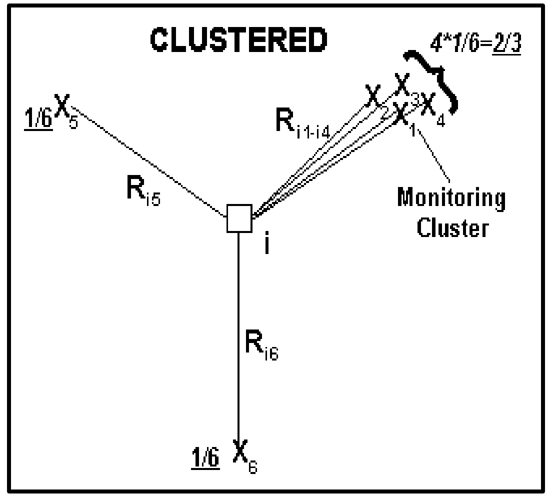
- **Declustering** reduces the relative weight of spatially clustered monitor sites during spatial interpolation.

- A site is clustered if the distances between the monitoring site and its neighboring sites are small compared to the distance between the monitoring site and the estimation point. For example, a group of sites in a city is considered unclustered when estimating the concentration within the city but is clustered when estimating concentrations in locations substantially outside of the city.

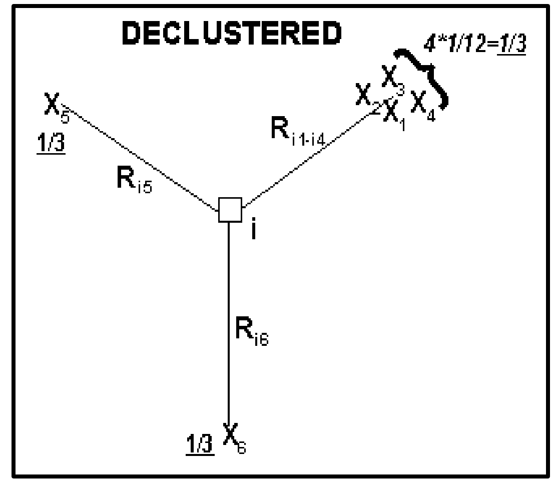
Declustering Configurations



The sites X_1, X_2, and X_3 are equidistant from the estimation point *i* and are unclustered. Standard interpolation applies equal weight; each site has 1/3 of the weight on the estimate at *i*.



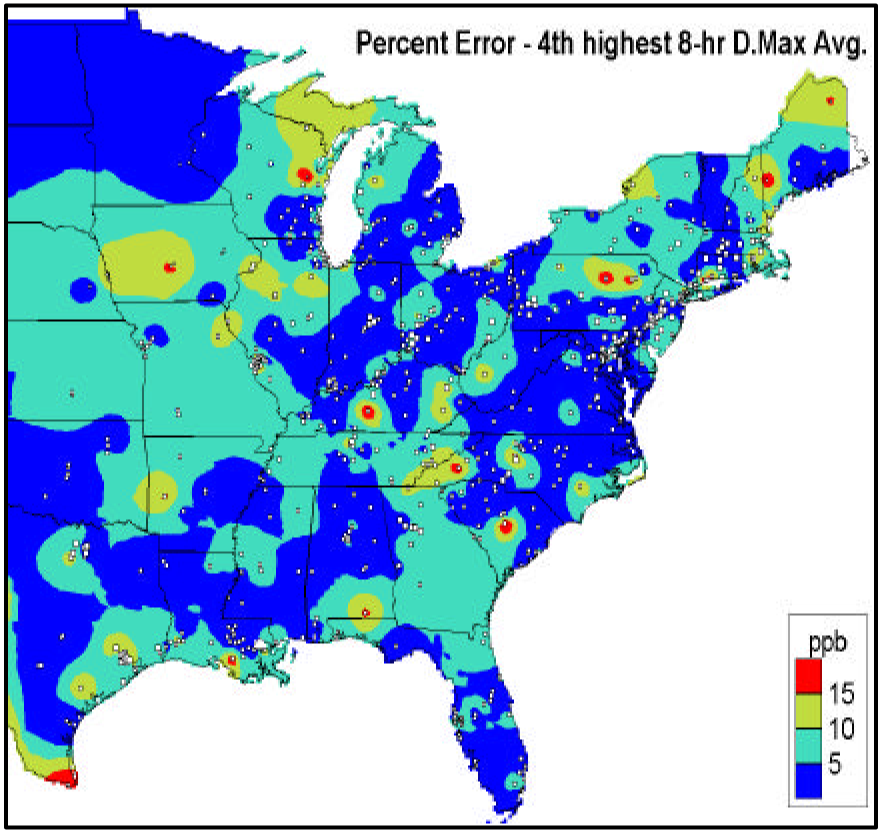
There is a cluster of four sites. When applying standard distance weighted interpolation, the cluster will account for 2/3 of estimated value at *i* while the two single sites each only account for 1/6 of the total weight.



Declustered weighing shows the proper allocation of the 1/3 weight to the cluster of sites.

Example: Concentration Estimation Error, E

- The error estimates in both metric of ozone concentration over the Eastern US ranges between 0-15 %.
- High estimation error is generally observed over areas with low station density.
- Low estimation error generally occurs over areas with high station density.



Calculating Concentration Deviation from NAAQS

- Deviation from NAAQS measures the station's value for compliance evaluation.
- The station ranking is according to the absolute difference between the station value and the NAAQS.
- The station whose concentration is closest to the standard (smallest deviation) is ranked #1.

Calculating Area of Station Sampling Zone

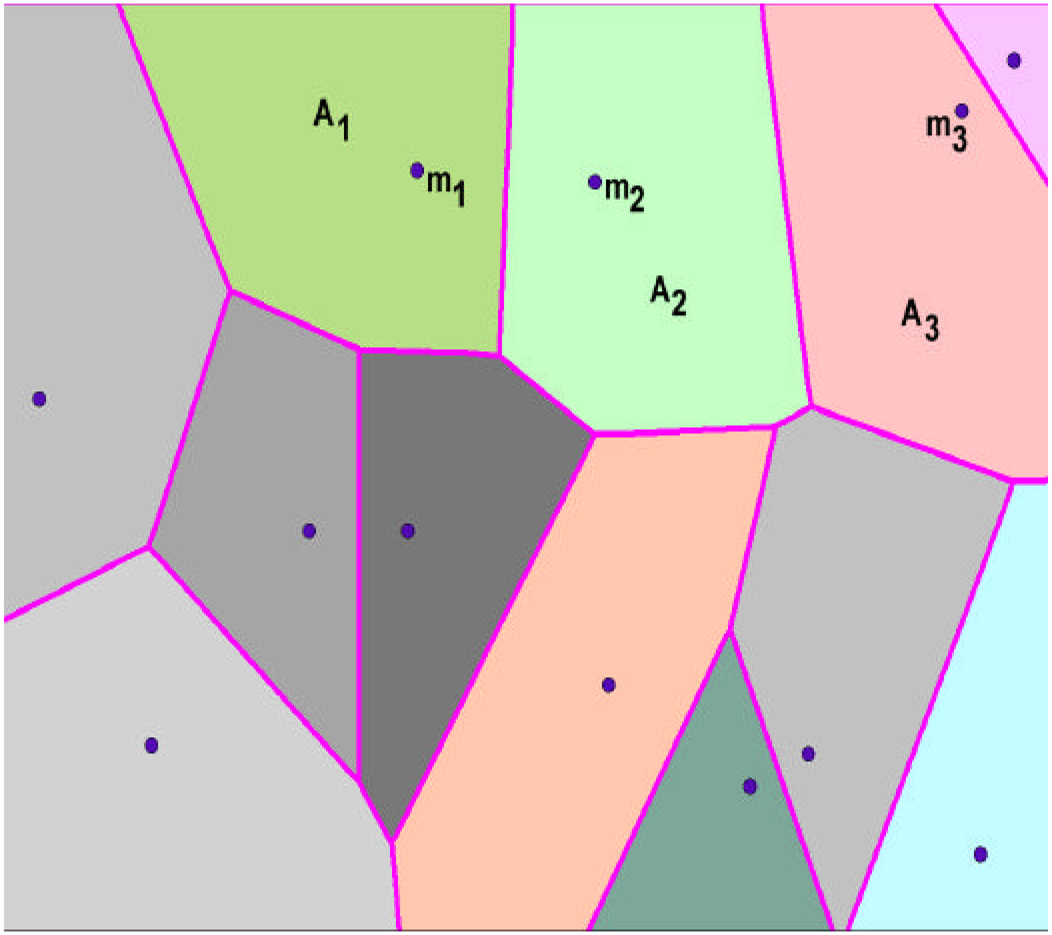
- The representative area for a monitor is calculated in two steps:

