





## **Final Report**

# **Emissions and Air Quality Modeling for SEMAP**

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## **Table of Contents**

| List of Figure | res  | v    |
|----------------|--|------|
| List of Table  | es   | xvii |
| List of Acro   | nyms   | XX   |
| Document C     | Change Record  | xxii |
| Chapter 1:     | Project Overview   | 1-1  |
| 1.1 II         | ntroduction  | 1-1  |
| 1.2 K          | Ley Personnel and Roles  | 1-1  |
| 1.2.1          | Georgia Institute of Technology (Georgia Tech)                           | 1-1  |
| 1.2.2          | University of North Carolina (UNC)                                       | 1-1  |
| 1.2.3          | Colorado State University (CSU)  | 1-2  |
| 1.3 T          | asks Performed   | 1-2  |
| 1.3.1          | Task 1: Project Management   | 1-2  |
| 1.3.2          | Task 2: Modeling Protocol  | 1-3  |
| 1.3.3          | Task 3: Data Acquisition/Dataset Preparation for Modeling and Evaluation | 1-4  |
| 1.3.4          | Task 4: Conceptual Description   | 1-6  |
| 1.3.5          | Task 5: 36 km/12 km Emissions/AQ Annual Actual Base Year Simulations     | 1-6  |
| 1.3.6          | Task 6: Model Configuration Diagnostic Sensitivity Modeling              | 1-9  |
| 1.3.7          | Task 7: Emissions and Air Quality Benchmark Simulations                  | 1-9  |
| 1.3.8          | Task 8: 36 km/12 km Annual Typical/Future Year Emissions AQ Modeling     | 1-9  |
| 1.3.9          | Task 9: Emission Sensitivity Modeling                                    | 1-10 |
| 1.3.10         | Task 10: Model Performance Evaluation                                    | 1-10 |
| 1.3.11         | Task 11: Future Year Model Projections                                   | 1-10 |
| 1.3.12         | Task 12: Interactive Database Tool                                       | 1-11 |
| 1.3.13         | Task 13: Receptor Modeling   | 1-13 |
| 1.3.14         | Task 14: Development of Technical Web Site                               | 1-13 |
| 1.3.15         | Task 15: Other Tasks as Assigned   | 1-14 |
| 1.3.16         | Task 16: Reporting   | 1-14 |
| 1.4 R          | eferences  | 1-14 |
| Chapter 2:     | Emissions Modeling   | 2-1  |
| 2.1 E          | missions Data, Modeling and Results                                      | 2-1  |
| 2.1.1          | SEMAP Emissions data collection and preparation                          | 2-2  |
| 2.1.2          | SEMAP 2007 Emissions Modeling Platform                                   | 2-6  |
| 2.1.3          | SEMAP Typical 2007 Modeling Platform                                     | 2-60 |

| 2.1.4      | SEMAP Base 2018 Modeling Platform                     | 2-64  |
|------------|---|-------|
| 2.2        | Errata  |       |
| 2.3        | State Emissions Summaries                             | 2-94  |
| 2.3.1      | 2007 Base   | 2-94  |
| 2.3.2      | 2007 Typical  | 2-108 |
| 2.3.3      | 2018 Base   | 2-109 |
| 2.4        | 2018 vs 2007 (Actual) State Total Comparisons         | 2-122 |
| 2.5        | References  | 2-130 |
| Chapter 3: | Air Quality Model Performance Evaluation              | 3-1   |
| 3.1        | Introduction  | 3-1   |
| 3.2        | Evaluation Methodology                                | 3-1   |
| 3.2.1      | Statistical Evaluation                                |       |
| 3.2.2      | Diagnostic Evaluation                                 |       |
| 3.3        | Performance Metrics and Goals                         | 3-1   |
| 3.4        | Observational Networks                                |       |
| 3.4.1      | AIRS  |       |
| 3.4.2      | IMPROVE   |       |
| 3.4.3      | CASTNet   |       |
| 3.4.4      | NADP  |       |
| 3.4.5      | SEARCH  |       |
| 3.4.6      | Quality Assurance                                     |       |
| 3.5        | Evaluation Products                                   |       |
| 3.6        | Initial Model Performance                             | 3-7   |
| 3.6.1      | Ozone   |       |
| 3.6.2      | PM <sub>2.5</sub>                                     |       |
| 3.6.3      | Acid Deposition                                       |       |
| 3.7        | Diagnostics   |       |
| 3.7.1      | Sensitivity to PBL height and Mixing Coefficients     |       |
| 3.7.2      | Sensitivity to Land-Water Interface                   |       |
| 3.7.3      | Sensitivity to Boundary Conditions                    |       |
| 3.7.4      | Sensitivity to Lightning NO <sub>x</sub> Emissions    |       |
| 3.7.5      | Sensitivity to Ground-level NO <sub>x</sub> Emissions |       |
| 3.7.6      | Uncertainties in Meteorological Inputs                |       |
| 3.7.7      | Recommendations for Final Model Configuration         |       |

| 3.8        | Final Model Performance                                   |      |
|------------|---|------|
| 3.8.1      | Ozone   |      |
| 3.8.2      | PM <sub>2.5</sub>   |      |
| 3.8.3      | Acid Deposition   |      |
| 3.9        | Typical vs. Actual Year Performance                       |      |
| 3.9.1      | Capping of fire emissions                                 |      |
| 3.9.2      | Ozone   |      |
| 3.9.3      | PM <sub>2.5</sub>   |      |
| 3.9.4      | Acid Deposition   |      |
| 3.10       | Conclusions   |      |
| 3.10.      | Ozone and precursors                                      |      |
| 3.10.2     | 2 PM <sub>2.5</sub>                                       |      |
| 3.10.3     | 3 PM <sub>2.5</sub> Components                            |      |
| 3.11       | References  |      |
| Chapter 4: | Future Year (2018) Simulation                             | 4-1  |
| 4.1        | Introduction  | 4-1  |
| 4.2        | Methodology   | 4-1  |
| 4.2.1      | Calculation of Ozone DVFs                                 | 4-1  |
| 4.2.2      | Calculation of PM <sub>2.5</sub> DVFs                     |      |
| 4.2.3      | Calculation of 2018 Visibility                            |      |
| 4.3        | Future Design Values                                      | 4-3  |
| 4.3.1      | Future Ozone Design Values                                | 4-4  |
| 4.3.2      | Future Annual PM <sub>2.5</sub> Design Values             | 4-15 |
| 4.3.3      | Future Daily PM <sub>2.5</sub> Design Values              |      |
| 4.4        | Projected changes in PM <sub>2.5</sub> composition        | 4-31 |
| 4.5        | Future Visibility Projections                             | 4-42 |
| 4.6        | Contributions to Light Extinctions                        | 4-45 |
| 4.7        | Progress towards Regional Haze Goals                      | 4-46 |
| 4.8        | Conclusions   | 4-69 |
| 4.9        | References  | 4-69 |
| Chapter 5: | Sensitivity of Ozone to NO <sub>x</sub> and VOC Emissions | 5-1  |
| 5.1        | Introduction  | 5-1  |
| 5.2        | Methodology   | 5-1  |
| 5.2.1      | Calculation of Absolute Sensitivities                     |      |
| 5.2.2      | Calculation of Relative Sensitivities                     |      |

| 5.2.3 | Normalized Sensitivities                            | 5-6  |
|-------|---|------|
| 5.3   | Absolute Sensitivities                              | 5-7  |
| 5.3.1 | Site-by-Site Absolute Sensitivities                 | 5-7  |
| 5.3.2 | State Summaries                                     | 5-20 |
| 5.4   | Relative Sensitivities                              | 5-43 |
| 5.4.1 | Relative Sensitivities to NO <sub>x</sub> emissions | 5-43 |
| 5.4.2 | Relative Sensitivities to VOC emissions             | 5-43 |
| 5.5   | Normalized Sensitivities                            | 5-66 |
| 5.6   | Conclusions   | 5-78 |
| 5.7   | References  | 5-79 |

# **List of Figures**

| Figure 1-1. 36-km (left) and 12-km (right) SEMAP air quality modeling grids  | 1-7            |
|--|----------------|
| Figure 1-2. Example SMOKE emissions analysis products: monthly tile plot (Left); pollutant bar cha (Right)   | art<br>1-8     |
| Figure 1-3. Location of various PM <sub>2.5</sub> monitors in the U.S. for SMAT  | 1-11           |
| Figure 2-1. Regional Planning Organization Map. Inventory data were collected for each RPO regio build the SEMAP EMP.  | n to<br>2-4    |
| Figure 2-2. SESARM 2007 state total CO emissions by inventory sector   | 2-8            |
| Figure 2-3. SESARM 2007 state total NOx emissions by inventory sector  | 2-9            |
| Figure 2-4. SESARM 2007 state total VOC emissions by inventory sector  | 2-10           |
| Figure 2-5. SESARM 2007 state total NH3 emissions by inventory sector  | 2-11           |
| Figure 2-6. SESARM 2007 state total SO2 emissions by inventory sector  | 2-12           |
| Figure 2-7. SESARM 2007 state total PM2.5 emissions by inventory sector  | 2-13           |
| Figure 2-8. SESARM state annual total 2007 nonpoint source emissions; note that the VOC emission divided by 10 to normalize their magnitude                        | ns are<br>2-17 |
| Figure 2-9. SESARM state average residential wood combustion temporal profiles   | 2-19           |
| Figure 2-10. RWC source diurnal temporal profile   | 2-20           |
| Figure 2-11. SESARM state annual total 2007 RWC source emissions; note that the CO emissions a divided by 5 to normalize their magnitude                           | re<br>2-20     |
| Figure 2-12. Road and fugitive dust vegetative scavenging multipliers on the SEMAP 36km modelin domain   | ng<br>2-23     |
| Figure 2-13. February 2007 total fugitive and road dust PM2.5; (A) is without meteorology adjustment (B) includes meteorology adjustment, (C) is ratio of (B)/(A)  | ent,<br>2-23   |
| Figure 2-14. SESARM state annual total 2007 road and fugitive dust source emissions; note that the values do not reflect the application of any adjustment factors | se<br>2-24     |
| Figure 2-15. SESARM state annual total 2007 fertilizer and livestock source emissions  | 2-27           |
| Figure 2-16. SESARM state annual total 2007 nonroad mobile source emissions; note that the CO emissions are divided by 10 to normalize their magnitude             | 2-29           |
| Figure 2-17. SESARM state annual total nonroad mobile NOx emissions by SCC Tier 3  | 2-30           |
| Figure 2-18. SESARM state annual total nonroad mobile VOC emissions by SCC Tier 3  | 2-30           |
| Figure 2-19. SESARM state annual total 2007 ALM source emissions; note that the CO emissions a divided by 2 to normalize their magnitude                           | re<br>2-32     |
| Figure 2-20. SESARM state annual total ALM NOx emissions by SCC Tier 2   | 2-33           |
| Figure 2-21. SESARM state annual total ALM VOC emissions by SCC Tier 2   | 2-33           |
| Figure 2-22. SESARM state annual total 2007 onroad mobile source emissions; note that the CO emissions are divided by 5 to normalize their magnitude               | 2-38           |

| Figure 2-23. Example of anomalous SO <sub>2</sub> emissions in the CEM data  | .2-41               |
|--|---------------------|
| Figure 2-24. Virginia Dominion-Hopewell #2 2007 CEM NO <sub>x</sub> emissions; illustration of anomalous d correction approach   | lata<br>.2-42       |
| Figure 2-25. West Virginia Mountaineer #1 2007 CEM SO <sub>2</sub> emissions; illustration of anomalous data correction approach   | ι<br>.2-42          |
| Figure 2-26. Virginia Stone Container Enterprises #2 2007 CEM NOx emissions; illustration of distribution of non-reporting period data   | .2-46               |
| Figure 2-27. SESARM state annual total 2007 non-CEM point source emissions   | .2-48               |
| Figure 2-28. SESARM state annual total 2007 CEM point source emissions; note that the NOx emissions are divided by 2 and the SO2 emissions are divided by 5 to normalize their magnitudes                            | ions<br>.2-49       |
| Figure 2-29. Atlanta Jackson-Hartsfield (L) and average small airport (R) pollutant-specific vertical emissions profiles.  | .2-50               |
| Figure 2-30. SESARM state annual total 2007 airport point source emissions   | .2-51               |
| Figure 2-31. Diurnal distribution of the fire emissions used for the SEMAP modeling  | .2-53               |
| Figure 2-32. SESARM state annual total 2007 fire emissions; note that the CO emissions are divided to normalize their magnitude  | by 5<br>.2-54       |
| Figure 2-33. SESARM state annual total 2007 biogenic emissions   | .2-56               |
| Figure 2-34.Comparison of 2007 fire PM2.5 inventories for the SESARM and bordering states  | .2-61               |
| Figure 2-35. Box plots of Louisiana year fire emissions from SMARTFIRE1 and FAT  | .2-62               |
| Figure 2-36. SESARM state annual total typical year fire emissions; note that the CO emissions are divided by 5 to normalize their magnitude   | .2-63               |
| Figure 2-37. SESARM base 2007 and typical annual total fire emissions of NOx, VOC, and PM2.5   | .2-63               |
| Figure 2-38. SESARM 2018 state total CO emissions by inventory sector  | .2-65               |
| Figure 2-39. SESARM 2018 state total NOx emissions by inventory sector   | .2-66               |
| Figure 2-40. SESARM 2018 state total VOC emissions by inventory sector   | .2-67               |
| Figure 2-41. SESARM 2007 state total NH3 emissions by inventory sector   | .2-68               |
| Figure 2-42. SESARM 2018 state total SO2 emissions by inventory sector   | .2-69               |
| Figure 2-43. SESARM 2018 state total PM2.5 emissions by inventory sector   | .2-70               |
| Figure 2-44. SEMAP 2018 modeling emissions with 2007 data for the MWRPO, CENRAP and WRA states (left); 2018 emissions for the entire country (right); difference in January monthly total prelimit 2018 NOx (bottom) | AP<br>nary<br>.2-72 |
| Figure 2-45. SESARM state annual total 2018 nonpoint source emissions; note that the VOC emission are divided by 10 to normalize their magnitude   | ns<br>.2-73         |
| Figure 2-46. SESARM state annual total 2018 RWC source emissions; note that the CO emissions are divided by 5 to normalize their magnitude   | e<br>.2-74          |
| Figure 2-47. SESARM state annual total 2018 road and fugitive dust source emissions; note that these values do not reflect the application of any adjustment factors   | e<br>.2-75          |
| Figure 2-48. SESARM state annual total 2018 fertilizer and livestock source emissions  | .2-76               |

| Figure 2-49. SESARM state annual total 2018 nonroad mobile source emissions; note that the CO emissions are divided by 10 to normalize their magnitude   |
|--|
| Figure 2-50. SESARM state annual total 2018 ALM source emissions; note that the CO emissions are divided by 2 to normalize their magnitude   |
| Figure 2-51. Scatter plot of 2018 vs 2007 onroad mobile NO emissions; each point represents a different county   |
| Figure 2-52. Bar plot showing the 2007, 2018 and 2018/2007 ratios for onroad mobile NO emissions for each county in Georgia  |
| Figure 2-53. County maps of SEMAP 2007, 2018, and 2018/2007 ratios of MOVES emissions2-86  |
| Figure 2-54. SESARM state annual total 2018 onroad mobile source emissions; note that the CO emissions are divided by 5 to normalize their magnitude2-87                                       |
| Figure 2-55. Timeseries of 2007 and 2018 hourly CEM NOx at Bowen Power Plant in Georgia2-89  |
| Figure 2-56. SESARM state annual total 2018 non-CEM point source emissions; note that the CO emissions are divided by 2 to normalize their magnitude   |
| Figure 2-57. SESARM state annual 2018 CEM point source emissions; note that the NOx and SO2 emissions are divided by 2 to normalize their magnitudes2-91                                       |
| Figure 2-58. SESARM state annual total 2018 airport point source emissions2-92   |
| Figure 2-59. 2007 actual and 2018 annual total CO emissions by SESARM state2-122   |
| Figure 2-60. 2007 actual and 2018 annual total NOx emissions by SESARM state2-122  |
| Figure 2-61. 2007 actual and 2018 annual total VOC emissions by SESARM state2-123  |
| Figure 2-62. 2007 actual and 2018 annual total NH3 emissions by SESARM state2-123  |
| Figure 2-63. 2007 actual and 2018 annual total SO <sub>2</sub> emissions by SESARM state2-124  |
| Figure 2-64. 2007 actual and 2018 annual total PM2.5 emissions by SESARM state2-124  |
| Figure 2-65. Alabama annual emissions differences (2018-2007 actual) by pollutant2-125   |
| Figure 2-66. Florida annual emissions differences (2018-2007 actual) by pollutant2-125   |
| Figure 2-67. Georgia annual emissions differences (2018-2007 actual) by pollutant2-126   |
| Figure 2-68. Kentucky annual emissions differences (2018-2007 actual) by pollutant2-126  |
| Figure 2-69. Mississippi annual emissions differences (2018-2007 actual) by pollutant2-127   |
| Figure 2-70. North Carolina annual emissions differences (2018-2007 actual) by pollutant2-127  |
| Figure 2-71. South Carolina annual emissions differences (2018-2007 actual) by pollutant2-128  |
| Figure 2-72. Tennessee annual emissions differences (2018-2007 actual) by pollutant2-128   |
| Figure 2-73. Virgina annual emissions differences (2018-2007 actual) by pollutant2-129   |
| Figure 2-74. West Virginia annual emissions differences (2018-2007 actual) by pollutant2-129   |
| Figure 3-1. Initial fractional biases of total $PM_{2.5}$ and its major components versus the observed average total $PM_{2.5}$ concentration at IMPROVE sites in the domain for the year 2007 |
| Figure 3-2. Changes in early morning NOx concentrations after the minimum PBL height and minimum Kzz modifications: 11 UTC August 8, 2007  |

| Figure 3-3. Changes in nighttime/early morning ozone after the minimum PBL height and minimum K <sub>zz</sub> modifications: 11 UTC August 8, 2007   |
|--|
| Figure 3-4. Changes in afternoon $NO_x$ concentrations after the minimum PBL height and minimum $K_{zz}$ modifications: 20 UTC August 8, 2007  |
| Figure 3-5. Changes in afternoon ozone after the minimum PBL height and minimum K <sub>zz</sub> modifications: 19 UTC August 8, 2007   |
| Figure 3-6. Changes made to the land-water interface: land to water (red), no change (gray), and water to land (blue)  |
| Figure 3-7. Difference in early morning $NO_x$ concentrations between the sensitivity run with modified PBL heights along the coast and the sensitivity run with minimum PBL height and minimum $K_{zz}$ modifications: 11 UTC August 8, 2007          |
| Figure 3-8. Difference in nighttime/early morning ozone concentrations between the sensitivity run with modified PBL heights along the coast and the sensitivity run with minimum PBL height and minimum $K_{zz}$ modifications: 11 UTC August 8, 2007 |
| Figure 3-9. Difference in afternoon $NO_x$ concentrations between the sensitivity run with modified PBL heights along the coast run and the sensitivity run with minimum PBL height and minimum $K_{zz}$ modifications: 20 UTC August 8, 2007          |
| Figure 3-10. Difference in afternoon ozone concentrations between the sensitivity run with modified PBL heights along the coast and the sensitivity run with minimum PBL height and minimum K <sub>zz</sub> modifications: 19 UTC August 8, 2007       |
| Figure 3-11. Changes in afternoon ozone due to 50% reduction of boundary conditions: 20 UTC August 8, 2007   |
| Figure 3-12. Changes in afternoon ozone due to 50% reduction of boundary conditions: 20 UTC August 15, 2007  |
| Figure 3-13. Changes in afternoon ozone after turning off lightning NO <sub>x</sub> emissions: 20 UTC August 8, 2007   |
| Figure 3-14. Changes in afternoon ozone after turning off lightning NO <sub>x</sub> emissions: 20 UTC August 15, 2007  |
| Figure 3-15. Changes in afternoon ozone after 30% reduction of ground-level NO <sub>x</sub> emissions: 20 UTC August 8, 2007   |
| Figure 3-16. Changes in afternoon ozone after 30% reduction of ground-level NO <sub>x</sub> emissions: 20 UTC August 15, 2007  |
| Figure 3-17. Modeled (left) and observed (right) clouds (top) and rain (bottom): 21 UTC August 8, 2007 (provided by Mr. Nick Witcraft of North Carolina DENR, Division of Air Quality)   |
| Figure 3-18. Comparison of observed (red) and modeled (blue) wind speeds in Atlanta (from page 61 of AER's WRF Performance Evaluation Report-Part 1)   |
| Figure 3-19. Final fractional biases of total $PM_{2.5}$ and its major components versus the observed average total $PM_{2.5}$ concentration at IMPROVE sites in the domain for the year 2007  |
| Figure 3-20. Fractional biases of total $PM_{2.5}$ and its major components in the 2007 typical emissions scenario versus the observed average total $PM_{2.5}$ concentration at IMPROVE sites in the domain for the year 2007                         |
| Figure 3-21. April 2007 mean normalized biases (MNB) in 8-hr maximum O <sub>3</sub> at AQS sites   |

