# Evaluation of Alternative Methods for Characterizing Air Quality to Estimate Population Exposures—Wisconsin

Presented by

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# AUTHORS

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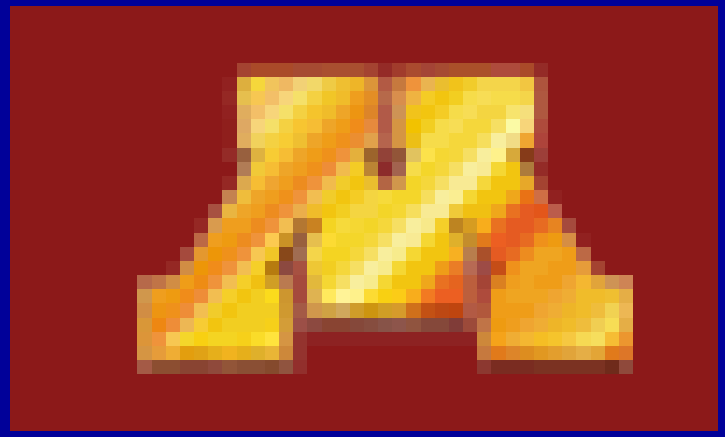


# SPECIAL THANKS

- EPA
  - Providing Data
  - Analytic Support
  - www.epa.gov
- Ambarish Vaidyanathan
  - GIS Mapping

# BACKGROUND

5% of 6 million annual hospital admissions for cardiovascular disease (CVD) in the U.S. can be attributed to airborne particulate matter (PM2.5).[1]

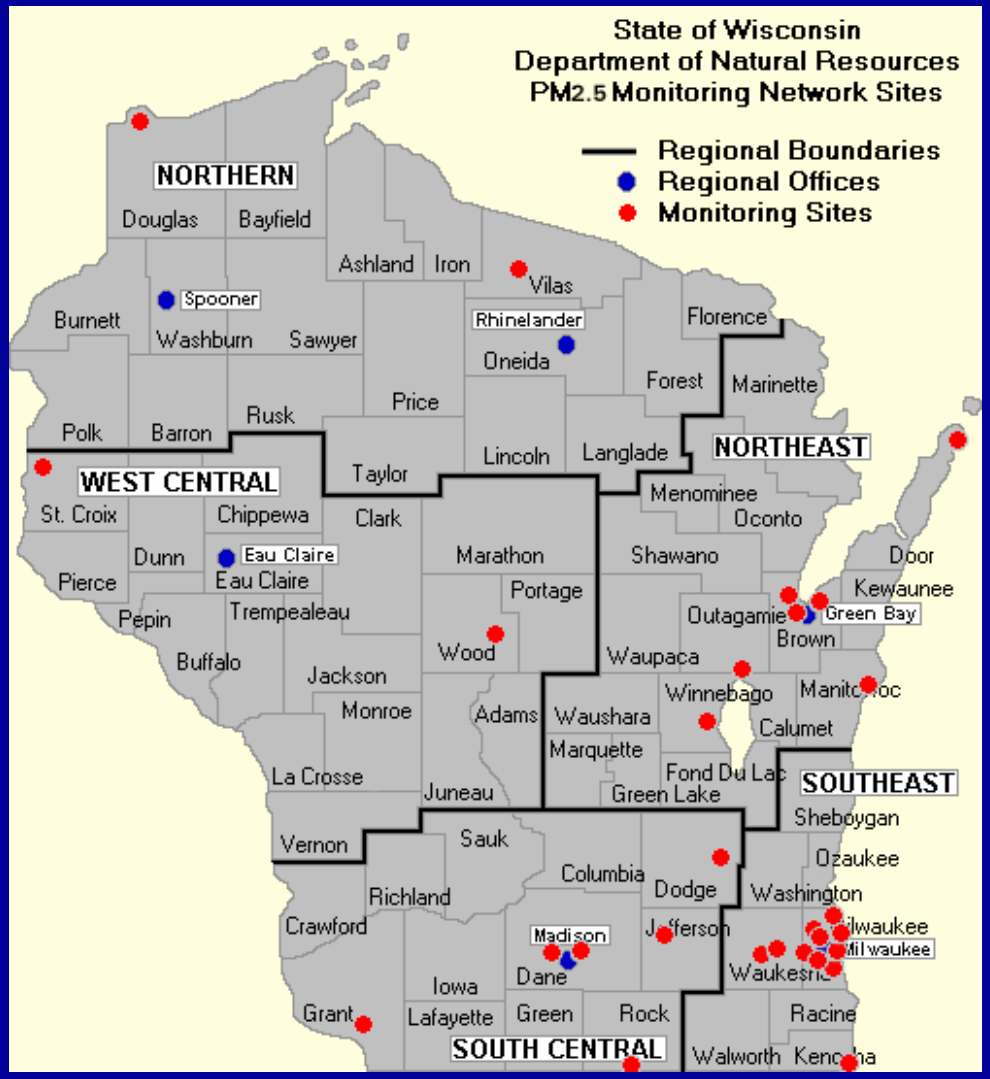
# BACKGROUND

- Understanding the relation between cardiovascular disease and PM2.5 is difficult due to the lack of ability to accurately assess exposure.
- The most commonly used method of assigning exposure to individuals or populations in research studies is proximity to air monitor(s).

# BACKGROUND

- Monitors provide information for one geographic location; however:
  - Very few monitors provide daily PM2.5 measurements, creating <u>temporal</u> gaps.
  - Few monitors are located in rural areas, creating <u>spatial</u> gaps.