    1) Thiessan polygons are constructed for the monitor network.

    2) The area in square kilometers is calculated for each polygon.

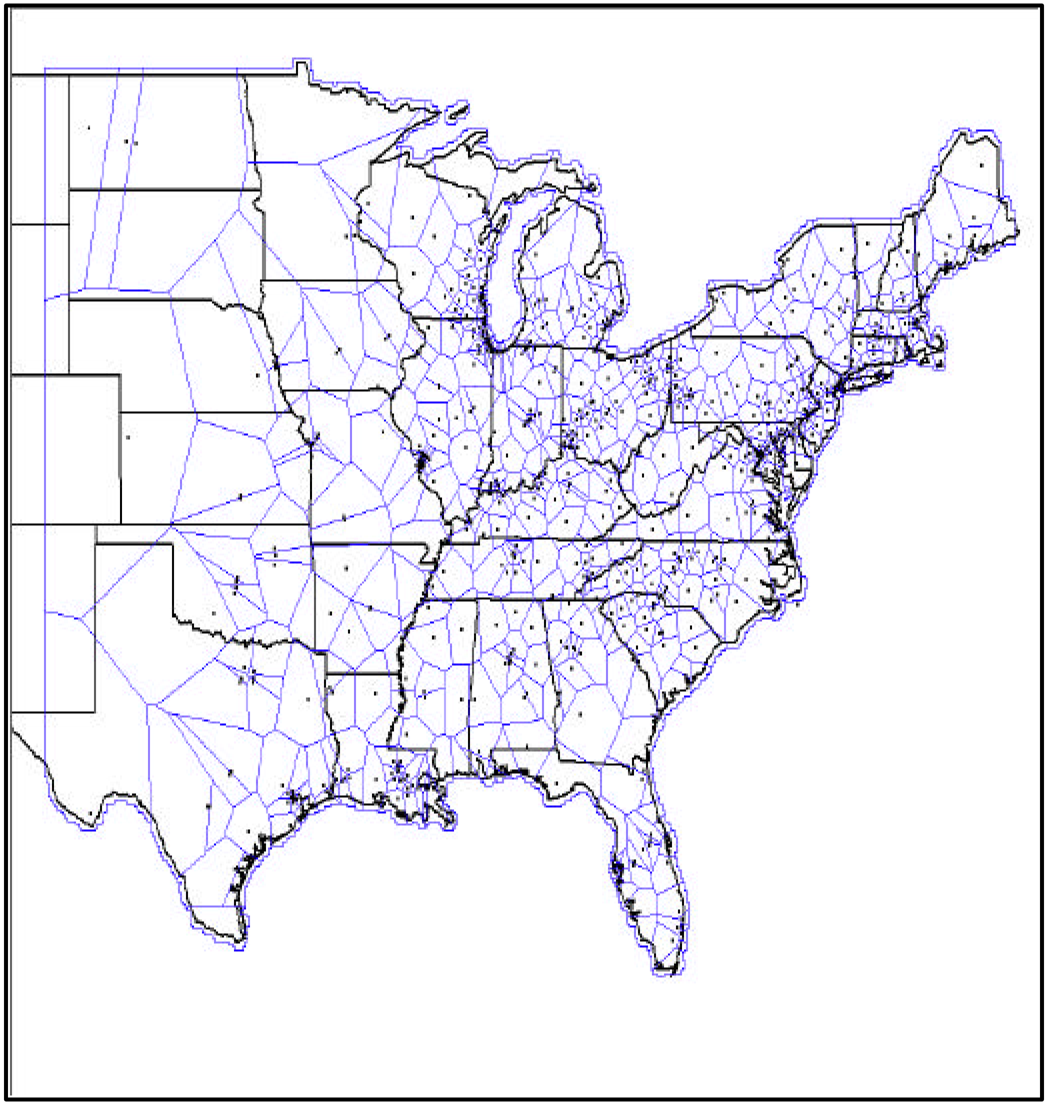
Station Representative Area

- The thiessan polygon borders encompass the area that is nearer to one particular monitor than any other monitor; its *representative* area.
- These polygons are converted to shapefile format and the area for each polygon in square kilometers is then calculated using ArcView Spatial Analyst polygon area calculation functions.