| Figure 3-22. May 2007 mean normalized biases (MNB) in 8-hr maximum O3 at AQS sites3-32                       | 2 |
|--|---|
| Figure 3-23. June 2007 mean normalized biases (MNB) in 8-hr maximum O <sub>3</sub> at AQS sites3-33          | 3 |
| Figure 3-24. July 2007 mean normalized biases (MNB) in 8-hr maximum O <sub>3</sub> at AQS sites3-34          | ł |
| Figure 3-25. August 2007 mean normalized biases (MNB) in 8-hr maximum O3 at AQS sites                        | 5 |
| Figure 3-26. September 2007 mean normalized biases (MNB) in 8-hr maximum O3 at AQS sites3-36                 | 5 |
| Figure 3-27. October 2007 mean normalized biases (MNB) in 8-hr maximum O3 at AQS sites3-37                   | 7 |
| Figure 3-28. April 2007 mean normalized errors (MNE) in 8-hr maximum O3 at AQS sites3-38                     | 3 |
| Figure 3-29. May 2007 mean normalized errors (MNE) in 8-hr maximum O <sub>3</sub> at AQS sites               | ) |
| Figure 3-30. June 2007 mean normalized errors (MNE) in 8-hr maximum O3 at AQS sites                          | ) |
| Figure 3-31. July 2007 mean normalized errors (MNE) in 8-hr maximum O3 at AQS sites3-41                      | l |
| Figure 3-32. August 2007 mean normalized errors (MNE) in 8-hr maximum O <sub>3</sub> at AQS sites3-42        | 2 |
| Figure 3-33. September 2007 mean normalized errors (MNE) in 8-hr maximum O3 at AQS sites3-43                 | 3 |
| Figure 3-34. October 2007 mean normalized errors (MNE) in 8-hr maximum O3 at AQS sites3-44                   | ł |
| Figure 3-35. January 2007 mean fractional biases (MFB) in 24-hr average PM <sub>2.5</sub> at AQS sites3-45   | 5 |
| Figure 3-36. February 2007 mean fractional biases (MFB) in 24-hr average PM <sub>2.5</sub> at AQS sites3-46  | 5 |
| Figure 3-37. March 2007 mean fractional biases (MFB) in 24-hr average PM <sub>2.5</sub> at AQS sites3-47     | 7 |
| Figure 3-38. April 2007 mean fractional biases (MFB) in 24-hr average PM <sub>2.5</sub> at AQS sites3-48     | 3 |
| Figure 3-39. May 2007 mean fractional biases (MFB) in 24-hr average PM <sub>2.5</sub> at AQS sites3-49       | ) |
| Figure 3-40. June 2007 mean fractional biases (MFB) in 24-hr average PM <sub>2.5</sub> at AQS sites3-50      | ) |
| Figure 3-41. July 2007 mean fractional biases (MFB) in 24-hr average PM <sub>2.5</sub> at AQS sites3-51      | l |
| Figure 3-42. August 2007 mean fractional biases (MFB) in 24-hr average PM <sub>2.5</sub> at AQS sites3-52    | 2 |
| Figure 3-43. September 2007 mean fractional biases (MFB) in 24-hr average PM <sub>2.5</sub> at AQS sites3-53 | 3 |
| Figure 3-44. October 2007 mean fractional biases (MFB) in 24-hr average PM <sub>2.5</sub> at AQS sites       | ł |
| Figure 3-45. November 2007 mean fractional biases (MFB) in 24-hr average PM <sub>2.5</sub> at AQS sites3-55  | 5 |
| Figure 3-46. December 2007 mean fractional biases (MFB) in 24-hr average PM <sub>2.5</sub> at AQS sites3-56  | 5 |
| Figure 3-47. January 2007 mean fractional errors (MFE) in 24-hr average PM <sub>2.5</sub> at AQS sites       | 7 |
| Figure 3-48. February 2007 mean fractional errors (MFE) in 24-hr average PM <sub>2.5</sub> at AQS sites      | 3 |
| Figure 3-49. March 2007 mean fractional errors (MFE) in 24-hr average PM <sub>2.5</sub> at AQS sites3-59     | ) |
| Figure 3-50. April 2007 mean fractional errors (MFE) in 24-hr average PM <sub>2.5</sub> at AQS sites3-60     | ) |
| Figure 3-51. May 2007 mean fractional errors (MFE) in 24-hr average PM <sub>2.5</sub> at AQS sites3-61       | l |
| Figure 3-52. June 2007 mean fractional errors (MFE) in 24-hr average PM <sub>2.5</sub> at AQS sites3-62      | 2 |
| Figure 3-53. July 2007 mean fractional errors (MFE) in 24-hr average PM <sub>2.5</sub> at AQS sites          | 3 |
| Figure 3-54. August 2007 mean fractional errors (MFE) in 24-hr average PM <sub>2.5</sub> at AQS sites        | ł |
| Figure 3-55. September 2007 mean fractional errors (MFE) in 24-hr average PM <sub>2.5</sub> at AQS sites3-65 | 5 |
| Figure 3-56. October 2007 mean fractional errors (MFE) in 24-hr average PM <sub>2.5</sub> at AQS sites3-66   | 5 |

Figure 3-57. November 2007 mean fractional errors (MFE) in 24-hr average PM<sub>2.5</sub> at AQS sites.......3-67

Figure 3-58. December 2007 mean fractional errors (MFE) in 24-hr average PM<sub>2.5</sub> at AQS sites. .......3-68

Figure 3-59. January 2007 mean fractional biases (MFB) in 24-hr average PM<sub>2.5</sub> sulfate at CSN sites. 3-69 Figure 3-60. February 2007 mean fractional biases (MFB) in 24-hr average PM<sub>2.5</sub> sulfate at CSN sites. ..3-70

Figure 3-61. March 2007 mean fractional biases (MFB) in 24-hr average PM<sub>2.5</sub> sulfate at CSN sites. ..3-71

Figure 3-62. April 2007 mean fractional biases (MFB) in 24-hr average PM<sub>2.5</sub> sulfate at CSN sites. ....3-72

Figure 3-63. May 2007 mean fractional biases (MFB) in 24-hr average PM<sub>2.5</sub> sulfate at CSN sites. .....3-73

Figure 3-64. June 2007 mean fractional biases (MFB) in 24-hr average PM<sub>2.5</sub> sulfate at CSN sites. .....3-74

Figure 3-65. July 2007 mean fractional biases (MFB) in 24-hr average PM<sub>2.5</sub> sulfate at CSN sites. ......3-75

Figure 3-66. August 2007 mean fractional biases (MFB) in 24-hr average PM<sub>2.5</sub> sulfate at CSN sites. .3-76

Figure 3-67. September 2007 mean fractional biases (MFB) in 24-hr average  $PM_{2.5}$  sulfate at CSN sites. 3-77

Figure 3-68. October 2007 mean fractional biases (MFB) in 24-hr average  $PM_{2.5}$  sulfate at CSN sites. 3-78 Figure 3-69. November 2007 mean fractional biases (MFB) in 24-hr average  $PM_{2.5}$  sulfate at CSN sites. 3-79

Figure 3-70. December 2007 mean fractional biases (MFB) in 24-hr average  $PM_{2.5}$  sulfate at CSN sites. 3-80

Figure 3-71. January 2007 mean fractional biases (MFB) in 24-hr average PM<sub>2.5</sub> nitrate at CSN sites..3-81

Figure 3-72. February 2007 mean fractional biases (MFB) in 24-hr average  $PM_{2.5}$  nitrate at CSN sites....3-82

Figure 3-73. March 2007 mean fractional biases (MFB) in 24-hr average PM<sub>2.5</sub> nitrate at CSN sites....3-83

Figure 3-74. April 2007 mean fractional biases (MFB) in 24-hr average PM<sub>2.5</sub> nitrate at CSN sites......3-84

Figure 3-75. May 2007 mean fractional biases (MFB) in 24-hr average PM<sub>2.5</sub> nitrate at CSN sites......3-85

Figure 3-76. June 2007 mean fractional biases (MFB) in 24-hr average PM<sub>2.5</sub> nitrate at CSN sites......3-86

Figure 3-77. July 2007 mean fractional biases (MFB) in 24-hr average PM<sub>2.5</sub> nitrate at CSN sites......3-87

Figure 3-78. August 2007 mean fractional biases (MFB) in 24-hr average PM<sub>2.5</sub> nitrate at CSN sites...3-88

Figure 3-79September 2007 mean fractional biases (MFB) in 24-hr average  $PM_{2.5}$  nitrate at CSN sites. ..3-89

Figure 3-80. October 2007 mean fractional biases (MFB) in 24-hr average PM<sub>2.5</sub> nitrate at CSN sites. 3-90

Figure 3-81. November 2007 mean fractional biases (MFB) in 24-hr average  $PM_{2.5}$  nitrate at CSN sites. 3-91

Figure 3-82. December 2007 mean fractional biases (MFB) in 24-hr average  $PM_{2.5}$  nitrate at CSN sites...3-92

| Figure 3-83. January 2007 mean fractional biases (MFB) in 24-hr average PM <sub>2.5</sub> ammonium at CSN sites. |   |
|--|---|
|  | ì |
| Figure 3-84. February 2007 mean fractional biases (MFB) in 24-hr average PM <sub>2.5</sub> ammonium at CSN       |   |
| sites  | ŀ |

| Figure 3-85. March 2007 mean fractional biases (MFB) in 24-hr average PM <sub>2.5</sub> ammonium at CSN sites.<br>3-95     |
|--|
| Figure 3-86. April 2007 mean fractional biases (MFB) in 24-hr average PM <sub>2.5</sub> ammonium at CSN sites3-96          |
| Figure 3-87. May 2007 mean fractional biases (MFB) in 24-hr average $PM_{2.5}$ ammonium at CSN sites3-97                   |
| Figure 3-88. June 2007 mean fractional biases (MFB) in 24-hr average $PM_{2.5}$ ammonium at CSN sites3-98                  |
| Figure 3-89. July 2007 mean fractional biases (MFB) in 24-hr average PM <sub>2.5</sub> ammonium at CSN sites3-99           |
| Figure 3-90. August 2007 mean fractional biases (MFB) in 24-hr average PM <sub>2.5</sub> ammonium at CSN sites.<br>        |
| Figure 3-91. September 2007 mean fractional biases (MFB) in 24-hr average PM <sub>2.5</sub> ammonium at CSN sites          |
| Figure 3-92. October 2007 mean fractional biases (MFB) in 24-hr average PM <sub>2.5</sub> ammonium at CSN sites.<br>       |
| Figure 3-93. November 2007 mean fractional biases (MFB) in 24-hr average PM <sub>2.5</sub> ammonium at CSN sites           |
| Figure 3-94. December 2007 mean fractional biases (MFB) in 24-hr average PM <sub>2.5</sub> ammonium at CSN sites           |
| Figure 3-95. January 2007 mean fractional biases (MFB) in 24-hr average PM <sub>2.5</sub> elemental carbon at CSN sites    |
| Figure 3-96. February 2007 mean fractional biases (MFB) in 24-hr average PM <sub>2.5</sub> elemental carbon at CSN sites   |
| Figure 3-97. March 2007 mean fractional biases (MFB) in 24-hr average PM <sub>2.5</sub> elemental carbon at CSN sites      |
| Figure 3-98. April 2007 mean fractional biases (MFB) in 24-hr average PM <sub>2.5</sub> elemental carbon at CSN sites.     |
| Figure 3-99. May 2007 mean fractional biases (MFB) in 24-hr average PM <sub>2.5</sub> elemental carbon at CSN sites        |
| Figure 3-100. June 2007 mean fractional biases (MFB) in 24-hr average PM <sub>2.5</sub> elemental carbon at CSN sites      |
| Figure 3-101. July 2007 mean fractional biases (MFB) in 24-hr average PM <sub>2.5</sub> elemental carbon at CSN sites.     |
| Figure 3-102. August 2007 mean fractional biases (MFB) in 24-hr average PM <sub>2.5</sub> elemental carbon at CSN sites    |
| Figure 3-103. September 2007 mean fractional biases (MFB) in 24-hr average PM <sub>2.5</sub> elemental carbon at CSN sites |
| Figure 3-104. October 2007 mean fractional biases (MFB) in 24-hr average PM <sub>2.5</sub> elemental carbon at CSN sites   |

| Figure 3-105. November 2007 mean fractional biases (MFB) in 24-hr average PM <sub>2.5</sub> elemental carbon at CSN sites   |
|---|
| Figure 3-106. December 2007 mean fractional biases (MFB) in 24-hr average PM <sub>2.5</sub> elemental carbon at CSN sites   |
| Figure 3-107. January 2007 mean fractional biases (MFB) in 24-hr average PM <sub>2.5</sub> organic carbon at CSN sites      |
| Figure 3-108. February 2007 mean fractional biases (MFB) in 24-hr average PM <sub>2.5</sub> organic carbon at CSN sites     |
| Figure 3-109. March 2007 mean fractional biases (MFB) in 24-hr average PM <sub>2.5</sub> organic carbon at CSN sites        |
| Figure 3-110. April 2007 mean fractional biases (MFB) in 24-hr average PM <sub>2.5</sub> organic carbon at CSN sites        |
| Figure 3-111. May 2007 mean fractional biases (MFB) in 24-hr average PM <sub>2.5</sub> organic carbon at CSN sites          |
| Figure 3-112. June 2007 mean fractional biases (MFB) in 24-hr average PM <sub>2.5</sub> organic carbon at CSN sites         |
| Figure 3-113. July 2007 mean fractional biases (MFB) in 24-hr average PM <sub>2.5</sub> organic carbon at CSN sites         |
| Figure 3-114. August 2007 mean fractional biases (MFB) in 24-hr average PM <sub>2.5</sub> organic carbon at CSN sites       |
| Figure 3-115. September 2007 mean fractional biases (MFB) in 24-hr average PM <sub>2.5</sub> organic carbon at CSN sites    |
| Figure 3-116. October 2007 mean fractional biases (MFB) in 24-hr average PM <sub>2.5</sub> organic carbon at CSN sites      |
| Figure 3-117. November 2007 mean fractional biases (MFB) in 24-hr average PM <sub>2.5</sub> organic carbon at CSN sites     |
| Figure 3-118. December 2007 mean fractional biases (MFB) in 24-hr average PM <sub>2.5</sub> organic carbon at CSN sites     |
| Figure 4-1. Illustration of how the design value can shift into a different cell in a 3×3 block of cells around the monitor |
| Figure 4-2. Five year (2005-2009) weighted average O <sub>3</sub> DVCs4-5   |
| Figure 4-3. 2018 O <sub>3</sub> DVFs: 3×3 RRF & 2007 DVC4-6   |
| Figure 4-4. 2018 O <sub>3</sub> DVFs: 1x1 RRF & 2007 DVC  |
| Figure 4-5. 2018 O <sub>3</sub> DVFs: 3×3 RRF & 2005-2009 DVC   |
| Figure 4-6. 2018 O <sub>3</sub> DVFs: 1×1 RRF & 2005-2009 DVC   |
| Figure 4-7. 2018 O <sub>3</sub> DVFs calculated using 2007 DVCs vs. 5-year weighted DVCs                                    |
| Figure 4-8. 2018 O <sub>3</sub> DVFs calculated using 3×3 Max vs. 1×1 Cell RRFs   |
| Figure 4-9. 2007 Annual PM <sub>2.5</sub> DVC   |
| Figure 4-10. 5-Year (2005-09) Annual PM <sub>2.5</sub> DVC  |

| Figure 4-11. 2018 Annual PM <sub>2.5</sub> DVFs: 3×3 RRF & 2007 DVC4-18   |
|---|
| Figure 4-12. 2018 Annual PM <sub>2.5</sub> DVFs: 1x1 RRF & 2007 DVC4-19   |
| Figure 4-13. 2018 Annual PM <sub>2.5</sub> DVFs: 3×3 RRF & 2005-2009 DVC  |
| Figure 4-14. 2018 Annual PM <sub>2.5</sub> DVFs: 1×1 RRF & 2005-2009 DVC  |
| Figure 4-15. Annual PM <sub>2.5</sub> DVFs calculated using 2007 DVCs vs. 5-year weighted DVCs4-22  |
| Figure 4-16. Annual PM <sub>2.5</sub> DVFs calculated using 3×3 Cell Average vs. 1×1 Cell RRFs4-23  |
| Figure 4-17. 2007 Daily PM <sub>2.5</sub> DVC4-24   |
| Figure 4-18. 5-Year (2005-09) Daily PM <sub>2.5</sub> DVC   |
| Figure 4-19. 2018 Daily PM <sub>2.5</sub> DVFs: 3×3 RRF & 2007 DVC4-26  |
| Figure 4-20. 2018 Daily PM <sub>2.5</sub> DVFs: 1x1 RRF & 2007 DVC4-27  |
| Figure 4-21. 2018 Daily PM <sub>2.5</sub> DVFs: 3×3 RRF & 2005-2009 DVC4-28   |
| Figure 4-22. 2018 Daily PM <sub>2.5</sub> DVFs: 1×1 RRF & 2005-2009 DVC   |
| Figure 4-23. 2018 Daily PM <sub>2.5</sub> DVFs calculated using 2007 DVCs vs. 5-year weighted DVCs4-30  |
| Figure 4-24. 2018 Daily PM <sub>2.5</sub> DVFs calculated using 3×3 cell average vs. 1×1 cell RRFs4-31  |
| Figure 4-25. 2007 and 2018 PM <sub>2.5</sub> compositions at Alabama sites for annual (top) and daily (bottom)<br>PM <sub>2.5</sub> design values     |
| Figure 4-26. 2007 and 2018 PM <sub>2.5</sub> compositions at Florida sites for annual (top) and daily (bottom) PM <sub>2.5</sub> design values        |
| Figure 4-27. 2007 and 2018 PM <sub>2.5</sub> compositions at Georgia sites for annual (top) and daily (bottom) PM <sub>2.5</sub> design values        |
| Figure 4-28. 2007 and 2018 PM <sub>2.5</sub> compositions at Kentucky sites for annual (top) and daily (bottom)<br>PM <sub>2.5</sub> design values    |
| Figure 4-29. 2007 and 2018 PM <sub>2.5</sub> compositions at Mississippi sites for annual (top) and daily (bottom) PM <sub>2.5</sub> design values    |
| Figure 4-30. 2007 and 2018 PM <sub>2.5</sub> compositions at North Carolina sites for annual (top) and daily (bottom) PM <sub>2.5</sub> design values |
| Figure 4-31. 2007 and 2018 PM <sub>2.5</sub> compositions at South Carolina sites for annual (top) and daily (bottom) PM <sub>2.5</sub> design values |
| Figure 4-32. 2007 and 2018 PM <sub>2.5</sub> compositions at Tennessee sites for annual (top) and daily (bottom)<br>PM <sub>2.5</sub> design values   |
| Figure 4-33. 2007 and 2018 PM <sub>2.5</sub> compositions at Virginia sites for annual (top) and daily (bottom) PM <sub>2.5</sub> design values       |
| Figure 4-34. 2007 and 2018 PM <sub>2.5</sub> compositions at West Virginia sites for annual (top) and daily (bottom) PM <sub>2.5</sub> design values  |
| Figure 4-35. Best Visibility DVF: 3×3 vs. 1×1   |
| Figure 4-36. Worst Visibility DVF: 3×3 vs. 1×1  |
| Figure 4-37. Comparison of contributions of PM <sub>2.5</sub> components to light extinction on best 20% visibility days in 2007 and 20184-45         |

| Figure 4-38. Comparison of contributions of PM <sub>2.5</sub> components to light extinction on worst 20% visibility days in 2007 and 20184-46 |
|--|
| Figure 4-39. Visibility progress at Breton on 20% worst (top) and 20% best (bottom) days4-47   |
| Figure 4-40. Visibility progress at Brigantine on 20% worst (top) and 20% best (bottom) days4-48   |
| Figure 4-41. Visibility progress at Caney Creek on 20% worst (top) and 20% best (bottom) days4-49  |
| Figure 4-42. Visibility progress at Cape Romain on 20% worst (top) and 20% best (bottom) days4-50  |
| Figure 4-43. Visibility progress at Chassahowitzka on 20% worst (top) and 20% best (bottom) days4-51   |
| Figure 4-44. Visibility progress at Cohutta on 20% worst (top) and 20% best (bottom) days4-52  |
| Figure 4-45. Visibility progress at Dolly Sods on 20% worst (top) and 20% best (bottom) days4-53   |
| Figure 4-46. Visibility progress at Everglades on 20% worst (top) and 20% best (bottom) days   |
| Figure 4-47. Visibility progress at Great Smoky Mountains on 20% worst (top) and 20% best (bottom) days4-55                                    |
| Figure 4-48. Visibility progress at Hercules Glade on 20% worst (top) and 20% best (bottom) days4-56   |
| Figure 4-49. Visibility progress at James River Face on 20% worst (top) and 20% best (bottom) days.4-57  |
| Figure 4-50. Visibility progress at Linville Gorge on 20% worst (top) and 20% best (bottom) days4-58   |
| Figure 4-51. Visibility progress at Mammoth Cave on 20% worst (top) and 20% best (bottom) days4-59   |
| Figure 4-52. Visibility progress at Cadiz on 20% worst (top) and 20% best (bottom) days4-60  |
| Figure 4-53. Visibility progress at Mingo on 20% worst (top) and 20% best (bottom) days4-61  |
| Figure 4-54. Visibility progress at Okefenokee on 20% worst (top) and 20% best (bottom) days4-62   |
| Figure 4-55. Visibility progress at Saint Marks on 20% worst (top) and 20% best (bottom) days4-63  |
| Figure 4-56. Visibility progress at Shenandoah on 20% worst (top) and 20% best (bottom) days4-64   |
| Figure 4-57. Visibility progress at Shining Rock on 20% worst (top) and 20% best (bottom) days4-65   |
| Figure 4-58. Visibility progress at Sipsey on 20% worst (top) and 20% best (bottom) days4-66   |
| Figure 4-59. Visibility progress at Swanquarter on 20% worst (top) and 20% best (bottom) days4-67  |
| Figure 4-60. Visibility progress at Upper Buffalo on 20% worst (top) and 20% best (bottom) days4-68  |
| Figure 5-1. Absolute NO <sub>x</sub> sensitivities at Atlanta, GA (all days)5-8  |
| Figure 5-2. Absolute NO <sub>x</sub> sensitivities at Atlanta, GA (days with $O_3 \ge 75$ ppb in 2007)5-9                                      |
| Figure 5-3. Absolute NO <sub>x</sub> sensitivities at Atlanta, GA (days with $O_3 \ge 70$ ppb in 2018)5-10                                     |
| Figure 5-4. Absolute VOC sensitivities at Atlanta, GA (all days)5-11   |
| Figure 5-5. Absolute VOC sensitivities at Atlanta, GA (days with $O_3 \ge 75$ ppb in 2007)5-12   |
| Figure 5-6. Absolute VOC sensitivities at Atlanta, GA (days with $O_3 \ge 70$ ppb in 2018)5-13   |
| Figure 5-7. Absolute NO <sub>x</sub> sensitivities at Baltimore, MD (all days)   |
| Figure 5-8. Absolute NO <sub>x</sub> sensitivities at Baltimore, MD (days with $O_3 \ge 75$ ppb in 2007)5-15                                   |
| Figure 5-9. Absolute NO <sub>x</sub> sensitivities at Baltimore, MD (days with $O_3 \ge 70$ ppb in 2018)5-16                                   |
| Figure 5-10. Absolute VOC sensitivities at Baltimore, MD (all days)  |