# BACKGROUND




## Location of PM2.5 Monitors in Wisconsin

- There are 7 monitors in Milwaukee County, but only 2 have daily output. (temporal gap)
- The majority of monitors are located near Milwaukee, Madison, and Green Bay. (spatial gap)

# BACKGROUND

- Several air quality characterization methods can potentially fill these temporal and spatial gaps but have not been explored for their utility as part of **public health surveillance**.

# BACKGROUND

- There are 3 methods we explored:
  - **Kriging**
    - Mathematical interpolation method
    - Monitoring data
  - **Community Multi-Scale Air Quality (CMAQ)**
    - Photochemical grid model
    - Facility emissions & meteorological data
  - **Hierarchical Bayesian**
    - Mathematical interpolation method
    - Monitoring data combined with CMAQ estimates

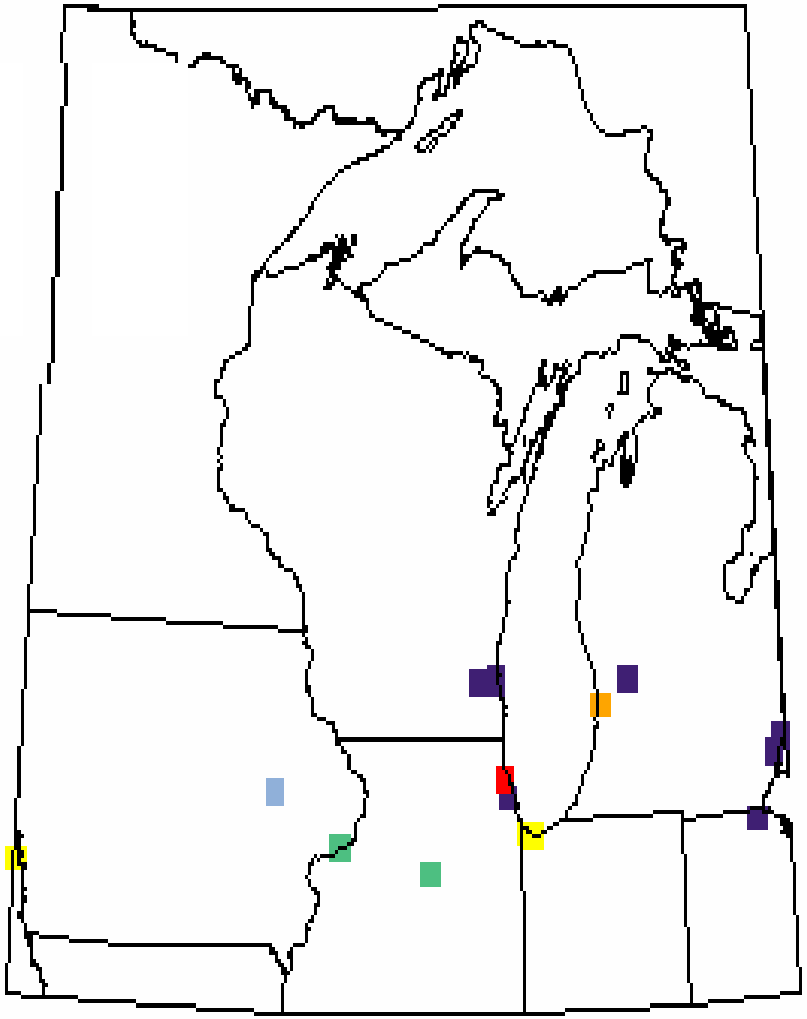
# MAPS

- Comparison between the monitor observation maps for January 12 vs. January 13 demonstrate temporal gaps.
- Comparison between monitor observations and each of the 3 methods demonstrate spatial gaps.
- The maps also demonstrate the different outcomes of each method.