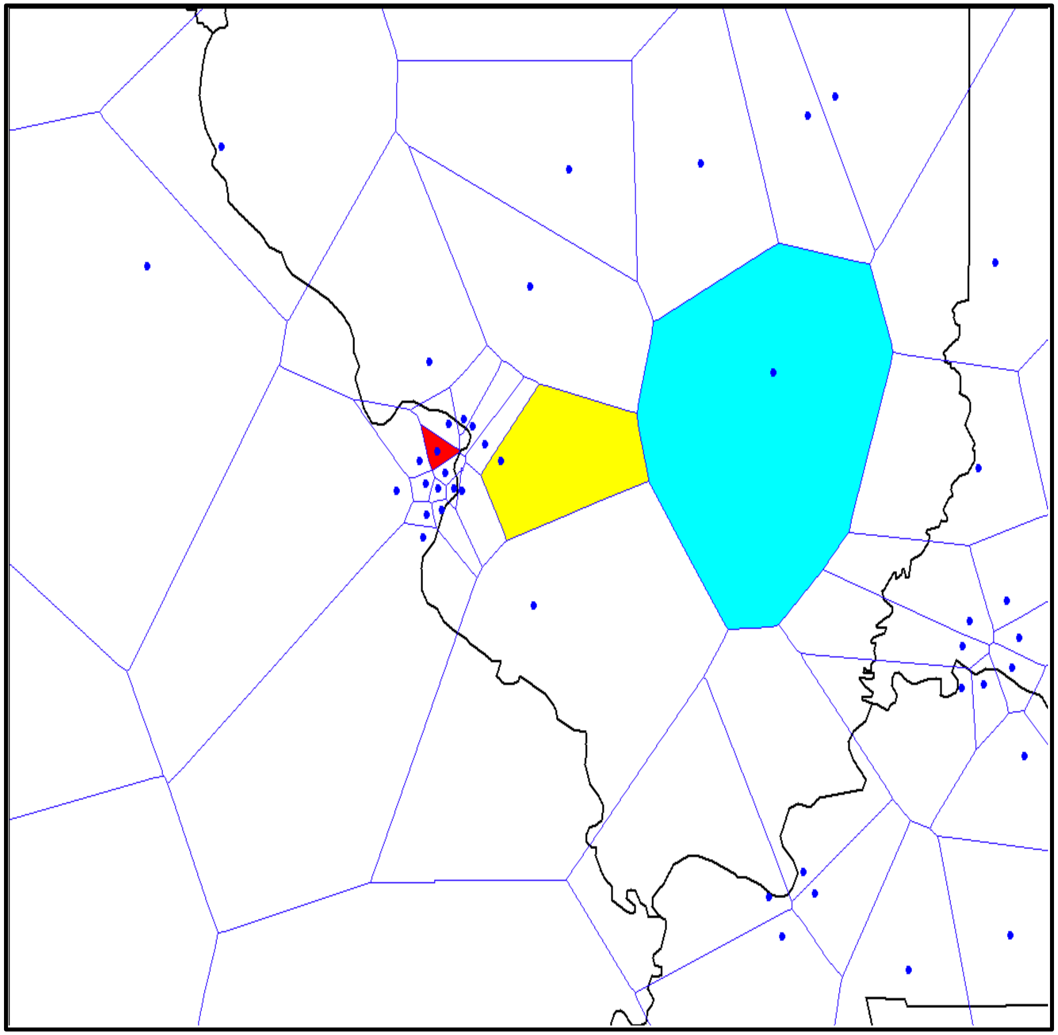
Station Sampling Zones

- Every location on the map is assigned to the **closest monitoring station**.
- At the boundaries the distance to two stations is equal.
- Following the above rules, the ‘sampling zone’ surrounding each site is a **polygon**.
- The **the area** (km^2) of each polygon **is calculated.**

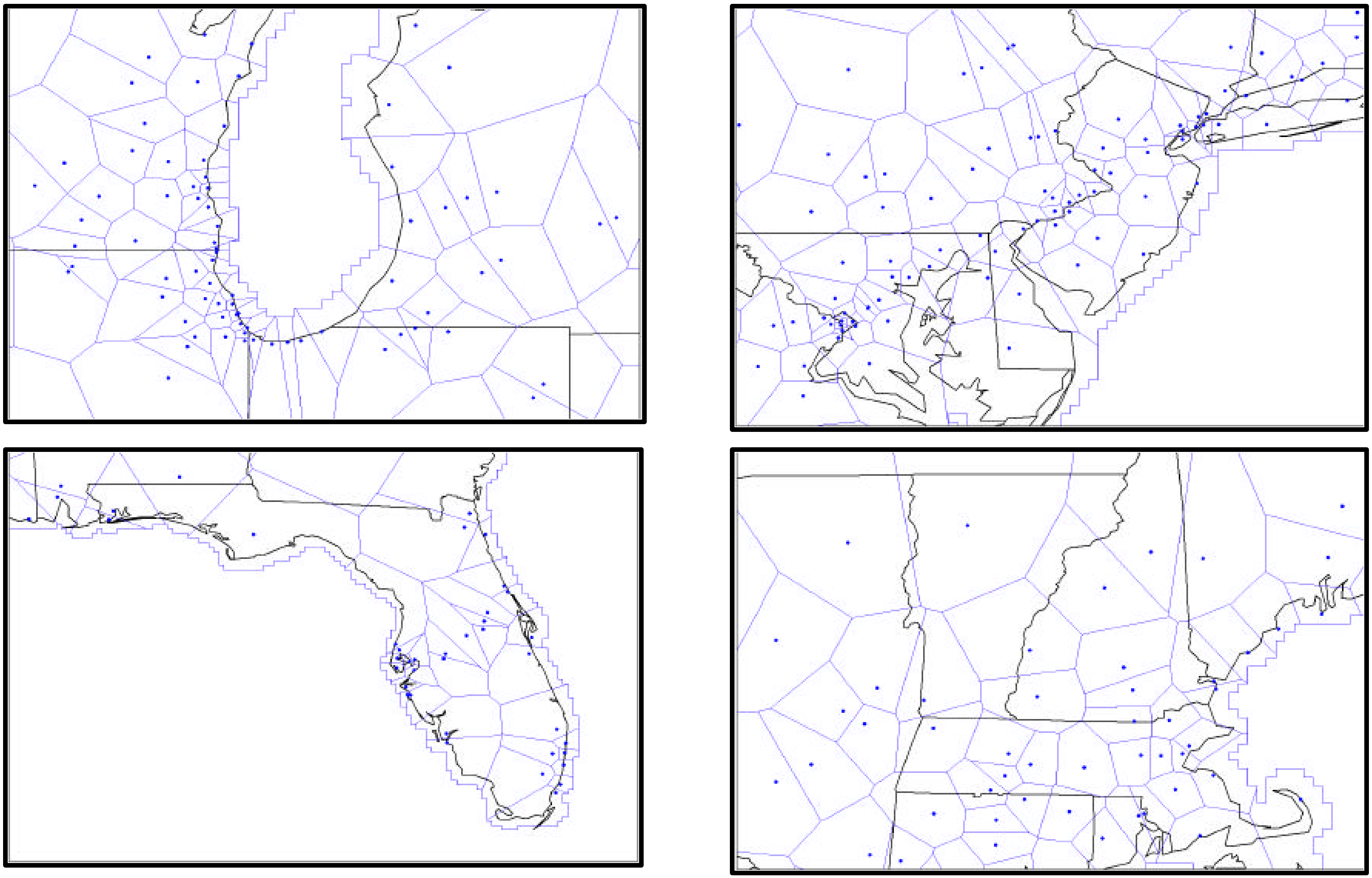


Sampling Zone Illustrations (St. Louis, MO)

- There are three different types of sampling zones:
- **Single** monitoring stations that are far from other stations (light blue) have **large and symmetric** sampling zones.
- Stations inside **clusters** (red) in urban areas have **small but symmetric** sampling zones.
- Stations on the **edge of clusters** (yellow) have larger **asymmetric**, elongated sampling zones.