| Figure 5-11. Absolute VOC sensitivities at Baltimore, MD (days with $O_3 \ge 75$ ppb in 2007)                   | 5-18 |
|---|------|
| Figure 5-12. Absolute VOC sensitivities at Baltimore, MD (days with $O_3 \ge 70$ ppb in 2018)                   | 5-19 |
| Figure 5-13. Absolute NO <sub>x</sub> sensitivities at Alabama sites (days with $O_3 \ge 70$ ppb in 2018)       | 5-21 |
| Figure 5-14. Absolute NO <sub>x</sub> sensitivities at Florida sites (days with $O_3 \ge 70$ ppb in 2018)       | 5-22 |
| Figure 5-15. Absolute NO <sub>x</sub> sensitivities at Georgia sites (days with $O_3 \ge 70$ ppb in 2018)       | 5-23 |
| Figure 5-16. Absolute $NO_x$ sensitivities at Kentucky sites (days with $O_3 \ge 70$ ppb in 2018)               | 5-24 |
| Figure 5-17. Absolute NO <sub>x</sub> sensitivities at Maryland sites (days with $O_3 \ge 70$ ppb in 2018)      | 5-25 |
| Figure 5-18. Absolute $NO_x$ sensitivities at Mississippi sites (days with $O_3 \ge 70$ ppb in 2018)            | 5-26 |
| Figure 5-19. Absolute $NO_x$ sensitivities at North Carolina sites (days with $O_3 \ge 70$ ppb in 2018)         | 5-27 |
| Figure 5-20. Absolute $NO_x$ sensitivities at South Carolina sites (days with $O_3 \ge 70$ ppb in 2018)         | 5-28 |
| Figure 5-21. Absolute NO <sub>x</sub> sensitivities at Tennessee sites (days with $O_3 \ge 70$ ppb in 2018)     | 5-29 |
| Figure 5-22. Absolute $NO_x$ sensitivities at Virginia sites (days with $O_3 \ge 70$ ppb in 2018)               | 5-30 |
| Figure 5-23. Absolute NO <sub>x</sub> sensitivities at West Virginia sites (days with $O_3 \ge 70$ ppb in 2018) | 5-31 |
| Figure 5-24. Absolute VOC sensitivities at Alabama sites (days with $O_3 \ge 70$ ppb in 2018)                   | 5-32 |
| Figure 5-25. Absolute VOC sensitivities at Florida sites (days with $O_3 \ge 70$ ppb in 2018)                   | 5-33 |
| Figure 5-26. Absolute VOC sensitivities at Georgia sites (days with $O_3 \ge 70$ ppb in 2018)                   | 5-34 |
| Figure 5-27. Absolute VOC sensitivities at Kentucky sites (days with $O_3 \ge 70$ ppb in 2018)                  | 5-35 |
| Figure 5-28. Absolute VOC sensitivities at Maryland sites (days with $O_3 \ge 70$ ppb in 2018)                  | 5-36 |
| Figure 5-29. Absolute VOC sensitivities at Mississippi sites (days with $O_3 \ge 70$ ppb in 2018)               | 5-37 |
| Figure 5-30. Absolute VOC sensitivities at North Carolina sites (days with $O_3 \ge 70$ ppb in 2018)            | 5-38 |
| Figure 5-31. Absolute VOC sensitivities at South Carolina sites (days with $O_3 \ge 70$ ppb in 2018)            | 5-39 |
| Figure 5-32. Absolute VOC sensitivities at Tennessee sites (days with $O_3 \ge 70$ ppb in 2018)                 | 5-40 |
| Figure 5-33. Absolute VOC sensitivities at Virginia sites (days with $O_3 \ge 70$ ppb in 2018)                  | 5-41 |
| Figure 5-34. Absolute VOC sensitivities at West Virginia sites (days with $O_3 \ge 70$ ppb in 2018)             | 5-42 |
| Figure 5-35. Relative NO <sub>x</sub> sensitivities at Alabama sites  | 5-44 |
| Figure 5-36. Relative NO <sub>x</sub> sensitivities at Florida sites  | 5-45 |
| Figure 5-37. Relative NO <sub>x</sub> sensitivities at Georgia sites  | 5-46 |
| Figure 5-38. Relative NO <sub>x</sub> sensitivities at Kentucky sites   | 5-47 |
| Figure 5-39. Relative NO <sub>x</sub> sensitivities at Maryland sites   | 5-48 |
| Figure 5-40. Relative NO <sub>x</sub> sensitivities at Mississippi sites  | 5-49 |
| Figure 5-41. Relative NO <sub>x</sub> sensitivities at North Carolina sites                                     | 5-50 |
| Figure 5-42. Relative NO <sub>x</sub> sensitivities at South Carolina sites                                     | 5-51 |
| Figure 5-43. Relative NO <sub>x</sub> sensitivities at Tennessee sites  | 5-52 |
| Figure 5-44. Relative NO <sub>x</sub> sensitivities at Virginia sites   | 5-53 |
| Figure 5-45. Relative NO <sub>x</sub> sensitivities at West Virginia sites                                      | 5-54 |

| Figure 5-46. Relative VOC sensitivities at Alabama sites                              | 5-55 |
|---|------|
| Figure 5-47. Relative VOC sensitivities at Florida sites                              | 5-56 |
| Figure 5-48. Relative VOC sensitivities at Georgia sites                              | 5-57 |
| Figure 5-49. Relative VOC sensitivities at Kentucky sites                             | 5-58 |
| Figure 5-50. Relative VOC sensitivities at Maryland sites                             | 5-59 |
| Figure 5-51. Relative VOC sensitivities at Mississippi sites                          | 5-60 |
| Figure 5-52. Relative VOC sensitivities at North Carolina sites                       | 5-61 |
| Figure 5-53. Relative VOC sensitivities at South Carolina sites                       | 5-62 |
| Figure 5-54. Relative VOC sensitivities at Tennessee sites                            | 5-63 |
| Figure 5-55. Relative VOC sensitivities at Virginia sites                             | 5-64 |
| Figure 5-56. Relative VOC sensitivities at West Virginia sites                        | 5-65 |
| Figure 5-57. Normalized NO <sub>x</sub> and VOC sensitivities at Alabama sites        | 5-67 |
| Figure 5-58. Normalized NO <sub>x</sub> and VOC sensitivities at Florida sites        | 5-68 |
| Figure 5-59. Normalized NO <sub>x</sub> and VOC sensitivities at Georgia sites        | 5-69 |
| Figure 5-60. Normalized NO <sub>x</sub> and VOC sensitivities at Kentucky sites       | 5-70 |
| Figure 5-61. Normalized NO <sub>x</sub> and VOC sensitivities at Mississippi sites    | 5-71 |
| Figure 5-62. Normalized NO <sub>x</sub> and VOC sensitivities at North Carolina sites | 5-72 |
| Figure 5-63. Normalized NO <sub>x</sub> and VOC sensitivities at South Carolina sites | 5-73 |
| Figure 5-64. Normalized NO <sub>x</sub> and VOC sensitivities at Tennessee sites      | 5-74 |
| Figure 5-65. Normalized NO <sub>x</sub> and VOC sensitivities at Virginia sites       | 5-75 |
| Figure 5-66. Normalized NO <sub>x</sub> and VOC sensitivities at West Virginia sites  | 5-76 |
| Figure 5-67. Average normalized NO <sub>x</sub> and VOC sensitivities at SEMAP states | 5-77 |
| Figure 5-68. Ratios of normalized sensitivities (NO <sub>x</sub> /VOC) at SEMAP sites | 5-78 |

## **List of Tables**

| Table 1-1. Ambient air quality data available for model performance evaluation and input to receptor   models for the Southeast.                         | or<br>1-6   |
|--|-------------|
| Table 1-2. CMAQ configuration options  | 1-8         |
| Table 2-1. SEMAP emission inventory processing sectors   | 2-5         |
| Table 2-2. Tier 2 descriptions of sources in the SEMAP nonpoint processing sector  | 2-16        |
| Table 2-3. SEMAP RWC processing sector SCCs and Tier 3-4 descriptions  | 2-18        |
| Table 2-4. SEMAP road and fugitive dust sector SCCs  | 2-22        |
| Table 2-5. Spatial surrogates used for modeling the SEMAP road and fugitive dust sources   | 2-24        |
| Table 2-6. SEMAP livestock and fertilizer Tier 2-3 SCC descriptions  | 2-26        |
| Table 2-7. SEMAP nonroad mobile processing sector Tier 3 SCC descriptions  | 2-28        |
| Table 2-8. SEMAP ALM processing sector SCC descriptions  | 2-31        |
| Table 2-9. SEMAP state onroad mobile 2007 inventory versions   | 2-36        |
| Table 2-10. SEMAP SMOKE-MOVES input files  | 2-36        |
| Table 2-11. SEMAP SMOKE-MOVES modeled emissions processes  | 2-37        |
| Table 2-12. SESARM state 2007 CEM anomaly correction summary   | 2-43        |
| Table 2-13. Stone Container Enterprises #2 2007 CEM NOx emissions before and after distribution non-reporting period data.                               | of<br>2-46  |
| Table 2-14. SEMAP 2007 Canada emissions in the 36-km CONUS domain (TPY)  | 2-57        |
| Table 2-15. SEMAP 2007 Mexico emissions in the 36-km CONUS domain (TPY)  | 2-59        |
| Table 2-16. SEMAP spatial surrogate data   | 2-60        |
| Table 2-17. SESARM CEM sources with seasonal controls in 2007 and annual controls in 2018  | 2-88        |
| Table 2-18. SEMAP 2007 nonpoint source emissions state totals (TPY)  | 2-94        |
| Table 2-19. SEMAP 2007 RWC source emissions state totals (TPY)   | 2-95        |
| Table 2-20. SEMAP 2007 road and fugitive dust source emissions state totals (TPY); note that only   MANE-VU states include vegetative adjustment factors | the<br>2-96 |
| Table 2-21. SEMAP 2007 livestock and fertilizer source emissions state totals (TPY)  | 2-98        |
| Table 2-22. SEMAP 2007 nonroad source emissions state totals (TPY)   | 2-99        |
| Table 2-23. SEMAP 2007 alm source emissions state totals (TPY)   | 2-100       |
| Table 2-24. SEMAP 2007 onroad mobile source emissions state totals (TPY)   | 2-101       |
| Table 2-25. SEMAP 2007 total point source emissions state totals (TPY)   | 2-103       |
| Table 2-26. SEMAP 2007 total airport point source emissions state totals (TPY)   | 2-104       |
| Table 2-27. SEMAP 2007 total fire emissions state totals (TPY)   | 2-105       |
| Table 2-28. SEMAP 2007 near and offshore shipping totals (TPY)   | 2-106       |

| Table 2-29. SEMAP 2007 total biogenic source emissions state totals (TPY)  | 2-107       |
|--|-------------|
| Table 2-30. SEMAP typical year total fire emissions state totals (TPY)   | 2-108       |
| Table 2-31. SEMAP 2018 nonpoint source emissions state totals (TPY)  | 2-109       |
| Table 2-32. SEMAP 2018 RWC source emissions state totals (TPY)   | 2-110       |
| Table 2-33. SEMAP 2018 road and fugitive dust source emissions state totals (TPY); note that only t   MANE-VU states include vegetative adjustment factors | he<br>2-112 |
| Table 2-34. SEMAP 2018 livestock and fertilizer source emissions state totals (TPY)  | 2-113       |
| Table 2-35. SEMAP 2018 nonroad source emissions state totals (TPY)   | 2-114       |
| Table 2-36. SEMAP 2018 alm source emissions state totals (TPY)   | 2-115       |
| Table 2-37. SEMAP 2018 onroad mobile source emissions state totals (TPY)   | 2-117       |
| Table 2-38. SEMAP 2018 total point source emissions state totals (TPY)   | 2-118       |
| Table 2-39. SEMAP 2018 total airport point source emissions state totals (TPY)   | 2-119       |
| Table 2-40. SEMAP 2018 in-port, near and offshore shipping totals (TPY)  | 2-120       |
| Table 3-1. Definitions of the fractional bias and fractional error statistical model performance metrics   | s3-2        |
| Table 3-2. SEMAP model performance goals and criteria for components of fine particle mass   | 3-2         |
| Table 3-3. Observational data used for model performance evaluation  | 3-3         |
| Table 3-4. Bugle Plots (PM <sub>2.5</sub> )  | 3-5         |
| Table 3-5. Quantile-Quantile Plots   | 3-5         |
| Table 3-6. Scatter Plots   | 3-5         |
| Table 3-7. Soccer Plots (PM2.5)  | 3-6         |
| Table 3-8. Stacked Bar Charts  | 3-6         |
| Table 3-9. Tables of Statistics  | 3-6         |
| Table 3-10. Tile Plots   | 3-6         |
| Table 3-11. Time Series Plots  | 3-7         |
| Table 3-12. Statistical evaluation metrics of total PM2.5 for CSN sites in North Carolina during Augu 2007   | st<br>3-8   |
| Table 3-13. Minimum PBL heights used in the sensitivity run  | .3-10       |
| Table 3-14. Minimum $K_{zz}$ values used in CMAQ 5.0 and in the sensitivity run (also in CMAQ 4.7.1)   | .3-10       |
| Table 3-15. Statistical evaluation metrics of total PM2.5 for CSN sites in North Carolina during Augu 2007   | st<br>3-25  |
| Table 3-16. Statistical evaluation metrics of $PM_{2.5}$ for CSN sites in North Carolina during August 200 28  | 07.3-       |
| Table 4-1. 2018 Ozone "Nonattainment" (DVF $\geq$ 75 ppb based on 2005-2009 DVC)   | 4-12        |
| Table 4-2. 2018 Ozone "Maintenance" (DVF < 75 ppb based on 2005-2009 DVC but DVF $\geq$ 75 ppb based on 2007 DVC)  | 4-14        |

| Table 4-3. 5-year average (2005-2009) current visibility design values and future visibility pr deciViews) using 3x3 cell average RRFs. | ojections (in<br>4-44 |
|---|-----------------------|
| Table 5-1. Emission sectors that were reduced   |                       |
| Table 5-2. Emission sectors that remained unchanged   | 5-4                   |
| Table 5-3. Updates to the previous sensitivity analysis   | 5-4                   |
| Table 5-4. Emission Reductions (30% of annual average emissions)  | 5-6                   |

# **List of Acronyms**

| AIRS    | Aerometric Information Retrieval System                     |  |  |
|---------|---|--|--|
| AMET    | Atmospheric Model Evaluation Tool                           |  |  |
| AOD     | Aerosol Optical Depth                                       |  |  |
| AQM     | Air Quality Model   |  |  |
| BC      | Boundary Conditions   |  |  |
| BEIS3   | Biogenic Emission Inventory System, version 3               |  |  |
| CAMx    | Comprehensive Air quality Model with eXtension              |  |  |
| CB05    | Carbon Bond—Version 2005                                    |  |  |
| CEM     | Continuous Emissions Monitor                                |  |  |
| CEMPD   | Center for Environmental Modeling for Policy Development    |  |  |
| CENRAP  | Central Regional Air Planning (association)                 |  |  |
| CIRA    | Cooperative Institute for Research in the Atmosphere        |  |  |
| CMAS    | Community Modeling and Analysis System                      |  |  |
| CMAQ    | Community Multiscale Air Quality                            |  |  |
| CSN     | Chemical Speciation Network                                 |  |  |
| CTM     | Chemistry-Transport Model                                   |  |  |
| DDM     | Decoupled Direct Method                                     |  |  |
| DVC     | Current Year Design Value                                   |  |  |
| DVF     | Future Year Design Value                                    |  |  |
| EC      | Elemental Carbon  |  |  |
| EGU     | Electric Generating Unit                                    |  |  |
| EMP     | Emissions Modeling Platform                                 |  |  |
| FAQS    | Fall-line Air Quality Study                                 |  |  |
| FB      | Fractional Bias   |  |  |
| FE      | Fractional Error  |  |  |
| GIS     | Geographic Information System                               |  |  |
| GIT     | Georgia Institute of Technology                             |  |  |
| HAP     | Hazardous Air Pollutant                                     |  |  |
| IC      | Initial Conditions  |  |  |
| IDT     | Interactive Database Tool                                   |  |  |
| I/O API | Input/Output Applications Programming Interface             |  |  |
| IMPROVE | Interagency Monitoring of Protected Visibility Environments |  |  |
| JFSP    | Joint Fire Science Program                                  |  |  |
| MAQSIP  | Multiscale Air Quality Simulation Platform                  |  |  |
| MAT     | Modeled Attainment Test                                     |  |  |
| MCIP    | Meteorology-Chemistry Interface Processor                   |  |  |
| MEGAN   | Model of Emissions of Gases and Aerosols from Nature        |  |  |
| MSA     | Metropolitan Statistical Area                               |  |  |
| NAAQS   | National Ambient Air Quality Standards                      |  |  |
| NASA    | National Aeronautics and Space Administration               |  |  |
| NATA    | National-scale Air Toxics Assessment                        |  |  |
| NCDAQ   | North Carolina Division of Air Quality                      |  |  |
| NEI     | National Emissions Inventory                                |  |  |
| netCDF  | network Common Data Form                                    |  |  |
| NIF     | National Emissions Inventory Input Format                   |  |  |
| NMIM    | National Mobile Inventory Model                             |  |  |
| NMOC    | Non-Methane Organic Compounds                               |  |  |

| OAQPS    | Office of Air Quality Planning and Standards   |  |
|----------|--|--|
| OC       | Organic Carbon   |  |
| ORD      | Office of Research and Development   |  |
| ORL      | One-Record-per-Line  |  |
| OSAT     | Ozone Source Apportionment Technology  |  |
| OTAQ     | Office of Transportation and Air Quality   |  |
| PAMS     | Photochemical Assessment Monitoring Stations   |  |
| PAVE     | Package for Analysis and Visualization of Environmental Data                         |  |
| PM       | Particulate Matter   |  |
| PPTM     | Particle and Precursor Tagging Methodology   |  |
| PSAT     | PM Source Apportionment Technology   |  |
| QA       | Quality Assurance  |  |
| QAPP     | Quality Assurance Project Plan   |  |
| QC       | Quality Control  |  |
| RDBMS    | Relational Database Management System  |  |
| RFP      | Request for Proposal   |  |
| ROSES    | Research Opportunities in Space and Earth Sciences                                   |  |
| RPO      | Regional Planning Organization   |  |
| RRF      | Relative Reduction Factor  |  |
| SAMI     | Southern Appalachian Mountains Initiative  |  |
| SANDWICH | Sulfates, Adjusted Nitrates, Derived Water, Inferred Carbonaceous Mass and estimated |  |
|          | aerosol acidity (H+)   |  |
| SDBMS    | Spatial Database Management System   |  |
| SEARCH   | Southeastern Aerosol Research and Characterization Study                             |  |
| SEMAP    | Southeastern Modeling, Analysis, and Planning  |  |
| SERDP    | Strategic Environmental Research and Development Program                             |  |
| SLAMS    | State and Local Air Monitoring Stations  |  |
| STN      | Speciated Trends Network   |  |
| TAWG     | Technical Analysis Work Group  |  |
| UNC      | University of North Carolina   |  |
| VIEWS    | Visibility Information Exchange Web System   |  |
| WRAP     | Western Regional Air Partnership   |  |

# **Document Change Record**

| Revision | Date              | Remarks  |
|----------|-------------------|--|
| 0.1      | October 15, 2014  | Draft version for SESARM review  |
| 0.2      | November 21, 2014 | Replaced Figures 2-2 through 2-7 to correct switch of VA and WV emissions totals |
| 1.0      | December 31, 2014 | Revised version after SESARM review  |
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## **Chapter 1: Project Overview**

## 1.1 Introduction

In 2009, SESARM initiated a new Southeastern Modeling, Analysis and Planning (SEMAP) project to produce technical analyses to aid member states, in the development of SIPs for O<sub>3</sub> and PM<sub>2.5</sub>, and in the demonstration of reasonable progress for the regional haze rule, required under the Clean Air Act Amendments. Specifically, since the precursor emissions and some of the atmospheric chemical processes are interlinked in the way one can control the chemical formation for fine particles, ozone and regional haze, an integrated assessment using a one-atmosphere modeling approach is needed to address the air pollution problems in the SESARM states. It is anticipated that this analysis will help the SESARM state agencies to protect human health as well as the environment from the impacts of air pollutants.