# Monitor Observations

## PM 2.5 Daily Average

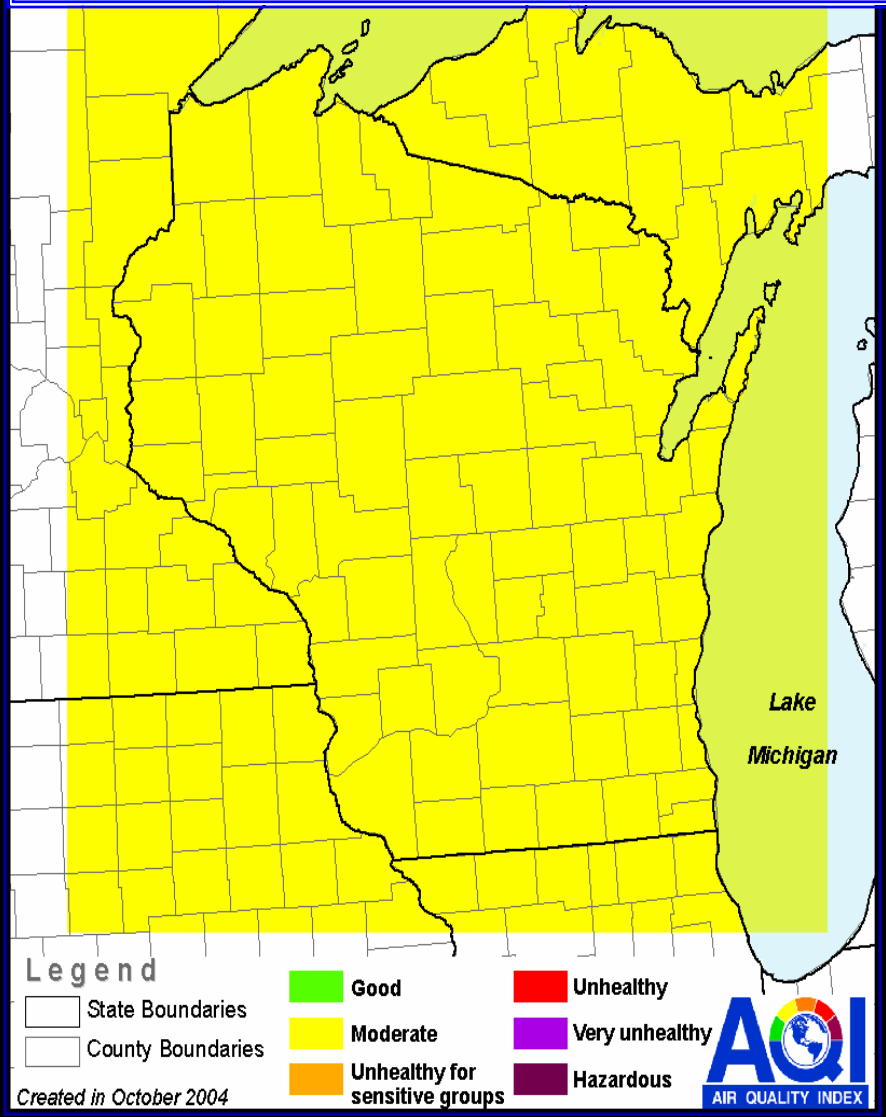
**January 12, 2001**



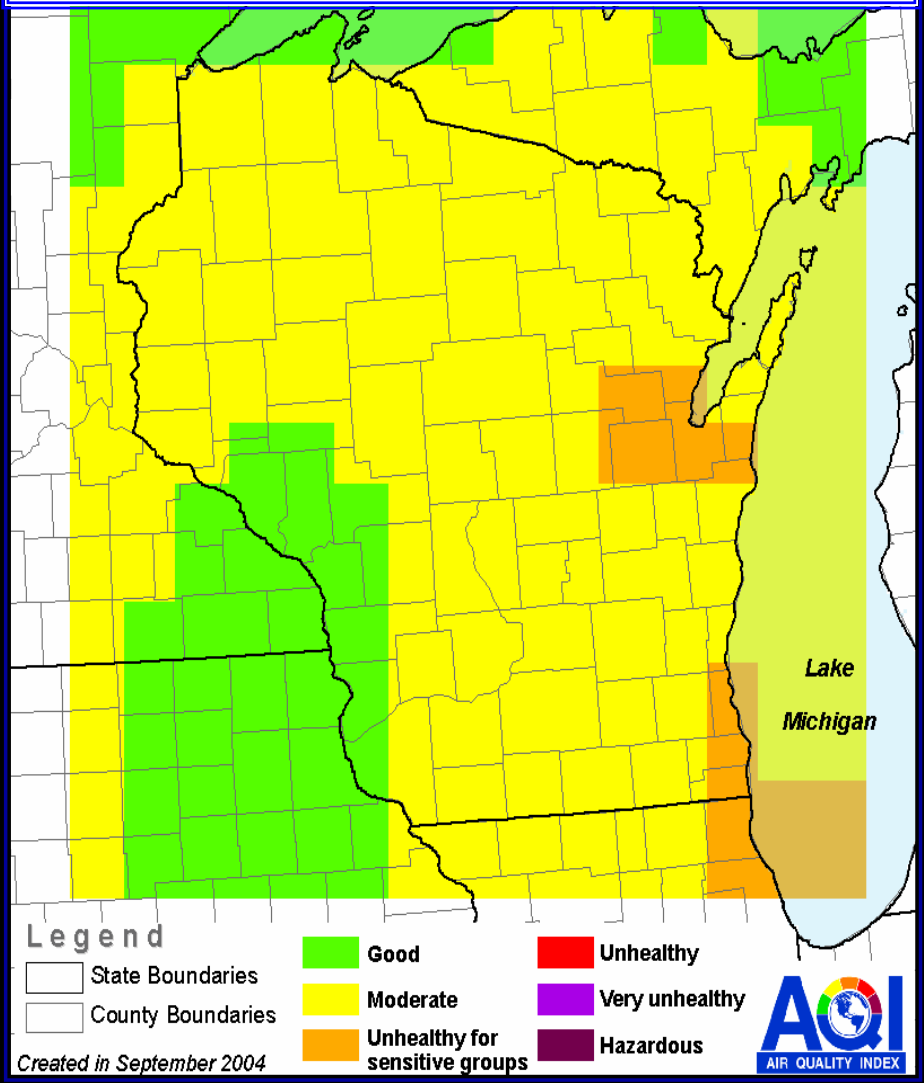
# Kriging

## PM 2.5 Daily Average

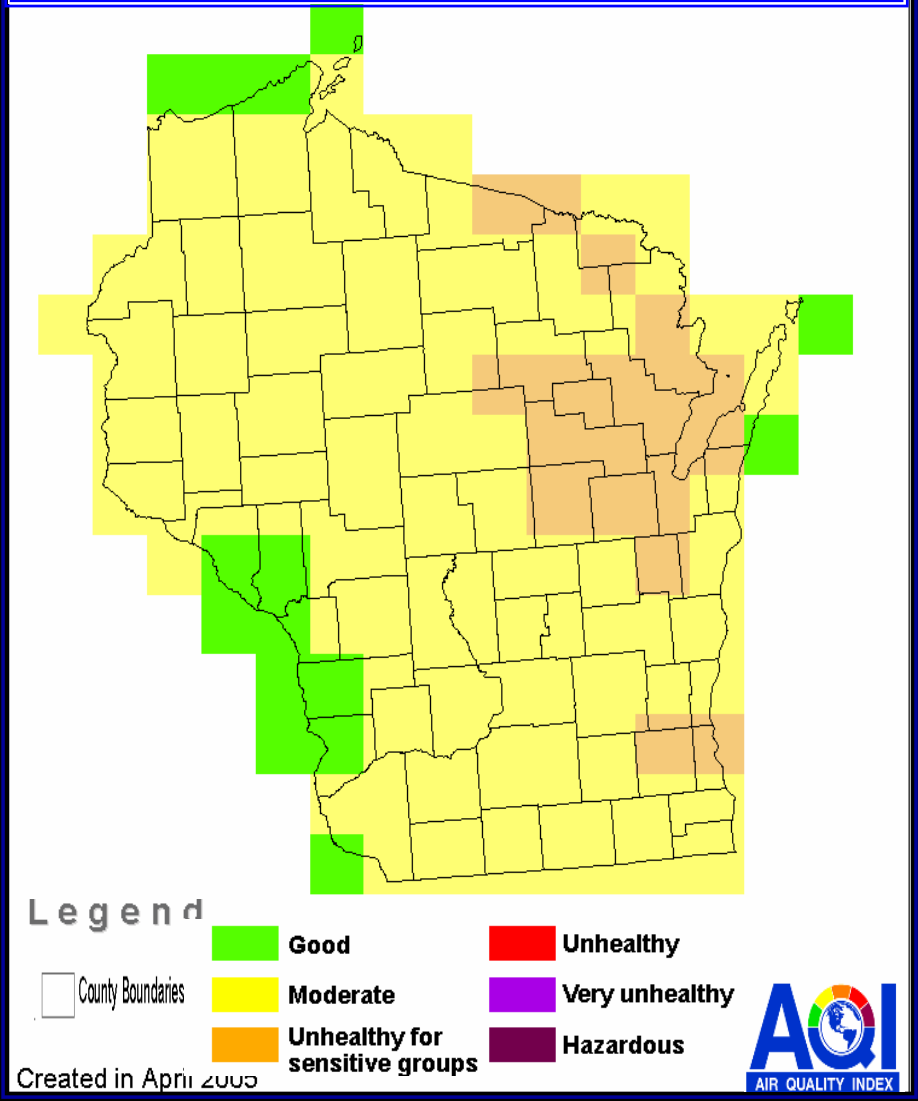
**January 12, 2001**



# CMAQ
## PM 2.5 Daily Average
### January 12, 2001



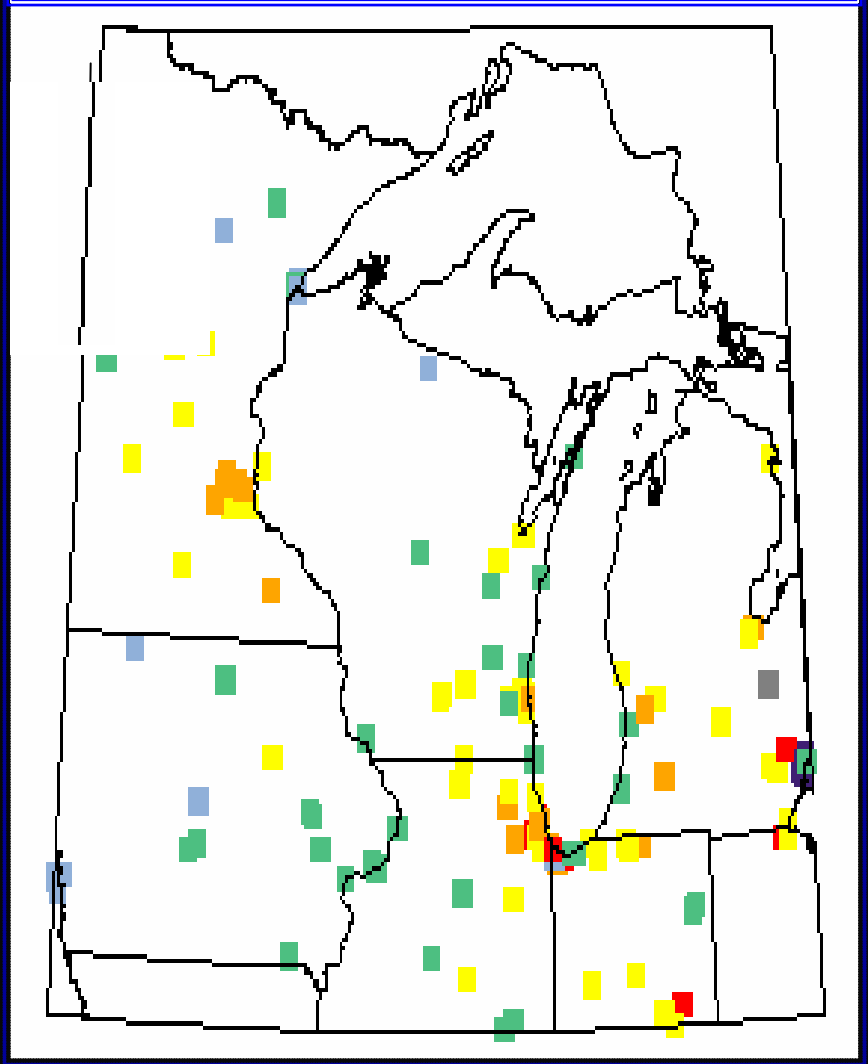

# Hierarchical Bayesian
## PM 2.5 Daily Average
### January 12, 2001



# Monitor Observations

## PM 2.5 Daily Average

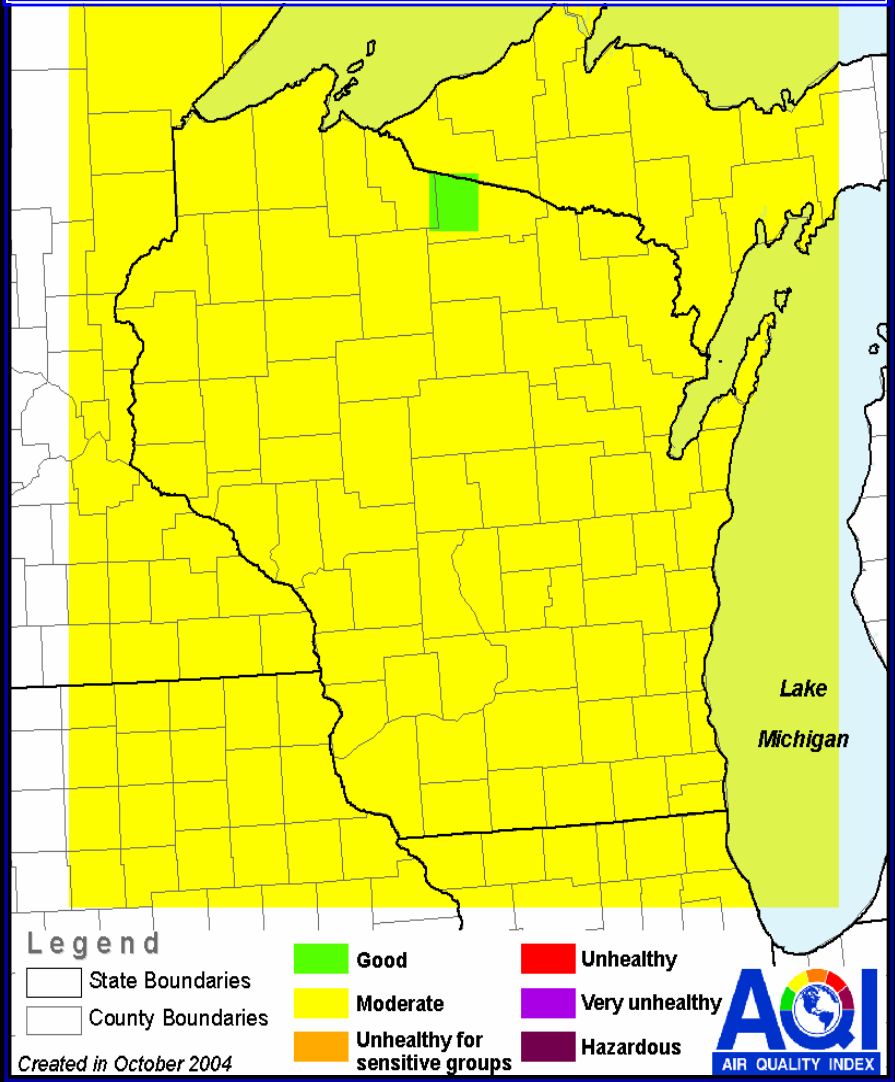
**January 13, 2001**



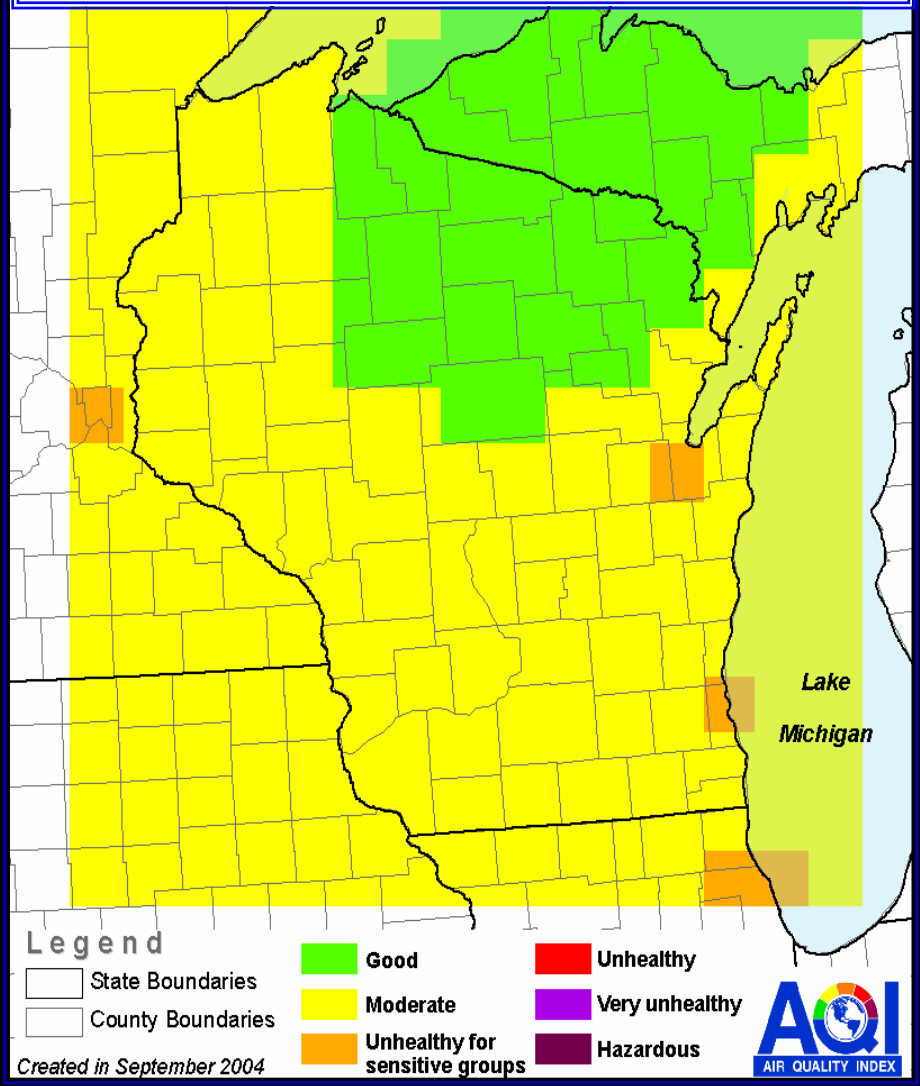
# Kriging

## PM 2.5 Daily Average

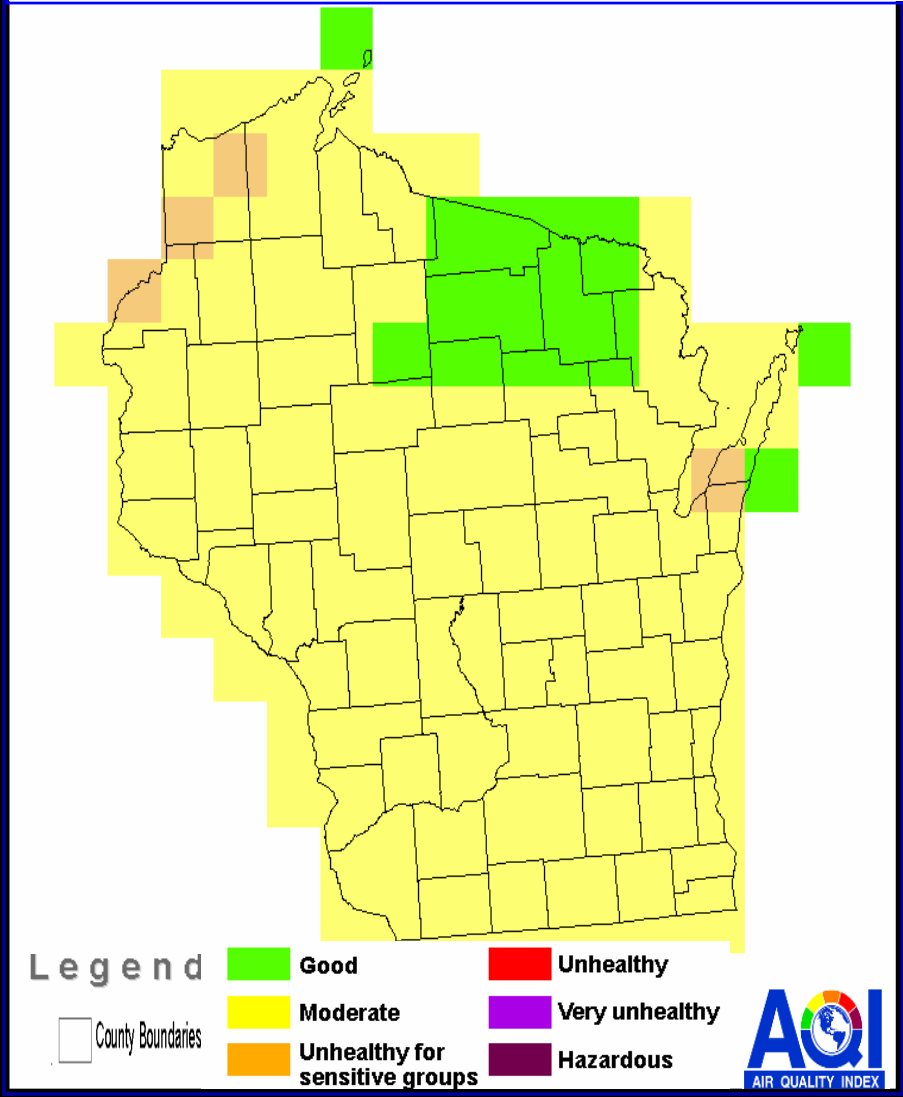