Station Sampling Zones in Different Parts of EUS



Calculating Population in Station Sampling Zone

•The representative population for a monitor is calculated in three steps:

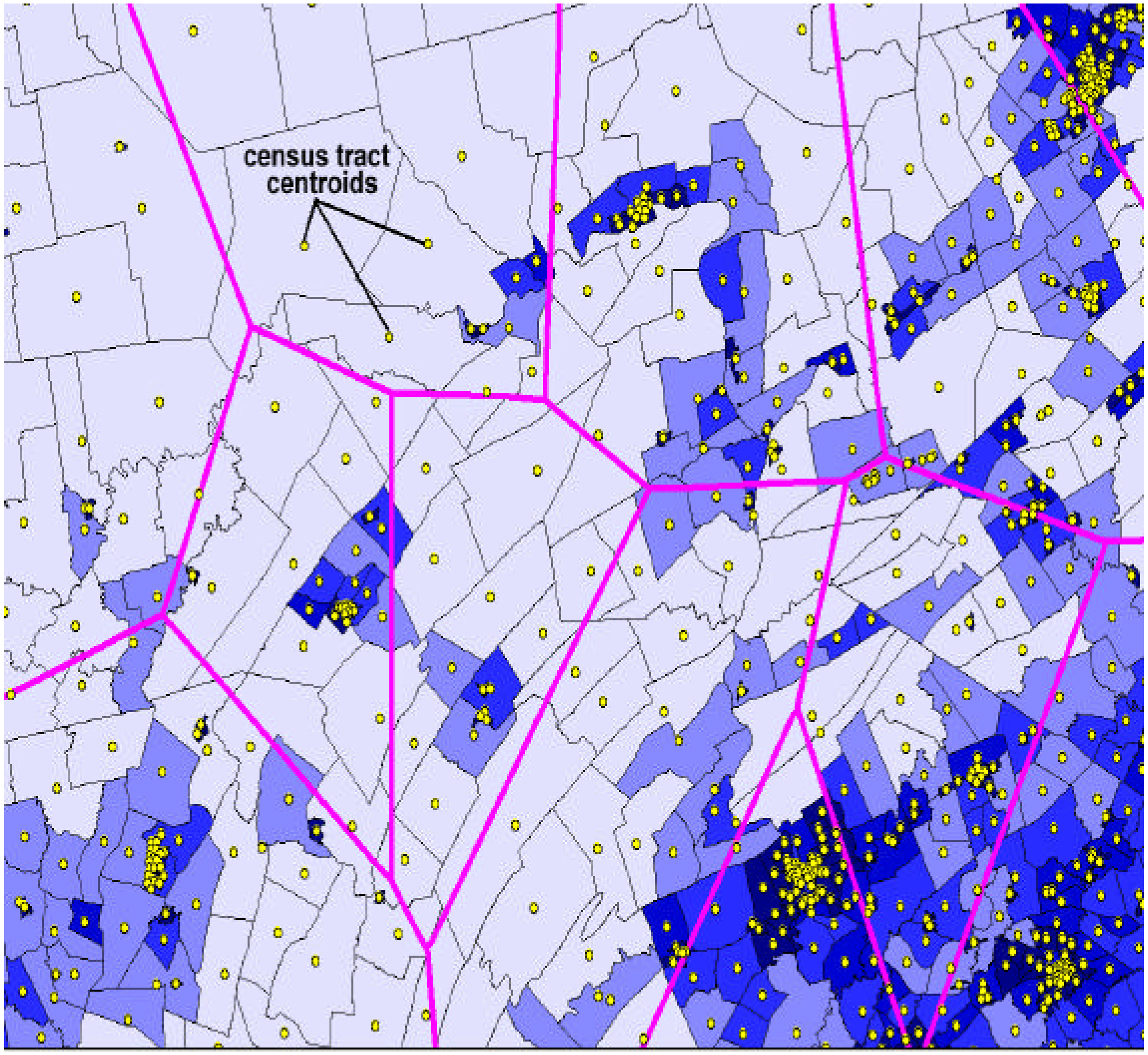
1) Population data at the census tract were obtained.

2) The population from each census tract was assigned to a specific station's sampling zone.

3) The sum of all census tracts is a station sapling zone was calculated.

Census Tract Population Data

- The population data used for determining a station's population is from ESRI's census tract file with estimated 1999 populations.
- The centroid of each census tract is associated with a station area.
- The census tract populations for all centroids that fall within a station's area are summed.



Population Density

- The population density is highly textured; it varies by three orders of magnitude over the EUS.

- Large populations in station sampling zones may arise in:
  - areas of high population density, e.g. NY City
  - large sampling zone, e.g. Kansas-Colorado.

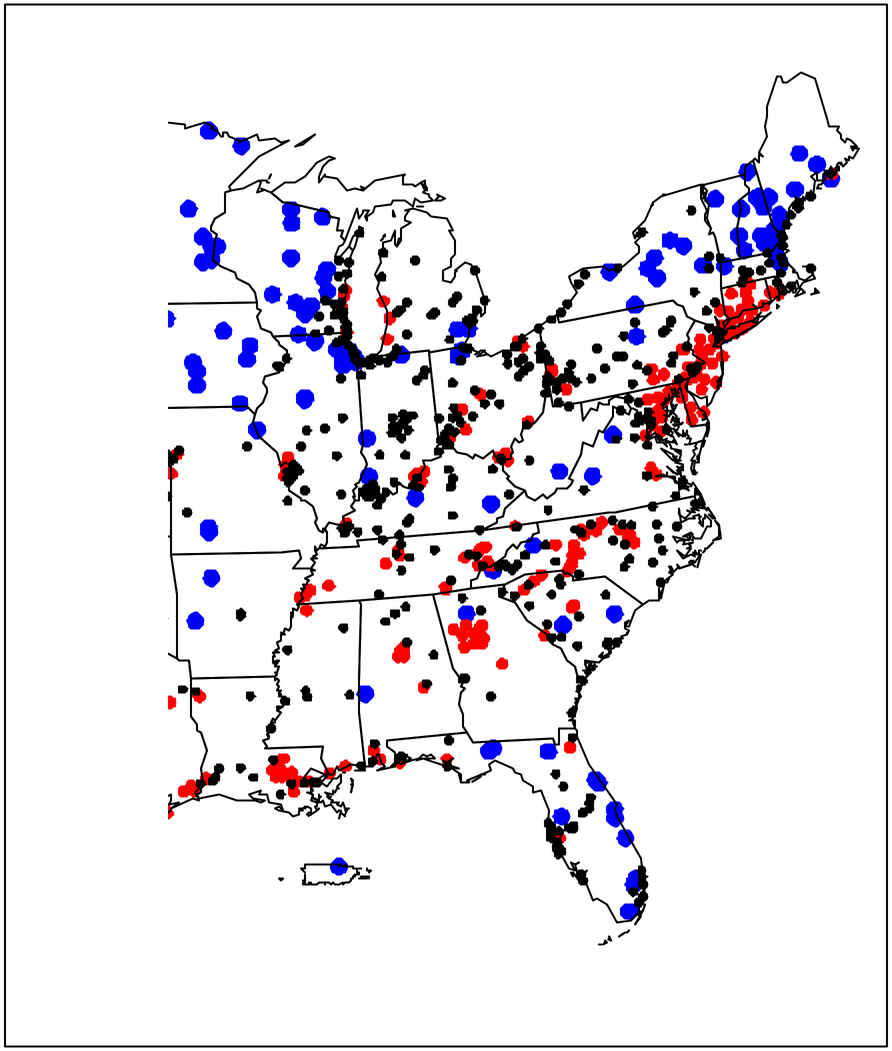
- A population of zero in a station sampling zone may arise:
  - where no census tract centroids fall within a station's area
  - where all of the tracts in the station's area have zero population (hundreds of tracts have populations of zero.)