To address the air quality and emissions modeling needs of the SEMAP project, Georgia Institute of Technology Environmental Engineering Department (Georgia Tech), the University of North Carolina Institute for the Environment (UNC) and the Colorado State University Cooperative Institute for Research in the Atmosphere (CSU) formed a team. The work was performed under a contract (Contract # S-2010-04-01 executed on April 13, 2010 and its 11 amendments) between SESARM and Georgia Tech, the lead organization, and Georgia Tech subcontracts to UNC and CSU. Dr. Talat Odman from Georgia Tech acted as the project principal investigator. Mr. Zac Adelman from UNC and Mr. Shawn McClure from CSU were the co-investigators. They were joined by a large number of investigators and staff from all three institutions to perform the tasks of this project.

This document presents the final report for the project. Its intent is to describe the methods and approaches that were used in the project and to present the results. After a brief introduction of the key personnel in leading roles, the tasks performed will be summarized in this first chapter. The task descriptions contain a list of related deliverables and information on how to reach them. Chapter 2 is a complete documentation of the emissions modeling performed in this project. The emissions that were prepared for subsequent air quality modeling are documented in detail. Three chapters are devoted to the air quality modeling pieces. The performance of the air quality model is evaluated in Chapter 3. The air quality simulation of the year 2018 is documented and projected ozone,  $PM_{2.5}$  and haze levels are presented in Chapter 4. Finally, the sensitivity of ozone to  $NO_x$  and VOC emissions is addressed in Chapter 5.

## 1.2 Key Personnel and Roles

## 1.2.1 Georgia Institute of Technology (Georgia Tech)

**Dr. Talat Odman,** Principal Research Engineer in the School of Civil and Environmental Engineering at Georgia Institute of Technology, was the Project Manager and Principal Investigator.

**Dr. Yongtao Hu**, Senior Research Scientist in the School of Civil and Environmental Engineering was the Air Quality Model and Data Manager.

## 1.2.2 University of North Carolina (UNC)

**Mr. Zachariah Adelman**, Research Associate at the UNC Institute for the Environment, was the UNC Project Manager and Co-Principal Investigator in charge of Emissions Data Management.

**Dr. Saravanan Arunachalam**, Research Associate Professor at the UNC Institute for the Environment, was the Air Quality Data Manager.

**Dr. Adel Hanna**, Research Professor and the Director of the Center for Environmental Modeling for Policy Development (CEMPD) of the Institute for the Environment at UNC, was the Quality Assurance Manager.

**Ms. Uma Shankar,** Research Associate at the UNC Institute for the Environment, was the Observavational Data Manager.

**Dr. Aijun Xiu,** Research Associate at the UNC Institute for the Environment, was the Meteorology Data Manager.

**Ms. Jeanne Eichinger**, Senior Technical Editor for the UNC Institute for the Environment, was the Documentation and Deliverables Manager.

## 1.2.3 Colorado State University (CSU)

**Mr. Shawn McClure**, Software Engineer for the Cooperative Institute for Research in the Atmosphere (CIRA), was the CSU Project Manager and Co-Principal Investigator in charge of Interactive Database Tool and Technical Website development.

## 1.3 Tasks Performed

This section presents an overview of the work performed. The project was broken into 16 tasks. The overview of each task starts with the name of the task leader who was responsible for the technical oversight as well as managing the performance and deliverables for the task. A brief statement of the objectives of the task is followed by a summary of the technical approach used to accomplish those objectives. Finally, the list of deliverables under each task is presented along with information on where to find them.

### 1.3.1 Task 1: Project Management

Our team used a matrix of project managers, task technical leaders, data managers, and technical staff to satisfy the planning, documentation, and technical requirements of this contract. Dr. Talat Odman from Georgia Tech served as the principal technical leader and overall project manager. Mr. Zac Adelman from UNC served as the project co-investigator managing the modeling, development, and evaluation work at UNC. Ms. Jeanne Eichinger of UNC served as the documentation coordinator for the entire project. Senior members of the project team served as data managers for each of the key data components collected and generated during the SEMAP project. As curators of the project data, the data managers were responsible for the acquisition and initial screening of model input data and observational data, confirming that they are the correct data for the SEMAP project modeling grids and time periods. They also supervised the quality control (QC) of the data generated during the project, ensuring the generation and utilization of quality assurance (QA) products. Finally the data managers were responsible for the accumentation of their data.

Communication with the Project Coordinator, SEMAP Technical Analysis Work Group (TAWG) and other SESARM contractors was accomplished through conference calls. Other project management activities included responding to questions raised by the SEMAP Project Coordinator or other project participants; coordination of all members of the project team to assure the timely flow of data and delivery of products, tracking and reporting progress and making sure that the SEMAP project schedule is followed; reporting problems and concerns, along with options for solutions, to the SEMAP Project Coordinator; identifying resources for revisions and additional work.

## 1.3.1.1 Final Project Work Plan

The objective of the project work plan was to ensure that the SEMAP project objectives are understood completely and accurately, and that measures aligned to EPA guidance are taken to achieve those

objectives on time and within budget. A draft work plan was developed describing the methods and approaches to be used in the project, including information about the products and software tools that will be employed for evaluation as well as the emissions and air quality modeling website that will be developed. Team leaders, deliverables and schedule were specified for each task. The projected levels of effort and associated costs were also included. The work plan was finalized by incorporating the direction received from SESARM. The final version is available at:

http://www.ie.unc.edu/cempd/projects/SEMAP/secure/documents/PWP\_SEMAP\_DRAFT\_4-27-10\_UNC\_CIRA\_Gatech.pdf.

## 1.3.1.2 Quality Assurance Project Work Plan

The overall objective of the Quality Assurance Project Plan (QAPP) is to ensure that deliverables are of sufficient quality to support their intended use by SESARM and participating agencies. The deliverables can include, but are not limited to datasets (including modeling inputs/outputs), software documentation, presentations, technology transfer efforts, and all forms of communication. We prepared a draft plan and revised it twice: once after SEMAP internal review and again after US EPA review. The EPA approved quality assurance project plan is available at:

http://www.ie.unc.edu/cempd/projects/SEMAP/secure/documents/QAPP\_SEMAP\_DRAFT\_5-10-10.pdf.

## 1.3.2 Task 2: Modeling Protocol

The objective of this task was to establish a living document that describes the data, methodologies, and techniques used to conduct, complete, and document all modeling and evaluation tasks in the SEMAP modeling project. We prepared an initial version of the emissions and air quality modeling protocol. The protocol described all aspects of the data collection, modeling, evaluation, and archival that will be conducted during the SEMAP project, including:

- The technical modeling approach
- Evaluation of methods and techniques for thoroughly and efficiently analyzing large amounts of data
- Recommended model configurations
- Emissions processing methods and data sources
- Ancillary emissions data configuration, (e.g. sources and evaluation of temporal, chemical speciation, and spatial surrogate data)
- Vegetation and land use data
- Development of initial and boundary conditions
- Chemistry parameters/chemical mechanism configurations
- Vertical diffusivity parameters
- Computer resources
- Project schedule
- Quality assurance procedures for each task, including procedures for identifying and correcting errors
- Observational data sets to be used for model performance evaluations and additional analyses

The protocol was revised during the course of the project based upon feedback from SESARM, and based upon other developments during the modeling. For instance, the results from one diagnostic sensitivity

simulation provided the motivation for performing another sensitivity that was not originally planned. To address the needs of a 'living' document as discussed above, we posted the modeling protocol on a Wiki, which facilitates collaborative modification as well as being able to track the changes over time. The Wiki can be reached at:

#### http://www.airqualitymodeling.org/semapwiki/index.php?title=Main\_Page

We implemented the methods and techniques described in the modeling protocol to guide the data handling, modeling, and evaluation of all work conducted on the SEMAP project.

### 1.3.3 Task 3: Data Acquisition/Dataset Preparation for Modeling and Evaluation

This task was divided into subtasks for each of the different classes of data used in the SEMAP project. The subsections below describe the detailed approaches used to acquire and prepare each dataset for modeling and evaluation.

### 1.3.3.1 Emissions

We developed a collection of emissions modeling platforms (EMPs) for the SEMAP modeling project. An EMP is a collection of data and modeling tools needed to simulate emissions in support of air quality modeling studies. In addition to being useful for organizing emissions modeling tasks, EMPs provide a clean method for packaging and distributing all of the data and scripts needed to reproduce an emissions simulation. We acquired the appropriate emissions inventory data to run and evaluate the air quality modeling, including:

- 2007 emissions data for the SEMAP states
- Future year emissions data for the SEMAP states
- 2007 emissions data for the non-SEMAP states
- Future year emissions data for the non-SEMAP states
- 2007 emissions data for Canada and Mexico
- The gridded land use and emission factor data

From these inventories we prepared the following EMP's to support the air quality modeling:

- 2007 Actual
- 2007 Typical
- 2018 Baseline

A detailed description of the emissions inventory data used and the EMPs developed in this project can be found in Chapter 2.

#### 1.3.3.2 Meteorology

We acquired the Weather Research and Forecasting (WRF) model output data from SESARM (Atmospheric and Environmental Research, 2011). WRF model version 3.1.1 was used in SESARM's meteorological modeling with the following options: 1) Morrison moist physics, 2) RRTMG radiative transfer model for long wave and short wave radiation, 3) Pleim-Xiu land surface model (PX) with 2 soil layers, 4) Asymmetric Convective Mixing PBL model version 2 (ACM2), 5) PX surface layer, and 6) Kain-Fritsch cumulus parameterization.

We processed the WRF model outputs with the Meteorology-Chemistry Interface Processor (MCIP) for input to the emissions (SMOKE) and air quality (CMAQ) modeling, using the 22-layer vertical

structure defined by SEMAP. After completing the MCIP processing of the SEMAP WRF data, we created a series of quality assurance and analysis products and posted them to the project website at UNC. These products include plots of:

- Hourly 2-m temperatures overlaid with wind vectors,
- Hourly planetary boundary layer (PBL) heights,
- Hourly cloud fractions,
- Hourly precipitation,
- Hourly surface radiation,
- Daily maximum 2-m temperatures, and
- Comparisons between MCIP and WRF of PBL heights, 2-m temperatures, 10-m winds, and, for several model layers, ambient temperatures, and wind speeds,

for both the 36-km and 12-km modeling domains. These plots were reviewed by members of the SEMAP Technical Analysis Work Group.

### 1.3.3.3 Initial and Boundary Conditions

GEOS-Chem based initial and boundary conditions were acquired from the SEMAP project coordinator, quality assured and prepared for CMAQ simulations. The GEOS-Chem model version 8-02-04 was employed by the Georgia Environmental Protection Division to generate these initial and boundary conditions (Zeng and Boylan, 2011a). An evaluation of model performance in this 2007 GEOS-Chem simulation can be found in Zeng and Boylan (2011b).

## 1.3.3.4 Ambient Air Quality Data

The ambient air quality data that was used for evaluating model performance are summarized in Table 1-1. The networks providing these data are described below.

**AIRS:** AIRS compiles and provides access to datasets from multiple national observational networks/programs including STN/CSN, SLAMS and PAMS. The STN/CSN network provides 24-hr measurements of PM<sub>2.5</sub> and its composition. The SLAMS network provides hourly measurements of criteria air pollutants including PM<sub>2.5</sub>, PM<sub>10</sub>, O<sub>3</sub>, SO<sub>2</sub>, NO<sub>2</sub>, CO, etc. The PAMS network measures photochemical smog related species such as O<sub>3</sub>, NO, NO<sub>2</sub>, NO<sub>y</sub>, NMOC, and VOC compounds in non-attainment areas.

**IMPROVE:** IMRPOVE includes measurements of chemical constituents of PM<sub>2.5</sub> as well as related gaseous species at Class I areas.

<u>CASTNet</u>: CASTNet provides dry and wet acid deposition at rural sites as well as ozone and chemical constituents of  $PM_{2.5}$ .

**SEARCH:** SEARCH provides continuous and speciated PM data in one urban and one rural location in Alabama, Georgia, Florida, and Mississippi. In addition to 24-hr PM mass (fine and coarse) and composition (EC, OC, sulfate, nitrate, ammonium, and metals) SEARCH provides hourly PM mass and ion components (BC, OC, sulfate, nitrate, and ammonium) and a wide range of complementary gaseous species (O<sub>3</sub>, NO, NO<sub>2</sub>, NO<sub>y</sub>, HNO<sub>3</sub>, SO<sub>2</sub>, CO, and CO<sub>2</sub>).

| Variable                                | Averaging time        | Networks                             |
|---|-----------------------|--------------------------------------|
| PM <sub>10</sub>                        | daily, hourly         | AIRS, IMPROVE, SEARCH                |
| PM <sub>2.5</sub>                       | daily, hourly         | AIRS, IMPROVE, SEARCH                |
| Sulfate                                 | daily, hourly, weekly | AIRS, IMPROVE, SEARCH, CASTNet       |
| Nitrate                                 | daily, hourly         | AIRS, IMPROVE, SEARCH                |
| Ammonium                                | daily, hourly, weekly | AIRS, SEARCH, CASTNet <sup>(a)</sup> |
| EC (BC)                                 | daily, hourly         | AIRS, IMPROVE, SEARCH                |
| OC                                      | daily, hourly         | AIRS, IMPROVE, SEARCH                |
| Trace Metals in PM <sub>2.5</sub>       | daily                 | AIRS, IMPROVE, SEARCH                |
| NO, NO <sub>2</sub> and NO <sub>y</sub> | hourly                | AIRS, SEARCH                         |
| SO <sub>2</sub>                         | hourly, daily, weekly | AIRS, CASTNet, IMPROVE, SEARCH       |
| VOCs, HAPs                              | hourly                | AIRS, SEARCH <sup>(b)</sup>          |
| Total Nitrate <sup>1</sup>              | daily, weekly         | CASTNet, SEARCH                      |

Table 1-1. Ambient air quality data available for model performance evaluation and input to receptormodels for the Southeast.

(a) Ammonium data from IMPROVE are estimated from sulfate and nitrate based on complete neutralization of those ions. Independent measurements from CASTNet are more appropriate for model evaluation purposes.

(b) Aerosol Research & Inhalation Epidemiological Study (ARIES) program measures HAPs and other VOCs at the SEARCH sites in Atlanta, GA area.

(c) CASTNet weekly measurements of PM nitrate and HNO<sub>3</sub> will be evaluated as total nitrate due to issues relating to filter-based methods to collect volatile nitrate species.

## 1.3.4 Task 4: Conceptual Description

The objective of this task was to develop a qualitative characterization of the nature of the ozone, PM<sub>2.5</sub>, and regional haze problem in the SEMAP region. We gathered all readily available information from the SEMAP states and other sources. This included ozone and PM<sub>2.5</sub> design values for monitors in the Southeast, speciated PM data, best/worst visibility day information, emissions information, and answers to questions in Chapter 11 of EPA's *Guidance on the Use of Models and Other Analyses for Demonstrating Attainment of Air Quality Goals for Ozone, PM<sub>2.5</sub>, and Regional Haze (April 2007). Results from previous modeling studies in the region included daily air quality forecasts since 2006 (Odman et al., 2007a), the emission sensitivity modeling for VISTAS, and analyses of the sources of O<sub>3</sub>, PM, and haze problems in the region (Odman et al., 2007b; Odman et al., 2009). We reviewed these results to better understand the nonattainment problem in terms of urban versus rural areas and coastal, inland and mountain areas in the SEMAP region. We prepared a draft interim conceptual description report according to EPA Guidance and finalized it after SEMAP TAWG review. This report can be found at:* 

http://semap.ce.gatech.edu/sites/default/files/files/final\_conceptual\_description\_v1.1.pdf

## 1.3.5 Task 5: 36 km/12 km Emissions/AQ Annual Actual Base Year Simulations

The objective of this task was to develop a final annual "actual" 2007 base year air quality model simulation on 36-km and 12-km resolution modeling grids (Figure 1-1). This was accomplished by performing and evaluating the following two annual simulations:



Figure 1-1. 36-km (left) and 12-km (right) SEMAP air quality modeling grids

- 2007 Actual Initial SMOKE & Initial CMAQ (to be performed before Task 6)
- 2007 Actual Final SMOKE & Final CMAQ (to be performed after Task 6)

We used the "2007 Actual" emissions modeling platform (EMP) developed in Task 3 with SMOKE version 2.6 and version 3.0 to prepare emissions inputs for CMAQ. The initial "Actual 2007" simulation was performed using CMAQ version 5.0.1 with the configuration shown in Table 1-2 and the following runtime options:

- 1) Windblown dust: NO
- 2) Lightning NO<sub>x</sub>: Inline informed by lightning detection network data.<sup>1</sup>
- 3) In-line deposition velocities: YES
- 4) Ammonia bi-directional flux: NO<sup>2</sup>
- 5) Surface HONO interaction: YES<sup>3</sup>
- 6) BEIS or MEGAN for biogenic emissions: BEIS
- 7) In-line biogenic emissions: NO
- 8) In-line plume rise: YES

The CMAQ model configuration was modified after the diagnostic sensitivity tests in Task 6 below for the final "Actual 2007" simulation.

<sup>&</sup>lt;sup>1</sup> We used the monthly flash count frequency (flash  $/ m^2$ ) file that EPA prepared for the CONUS 12-km grid.

 $<sup>^{2}</sup>$  Investigating the difference in NH<sub>3</sub> emissions this option would create over those already in use is a research project that may not fit well into the modeling schedule.

 $<sup>^{3}</sup>$  HONO is produced via heterogeneous reaction on ground surfaces. This used to affect NO<sub>2</sub> deposition in prior versions but not anymore.

| Model Parameter          | CMAQ_v5.0   |
|--------------------------|---|
| Horizontal Advection     | Yamartino (hyamo)                                     |
| Vertical Advection       | WRF (vwrf <sup>4</sup> )                              |
| Horizontal Diffusion     | Multiscale  |
| Vertical Diffusion       | Advanced Convective Method (ACM2)                     |
| Gas Chemistry Mechanism  | CB05 with Chlorine (cb05tucl_ae6_aq <sup>5</sup> )    |
| Gas Chemistry Solver     | Euler Backward Iterative (ebi_cb05tucl)               |
| Aerosol Mechanism        | CMAQ 6 <sup>th</sup> Generation (aero6 <sup>6</sup> ) |
| Clouds/Aqueous Chemistry | ACM clouds with aero6 (cloud_acm_ae6)                 |
| Plume in Grid            | none  |

| Table 1-2.   | CMA0  | configuration     | options |
|--------------|-------|-------------------|---------|
| 1 10000 1 20 | Ching | 2011915111 111011 | opnons  |

Quality of emissions inputs to CMAQ was assured through a systematic process. In addition to generating quality assurance reports that summarize annual and typical ozone season day emissions by county, pollutant, and SCC for all states and countries in the SEMAP modeling domain, we produced time series, spatial plots, and vertical profiles of the emissions results to aid in the QA/QC and evaluation of the SMOKE output.

Figure 1-2 shows an example of two types of plots that are automatically generated using the emissions QA/QC tool used in the SEMAP project. Quality of the air quality simulations was assured through visualization of the modeling results and the model performance evaluation under Task 10.



Figure 1-2. Example SMOKE emissions analysis products: monthly tile plot (Left); pollutant bar chart (Right)

<sup>&</sup>lt;sup>4</sup> First the change in column mass is computed and then the vertical velocity is computed layer-by-layer using the horizontal mass divergence.

<sup>&</sup>lt;sup>5</sup> Updated toluene chemistry and reactions of toluene and xylene with chlorine

<sup>&</sup>lt;sup>6</sup> PM-other speciation includes non-carbon organic matter and metals. Primary organic carbon is aged. ISORROPIA v1.7 is replaced with ISORROPIA v.2.1 which treats the thermodynamics of crustal material.

Two drives were prepared all the inputs and outputs of the "Actual 2007" SMOKE and CMAQ simulations. A detailed discussion of the "Actual 2007" emissions can be found in Chapter 2. The results of the "Actual 2007" simulations are summarized in Chapter 3.

### 1.3.6 Task 6: Model Configuration Diagnostic Sensitivity Modeling

Diagnostic sensitivity modeling was performed to determine the final model configuration that will be used in 2007 typical and future year simulations as well as emissions sensitivity modeling. These diagnostic tests and the final model configuration are described in Chapter 3.

### 1.3.7 Task 7: Emissions and Air Quality Benchmark Simulations

We created a custom data transfer and benchmarking protocol for the SEMAP project, where we incorporated the following steps:

- a) Verify the computing architecture (OS, processors), compiler versions available
- b) Install netCDF, I/O API
- c) Install and run SMOKE for a 5-day period
- d) Install and run CMAQ for a 5-day period
- e) Compare outputs from above with the outputs created by the SEMAP project modeling team as part of Task 5, and generate paired statistics.

In this protocol, we included detailed step-by-step instructions for each of the above and discussed steps to ensure that the model outputs (from the Georgia Tech/UNC runs) are reproducible within reasonable bounds. Further, we provided explicit instructions to ensure that the model versions, associated libraries, and compilers used for the Georgia Tech/UNC modeling are documented. Along with this protocol, we provided an archive (Linux tar file) that includes all of the code and scripts that the Georgia Tech/UNC modelers used for the SEMAP simulations. We included a README file along with this archive to distinguish between the various scripts and possible iterations that the team went through during the course of the project. The SMOKE and CMAQ archives and their README files can be downloaded from the SEMAP ftp site at CSU.