**January 13, 2001**



# CMAQ
## PM 2.5 Daily Average
### January 13, 2001




# Hierarchical Bayesian
## PM 2.5 Daily Average
### January 13, 2001



# STUDY QUESTION

**Of these available 3 methods which one is the most valid and reliable relative to monitor observations and the referent method for assigning exposure (monitor proximity) given the following parameters:**

- **Assigning an average PM2.5 concentration estimate to the <u>county</u>**
  - **Using 36km resolution vs. 12km or 4km resolution**
- **Cardiovascular hospitalization cases aggregated to the <u>county</u> level**
  - **Confidentiality restrictions in Wisconsin require health data to be aggregated at the county level for any data user outside of the health department.**

# OBJECTIVES

- To evaluate the relative **validity** of these 3 methods by comparing PM2.5 concentration ***estimates*** to ***measures*** obtained from monitors.

- To assess the **validity** and **reliability** of using these 3 methods to assign ***exposure classification*** using monitor proximity as the referent standard.

# METHODS—VALIDITY
## *ESTIMATES vs. MEASURES*

- For this study, 36km grid cells were used to estimate a daily average county-wide PM2.5 concentration estimate for 6 Wisconsin counties selected to represent:
  - urban and rural areas
  - different areas of the state
  - a mix of counties with and without monitors

# METHODS—VALIDITY
## *ESTIMATES vs. MEASURES*

The following counties were selected:

- Urban
  - Milwaukee
  - Ozaukee
- Rural
  - Wood
  - Portage
  - Douglas
  - Bayfield

# RESULTS—VALIDITY

*ESTIMATES vs. MEASURES*

# Means and Standard Deviations for Monitors and each of the 3 Methods for 6 Wisconsin Counties—2001

| COUNTY | Monitors | Kriging | CMAQ | Hierarchical Bayesian |
|---|---|---|---|---|
| Milwaukee | 13.7, 8.9 | 13.1, 7.5 | 17.1, 9.6 | 13.4, 8.0 |
| Ozaukee | 11.7, 7.8 | 12.3, 7.8 | 13.9, 8.4 | 11.9, 7.3 |
| Wood | 9.8, 6.3 | 10.3, 6.4 | 8.9, 6.3 | 9.9, 6.4 |
| Portage | 9.8, 6.3 | 10.3, 6.6 | 9.0, 6.4 | 10.2, 7.1 |
| Bayfield | 8.2, 4.5 | 8.4, 4.8 | 6.3, 5.1 | 9.9, 7.2 |
| Douglas | 8.2, 4.5 | 8.6, 4.8 | 7.3, 5.5 | 9.8, 6.9 |