Ranking of Stations

- For each of the five measures, the **stations are ranked** in importance. The upper quartile (75th percentile) and the lower quartile (25th percentile) of the stations are highlighted.
- The **focus is on** the stations with **low ranking** of their ‘value’ i.e. on candidate stations for elimination.
- This quartile ranking approach appears relevant for ozone and PM2.5, pollutants that frequently exceed the NAAQS.
- However, the quartile ranking probably is not as relevant for pollutants that frequently are below the NAAQS (CO, Pb, NO2, SO2 and PM10)

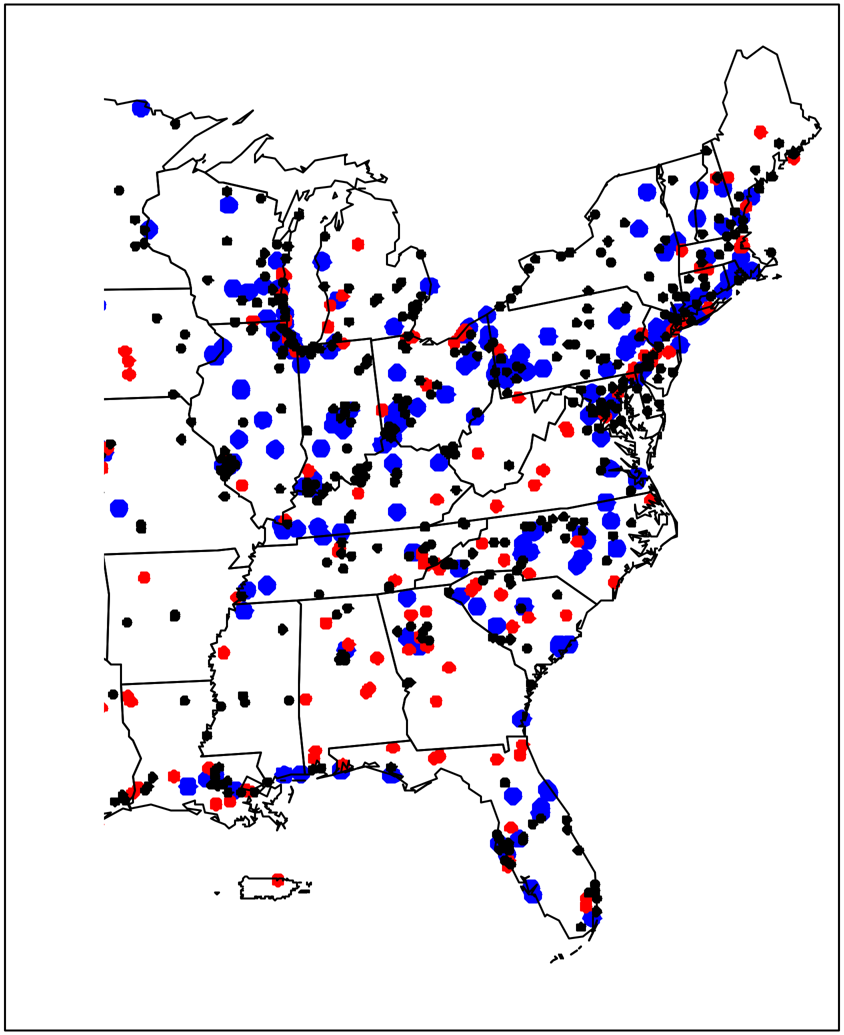
Example: O_3 Station Ranking by 2nd Max Concentration

- The daily max concentration is a factor in health risk.
- The stations with the highest O3 levels (red) are located over the NE Megalopolis, Ohio River Valley and the urban center in the Southeast: Dallas, Houston, Atlanta.
- The stations with the lowest O3 levels (blue) are located throughout the remainder EUS.
- Contiguous regions of low O3 are found in Florida, Upper Midwest, and the inland part of the Northeast.
- From O3 exposure perspective, the blue stations are ranked lowest.



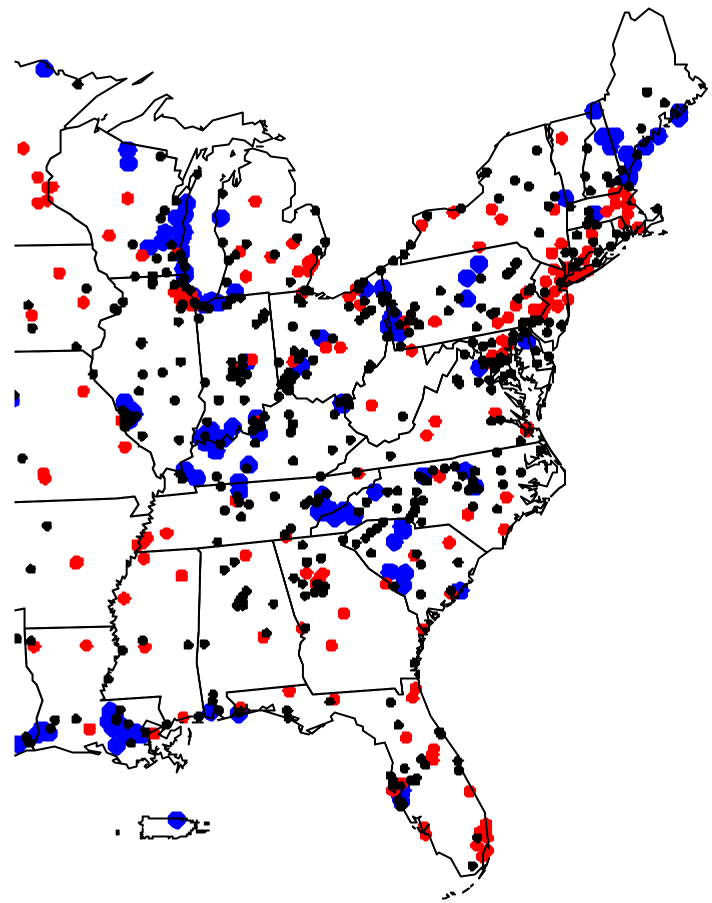
Example: O_3 Station Ranking by Estimation Uncertainty

- The **uncertainty** measures the ability to estimate the concentration from other data.
- The highest uncertainty (red) is found urban stations where the concentrations are highly variable in space and time, and at remote sites with significant spatial concentration gradients.
- The lowest uncertainty (blue) is at remote sites where the concentrations are more homogeneous in space and time, and at clustered urban sites.



Example: Ranking by Population in the Sampling Zone

- The number of persons in a station's sampling zone is a scaling factor for the overall health risk.
- Areas of large population per station (red) are found over the NE megalopolis but also over more remote areas.
- Small population/station (blue) is generally found remote sites but also in some urban clusters, e.g. Chicago, New Orleans, St. Louis.



1hr Ozone Data

Aggregate Ranking of Stations

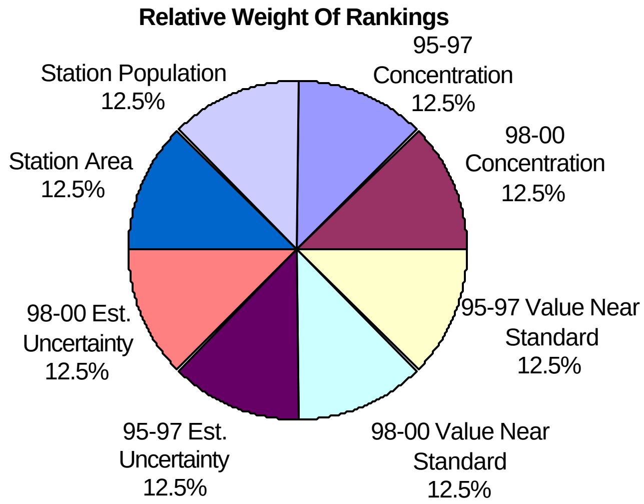
- **Rankings are aggregated** subjectively to yield overall evaluation.
- Aggregation of rankings is not **simply a weighing of the rankings** since it involves subjective judgments.
- However, once the relative weights of different rankings are available, (from the negotiation process) the current methodology allows their incorporation into the assessment
- The following pages illustrate several aggregate station rankings.