- SMOKE software tar file and the README file:
  - <u>ftp://viking.cira.colostate.edu/SEMAP/Benchmark/SMOKE/SEMAP\_SMOKE\_Benchma</u> <u>rking\_README\_v09-14.pdf</u>
  - <u>ftp://viking.cira.colostate.edu/SEMAP/Benchmark/SMOKE/SEMAP\_SMOKE\_Benchma</u> <u>rk\_Software\_v0914.tar.gz</u>
- CMAQ script/code archive and Benchmark and the README file:
  - o <u>ftp://viking.cira.colostate.edu/SEMAP/Benchmark/CMAQ/SEMAP\_CMAQv5.0.1\_Benc</u> <u>hmark\_Software\_v0914.tar.gz</u>
  - o <u>ftp://viking.cira.colostate.edu/SEMAP/Benchmark/CMAQ/SEMAP\_CMAQ\_Benchmark</u> <u>ing\_README\_v09-14.pdf</u>

### 1.3.8 Task 8: 36 km/12 km Annual Typical/Future Year Emissions AQ Modeling

The EMPs for the typical and future year emissions data prepared by UNC under Task 3 were combined with the actual 2007 meteorology and BCs used in Task 5 to simulate typical and future year air quality with CMAQ. The same SMOKE configuration, including the use of representative days to optimize the emissions processing tasks, was applied to the typical and future year simulations. We used the final

CMAQ model configuration from Task 5 to perform the annual simulations for this task on both SEMAP modeling grids.

Various analysis products were produced for the typical and future year simulations conducted here and posted to the project web site. Some of them can also be found in Chapter 3 (typical 2007) and Chapter 4 (2018 future year). In addition to the plots and statistics of the typical and future year simulations, we also produced analysis products comparing the future year results to the typical year simulation results.

## 1.3.9 Task 9: Emission Sensitivity Modeling

This task, which was planned to include source apportionment simulations and sensitivity simulations both with the Direct Decoupled Method (DDM) and the "Brute Force" method, was cancelled. Later, under Task 15, we performed 28 emission reduction simulations with CMAQ using the 12-km SEMAP grid during the 5-month  $O_3$  season. We analyzed the responses of 8-hour maximum  $O_3$  to 30% reductions of NO<sub>x</sub> and VOC emissions from the SESARM states and the neighboring RPOs.

### 1.3.10 Task 10: Model Performance Evaluation

The objective of this task was to evaluate the performance of the CMAQ model for O<sub>3</sub>, PM<sub>2.5</sub> and regional haze in the 2007 air quality simulations over the 12-km SEMAP domain, using a suite of comparisons of model outputs against ground-based observations. We calculated various model performance metrics and generated several types of graphics depicting model performance using the procedures identified in the Quality Assurance Project Plan (Task 1) and the Modeling Protocol (Task 2). We performed model performance evaluations for all 2007 simulations, including "Typical 2007". We provided all of the analyses described in Attachment A of the contract. Version 2.0 of the Atmospheric Model Evaluation Tool (AMET) was used to produce the analyses in the form of tables and graphic displays needed for this task. AMET offers the high degree of automation required to handle the large number of analyses listed in Attachment A.

All model performance metrics and graphics employed in this project are illustrated in Chapter 3 and the full set of performance evaluation products can be found on the project technical website.

## 1.3.11 Task 11: Future Year Model Projections

The objective of this task was to demonstrate progress towards regulatory goals for  $O_3$ ,  $PM_{2.5}$  and regional haze. The U.S. EPA guidance (U.S. EPA, 2007) for demonstrating modeled attainment of air quality goals for  $O_3$ ,  $PM_{2.5}$  and regional haze prescribes an approach to use model outputs in a relative sense. In this guidance, the attainment test methodology uses model outputs and ambient data to estimate future year concentrations. Specifically,

- 1. Relative Reduction Factor (RRF) = Model predicted change (in %) from base year to future year
- 2. Future Year Design Value (DVF) = Base Year Design Value (DVC) X RRF

This procedure is fairly straightforward for  $O_3$ , since there is only one component, and no speciation is involved. However, for  $PM_{2.5}$  and the regional haze reasonable progress, the attainment test needs to use all the  $PM_{2.5}$  species, where the RRFs need to be calculated for each individual  $PM_{2.5}$  speciated component, and total  $PM_{2.5}$  is reconstructed from the sum of all  $PM_{2.5}$  components. This procedure called the Speciated Modeled Attainment Test (SMAT) can be directly applied where speciated  $PM_{2.5}$ information is available. Since FRM monitors are the only ones that can be used to demonstrate attainment, the SMAT process can be applied relatively easily if the FRM monitors have collocated STN/CSN monitors. However, speciated information is not available at most FRM locations. Further, the measurements collected at the STN and IMPROVE monitors are not directly comparable to FRM measurements. To give a rough idea of this discrepancy, there are ~1200 FRM monitors in the country, but only ~250 STN and ~165 IMPROVE monitors, and over 75% of the FRM monitors do not have a collocated STN monitor. Figure 1-3 shows a map of the U.S. with the locations of the various monitors.



Figure 1-3. Location of various PM<sub>2.5</sub> monitors in the U.S. for SMAT

We applied the Modeled Attainment Test Software (MATS) (Abt Associates, 2009) to the 2018 future year in comparison to the 2007 typical base year, and computed RRFs and DVFs for  $O_3$ ,  $PM_{2.5}$  and for regional haze rate of progress. We computed DVFs at all monitoring locations, and also used the gradient adjusted interpolation option within MATS to perform this analysis at the unmonitored locations within the modeling domain.

We developed visual outputs of the DVFs for  $O_3$ ,  $PM_{2.5}$  and posted them to the project's technical website at Georgia Tech (<u>http://semap.ce.gatech.edu/node/1851</u>). Some of these products can also be found in Chapter 4. Regional haze projections were used by SEMAP in the glide slopes for evaluating the rate of progress towards regional haze goals on the best 20% and worst 20% visibility days. MATS inputs and outputs can be found at <u>http://semap.ce.gatech.edu/node/1852</u> as well as on the SEMAP-CMAQ drive.

## 1.3.12 Task 12: Interactive Database Tool

An interactive database tool was developed to allow the SEMAP states to easily review, compare, and make assessments of the emissions and air quality modeling results. The development was largely leveraged by the database and website infrastructure of the Visibility Information Exchange Web System Technical Support System (VIEWS/TSS), which were tailored to the needs of the SEMAP end users.

## 1.3.12.1 Raw Data and Metadata Analysis

As a first step toward importing and managing the SEMAP data to be accessed and served by the Interactive Database Tool (IDT), we identified the specific datasets and output products to be managed by the IDT and determined the best mechanisms for both initially acquiring these products as well as making updates to them over time if any revisions and/or corrections are made to the underlying data. Then we identifies the relevant subsets of both data and metadata to extract from the raw datasets for inclusion in the relational database management system (RDBMS).

Next, we acquired representative samples of each type of dataset to be managed and subsequently analyzed the internal schema of each dataset to identify and understand key aspects of both the data and metadata, such as column names, primary and candidate key fields, field lengths, value domains and ranges, data types, temporal frequencies, spatial granularity and distribution, etc. The external schema of the datasets were also studied in order to understand important characteristics such as file types (netCDF, HDF, etc.), naming conventions, temporal and spatial partitioning, and expected volume. These respective schemas were then compared to the existing schema of the VIEWS/TSS integrated database in order to determine the nature and extent of any modifications and/or extensions that were necessary to accommodate the SEMAP data. The entire process of understanding the schema of the SEMAP data and making any necessary extensions to the VIEWS database had to be handled as a cyclic process consisting of several iterations, depending upon the timing with which various datasets become available as modeling proceeded.

## 1.3.12.2 Database Design and Enhancement

When this inventory of target SEMAP data has been completed, we extended the schema of its relational and geospatial databases to accommodate the management of the data. To make these extensions, 1) database tables were defined and/or extended with the appropriate fields, data types, default values, and other specifications as necessary, 2) primary and candidate keys were determined for each modified table, 3) appropriate relationships and cardinality were defined between entities, and 4) the resulting entities and fields were normalized into at least 3<sup>rd</sup> Normal Form. The existing set of database codes, conventions, and lookup tables used in the database were extended as necessary to serve the SEMAP data. In addition, the operational and administrative infrastructures of the VIEWS database were enhanced to accommodate the increased density and volume of the SEMAP data. We 1) built appropriate table indexes, 2) developed inserted, updated, and deleted logic as needed, 3) implemented triggers and user-defined functions as indicated, 4) and created data definition language (DDL) scripts for managing and maintaining the database schema over time.

In preparation for actual data import, we developed the SQL stored procedures, scripts, and any associated program code for importing the data from its native format and transforming it into the integrated database schema. These operations included 1) the bulk import of data into as-is tables, 2) removal of any unnecessary native fields, 3) renaming and/or reorganizing of the source data columns, and 4) "pivoting" of source fields into the normalized schema. We also developed procedures and policies for verifying basic data integrity and completeness, such as SQL scripts to tally and compare checksums of the raw versus imported data to identify and correct any discrepancies.

## 1.3.12.3 Development of Interactive Database Tool

After the database has been appropriately enhanced, existing tools were extended in order to facilitate the creation of an IDT capable of providing online exploration, visualization, and analysis, of the SEMAP project data. Existing tools were examined to determine the optimal way to extend and possibly consolidate their user interface (UI) with the textual cues, selection items, and HTML controls that are relevant. These enhancements were implemented in a manner commensurate with current web UI design guidelines, and the IDT was developed as necessary to provide integrated, seamless access to the SEMAP
data. The IDT was designed to interact directly with the database and generate a variety of dynamic graphs, charts, plots, and maps. In particular, the VIEWS Query Wizard, Trends and Composition tools, Dataset Index, Site Browser, Image Browser, File System Browser, and Data Statistics tool were enhanced to provide seamless access to the SEMAP data and generate the appropriate output products. This enabled SEMAP IDT users to visualize and compare existing ground-based measurements, modeled data, and emissions inventories by using an integrated suite of tools that have already been tested and proven useful by a large community of users with similar goals and needs.

## 1.3.13 Task 13: Receptor Modeling

This task was cancelled.

# 1.3.14 Task 14: Development of Technical Web Site

### 1.3.14.1 Web/FTP Site Development

The purpose of the technical web site is to serve as the primary means for distributing emissions and air quality modeling results, data, and documentation to the SEMAP TAWG and SESARM states. Team member CSU created a website that is easy to understand, navigate, and interact with (http://views.cira.colostate.edu/SEMAP/).

# 1.3.14.1.1 Development of the Technical Website

The relevant tools previously developed for the VIEWS website have been modified to SEMAP project specifications and existing technologies and software infrastructure were leveraged to create a separate and distinct website with a SEMAP-specific logo, theme, and style. The lessons learned from the development of the VIEWS/TSS websites were applied to improve the features and operation of the SEMAP website.

The website is hosting the tools for serving the specific needs of the SEMAP end users. The technical web site is designed to serve as the primary means for 1) distributing and evaluating the emissions and air quality modeling results and summaries and 2) communicating the corresponding documentation to the SEMAP TAWG. The web site was organized so that SEMAP states can easily navigate through large amounts of data to quickly find information relevant to their specific areas of interest. In addition, the IDT and other website tools were designed to enable SEMAP users to easily locate and download arbitrary subsets of the data and relevant products to their local hard drives. To facilitate this, appropriate records were added to the VIEWS "meta-base" to ensure that the user would be able to easily identify the individual SEMAP datasets that are available through both the website and the FTP site. In addition, the various HTML selection controls used on the website pages were checked to make sure that the new metadata records are presented intuitively. Names and codes for the datasets were refined until collaborators agreed that it is straightforward for the end user to browse and select the data from the website tools.

The web site incorporates a logical set of menus, dropdown lists, selection boxes, and forms that allow interactive access to any of the graphical and statistical analyses generated throughout this project. CSU-CIRA is committed to work with end users to evolve and refine the tools as necessary to provide seamless access to the SEMAP data in a manner commensurate with desired thematic guidelines and data flow practices.

# 1.3.14.1.2 Delivery and Transfer of the IDT and Website

The website, database, IDT, and any supporting source code or software resources are designed in such a way that the system as a whole can be transferred to the Metro 4/SESARM or any other designated server, and can subsequently be configured to be fully functional in its new environment.

# 1.3.14.2 Data Transfer and Archival

All essential modeling data used and produced in the above tasks has been archived using a combination of electronic transfer protocols (HTTP and FTP) and physical storage media based on the size of the data being transferred. In general, model scripts, emissions input data, observational data, and analysis products can be transferred electronically from Web/FTP sites through an intuitive interface for accessing and downloading these data. Larger datasets, including model-ready meteorology (MCIP output), SMOKE output data, and air quality modeling results (CMAQ output) were loaded onto two external USB drives and made available to the SEMAP members by mail.

Additional archives of the SEMAP project data, including the sensitivity modeling data described under Task 15 below, are available at Georgia Tech and UNC back-up systems. These data will be maintained for up to three years following the completion of the SEMAP contract. If requested, we can provide all SEMAP modeling data to the SEMAP Project Coordinator on USB drives purchased for this project.

# 1.3.15 Task 15: Other Tasks as Assigned

This task was originally reserved for any other work that may be added to the project after project start. It was used primarily for a redefinition of the emission sensitivity modeling under Task 9. We performed five-month ozone season simulations with the CMAQ model on the 12-km SEMAP grid for 28 different emission reduction scenarios to quantify the sensitivities of ozone to NO<sub>x</sub> and VOC emissions. 2018 future year emissions were reduced by 30% for either anthropogenic NO<sub>x</sub> or anthropogenic VOCs, in each of the ten SESARM states, each of the three RPO portions in the 12-km SEMAP domain, and the State of Maryland. We prepared stacked bar charts of the ozone sensitivities and posed them to the project website at <a href="http://semap.ce.gatech.edu/node/1861">http://semap.ce.gatech.edu/node/1861</a>. A detailed discussion of this sensitivity analysis can be found in Chapter 5.

# 1.3.16 Task 16: Reporting

We prepared monthly reports to track the progress by project tasks. These reports were submitted to the SEMAP Project Coordinator each month. Interim technical reports were prepared at the completion of some tasks as required by the contract. We documented the data sources, methods, results, and lessons learned at the completion of each task milestone. We collated these documents into a final project report at the completion of the project.

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# **Chapter 2: Emissions Modeling**

# 2.1 Emissions Data, Modeling and Results

This section details the air pollution emissions data and processing approaches used to prepare emissions inputs for the SEMAP air quality model simulations. The process for creating model-ready emissions inputs includes defining the scope of the modeling study, collecting the most relevant data for the study, preparing the data for input to air quality modeling software, and performing quality assurance on both the data and preparation procedures. This process was led by the University of North Carolina Institute for the Environment (UNC) and began for the SEMAP project in early Summer 2010 with the initial scoping and data collection for year-2007 base case simulations. The project scope included gathering the best available year-2007 criteria pollutant inventory and ancillary emissions data for North America and preparing these for input to CMAQ. Following the 2007 base year emissions processing, UNC developed typical year, 2007-based emissions using averaged and smoothed fire inventories for the SESARM states. The emissions processing phase of the project concluded with the development of 2018 future year emissions estimates for North America. Data sources for the emissions estimates included SESARM, other Regional Planning Organizations, and the U.S. EPA. Once gathered, these data needed to be formatted for input to the Sparse Matrix Operator Kernel Emissions (SMOKE) system, concatenated into emissions processing sectors, and verified for completeness before being input to CMAQ.

SMOKE (<u>www.smoke-model.org</u>) is an open-source, Linux software suite for processing emissions inventory data into the formats required by gridded air quality models. The primary functions of SMOKE include:

- Inventory import read in point source or county inventories of air pollutants and verify that all of the fields that are necessary to properly characterize emissions are present
- Gridding allocate county or point emission inventories to model grid cells
- Speciation convert inventory pollutants to the chemical species required by air quality models
- Temporal allocation calculate hourly emissions from annual or daily inventory data
- Merging combine all of the emissions for multiple inventory sectors into a single file per day in the data format required by a particular air quality model
- Reporting/Quality assurance create tabulated summaries of the emissions that include different types of information (i.e. gridding, speciation, temporal) to use in verifying the emissions data and processing

UNC used a combination of SMOKE version 2.6 and version 3.0 for processing the emissions for the SEMAP project. SMOKE version 2.6, which was the current version of SMOKE at the start of the SEMAP modeling, was used for most of the inventory sectors other than on-road mobile. UNC used SMOKE version 3.0 to process the Motor Vehicle Emissions Simulator (MOVES) data for the base and future years. UNC developed or applied other specialized software for processing different inventory sectors, such as Continuous Emission Monitor (CEM) point sources and landing/takeoff (LTO) aircraft point sources.

UNC organized the emissions input and output datasets for the SEMAP project using Emissions Modeling Platforms (EMPs). An EMP consists of the software, scripts, and data used to develop emissions inputs for an air quality modeling simulation. For this project UNC developed the EMPs to prepare inputs to the Community Multiscale Air Quality (CMAQ) model version 5.0. EMPs are a useful construct, particularly for the distribution of emissions datasets because they organize all of the components of a simulation into a single platform. UNC developed three EMPs for the SEMAP project:

- SEMAP Base 2007 (Described in Section 2.1.2)
- SEMAP Typical 2007 (Described in Section 2.1.3)
- SEMAP Future 2018 (Described in Section 2.1.4)

Following a brief introduction to emissions data and processing, UNC will describe the details of each of these EMPs in Sections 2.1.2 through 2.1.4. Section 2.2 describes known issues or corrections made to the final SEMAP emissions results. Section 2.3 includes annual state total summaries for all of the SEMAP inventory sectors. Section 2.4 shows plots of the state total pollutant comparisons between the SEMAP 2007 and 2018 emissions results.

# 2.1.1 SEMAP Emissions data collection and preparation

Emissions data come in many forms and are generally based on the attributes required for characterizing particular aspects of emissions sources. Inventory data include spatio-temporal totals or averages of emissions fluxes for explicit pollution sources. In general, the SEMAP nonpoint inventories are annual county totals by source, with unique sources identified by state-county Federal Information Processing Standard (FIPS) codes and source classification codes (SCCs). The SEMAP point inventories are by stack, identified by a unique combination of FIPS code, SCC, facility code, stack code, and latitudelongitude coordinate. Additional attributes of the point inventories include stack height, exit gas temperature, and exit gas velocity. The SEMAP fire inventories are a type of point inventory and include daily acres burned and fuel loading estimates to be used for calculating buoyancy of individual fire plumes. The SEMAP project used the Motor Vehicle Emissions Simulator (MOVES) to estimate on-road mobile emissions. SESARM contractors ran MOVES (http://www.epa.gov/otag/models/moves/) in emission-factor mode for the SEMAP project. The SMOKE-ready on-road mobile inventory data are a combination of county-level activity data and emissions factor look-up tables output from MOVES for representative counties. The on-road mobile activity data include county-level vehicle miles traveled (VMT), vehicle population (VPOP), and averaged speed profiles by vehicle type and road class. The look-up tables for representative counties, which are output from MOVES emissions rate mode simulations, contain county-level emissions factors as a function of temperature, relative humidity, and speeds. Land cover data and biogenic emissions factors by land cover type were used to estimate biogenic emissions fluxes. UNC used non-inventory, or ancillary emissions data, to convert the inventories into the format required by CMAO.

Ancillary emissions data refer to the non-inventory data used to prepare emissions for input to an air quality model, including:

- *Spatial data.* Emissions from all anthropogenic non-point, on-road mobile sources, and non-road mobile sources, are estimated at the county level. Data files called spatial surrogates are used to map the county-level emission inventories to the model grid cells. Spatial surrogates are generated from Geographic Information System (GIS) Shapefiles using software that calculates the fractions of county-level different geospatial attributes in a model grid cell. For example, a Shapefile of the housing distribution in Los Angeles County is combined with a description of a modeling grid to calculate the percentage of L.A. County housing assigned to each grid cell. This information is then used to allocate county-level emission inventory sources that are associated with housing (e.g. residential wood combustion) to the modeling grids.
- *Temporal data.* Air quality modeling systems, such as CMAQ and CAMx, require hourly emissions input data. With the exception of a few source types (e.g. Continuous Emissions Monitoring data, biogenic emissions and some fire inventories), most inventory data include annual or daily emission estimates. Temporal profiles are used to compute hourly emissions from the annual or daily inventory estimates. The SMOKE model uses three types of temporal profiles:

- 1. <u>Monthly profiles</u>: Convert annual inventory to monthly emissions accounting for seasonal and other effects.
- 2. <u>Daily profiles</u>: Convert monthly emissions to daily emissions accounting for day-of-week and other effects.
- 3. <u>Hourly profiles</u>: Convert daily emissions to hourly emissions accounting for the diurnal variation in emissions (e.g., work schedules and commute times).
- Chemical speciation data. Emissions inventories have limited chemical composition information. The emissions inventories for SEMAP include 6 criteria pollutants: carbon monoxide (CO), nitrogen oxides (NO<sub>X</sub>), volatile organic compounds (VOC), ammonia (NH<sub>3</sub>), sulfur dioxide (SO<sub>2</sub>), particulate matter with a mean diameter < 10 µg/m<sup>3</sup> (PM<sub>10</sub>), and particulate matter with a mean diameter < 2.5 µg/m<sup>3</sup> (PM<sub>2.5</sub>). Chemical speciation profiles are used to describe the chemical compositions of the effluent from particular emissions sources. The exact specification of the source-specific emissions species is determined by the chemistry mechanism selected for the AQM simulation. Speciation profiles convert the inventory pollutants to more detailed source-specific species required by the AQM chemistry mechanism. For example, there is a speciation profile that converts the inventory pollutant NO<sub>X</sub> to the AQM input species NO, NO<sub>2</sub>, and HONO. Speciation profiles are required to convert inventory NO<sub>X</sub>, VOC, SO<sub>2</sub>, and PM<sub>2.5</sub> into AQM species. For the SEMAP emissions modeling UNC used the CB05 chemical mechanism and speciated the VOC emissions using source specific speciation profiles developed using the SPECIATE 4.3 database<sup>1</sup>.

Spatial surrogates, temporal profiles, and chemical speciation profiles are all assigned to inventory sources using cross-referencing data that match the profiles and inventory sources using country/state/county (FIPS) and SCCs.