UNITS = $\mu g/m^3$ *CMAQ = Community Multi-scale Air Quality model

# Means Differences for each of the 3 Methods (Monitor Measures = Referent Standard) for 6 Wisconsin Counties—2001

| COUNTY | Kriging | CMAQ | Hierarchical Bayesian |
|---|---|---|---|
| Milwaukee | -0.64 (-1.22,-0.04) | 3.42 (2.79,4.04) | -0.32 (-0.52,-0.13) |
| Ozaukee | 0.61 (0.18,1.05) | 2.28 (1.15,3.41) | 0.25 (-0.08,0.59) |
| Wood | 0.47 (0.02,0.92) | -0.94 (-1.70,-0.18) | 0.11 (-0.36,0.58) |
| Portage | 0.51 (0.07,0.96) | -0.82 (-1.57,-0.08) | 0.40 (-0.29,1.08) |
| Bayfield | 0.24 (-0.24,0.71) | -1.88 (-2.53,-1.22) | 1.70 (0.79,2.61) |
| Douglas | 0.47 (0.05,0.90) | -0.92 (-1.59,-0.25) | 1.61 (0.79,2.44) |

Red = Statistically Significant (95% Confidence Intervals)

UNITS = $\mu g/m^3$ *CMAQ = Community Multi-Scale Air Quality Model

# Correlation of Monitoring Measures and Concentration Estimates from each of the 3 Methods for 6 Wisconsin Counties—2001

| COUNTY | Kriging | CMAQ | Hierarchical Bayesian |
|---|---|---|---|
| Milwaukee | 0.77 | 0.79 | 0.98 |
| Ozaukee | 0.95 | 0.72 | 0.97 |
| Wood | 0.93 | 0.79 | 0.92 |
| Portage | 0.93 | 0.80 | 0.85 |
| Bayfield | 0.84 | 0.72 | 0.72 |
| Douglas | 0.87 | 0.73 | 0.75 |

*CMAQ = Community Multi-scale Air Quality model

# METHODS—VALIDITY & RELIABILITY

## *EXPOSURE CLASSIFICATION*

- Cardiovascular disease hospitalization cases were aggregated at the county level on a daily basis for year 2001 using the case definition of ischemic heart disease, congestive heart failure, cerebrovascular disease (stroke) admissions, principle diagnosis only (ICD-9-CM: 410-414, 428, 430-438).

*Only Milwaukee County had sufficient numbers of cases to be analyzed.

# METHODS—VALIDITY & RELIABILITY

## *EXPOSURE CLASSIFICATION*

- PM2.5 concentration estimates were available from all 4 sources (monitors and each of the 3 methods), for all of 2001 except for 2 days.

- The average of all monitoring sites for each day in 2001 was used to calculate a daily monitor measure for PM2.5.

# METHODS—VALIDITY & RELIABILITY

## *EXPOSURE CLASSIFICATION*

- Using the Air Quality Index (AQI), a daily PM2.5 concentration estimate of >40.4µg/m$^3$ is classified by EPA as "unhealthy".

- ***There is no known "healthy" exposure to PM2.5***, but for the purposes of this study, exposure was dichotomized to reflect "healthy" ($\leq$ 40.4µg/m$^3$) and "unhealthy" (>40.4µg/m$^3$) categories.

# METHODS—VALIDITY & RELIABILITY

## *EXPOSURE CLASSIFICATION*

- Exposure was assigned using the day of hospitalization for cardiovascular cases, no lag time was used.
  - Evidence from recent time-series studies of cardiovascular admissions suggests that PM effects tend to be maximal at lag 0, with some carryover to lag 1, with little evidence for important effects beyond lag 1.[6]

# METHODS—VALIDITY & RELIABILITY

## *EXPOSURE CLASSIFICATION*

- Monitor measures and concentration estimates from each of the 3 methods were used to assign an exposure classification to cardiovascular cases.

- For each of the 3 methods, measures of validity were calculated—sensitivity, specificity, positive predicted value (PPV), and negative predicted value (NPV).

# METHODS—VALIDITY & RELIABILITY

## *EXPOSURE CLASSIFICATION*

- Using the data in the 2X2 tables, measures of reliability—percent agreement and the Kappa coefficient—were calculated for each of the 3 methods.

# RESULTS—VALIDITY

*EXPOSURE CLASSIFICATION*

# Exposure Classification of Cardiovascular Cases in Milwaukee County Using Kriging Compared to Monitor Proximity—2001

| **Exposure Classification Comparison**<br><br>*Monitor Proximity vs Kriging* | | **Monitors (Referent Method)** | | ***Total*** |
|---|---|---|---|---|
| | | **PM2.5 >40.4µg/m³ U** | **PM2.5 ≤ 40.4µg/m³ H** | |
| **Kriging** | **PM2.5 >40.4µg/m³ U** | **UU 0** | **UH 0** | **0** |
| | **PM2.5 ≤ 40.4µg/m³ H** | **HU 116** | **HH 13,572** | **13,688** |
| | ***Total*** | **116** | **13,572** | **13,688** |

H=Healthy U=Unhealthy

# RESULTS—VALIDITY
## *EXPOSURE CLASSIFICATION*
## *Kriging*

- **Sensitivity = 0%**
- **Specificity = 100%**
- **PPV = undefined**
- **NPV = 99.2%**