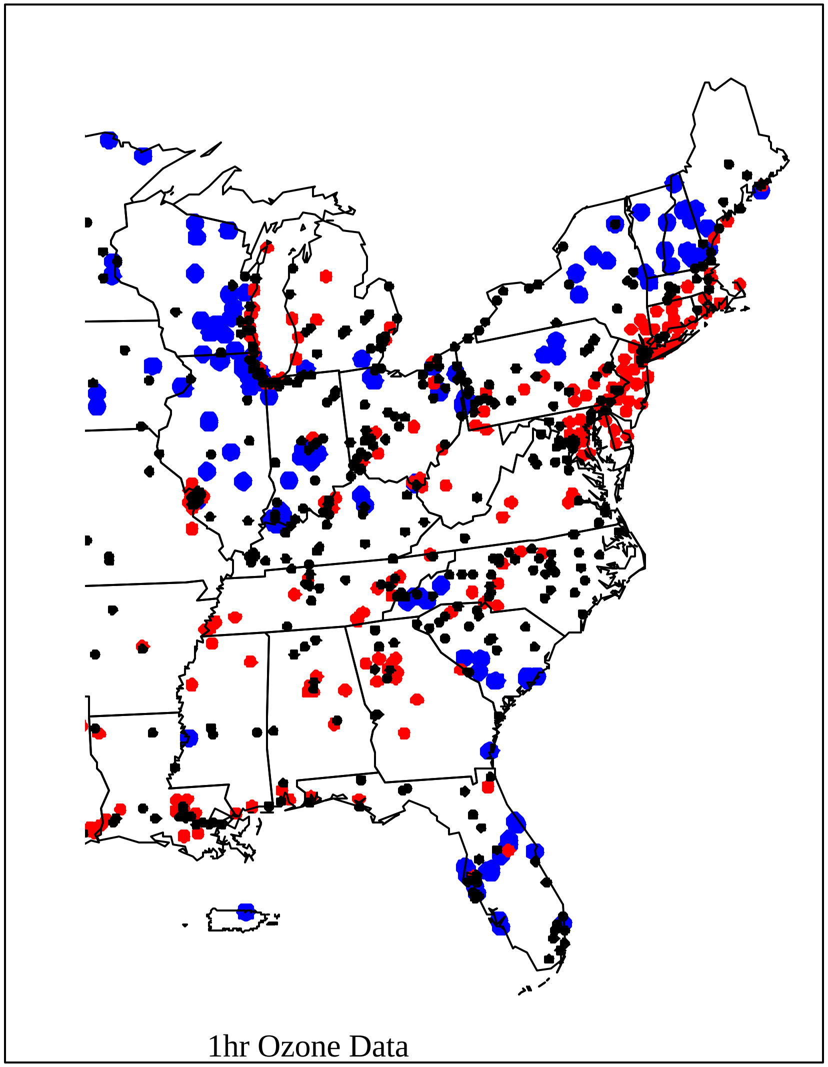
Four Weighting Systems

	Concentration	**Uncertainty**	**Value Near Standard**	**Area**	**Population**
W1: Equal Weight	20%	20%	20%	20%	20%
W2:NAAQS Compliance	30%	30%	30%	5%	5%
W3: exposure (population and land)/ AQI	30%	5%	5%	30%	30%
W4: ?	50%	50%	----------------	------	------------
W5:Tracking/ mod eval.	20%	40%		40%	

Example: 1hr O3 Aggregate Ranking – **Equal Weight**

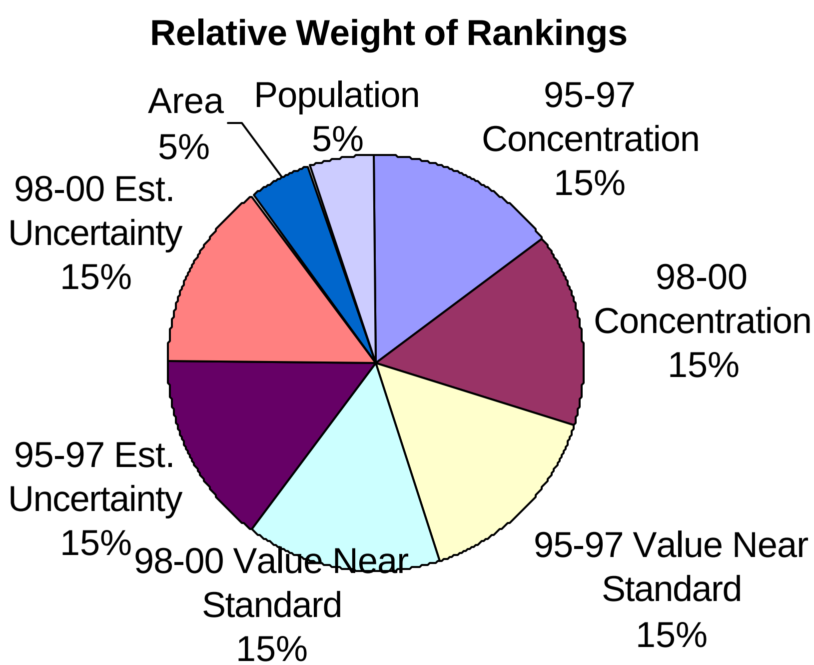
- 1hr Ozone data is split into 1995-1997 data and 1998-2000 data.
- 8 Measures are weighed equal at 12.5% each:
- High 'aggregate value' stations (red) are located over both urban and rural segments of the central EUS.
- Low 'value' sites (blue) are inter-dispersed with high value sites.
- Clusters of low value sites are found over Florida, Upper Midwest, and the inland portion of New England.

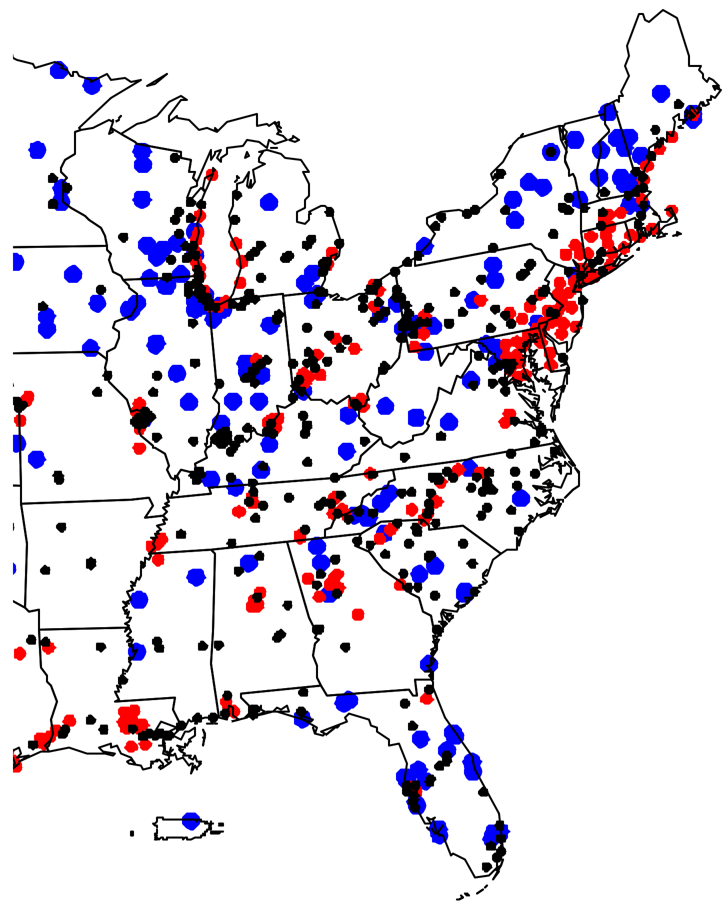




Example: 1hr O3 Aggregate Ranking – **NAAQS Compliance**

- This weighing of ranking give less weight to area and population.