# 2.1.1.1 2007 emissions data

The year 2007 emissions data for the SEMAP project came from several different sources. Inventory contractors on the SEMAP project produced the anthropogenic and fire inventories for the SESARM states (AMEC, 2013; TranSystems Corp., 2012a). UNC converted the SEMAP point and non-point NIF-formatted inventories to ORL format for input to SMOKE using SQL queries built into the Access databases delivered by the SEMAP inventory contractors. The anthropogenic inventories for the non-SESARM states, Canada, and Mexico came from either Regional Planning Organizations (RPOs) or EPA in SMOKE-ready format. Figure 2-1 is a map of the RPO regions corresponding to the inventory collection efforts for the SEMAP project. In general, UNC gathered inventory data by RPO region, with a preference for data distributed by the RPOs, to build a national 2007 EMP. UNC either collected the ancillary data from EPA or developed it specifically for the SEMAP project. UNC collected biogenic emissions inputs from EPA and the National Center for Atmospheric Research.

<sup>&</sup>lt;sup>1</sup> <u>http://www.epa.gov/ttnchie1/software/speciate/</u>



Figure 2-1. Regional Planning Organization Map. Inventory data were collected for each RPO region to build the SEMAP EMP.

Part of the preparation process of the inventory data included splitting the data into smaller subsectors. UNC split-up many of the SEMAP inventories to support the application of source-specific parameterizations of temporal and spatial patterns, to facilitate source-based emissions sensitivities, and to support targeted quality assurance of important inventory sectors. Although anthropogenic inventories can be generally classified as point, non-point, or mobile, UNC ended up with over 30 individual anthropogenic inventory sectors in the final SEMAP EMPs. Table 2-1 is a listing of the inventory processing sectors used for the SEMAP project. The table lists the inventory processing sectors, sector abbreviation, and code identifying the sector as either area (A), mobile (M), or point (P), the temporal resolution of the inventory, and any notes about how the data were prepared for the SEMAP modeling.

| Inventory Sector                                | AMP | <b>Temporal Resolution</b>   | Notes  |
|---|-----|--|--|
| Nonpoint ( <b>nonpt</b> )                       | A   | Annual   | Does not contain rwc, fdust, ft, or<br>lv sources (see below)                      |
| Residential Wood Combustion (rwc)               | A   | Annual   | Meteorology-based temporal allocation  |
| Fugitive dust ( <b>fdust</b> )                  | A   | Annual   | Does not include dust transport factors  |
| MARAMA fugitive dust ( <b>mv_fdust</b> )        | А   | Annual   | Includes dust transport factors  |
| Fertilizer ( <b>ft</b> )                        | А   | Annual   |  |
| Livestock (lv)                                  | A   | Annual   | Meteorology-based temporal allocation  |
| Mexico & Canada Nonpoint (nusar)                | А   | Annual   | Includes off-road mobile   |
| Off-road mobile (nonroad)                       | A   | Monthly  | Does not include locomotives, airports, or commercial marine                       |
| Locomotive & Marine (alm)                       | А   | Annual   |  |
| On-road mobile ( <b>usmb</b> )                  | М   | Monthly  | Does not include SESARM or<br>MANE-VU; generated from runs<br>inventory-mode MOVES |
| On-road mobile running PM ( <b>runpm</b> )      | М   | Monthly  | Does not include SESARM or<br>MANE-VU states                                       |
| On-road mobile start PM ( <b>startpm</b> )      | М   | Monthly  | Does not include SESARM or<br>MANE-VU states                                       |
| SESARM MOVES rate-per-distance<br>(sesarm_rpd)  | М   | Annual activity and<br>emissions factor look-<br>up tables by fuel-month | Does not include VA; monthly<br>MOVES emission rate look-up<br>tables              |
| SESARM MOVES rate-per-profile<br>(sesarm_rpp)   | M   | Annual activity and<br>emissions factor look-<br>up tables by fuel-month | Does not include VA; monthly<br>MOVES emission rate look-up<br>tables              |
| SESARM MOVES rate-per-vehicle<br>(sesarm_rpv)   | M   | Annual activity and<br>emissions factor look-<br>up tables by fuel-month | Does not include VA; monthly<br>MOVES emission rate look-up<br>tables              |
| Virginia MOVES rate-per-distance<br>(va_rpd)    | М   | Annual activity and<br>emissions factor look-<br>up tables by fuel-month | VA-only from SESARM MOVES<br>runs; monthly MOVES emission<br>rate look-up tables   |
| Virginia MOVES rate-per-profile<br>(va_rpp)     | М   | Annual activity and<br>emissions factor look-<br>up tables by fuel-month | VA-only from SESARM MOVES<br>runs; monthly MOVES emission<br>rate look-up tables   |
| Virginia MOVES rate-per-vehicle<br>(va_rpv)     | M   | Annual activity and<br>emissions factor look-<br>up tables by fuel-month | VA-only from SESARM MOVES<br>runs; monthly MOVES emission<br>rate look-up tables   |
| MANE-VU MOVES rate-per-distance<br>(manevu_rpd) | M   | Annual activity and<br>emissions factor look-<br>up tables by fuel-month | Does not include VA; gridded 12-<br>km hourly SMOKE output                         |
| MANE-VU MOVES rate-per-profile<br>(manevu_rpp)  | M   | Annual activity and<br>emissions factor look-<br>up tables by fuel-month | Does not include VA; gridded 12-<br>km hourly SMOKE output                         |

Table 2-1. SEMAP emission inventory processing sectors

| MANE-VU MOVES rate-per-vehicle (manevu_rpv)  | М | Annual activity and<br>emissions factor look- | Does not include VA; gridded 12-<br>km hourly SMOKE output  |
|--|---|---|---|
|  |   | up tables by fuel-month                       |   |
| Mexico & Canada on-road mobile               | А | Annual  |   |
| (nusmb)                                      |   |   |   |
| Airport points ( <b>airpt</b> )              | Р | Annual  | Modified by UNC to include<br>stack-heights for landing-takeoff<br>sources                                      |
| SESARM point fires ( <b>sesarm_ptf</b> )     | Р | Daily   | All SESARM states except MS;<br>acres burned and fuel loadings<br>used to calculate heat flux for<br>plume rise |
| Point fires ( <b>ptfire</b> )                | Р | Daily   | MS + all non-SESARM states  |
| Offshore commercial marine ( <b>ptseca</b> ) | Р | Annual  |   |
| SESARM EGU CEM point                         | Р | Hourly  | Hourly CEM data for electricity   |
| (sesarm_ptcem_EGU)                           |   |   | generating units (EGUs)   |
| SESARM non-EGU CEM point                     | Р | Hourly  | Hourly CEM data for non-EGUs  |
| (sesarm_ptcem_nEGU)                          |   |   |   |
| SESARM EGU non-CEM point                     | Р | Annual  |   |
| (sesarm_ptncem_EGU)                          |   |   |   |
| SESARM non-EGU non-CEM point                 | Р | Annual  |   |
| (sesarm_ptncem_nEGU)                         |   |   |   |
| MANE-VU CEM point ( <b>mv_ptcem</b> )        | Р | Hourly  | Hourly CEM data   |
| MANE-VU non-CEM point                        | Р | Annual  |   |
| (mv_ptncem)                                  |   |   |   |
| US point sources ( <b>uspt</b> )             | Р | Annual  |   |
| Mexico & Canada point ( <b>nuspt</b> )       | Р | Annual  |   |

# 2.1.1.2 2018 emissions data

Collection and preparation of the SEMAP 2018 inventories followed a similar pattern to the 2007 inventories. Inventory contractors on the SEMAP project produced the anthropogenic and typical year fire inventories for the SESARM states. UNC converted the SEMAP point and non-point NIF-formatted inventories to ORL format for input to SMOKE. UNC worked with SESARM to develop an approach to project the 2007 gridded on-road emissions data to 2018 using 2018/2007 ratios provided by each of the SESARM states. The anthropogenic inventories for the non-SESARM states, Canada, and Mexico came from either Regional Planning Organizations (RPOs) or EPA in SMOKE-ready format.

The inventory sector abbreviations in Table 2-1 will be referred to in subsequent sections. Descriptions of the sources of the inventories used in the different SEMAP EMPs and details on any special processing of these sectors are included below.

# 2.1.2 SEMAP 2007 Emissions Modeling Platform

The SEMAP Base 2007 EMP presents that best emissions data to estimate year 2007 emissions available during the SEMAP project. The inventory data for the SESARM states were developed specifically for this project and include improvements over the National Emission Inventory (NEI) data for this time period. UNC used local or regional inventories to estimate emissions for the regions outside of the SESARM states and defaulted to the NEI when other data were not available. The ancillary data used for the 2007 EMP came mostly from the EPA NEI 2008 version 2, with some improvements based on local sources of information.

This section presents the details of the data that UNC collected and processed for the SEMAP 2007 EMP. Section 2.1.2.1 first presents the overall results of the 2007 EMP in terms of the annual total emissions for each of the 10 SESARM states. The subsequent sections begin with a table describing the sources, versions, and notes on the inventory data for each of the RPO regions. These sections are organized by inventory processing sector and include details on the sector and any special processing used to prepare these data for input the CMAQ model.

# 2.1.2.1 SESARM state 2007 emissions summary

The plots in this section illustrate the contribution of the different inventory processing sectors to the annual total 2007 criteria pollutant emissions in the SESARM states. The stacked bar plots show the total emissions for each pollutant by state with each segment in the stack representing a different emissions processing sector. An important detail to keep in mind when reviewing all of the annual emissions summary plots in this report is that some of the emissions sectors have strong seasonal temporal patterns that are not reflected in the annual totals. Biogenic emissions, for example, are much higher in the warmer months than the cold months. For most of the continental U.S., biogenic sources contribute a much larger fraction of the total VOC emissions during the summer than the winter. This seasonality is somewhat lost in the annual total summary plots. Details of the processing and emissions totals for each sector are provided in the subsequent sections of this report.

#### Carbon Monoxide (CO)

In the 2007 SEMAP modeling, onroad mobile is the largest source of CO emissions in all of the SESARM states except Mississippi. Secondary important regional CO sources include nonroad mobile, fires, and biogenic sources. Overall Florida, Georgia, and North Carolina are the largest regional sources of CO. The sum of the onroad mobile CO emissions in these three states accounts for over half of the CO emitted in all of the SESARM states. West Virginia is the smallest regional source of CO.

#### Nitrogen Oxides (NOx)

Onroad mobile and CEM point are the largest sources of NOx in all of the SESARM states. Other large sources of NOx include nonroad mobile, non-CEM point, and aircraft/locomotive/marine sources. Florida and Georgia are the largest regional of source of NOx. West Virginia is the smallest regional source of NOx.

#### Volatile Organic Compounds (VOCs)

Biogenic sources are the dominant VOC source in all of the SESARM states. Significant anthropogenic sources of VOC include onroad mobile, nonpoint, nonroad mobile. Florida and Georgia are the largest sources of VOC in the region. West Virginia is the smallest regional source of VOC.

#### Ammonia (NH3)

Livestock is the dominant source of NH3 in all of the SESARM states. Other significant sources of NH3 include fires, fertilizer, and onroad mobile sources. North Carolina and Georgia are the largest regional sources of NH3. West Virginia is the smallest regional source of NH3.

#### Sulfur Dioxide (SO2)

SO2 emissions are dominated by CEM point sources in all of the SESARM states. Secondary sources of SO2 include non-CEM point and nonpoint sources. Georgia and Alabama are the largest regional sources of SO2. Mississippi is the smallest regional source.

#### Particulate Matter < 2.5 µm (PM2.5)

Unlike the other pollutants, no single inventory sector is the dominant PM2.5 source throughout the region. Fires are the largest source of PM2.5 in many of the states. Fugitive dust is also a large source of PM2.5 in many states. Other significant sources of PM2.5 include non-CEM point, CEM point, nonpoint,

and onroad mobile. Georgia and Florida are the largest regional sources of PM2.5, primarily because of an active fire year in 2007. West Virginia is the smallest regional source of PM2.5.



Figure 2-2. SESARM 2007 state total CO emissions by inventory sector



Figure 2-3. SESARM 2007 state total NOx emissions by inventory sector



Figure 2-4. SESARM 2007 state total VOC emissions by inventory sector



Figure 2-5. SESARM 2007 state total NH3 emissions by inventory sector



Figure 2-6. SESARM 2007 state total SO2 emissions by inventory sector



Figure 2-7. SESARM 2007 state total PM2.5 emissions by inventory sector

| Region  | Data Source | <b>Final Version</b> | Notes                                       |
|---------|-------------|----------------------|---|
| SESARM  | TranSystems | March 2012           | NIF to ORL conversion by UNC                |
| MANE-VU | MARAMA      | Version 3.3          | Downloaded from ftp.marama.org in ORL       |
|         |             |                      | format; VA removed by UNC                   |
| MWRPO   | LADCO       | BaseCv7              | NIF to ORL conversion by UNC                |
| CENRAP  | US EPA      | NEI2008v2            | Downloaded from                             |
| WRAP    | US EPA      | NEI2008v2            | ftp://ftp.epa.gov/EmisInventory/2008dev/ in |
|         |             |                      | ORL format                                  |

#### 2.1.2.2 U.S. Nonpoint (nonpt)

The **Nonpoint (or area)** data category contains emission estimates for sources which individually are too small in magnitude or too numerous to inventory as individual point sources, and which can often be estimated more accurately as a single aggregate source for a county or tribal area. Nonpoint emissions sources are summed over a geographic region, rather than specifically located. Examples of these sources include small industrial, residential, consumer product, and agricultural emissions. Explicit nonpoint inventory sources are defined by state and county (or tribal) identifiers and source classification codes (SCCs).

# TranSystems Corporation (2012a) developed the 2007 SESARM state nonpoint inventory for the SEMAP project. UNC obtained inventories for the northeast states from MARAMA and for the Great Lakes region from LADCO. UNC used the NEI2008v2 for the rest of the states in the U.S.

The nonpoint source category includes several sub-categories that merit special attention: residential wood combustion (RWC), fugitive dust, agricultural ammonia, and nonroad mobile. UNC extracted these nonpoint source sub-categories from the regional nonpoint inventories and processed them as separate emissions categories. Details on these sub-categories are provided in the following sections.

The remaining sources in the nonpoint processing sector following extraction of the sub-categories are listed in

Table 2-2, organized by SCC Tier 2 identification codes. Table 2-18 includes the 2007 state total annual nonpoint source emissions used for the SEMAP modeling. *Note that all of the results presented in this section include only the sources listed in* Table 2-18 *and do not include RWC, fugitive dust, agricultural ammonia, or offroad mobile source emissions.* 

Figure 2-8 displays the 2007 annual state total nonpoint emissions for the 10 SESARM states. Virginia is the largest emitter of nonpoint CO in the region, contributing 16.1% of the SESARM region total, followed by Kentucky (14.8%), Georgia (13%), and Tennessee (12.6%). Virginia is the largest emitter of nonpoint NOx (18.3%) in the region, followed by North Carolina (13.1%), Kentucky (13.1%), and Tennessee (12.9%). Virginia is the largest emitter of nonpoint NH3 (19.7%) in the region followed by Georgia (19%), Tennessee (15.2%), and North Carolina (11.8%). Virginia is also the largest emitter of nonpoint SO2 (20.3%) in the region, followed by Kentucky (18.6%), Tennessee (17.2%), and Florida (12.3%). Florida is the largest emitter of nonpoint VOC (25.5%) in the region, followed by North Carolina (13%), Georgia (12.3%), and Virginia (11.3%). Tennessee is the largest emitter of PM10 (16.7%) in the region, followed by Kentucky (15.5%), Florida (13%), and South Carolina (13%). Kentucky is the largest emitter of PM2.5 (14.8%) in the region, followed by South Carolina (14%), Virginia (12.9%), and Georgia (12%).

#### Table 2-2. Tier 2 descriptions of sources in the SEMAP nonpoint processing sector

| Industrial Processes; Chemical Manufacturing: SIC 28                       |
|--|
| Industrial Processes; Fabricated Metals: SIC 34                            |
| Industrial Processes; Food and Kindred Products: SIC 20                    |
| Industrial Processes; Industrial Processes: NEC                            |
| Industrial Processes; Industrial Refrigeration                             |
| Industrial Processes; Mineral Processes: SIC 32                            |
| Industrial Processes; Mining and Quarrying: SIC 14                         |
| Industrial Processes; Oil and Gas Exploration and Production               |
| Industrial Processes; Oil and Gas Production: SIC 13                       |
| Industrial Processes;Petroleum Refining: SIC 29                            |
| Industrial Processes; Rubber/Plastics: SIC 30                              |
| Industrial Processes; Secondary Metal Production: SIC 33                   |
| Industrial Processes; Wood Products: SIC 24                                |
| Miscellaneous Area Sources: Agriculture Production - Crops                 |
| Miscellaneous Area Sources: Catastrophic/Accidental Releases               |
| Miscellaneous Area Sources: Domestic Activity                              |
| Miscellaneous Area Sources: Domestic Animals Waste Emissions               |
| Miscellaneous Area Sources: Health Services                                |
| Miscellaneous Area Sources: Humans   |
| Miscellaneous Area Sources: Miscellaneous Renair Shons                     |
| Miscellaneous Area Sources Other Combustion                                |
| Miscellaneous Area Sources Wild Animals Waste Emissions                    |
| Mobile Sources: Aircraft   |
| Solvent Utilization: Degreesing  |
| Solvent Utilization, Degreasing  |
| Solvent Utilization: Graphic Arts  |
| Solvent Utilization, Otaphic Aits  |
| Solvent Utilization, Miscellancous Non industrial: Commercial              |
| Solvent Utilization, Miscellaneous Non-Industrial. Commercial              |
| Solvent Utilization; Miscellaneous Non-Industrial: Consumer                |
| Solvent Utilization; Miscellaneous Non-Industrial: Consumer and Commercial |
| Solvent Utilization; Rubber/Plastics                                       |
| Solvent Utilization; Surface Coating                                       |
| Stationary Source Fuel Combustion;Commercial/Institutional                 |
| Stationary Source Fuel Combustion; Electric Utility                        |
| Stationary Source Fuel Combustion;Industrial                               |
| Stationary Source Fuel Combustion; Residential                             |
| Storage and Transport;Bulk Materials Storage                               |
| Storage and Transport; Organic Chemical Storage                            |
| Storage and Transport; Organic Chemical Transport                          |
| Storage and Transport; Petroleum and Petroleum Product Storage             |
| Storage and Transport; Petroleum and Petroleum Product Transport           |
| Waste Disposal, Treatment, and Recovery; Composting                        |
| Waste Disposal, Treatment, and Recovery; Landfills                         |
| Waste Disposal, Treatment, and Recovery; Leaking Underground Storage Tanks |
| Waste Disposal, Treatment, and Recovery; On-site Incineration              |
| Waste Disposal, Treatment, and Recovery; Open Burning                      |
| Waste Disposal, Treatment, and Recovery; TSDFs                             |
| Waste Disposal, Treatment, and Recovery; Wastewater Treatment              |
|  |



Figure 2-8. SESARM state annual total 2007 nonpoint source emissions; note that the VOC emissions are divided by 10 to normalize their magnitude

| Region  | Data Source | <b>Final Version</b> | Notes                                       |
|---------|-------------|----------------------|---|
| SESARM  | TranSystems | March 2012           | NIF to ORL conversion by UNC                |
| MANE-VU | MARAMA      | Version 3.3          | Downloaded from ftp.marama.org in ORL       |
|         |             |                      | format; VA removed by UNC                   |
| MWRPO   | LADCO       | BaseCv7              | NIF to ORL conversion by UNC                |
| CENRAP  | US EPA      | NEI2008v2            | Downloaded from                             |
| WRAP    | US EPA      | NEI2008v2            | ftp://ftp.epa.gov/EmisInventory/2008dev/ in |
|         |             |                      | ORL format                                  |

#### 2.1.2.3 Residential wood combustion (RWC)

The **Residential wood combustion (RWC)** data category is a subsector of the nonpoint sector and contains emission estimates for residential heating and cooking devices that use wood or wood derivatives as their primary fuel. The RWC sector includes wood stoves, fireplaces, and wood furnaces.

TranSystems Corporation (2012a) developed the 2007 SESARM state RWC inventory for the SEMAP project. UNC obtained inventories for the northeast states from MARAMA and for the Great Lakes region from LADCO. UNC used the NEI2008v2 for the rest of the states in the U.S.

UNC defined RWC sources for the SEMAP project according to Tier 3 source classification codes (SCC). UNC extracted all nonpoint sources with Tier 3 codes 2104008 (Stationary Source Fuel Combustion;Residential;Wood) and 2014009 (Stationary Source Fuel Combustion;Residential;Firelog) into the RWC processing sector and eliminated these records from the nonpoint processing sector. The 11 SCCs that make up the SEMAP RWC sector are listed in Table 2-3, including the Tier 3-4 descriptions of these sources.

| 2104008100 - Fireplace: general   |
|---|
| 2104008210 - Woodstove: fireplace inserts; non-EPA certified              |
| 2104008220 - Woodstove: fireplace inserts; EPA certified; non-catalytic   |
| 2104008230 - Woodstove: fireplace inserts; EPA certified; catalytic       |
| 2104008300 - Woodstove: freestanding, general                             |
| 2104008310 - Woodstove: freestanding, non-EPA certified                   |
| 2104008320 - Woodstove: freestanding, EPA certified, non-catalytic        |
| 2104008330 - Woodstove: freestanding, EPA certified, catalytic            |
| 2104008400 - Woodstove: pellet-fired, general (freestanding or FP insert) |
| 2104008510 - Wood; Furnace: Indoor, cordwood-fired, non-EPA certified     |
| 2104009000 - Firelog; Total: All Combustor Types                          |

Table 2-3. SEMAP RWC processing sector SCCs and Tier 3-4 descriptions

UNC simulated RWC as an explicit processing sector in SMOKE to take advantage of the temporal profile generation tool Gentpro. Gentpro uses a regression model to estimate the daily temporal variability of RWC sources as a function of daily minimum temperatures. UNC developed this approach in cooperation with U.S. EPA as an improvement over the static RWC temporal profiles, which do not reflect variations in regional or annual climate. Gentpro creates county-specific temporal profiles for converting annual RWC emissions to daily emissions (Figure 2-9). Gentpro uses a threshold of 50°F to activate RWC emissions. A day will only factor into the annual distribution of RWC emissions if the county average daily minimum temperature is at or below 50°F. The algorithm allocates more emissions to colder days. A static diurnal profile (Figure 2-10) is then applied to convert the daily emissions to hourly for input to the air quality model. Adelman et al (2010) describe the development and testing of the Gentpro RWC temporal profile model.