- PPV = Positive Predicted Value
- NPV = Negative Predicted Value

# Exposure Classification of Cardiovascular Cases in Milwaukee County Using CMAQ Compared to Monitor Proximity—2001

| **Exposure Classification Comparison**<br><br>*Monitor Proximity vs CMAQ* | | **Monitors (Referent Method)** | | ***Total*** |
|---|---|---|---|---|
| | | **PM2.5 >40.4µg/m³ U** | **PM2.5 ≤ 40.4µg/m³ H** | |
| **CMAQ** | **PM2.5 >40.4µg/m³ U** | **UU 87** | **UH 232** | **319** |
| | **PM2.5 ≤ 40.4µg/m³ H** | **HU 29** | **HH 13,340** | **13,369** |
| | ***Total*** | **116** | **13,572** | **13,688** |

H=Healthy U=Unhealthy

# RESULTS—VALIDITY
## *EXPOSURE CLASSIFICATION CMAQ*

- **Sensitivity = 75%**
- **Specificity = 98.3%**
- **PPV = 27.3%**
- **NPV = 99.8%**

- PPV = Positive Predicted Value
- NPV = Negative Predicted Value

# Exposure Classification of Cardiovascular Cases in Milwaukee County Using Hierarchical Bayesian Compared to Monitor Proximity—2001

| **Exposure Classification Comparison**<br><br>*Monitor Proximity vs Hierarchical Bayesian* | | **Monitors (Referent Method)** | | ***Total*** |
|---|---|---|---|---|
| | | **PM2.5 >40.4μg/m³ U** | **PM2.5 ≤ 40.4μg/m³ H** | |
| **Hierarchical Bayesian** | **PM2.5 >40.4μg/m³ U** | **UU 0** | **UH 40** | **40** |
| | **PM2.5 ≤ 40.4μg/m³ H** | **HU 116** | **HH 13,532** | **13,648** |
| | ***Total*** | **116** | **13,572** | **13,688** |

H=Healthy U=Unhealthy

# RESULTS—VALIDITY

## *EXPOSURE CLASSIFICATION*

## *Hierarchical Bayesian*

- **Sensitivity = 0%**
- **Specificity = 99.7%**
- **PPV = 0%**
- **NPV = 99.2%**

- PPV = Positive Predicted Value
- NPV = Negative Predicted Value

# RESULTS—RELIABILITY
## *EXPOSURE CLASSIFICATION*

**Percent Agreement**

- **Kriging = 99.2%**
- **CMAQ = 98.1%**
- ***HB = 98.9%**

*HB = Hierarchical Bayesian

# RESULTS—RELIABILITY
## *EXPOSURE CLASSIFICATION*

**Kappa Coefficient**

- **Kriging = 0**
- **CMAQ = .39**
- **HB = $-4.36 \times 10^{-03}$**

**Fleiss, 1981**

| | |
|---|---|
| **0.91 – 1.00** | **Excellent** |
| **0.71 – 0.90** | **Good** |
| **0.51 – 0.70** | **Fair** |
| **0.00 – 0.50** | **Poor** |

*Kappa < 0 indicates observed %agreement is less than chance agreement

# DISCUSSION

- The means differences suggest that the 3 methods provide output that is statistically different from the monitor measures;
- However, it appears that these differences between monitors and the 3 methods rarely result in a difference of exposure classification in this simple dichotomous scheme.

# DISCUSSION

- Although Kriging and Hierarchical Bayesian interpolations correlated better with monitor measures than did CMAQ (which is expected since both kriging and Hierarchical Bayesian methods use monitor data and CMAQ does not), the CMAQ model has the best overall measures of validity for exposure assignment.

# DISCUSSION

- The kappa coefficient suggests that the high percent agreement for all 3 methods could be due to chance alone, but of the 3 methods, CMAQ observed percent agreement of 98.1% is the least likely to be due to chance.

# CONCLUSION

The findings of this study suggest that of the 3 methods, CMAQ is the least valid (but still moderate) when comparing concentration estimates to monitor measures, but that CMAQ is the most valid and reliable for assigning exposure relative to the referent method (monitor proximity).

# CONCLUSION

Utility for use in public health surveillance will ultimately be determined by the ability of the method to detect an association between exposure to PM2.5 and cardiovascular disease (CVD).

# LIMITATIONS OF THIS STUDY

- Use of 36km resolution vs. 12km or 4km.
- Use of county level aggregated health data vs. aggregation at the zip code or census tract levels.
- Use of a dichotomous classification scheme vs. more exposure categories or a continuous variable.

# Wisconsin's Response

- Address the resolution issues
  - Using 36km, 12km, or 4km resolutions for environmental data
  - Using zip code level of aggregated health data
  - Using a continuous variable for exposure
- Testing the ability to detect an association
  - PHASE Project
  - Case-Crossover Analysis

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# REFERENCES

[1]Schwartz, J. Air Pollution and Hospital Admissions for Heart Disease in Eight U.S. Counties. Epidemiology 1999; (10:17-22).

[2]Ramage L, Guy K. Expression of C-reactive protein and heat-shock protein-70 in the lung epithelial cell line A549, in response to PM10 exposure. Inhal Toxicol. 2004 Jun;16(6-7):447-52.

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[4]Campen MJ, McDonald JD, Gigliotti AP, et.al. Cardiovascular effects of inhaled diesel exhaust in spontaneously hypertensive rats. Cardiovasc Toxicol. 2003;3(4):353-61.

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# BACKGROUND

- How does PM2.5 contribute to cardiovascular mortality?
  - Increase in proteins in plasma known to be associated with CVD[2]
  - Lowers cardiac autonomic control[3]
  - Affects on pacemaking system[4]
  - Increases likelihood of atherosclerotic plaque rupture[5]