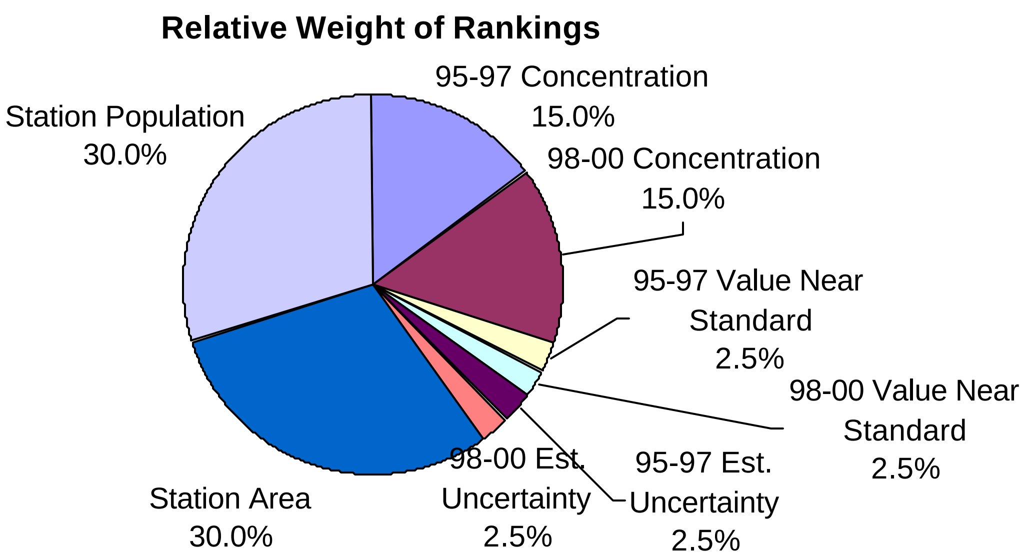


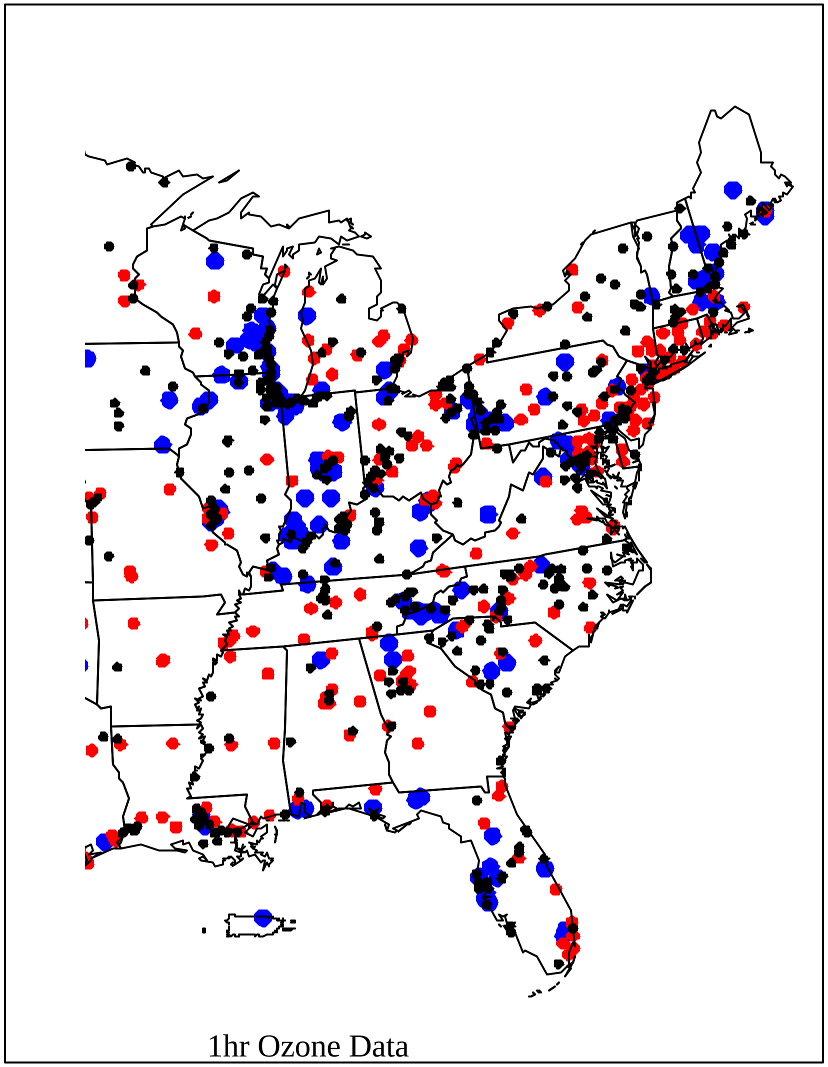


1hr Ozone Data

Example: 1hr O3 Aggregate Ranking - **Exposure**

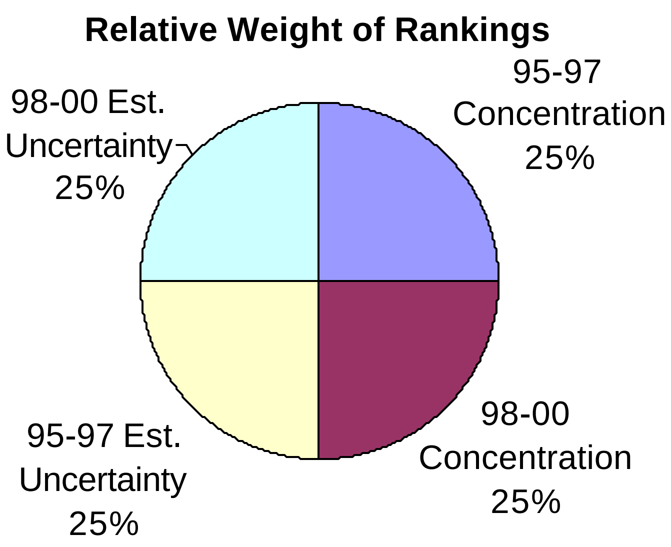
- This weighing of ranking adds extra weight for population.
- The high 'aggregate value' stations (red) are distributed throughout the urban and no-urban areas of EUS.