The program Gentpro creates a unique temporal profile for each county and SMOKE applies the countyspecific profiles to the RWC inventory sources. Figure 2-9 shows the state average RWC temporal profiles for each of the ten SESARM states. Each point plotted in the time series is an average of the daily fractions for all of the counties in the state. Note that the plot for Florida has a dependent axis scale that is 8x the scale of the rest of the states. This higher scale means that for most of the counties in Florida in 2007 the 50°F threshold was reached on relatively few days and the emissions are concentrated on those days. In the other SESARM states, where the threshold is reached more regularly, the RWC emissions are spread over a larger number of days.



Figure 2-9. SESARM state average residential wood combustion temporal profiles



Figure 2-10. RWC source diurnal temporal profile

Table 2-19 includes the 2007 state total annual RWC source emissions used for the SEMAP modeling. Figure 2-11 displays the 2007 state total RWC emissions for the 10 SESARM states. The distribution of RWC emissions is consistent across pollutants with Virginia contributing the highest emissions in the region with 18.5% of the 10-state total for all pollutants. Virginia is followed by North Carolina (15.5%), Kentucky (14.3%), and Tennessee (10.3%) as the next largest sources of regional total RWC emissions for all pollutants.



Figure 2-11. SESARM state annual total 2007 RWC source emissions; note that the CO emissions are divided by 5 to normalize their magnitude

| Region  | Data Source | <b>Final Version</b> | Notes                                       |
|---------|-------------|----------------------|---|
| SESARM  | TranSystems | March 2012           | NIF to ORL conversion by UNC                |
| MANE-VU | MARAMA      | Version 3.3          | Downloaded from ftp.marama.org in ORL       |
|         |             |                      | format; VA removed by UNC                   |
| MWRPO   | LADCO       | BaseCv7              | NIF to ORL conversion by UNC                |
| CENRAP  | US EPA      | NEI2008v2            | Downloaded from                             |
| WRAP    | US EPA      | NEI2008v2            | ftp://ftp.epa.gov/EmisInventory/2008dev/ in |
|         |             |                      | ORL format                                  |

EPA defines fugitive dust as "small particles of geological origin that are suspended into the atmosphere from non-ducted emitters (Watson et al., 2000)." This general definition includes particle emissions from wind erosion, roads, parking lots, construction sites, open pits and mines, agricultural fields, and material transfer operations. As an emissions inventory component, dust emission sources are typically accounted for as non-point sources, meaning that they are estimated as annual, state or county total emissions by source. For SEMAP, UNC defined three principal categories of dust emissions: (1) windblown dust; (2) paved and unpaved road dust; and (3) all other dust sources resulting from the mechanical disturbance of soils. The SEMAP **Fugitive Dust (fdust)** processing sector refers to the second and third categories of dust sources. Road dust sources represent particle emissions resulting from vehicles traveling on roadways or across parking lots. The road dust inventory is split between paved and unpaved roads. The third dust category above includes dust from agricultural, mining, and construction activities. Both of these categories are subsectors of the nonpoint inventory. Additional sources of dust-like particles, such as brake wear, tire wear and industrial sources, such as gypsum and cement plants, are included in the on-road mobile and point source inventory sectors.

TranSystems Corporation (2012a) developed the 2007 SESARM state fugitive dust inventory for the SEMAP project. UNC obtained inventories for the northeast states from MARAMA and for the Great Lakes region from LADCO. UNC used the NEI2008v2 for the rest of the states in the U.S.

UNC split the dust processing into two sectors: (1) **fdust** includes all states other than the MANE-VU states and (2) **fdust\_mv** includes only the MANE-VU states. It was necessary to split the dust inventories into these two processing sectors because the MANE-VU inventories include vegetative scavenging factors while the rest of the states do not. As described below, UNC applied adjustments to the dust emissions as a post process, outside of SMOKE. UNC needed to isolate the MANE-VU emissions to avoid double counting the vegetative scavenging adjustments.

Table 2-4 lists the inventory source classification codes (SCCs) included in the SEMAP road dust and fugitive dust inventories. These nonpoint sources of dust are quantified as annual, county total emissions. UNC extracted all of the SCCs in Table 2-4 from the nonpoint inventory into the fdust processing sector and eliminated these records from the nonpoint processing sector.

2275085000 - Mobile Sources; Aircraft; Unpaved Airstrips; Total 2294000000 - Mobile Sources; Paved Roads; All Paved Roads; Total: Fugitives 2296000000 - Mobile Sources; Unpaved Roads; All Unpaved Roads; Total: Fugitives 2311000000 - Industrial Processes: Construction: SIC 15 - 17; All Processes: Total 2311010000 - Industrial Processes; Construction: SIC 15 - 17; Residential; Total 2311020000 - Industrial Processes; Construction: SIC 15 - 17; Industrial/Commercial/Institutional; Total 2311030000 - Industrial Processes; Construction: SIC 15 - 17; Road Construction; Total 2325000000 - Industrial Processes; Mining and Quarrying: SIC 14; All Processes; Total 2601010000 - Waste Disposal, Treatment, and Recovery; On-site Incineration; Industrial; Total 2801000000 - Miscellaneous Area Sources; Agriculture Production - Crops; Agriculture - Crops; Total 2801000002 - Miscellaneous Area Sources; Agriculture Production - Crops; Agriculture - Crops; Planting 2801000003 - Miscellaneous Area Sources; Agriculture Production - Crops; Agriculture - Crops; Tilling 2801000005 - Miscellaneous Area Sources; Agriculture Production - Crops; Agriculture - Crops; Harvesting 2801000008 - Miscellaneous Area Sources; Agriculture Production - Crops; Agriculture - Crops; Transport 2805001000 - Miscellaneous Area Sources; Agriculture Production - Livestock; Beef cattle - finishing operations on feedlots (drylots);Dust Kicked-up by Hooves 2805001300 - Miscellaneous Area Sources; Agriculture Production - Livestock; Beef cattle - finishing operations on feedlots (drylots);Land application of manure 2805002000 - Miscellaneous Area Sources; Agriculture Production - Livestock; Beef cattle production composite; Not **Elsewhere Classified** 2805010000 - Miscellaneous Area Sources; Agriculture Production - Livestock; Dairy Operations; Total 2805018000 - Miscellaneous Area Sources; Agriculture Production - Livestock; Dairy cattle composite; Not Elsewhere Classified 2805020000 - Miscellaneous Area Sources; Agriculture Production - Livestock; Cattle and Calves Waste Emissions;Total

UNC extracted road and fugitive dust sources from the nonpoint inventory to a separate processing sectors to allow for the application of post-hoc adjustments to the dust emissions that account for two important dust emissions mitigation processes. The emissions factors for fugitive dust sources consider the parameters and conditions that produce dust emissions for different processes, such as the mechanisms of soil disturbance and the moisture and silt content of the disturbed surface. Although some fugitive dust emissions are based off of wind speeds and surface roughness, they do not explicitly include the direct effects of vegetative cover on dust scavenging and recent precipitation on dust emissions. Pace (2005) originally suggested the concept of a transportable fraction as the amount of dust that is not captured by near source removal. Pouliout et al. (2010) suggested a methodology for adjusting dust emissions following rain and snow events.

For the SEMAP modeling, UNC implemented fugitive dust reductions for both vegetative scavenging and precipitation impacts. Following the approach of Pouliot et al. (2010) UNC adjusted the fugitive and road dust emissions as a post-processing step after the emissions data were output from SMOKE. UNC used transport factors by BELD3 (Vukovich and Pierce, 2002) land cover category gridded to each of the SEMAP modeling domains to reduce the dust emissions. Vegetative scavenging factors were only applied to the **fdust** sector and not to the **fdust\_mv** sector. The BELD3 dust transport factors are available in Pouliot et al. (2010). Figure 2-12 is a plot of the fugitive dust transport multipliers on the 36-km SEMAP modeling grid. UNC multiplied the fugitive dust emissions output from SMOKE by these factors to

apply the vegetative scavenging reductions. The lower numbers in Figure 2-12 indicate larger reductions in the dust emissions.



Figure 2-12. Road and fugitive dust vegetative scavenging multipliers on the SEMAP 36km modeling domain

UNC applied precipitation adjustments to the dust emissions to account for recent rain or snow events that would mitigate dust emissions. The precipitation adjustments were applied to both the **fdust** and **fdust\_mv** sectors. Figure 2-13 illustrates an example of applying the precipitation adjustment to the dust emissions. The figure shows February 2007 total fugitive and road dust PM2.5 with and without the precipitation adjustment. The rightmost image in Figure 2-13 is a ratio of the PM2.5 emissions with and without the precipitation adjustment. The lower ratios in Figure 2-13 indicate larger reductions in the dust emissions. UNC applied the vegetative scavenging and precipitation adjustments to the dust emissions in series.



Figure 2-13. February 2007 total fugitive and road dust PM2.5; (A) is without meteorology adjustment, (B) includes meteorology adjustment, (C) is ratio of (B)/(A)

Table 2-20 (page 2-95) includes the 2007 state total annual road and fugitive dust source emissions used for the SEMAP modeling. *Note that only the MANE-VU state inventory includes vegetative scavenging factors; the rest of the state totals in* Table 2-20 *do not include any adjustments to the dust emissions. With the exception of the MANE-VU emissions, all dust emission adjustments were applied as a post-processing step to the SMOKE output files.* Figure 2-14 displays the 2007 state total emissions for the 10 SESARM states. Georgia is the largest emitter of road and fugitive dust PM10 in the region, contributing 24.7% of the SESARM region total, followed by Alabama (13.7%), Mississippi (12.6%), and Florida (12%).



Figure 2-14. SESARM state annual total 2007 road and fugitive dust source emissions; note that these values do not reflect the application of any adjustment factors

Table 2-5 lists the surrogate assignments that were used to map road dust and fugitive dust emissions to the SEMAP modeling grids.

| Inventory Sectors    | Surrogate | Surrogate Description       | Surrogate Source         |
|----------------------|-----------|-----------------------------|--------------------------|
| Paved Roads          | 240       | Total Road Miles            | US Census – TIGER (2010) |
| Unpaved Roads        | 130       | Rural Population            | US Census (2010)         |
| Construction         | 140       | Housing Change + Population | US Census (2010)         |
| Mining and Quarrying | 330       | Strip Mines/Quarries        | NLCD (1992)              |
| Livestock            | 310       | Total Agriculture           | NLCD (1992)              |
| Crop Production      | 310       | Total Agriculture           | NLCD (1992)              |

| Region  | Data Source | <b>Final Version</b> | Notes                                       |
|---------|-------------|----------------------|---|
| SESARM  | TranSystems | March 2012           | NIF to ORL conversion by UNC                |
| MANE-VU | MARAMA      | Version 3.3          | Downloaded from ftp.marama.org in ORL       |
|         |             |                      | format; VA removed by UNC                   |
| MWRPO   | LADCO       | BaseCv7              | NIF to ORL conversion by UNC                |
| CENRAP  | US EPA      | NEI2008v2            | Downloaded from                             |
| WRAP    | US EPA      | NEI2008v2            | ftp://ftp.epa.gov/EmisInventory/2008dev/ in |
|         |             |                      | ORL format                                  |

#### 2.1.2.5 Agricultural ammonia (lv and ft)

A broad category of many different types of emission sources, the nonpoint sector contains two agricultural sources that are significant emitters of NH<sub>3</sub>. **Livestock** and **fertilizer** sources are included in the nonpoint inventory and represent the majority of anthropogenic NH<sub>3</sub> emissions. As with most nonpoint sources, emissions in the agricultural NH<sub>3</sub> inventory is calculated as

$$\mathbf{E}_{i,s} = \mathbf{A}_{i,s} * \mathbf{F}_s$$

Where  $E_{i,s}$  = Emissions in county *i* for source *s* 

 $A_{i,s}$  = Activity in county *i* for source s

 $F_s$  = Emission factor for source *s* 

For livestock sources, the activity (A) is the population of a particular animal per county and the emission factor (F) is the emitted mass (kg) of NH<sub>3</sub> per animal per month. For fertilizer sources, A is the mass (kg) of fertilizer consumed per county and F is the % of N in the fertilizer volatilized as NH<sub>3</sub>. Livestock refers to domesticated animals intentionally reared for the production of food, fiber, or other goods or for the use of their labor. The definition of livestock in this category includes beef cattle, dairy cattle, ducks, geese, goats, horses, poultry, sheep, and swine. Fertilizer in this category refers to any nitrogen-based compound, or mixture containing such a compound, that is applied to land to improve plant fitness.

TranSystems Corporation (2012a) developed the 2007 SESARM state agricultural ammonia inventory for the SEMAP project. UNC obtained inventories for the northeast states from MARAMA and for the Great Lakes region from LADCO. UNC used the NEI2008v2 for the rest of the states in the U.S.

Table 2-6 lists the inventory SCC Tier 2 and 3 descriptions of the sources included in the SEMAP livestock and fertilizer inventories. These nonpoint sources of ammonia are quantified as annual, county total emissions. UNC extracted ammonia for all of the SCCs in Table 2-6 from the nonpoint inventory into the **lv** and **ft** processing sectors and eliminated these records from the nonpoint processing sector. If these SCCs included other pollutants, such as PM or VOC, they were left in the nonpoint processing sector.

| Agriculture Production - Crops; Fertilizer Application  |
|---|
| Agriculture Production - Livestock; Beef cattle - finishing operations on feedlots (drylots)              |
| Agriculture Production - Livestock; Beef cattle - finishing operations on pasture/range                   |
| Agriculture Production - Livestock; Beef cattle production composite                                      |
| Agriculture Production - Livestock;Cattle and Calves Waste Emissions                                      |
| Agriculture Production - Livestock; Dairy cattle composite  |
| Agriculture Production - Livestock;Dairy cattle - deep pit dairy  |
| Agriculture Production - Livestock;Dairy cattle - drylot/pasture dairy                                    |
| Agriculture Production - Livestock;Dairy cattle - flush dairy   |
| Agriculture Production - Livestock; Dairy cattle - scrape dairy   |
| Agriculture Production - Livestock; Dairy Operations  |
| Agriculture Production - Livestock; Goats Waste Emissions   |
| Agriculture Production - Livestock;Hog Operations   |
| Agriculture Production - Livestock; Horses and Ponies Waste Emissions                                     |
| Agriculture Production - Livestock; Poultry Operations  |
| Agriculture Production - Livestock; Poultry production - broilers   |
| Agriculture Production - Livestock; Poultry production - layers with dry manure management systems        |
| Agriculture Production - Livestock; Poultry production - layers with wet manure management systems        |
| Agriculture Production - Livestock;Poultry production - turkeys   |
| Agriculture Production - Livestock; Poultry Waste Emissions   |
| Agriculture Production - Livestock; Sheep and Lambs Waste Emissions                                       |
| Agriculture Production - Livestock; Swine production composite  |
| Agriculture Production - Livestock; Swine production - deep-pit house operations (unspecified animal age) |
| Agriculture Production - Livestock; Swine production - operations with lagoons (unspecified animal age)   |
| Agriculture Production - Livestock; Swine production - outdoor operations (unspecified animal age)        |

UNC extracted livestock and fertilizer sources from the nonpoint inventory to separate processing sectors for the purposes of explicitly tracking agricultural NH3 sources and to take advantage of the Gentpro algorithm for estimating meteorology-based hourly temporal profiles for livestock emissions. Adelman et al (2010) describe the implementation of an algorithm in Gentpro that uses county-averaged hourly temperatures and wind speeds to convert monthly livestock emissions to hourly estimates. For the SEMAP modeling UNC used state-specific temporal profiles distributed as part of the U.S EPA 2005 EMP to convert the annual inventory to monthly emission estimates. UNC then used the hourly 36 and 12-km SEMAP meteorology-based temporal profile approach is only applicable to livestock sources. UNC used static, state-specific temporal profiles from the U.S. EPA 2005 EMP to convert the annual fertilizer inventory to hourly estimates.

Table 2-21 includes the 2007 state total annual fertilizer and livestock NH3 source emissions used for the SEMAP modeling. Figure 2-15 displays the 2007 state total emissions for the 10 SESARM states. North Carolina is the largest emitter of livestock NH3 in the region, contributing 32% of the SESARM region total, followed by Georgia (15.4%), Alabama (11.5%), and Mississippi (9.6%). Kentucky is the largest emitter of fertilizer NH3 in the region, contributing 18.6% of the SESARM region total, followed by North Carolina (15.1%), Mississippi (13.1%), and Georgia (11.2%).



Figure 2-15. SESARM state annual total 2007 fertilizer and livestock source emissions

#### 2.1.2.6 Offroad mobile (nonroad)

| Region  | Data Source | <b>Final Version</b> | Notes                                       |
|---------|-------------|----------------------|---|
| SESARM  | TranSystems | March 2012           | Monthly ORL-formatted files provided by     |
|         |             |                      | TranSystems                                 |
| MANE-VU | MARAMA      | Version 3.3          | Downloaded from ftp.marama.org in ORL       |
|         |             |                      | format; VA removed by UNC                   |
| MWRPO   | LADCO       | BaseCv7              | NIF to ORL conversion by UNC                |
| CENRAP  | US EPA      | NEI2008v2            | Downloaded from                             |
| WRAP    | US EPA      | NEI2008v2            | ftp://ftp.epa.gov/EmisInventory/2008dev/ in |
|         |             |                      | ORL format                                  |

**Offroad mobile (nonroad)** source emissions result from the use of fuel in a diverse collection of vehicles and equipment that usually do not travel along paved or un-paved roadways, including vehicles and equipment in the following categories:

- Recreational vehicles, such as all-terrain vehicles, off-road motorcycles and snow mobiles;
- Logging equipment, such as chain saws;

- Agricultural equipment, such as tractors;
- Construction equipment, such as graders and back hoes;
- Industrial equipment, such as fork lifts, sweepers and cranes; and
- Residential and commercial lawn and garden equipment, such as lawn mowers and leaf and snow blowers

The NONROAD emissions model predicts emissions for almost all non-road equipment including the categories listed above. The model includes more than 80 basic and 260 specific types of non-road equipment, and further stratifies equipment types by horsepower rating. Fuel types include gasoline, diesel, compressed natural gas (CNG), and liquefied petroleum gas (LPG). NONROAD does not provide emission estimates for the airplane, locomotive and commercial marine non-road mobile source categories.

The NONROAD model estimates emissions for each specific type of non-road equipment by multiplying the following input data estimates:

• Equipment population for base year (or base year population grown to a future

year), distributed by age, power, fuel type, and application;

- Average load factor expressed as average fraction of available power;
- Available power in horsepower;
- Activity in hours of use per year; and
- Emission factor with deterioration and/or new standards.

TranSystems Corporation (2012a) developed the 2007 SESARM state nonroad mobile inventory for the SEMAP project. UNC obtained inventories for the northeast states from MARAMA and for the Great Lakes region from LADCO. UNC used the NEI2008v2 for the rest of the states in the U.S.

The SEMAP nonroad mobile processing sector includes only sectors from the NONROAD model. Table 2-7 shows the Tier 3 SCC's included in the nonroad processing sector. UNC split the aircraft, locomotive, commercial marine, pleasure craft, and airport point sources to separate processing categories. UNC combined monthly nonroad inventories for the ten SESARM states with monthly inventories for the other RPOs to create national nonroad emissions estimates for the SEMAP project. UNC developed a special nonroad temporal profile cross-reference dataset that assigns flat monthly profiles to all of the nonroad SCCs to avoid double temporalization of the emissions.

#### Table 2-7. SEMAP nonroad mobile processing sector Tier 3 SCC descriptions

| 22650020: Construction and Mining Equipment        |
|--|
| 22600030: Industrial Equipment                     |
| 22600040: Lawn and Garden Equipment                |
| 22600050: Agricultural Equipment                   |
| 22600060: Commercial Equipment                     |
| 22600070: Logging Equipment                        |
| 22650010: Recreational Equipment                   |
| 22700090 <sup>,</sup> Underground Mining Equipment |

Table 2-22 includes the 2007 state total annual nonroad source emissions used for the SEMAP modeling. Figure 2-16 displays the 2007 state total emissions for the 10 SESARM states. Florida is the largest emitter of nonroad emissions in the region, contributing about 27% of the SESARM region total nonroad emissions for all pollutants, followed by Georgia and North Carolina (13.5%), Virginia (10.0%), and Tennessee (9.0%). Figure 2-17 and Figure 2-18 show the contribution of the different Tier 3 SCCs to the annual state total NOx and VOC emissions for each SESARM states. Different sources then contribute to the total in different proportions for each state. For most SESARM states lawn and garden equipment is the largest VOC emitter in this sector. Other large sources of nonroad VOC include recreational equipment and commercial equipment.