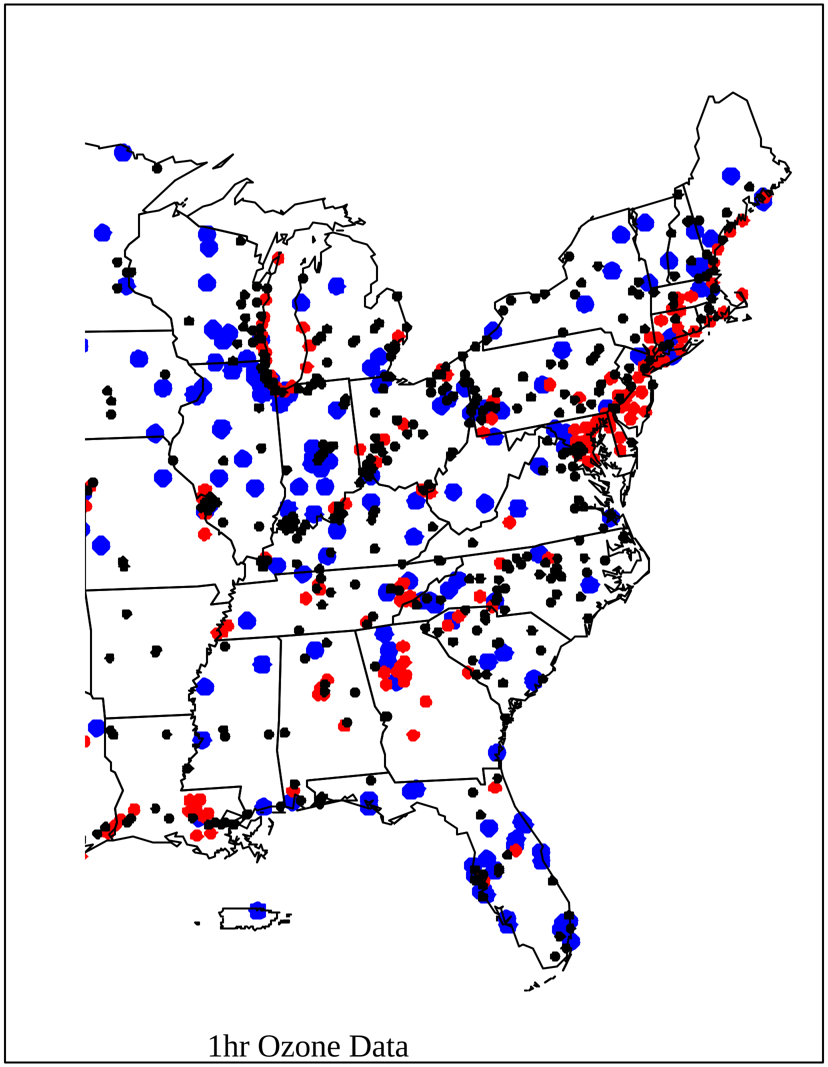




Example: 1hr O3 Aggregate Ranking

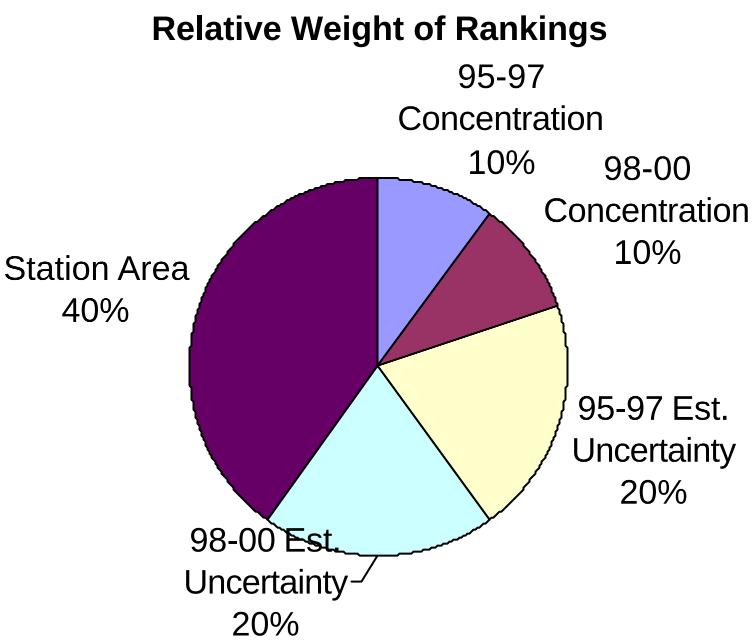
- This weighing of ranking looks only at concentration and estimation uncertainty.

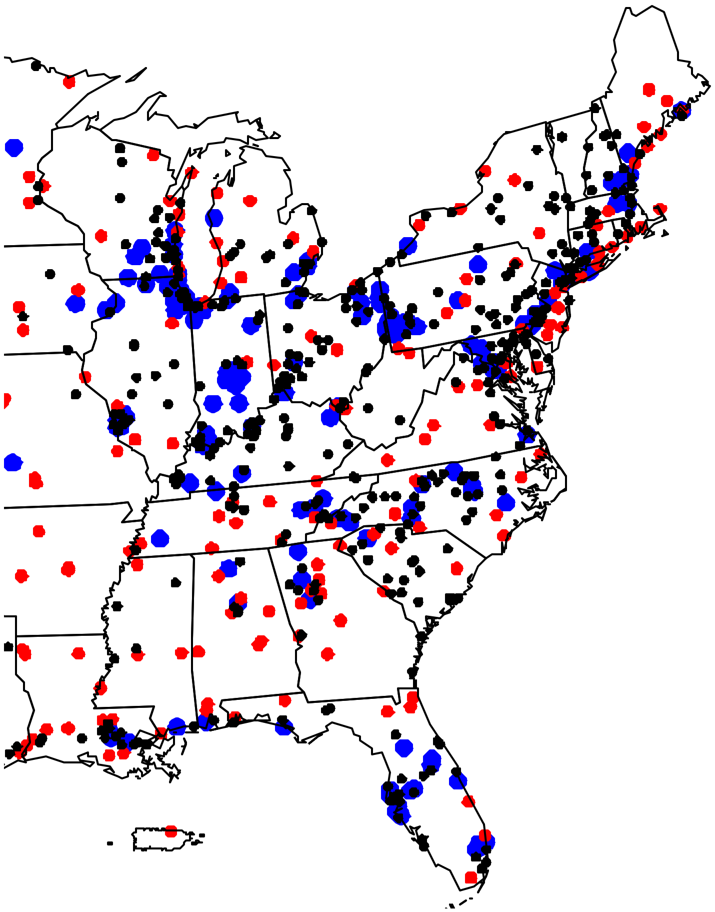




Example: 1hr O3 Aggregate Ranking - **Tracking**

- This weighing of ranking gives the greatest weight to estimation uncertainty and station area. It also includes concentration.





1hr Ozone Data

Assessment Outputs

- The preliminary outputs for the National Assessment are:
  - **Pie charts** for each pollutant showing 5 and 10 year trends
  - **Maps** for each pollutant showing which sites are above the NAAQS
  - **Maps** for each pollutant-metric-measure delineating sites in the
    - Top National quartile (‘most important’) - red markers
    - Bottom National quartile (‘least important’) - blue markers
    - Middle 2 National quartiles - black markers
  - Five **composite maps** for each pollutant aggregating all metric-measures
  - A **table** of the actual Q1 and Q3 threshold values for each pollutant-metric-measure
  - **Bar charts** for each pollutant-metric measure (and aggregate pollutant) showing the Regional breakdown of percent of sites in the National quartiles
  - **Spreadsheets** (separate from this file) for each pollutant showing
    - The actual calculated values for each metric-measure
    - The corresponding National ranking
    - The corresponding National quartile
  - An **aggregate pollutant map**: Aggregates all composite pollutant maps using equal weighting for each pollutant measured at the site