Figure 2-16. SESARM state annual total 2007 nonroad mobile source emissions; note that the CO emissions are divided by 10 to normalize their magnitude



Figure 2-17. SESARM state annual total nonroad mobile NOx emissions by SCC Tier 3





| Region  | Data Source | <b>Final Version</b> | Notes                                       |
|---------|-------------|----------------------|---|
| SESARM  | TranSystems | March 2012           | NIF to ORL conversion by UNC                |
| MANE-VU | MARAMA      | Version 3.3          | Downloaded from ftp.marama.org in ORL       |
|         |             |                      | format; VA removed by UNC                   |
| MWRPO   | LADCO       | BaseCv7              | NIF to ORL conversion by UNC                |
| CENRAP  | US EPA      | NEI2008v2            | Downloaded from                             |
| WRAP    | US EPA      | NEI2008v2            | ftp://ftp.epa.gov/EmisInventory/2008dev/ in |
|         |             |                      | ORL format                                  |

#### 2.1.2.7 Aircraft locomotive marine (ALM)

**The Aircraft, locomotive, marine (ALM)** source emissions are a combination of on-rail locomotive, pleasure craft, and commercial marine equipment that are taken from a combination of the nonroad mobile and nonpoint (area) inventories. The aircraft emissions, including airport support equipment, have been moved out of the ALM processing category to a subsector of the point inventory called airport point sources (airpt).

TranSystems Corporation (2012a) developed the 2007 SESARM state ALM and airpt inventories for the SEMAP project. UNC obtained inventories for the northeast states from MARAMA and for the Great Lakes region from LADCO. UNC used the NEI2008v2 for the rest of the states in the U.S.

Table 2-8 lists all of the SCCs and descriptions in the SEMAP project ALM processing sector.

| 2280000000 | Mobile Sources; Marine Vessels, Commercial; All Fuels; Total, All Vessel Types        |
|------------|---|
| 2280002100 | Mobile Sources; Marine Vessels, Commercial; Diesel; Port emissions                    |
| 2280002200 | Mobile Sources; Marine Vessels, Commercial; Diesel; Underway emissions                |
| 2282005010 | Mobile Sources; Pleasure Craft; Gasoline 2-Stroke; Outboard                           |
| 2282005015 | Mobile Sources; Pleasure Craft; Gasoline 2-Stroke; Personal Water Craft               |
| 2282010005 | Mobile Sources; Pleasure Craft; Gasoline 4-Stroke; Inboard/Sterndrive                 |
| 2282020005 | Mobile Sources; Pleasure Craft; Diesel; Inboard/Sterndrive                            |
| 2282020010 | Mobile Sources;Pleasure Craft;Diesel;Outboard   |
| 2285000000 | Mobile Sources; Railroad Equipment; All Fuels; Total                                  |
| 2285002006 | Mobile Sources; Railroad Equipment; Diesel; Line Haul Locomotives: Class I Operations |
| 2285002007 | Mobile Sources; Railroad Equipment; Diesel; Line Haul Locomotives: Class II / III     |
| 2285002008 | Mobile Sources; Railroad Equipment; Diesel; Line Haul Locomotives: Passenger Trains   |
| 2285002010 | Mobile Sources; Railroad Equipment; Diesel; Yard Locomotives                          |
| 2285002015 | Mobile Sources; Railroad Equipment; Diesel; Railway Maintenance                       |
| 2285004015 | Mobile Sources; Railroad Equipment; Gasoline, 4-Stroke; Railway Maintenance           |
| 2285006015 | Mobile Sources; Railroad Equipment; LPG; Railway Maintenance                          |

#### Table 2-8. SEMAP ALM processing sector SCC descriptions

Table 2-26 includes the 2007 state total annual ALM source emissions used for the SEMAP modeling. Figure 2-19 displays the 2007 state total ALM emissions for the 10 SESARM states. Florida is the largest emitter of ALM emissions in the region, contributing about 21% of the NOx and 40% of the VOC emissions for the SESARM region ALM sources. Other large regional sources of ALM NOx include Virginia (13.3%), Alabama (11.2%), and Georgia (10.6%). The other large regional sources of ALM VOC include North Carolina (10.1%) and Alabama (8.3%). Figure 2-20 and Figure 2-21 show the contribution of the different ALM Tier 2 SCCs to the annual state total NOx and VOC emissions for each SESARM state. Commercial marine vessels are the largest NOx emitter in this sector for all SESARM states. For all states other than Florida, railroad equipment is the next largest source of ALM NOx. Pleasure craft is by far the dominant source of ALM VOC emissions, with Florida contributing 40% to the regional total pleasure craft VOC emissions.



Figure 2-19. SESARM state annual total 2007 ALM source emissions; note that the CO emissions are divided by 2 to normalize their magnitude


Figure 2-20. SESARM state annual total ALM NOx emissions by SCC Tier 2



Figure 2-21. SESARM state annual total ALM VOC emissions by SCC Tier 2

| Region       | Data Source   | Final Version           | Notes                              |
|--------------|---------------|-------------------------|------------------------------------|
| SESARM       | AMEC/Alpine   | September 11, 2011      | MOVES 2010a run in emissions       |
| (without VA) | Geophysics    |                         | factor mode                        |
| VA           | AMEC/Alpine   | February 7, 2012 EI and | MOVES 2010a run in emissions       |
|              | Geophysics/VA | September 11, 2011      | factor mode with VMT and VPOP      |
|              | DEQ           | MOVES                   | updates provided by VA DEQ         |
| MANE-VU      | MARAMA        |                         | Gridded to the OTC 36 and 12-km    |
| (without VA) |               |                         | modeling grids                     |
| MWRPO        | US EPA        | NEI2005v4               | MOVES2010a run in emissions        |
| CENRAP       | US EPA        | NEI2005v4               | inventory mode, monthly            |
| WRAP         | US EPA        | NEI2005v4               | inventories with adjustments for   |
|              |               |                         | running and start PM emissions;    |
|              |               |                         | downloaded from                    |
|              |               |                         | ftp://ftp.epa.gov/EmisInventory/20 |
|              |               |                         | 05v4/2005emis/                     |

## 2.1.2.8 Onroad mobile

The **Onroad Mobile (or onroad)** data category describes a wide variety of vehicles, engines, and equipment that under their own power can move from one location to another on paved and un-paved roads. There is a distinction between on-road sources and those sources that are non-road. On-road sources include vehicles used for the transportation of passengers or freight. Non-road sources distinguish between commercial-military marine vessels/railroad (on-rail)/aircraft and all other non-road categories (e.g., construction equipment, recreational equipment, agricultural equipment, etc.).

On-road mobile sources include light-duty vehicles, light-duty trucks, heavy-duty vehicles, buses and motorcycles used for transportation of goods and passengers on established roadways. On-road vehicles may be fueled with gasoline, diesel fuel, or alternative fuels such as alcohol or natural gas.

The Motor Vehicle Emissions Simulator (MOVES<sup>2</sup>) is EPA's current tool to construct on-road mobile source emissions estimates for national, state, and county level inventories of criteria air pollutants, greenhouse gas emissions, and some mobile source air toxics from highway vehicles (EPA, 2012a). In addition, MOVES can make projections for energy consumption (total, petroleum-based, and fossil-based). EPA requires that all new regulatory modeling use the MOVES model for mobile source emissions (EPA, 2012c).

The SEMAP on-road mobile source emission modeling was conducted using MOVES2010a. In April 2012 EPA released MOVES2010b after SESARM contractors completed their MOVES simulations. According to EPA's documentation, the primary difference between MOVES2010b and MOVES2010a is related to performance issues (e.g., computing run time) and the emission estimates produced by the two versions of MOVES are nearly identical<sup>3</sup>. EPA's technical guidance for State Implementation Plans (SIPs) and transportation conformity notes that studies that started with MOVES2010a do not have to switch to the new MOVES2010b (EPA, 2012b<sup>4</sup>).

<sup>&</sup>lt;sup>2</sup> <u>http://www.epa.gov/otaq/models/moves/index.htm</u>

<sup>&</sup>lt;sup>3</sup> <u>http://www.epa.gov/otaq/models/moves/documents/420f12014.pdf</u>

<sup>&</sup>lt;sup>4</sup> <u>http://www.epa.gov/otaq/models/moves/documents/420b12028.pdf</u>

MOVES2010a can be configured to estimates emissions directly (i.e., emissions inventory mode) or estimates emissions factors (i.e., emissions factor mode). There are two main approaches for using MOVES to generate hourly gridded speciated emission inputs needed for photochemical grid models:

- Emissions Inventory Mode (EIM): Run MOVES in emissions inventory mode using countyspecific representative hourly temperature, vehicle miles traveled (VMT) and other inputs (e.g., fleet mix and fuel type) to generate hourly, daily, monthly, or annual county-level on-road mobile source emissions. The Sparse Matrix Operator Kernel Emissions (SMOKE) emissions modeling system is then used to grid, temporalize, and speciate the county-level MOVES inventories.
- Emissions Factor Mode (EFM): Use the SMOKE-MOVES tool that accesses a MOVES emission factor lookup table using gridded hourly meteorological data and representative VMT, vehicle population (VPOP), fleet mix, fuel type, etc. for the grid cell to generate gridded hourly on-road emission estimates that are then speciated into the appropriate chemical species. The MOVES lookup table is generated by running MOVES multiple times in emissions factor mode for different temperatures, fuel types, etc.

UNC used a combination of MOVES2010a EFM and EIM simulations to estimate the 2007 base year onroad emissions for the SEMAP project. UNC used 2007 MOVES EIM results from the US EPA NEI2005v4 modeling platform for the LADCO, CENRAP, and WRAP states. These data included monthly, county-level criteria pollutant inventories and Python scripts for adjusting the start and running PM emissions based on simulated temperatures. MANE-VU provided hourly, gridded SMOKE-output emissions on the CONUS 36-km domain and the MANE-VU 12-km domain produced from an annual 2007 MOVES EFM simulation. These results did not include emissions for VA. UNC had to re-grid the 12-km MAVE-VU MOVES results to the SESARM 12-km domain. Alpine Geophysics provided annual MOVES EFM inventories, look-up tables, and MOVES meteorology inputs for all SESARM states, including VA. UNC ran these data through the SMOKE-MOVES processor to generate hourly emissions estimates for three MOVES operating modes: rate-per-distance (RPD), rate-per-vehicle (RPV), and rate-per-profile (RPP). Details of this processing are included below.

## SESARM SMOKE-MOVES Processing

UNC received year 2007 onroad mobile inventories for the 10 SESARM states that included annual, county-level total vehicle miles traveled (VMT), total vehicle population (VPOP), and average speeds. Table 2-9 lists the versions of the onroad mobile inventory files used for the SEMAP final base 2007 emissions estimates. Table 2-10 describes and lists the versions and origins of the other SMOKE-MOVES input files. Alpine Geophysics provided MOVES emissions factor lookup tables, a reference county cross-reference file (MCREF), and fuel months for each SESARM state. UNC developed the MOVES emissions process (MEPROC) file for each of the MOVES operating modes (Table 2-11). The SESARM states commented on and/or provided updates to the MOVES county speed cross-reference (SPDREF) and profile (SPDPRO) files:

- AL MOVES default county average speeds from March 2011
- FL EPA OTAQ county speed profiles
- GA State updates to the OTAQ county speed profiles
- KY EPA OTAQ county speed profiles
- MS MOVES default county average speeds from March 2011
- NC State updates to the OTAQ county speed profiles
- SC EPA OTAQ county speed profiles
- TN (Shelby County) State updates to the county average speed inventory
- TN (Rest of state) State updates to the OTAQ county speed profiles

- VA State updates to the county average speed inventory
- WV EPA OTAQ county speed profiles

| State | VPOP           | VMT            | SPEED          |
|-------|----------------|----------------|----------------|
| AL    | v1 (18Aug2011) | v1 (18Aug2011) | v1 (18Aug2011) |
| FL    | v2 (11Sep2011) | v1 (18Aug2011) | v1 (18Aug2011) |
| GA    | v1 (18Aug2011) | v1 (18Aug2011) | v1 (18Aug2011) |
| KY    | v1 (18Aug2011) | v1 (18Aug2011) | v1 (18Aug2011) |
| MS    | v1 (18Aug2011) | v2 (11Sep2011) | v2 (11Sep2011) |
| NC    | v1 (18Aug2011) | v1 (18Aug2011) | v1 (18Aug2011) |
| SC    | v1 (18Aug2011) | v1 (18Aug2011) | v1 (18Aug2011) |
| TN    | v1 (18Aug2011) | v1 (18Aug2011) | v2 (11Sep2011) |
| VA    | v3 (07Feb2012) | v3 (07Feb2012) | v3 (07Feb2012) |
| WV    | v1 (18Aug2011) | v2 (11Sep2011) | v2 (11Sep2011) |

Table 2-9. SEMAP state onroad mobile 2007 inventory versions

#### Table 2-10. SEMAP SMOKE-MOVES input files

| File       | Data Source          | Final Version | Notes   |
|------------|----------------------|---------------|---|
| EFTable    | Alpine<br>Geophysics | 31Aug2012     | MOVES2010a emissions factor tables for representative counties  |
| MCREF      | Alpine<br>Geophysics | 31Aug2012     | Representative county emissions factor cross-reference file   |
| MEPROC     | UNC                  | 05Sep2011     | MOVES emissions process table, defines<br>the pollutant emissions generated from the<br>MOVES processes |
| Fuel month | Alpine<br>Geophysics | 31Aug2012     | Representative county fuel month cross-<br>reference file   |
| SPDREF     | EPA/SESARM           | 09Dec2011     | County/SCC speed profile assignments  |
| SPDPRO     | EPA/SESARM           | 09Dec2011     | Diurnal speed profile look up table   |

| MOVES<br>Process | Mode              | Pollutants   |
|------------------|-------------------|--|
| RPD              | Exhaust (EXH)     | CO, NO, NO2, HONO, SO2, NH3, TOG,<br>VOC_INV, POC, PEC, PSO4, PNO3,<br>PMFINE, NH4, PMC          |
|                  | Evaporative (EVP) | CO, NO, NO2, HONO, SO2, NH3, TOG,<br>VOC_INV   |
|                  | Brake wear (BRK)  | PM25BRAKE, PMC   |
|                  | Tire wear (TIR)   | PM25TIRE, PMC  |
| RPP              | EVP               | TOG, VOC_INV, BENZENE  |
| RPV              | EXH               | CO, NO, NO2, HONO, SO2, NH3, TOG,<br>VOC_INV, BENZENE, POC, PEC, PSO4,<br>PNO3, PMFINE, NH4, PMC |
|                  | EVP               | CO, NO, NO2, HONO, SO2, NH3, TOG,<br>VOC_INV, BENZENE  |

Table 2-11. SEMAP SMOKE-MOVES modeled emissions processes

Table 2-24 includes the 2007 state total annual onroad mobile source emissions used for the SEMAP modeling. Note that for all of the states outside of the SESARM region the totals in Table 2-24 are derived from the gridded SMOKE output files using a GIS. UNC needed to use a post-processing GIS program to estimate the state totals for the MARAMA states because UNC didn't process these emissions through SMOKE-MOVES and received only gridded SMOKE output data from MANE-VU. UNC needed to use this GIS approach for the MWRPO, CENRAP, and WRAP states because these emissions were processed using a post-processing (post-SMOKE) program to apply temperature adjustments to the emissions. The implication of using a GIS to estimate the state totals is that there will be errors of about 1-3% in the annual state totals due to misalignments between the GIS state boundary layer and the modeling grid.

Figure 2-22 displays the 2007 state total onroad mobile emissions for the 10 SESARM states. Florida is the largest emitter of onroad mobile emissions in the region, contributing about 22% of the NOx and 23% of the VOC emissions for the SESARM region onroad sources. Other large regional sources of onroad mobile NOx include Georgia (17.6%), North Carolina (12.5%), and Tennessee (11.1%). The other large regional sources of onroad mobile VOC include Georgia (16.7%), North Carolina (14.3%), and West Virginia (10%).



Figure 2-22. SESARM state annual total 2007 onroad mobile source emissions; note that the CO emissions are divided by 5 to normalize their magnitude

| Region  | Data Source | <b>Final Version</b> | Notes                                       |
|---------|-------------|----------------------|---|
| SESARM  | AMEC        | 2007v1.10a           | NIF to ORL conversion by UNC                |
| MANE-VU | MARAMA      | Version 3.3          | Downloaded from ftp.marama.org in ORL       |
|         |             |                      | format; VA removed by UNC                   |
| MWRPO   | US EPA      | NEI2008v2            | Downloaded from                             |
| CENRAP  |             |                      | ftp://ftp.epa.gov/EmisInventory/2008dev/ in |
| WRAP    |             |                      | ORL format                                  |

2.1.2.9 EGU and Non-EGU point

The **Point** data category contains emission estimates for sources that are inventoried at specific geographic locations using latitude and longitude coordinates. While point emissions data are typically inventories of sources that emit from a stack, other discrete emissions sources, such as airports and landfills, can also be characterized as point sources. In general, point sources can be characterized as **elevated** or **low-level** sources. Elevated point sources produce emissions at elevations above the surface and are typically emitted from a smoke stack. Elevated point source inventories include stack parameters for each source (stack height, stack diameter, exit gas velocity, exit gas temperature) that are used to calculate an hourly vertical plume distribution (i.e., plume rise) for the emissions from the source. Examples of elevated point sources include power plants, smelters, and cement kilns. Low-level point sources that do not result in significant plume rise for the emissions from these sources, such as stack heights of 0. Examples of low-level point sources include wastewater treatment facilities, quarries, and landfills. For emissions modeling purposes, point sources are defined by an administrative unit (state and county (or

tribal) codes), release point (plant, stack, and unit identifier), release location (latitude and longitude coordinate), SCC codes and SIC codes.

Other ways to separate the point source inventory include by electric generating unit (EGU) versus non-EGU sources and Continuous Emission Monitoring (CEM) vs. non-CEM sources. For the SEMAP modeling UNC used these distinctions to define the point source processing sectors based on whether the sources have records in the EPA Clean Air Markets Division (CAMD) CEM database and if they're EGU or non-EGU sources. The SESARM and MANE-VU states further defined their CEM point inventories based on whether they reported emissions to CAMD on annual or ozone-season cycles.

AMEC (2013) developed the 2007 SESARM state point inventory for the SEMAP project. UNC obtained the 2007 point inventory for the northeast states from MARAMA. UNC used the NEI2008v2 for the rest of the states in the U.S.

To accommodate the different data requirements of the point source inventories used for the SEMAP project, UNC defined the following emissions processing categories:

- SESARM EGU CEM point (sesarm\_ptcem\_EGU)
  - Criteria air pollutants for EGU sources that reported to CAMD for all SESARM states, including VA
  - Includes CEM data with anomalies removed and for partial reporting units (see next section)
  - o Hourly CEM and annual point inventories normalized based on state guidance
- SESARM non-EGU CEM point (sesarm\_ptcem\_nEGU)
  - Criteria air pollutants for non-EGU sources that reported to CAMD for all SESARM states, including VA
  - Includes CEM data with anomalies removed and for partial reporting units (see next section)
  - Hourly CEM and annual point inventories normalized based on state guidance
- SESARM EGU non-CEM point (sesarm\_ptncem\_EGU)
  - Criteria air pollutants for EGU sources that did not report to CAMD for all SESARM states, including VA
- SESARM non-EGU non-CEM point (sesarm\_ptncem\_nEGU)
  - Criteria air pollutants for non-EGU sources that did not report to CAMD for all SESARM states, including VA
- MANE-VU CEM point (**mv\_ptcem**)
  - Criteria air pollutants for all MANE-VU states except VA
  - Includes CEM units that report to CAMD for 12-months of the year, 5-month (ozone season only) reporting CEM units, and 6-month reporting CEM units for sources in MD
  - o Includes 2007 hourly CEM inventories from MARAMA
- MANE-VU non-CEM point (**mv\_ptncem**)
  - Criteria air pollutants for all MANE-VU states except VA
  - Seven month non-ozone season emissions for CEM units that only report to CAMD during the ozone season

- Includes a corresponding set of temporal profiles for these sources
- US point sources (**uspt**)
  - Criteria air pollutants from the NEI08v2 for the MWRPO, CENRAP, and WRAP states, tribes, and Gulf of Mexico offshore drilling platforms
  - o Includes MANE-VU (MARAMAv3.3) sources without CEM data
  - Includes 2007 hourly CEM inventories from CAMD
  - Does not include airports (see Section 2.1.2.10 on Airport points)

Other emissions source categories that are inventoried as point sources include airports, fires, and commercial shipping. These categories are described in subsequent sections of this report.

UNC worked with Georgia Environmental Protection Division (GA EPD) to generate annual CEM inventories for sources in the SESARM states that operate annually but only report emissions to CAMD for the ozone season. UNC also developed an approach to identify and remove anomalous data points in the CAMD CEM inventories. Details of CEM data and how these data are prepared for emissions modeling are included in the next sections.

## 2.1.2.9.1 CEM anomaly corrections and gapfilling

UNC developed a methodology for blending hourly CEM data with annual inventories to ensure both internal consistency in the inventory data and accuracy in representing the temporal emissions patterns of large point sources. These methods were developed through discussions between the UNC-IE, SESARM, and the SEMAP EGU working group. All of the methods described here were applied to the final version of the SESARM "actual" 2007 point source inventory developed for the SEMAP project.

Under Part 75 of Volume 40 in the Code of Federal Regulations, CEM and reporting is required for large EGUs and industrial facilities. The U.S. EPA Clean Air Markets Division (CAMD) collects and distributes hourly CEM data for NOx and SO2 emissions (lbs/hr), heat input (mmBTU), gross load (MW), and steam load (1000 lbs/hr) for thousands of U.S. sources from the year 1995 to the present. Some units are required to report hourly emissions year-round (annual reporters), while other units are only required to report hourly emissions for part of the year (partial year reporters). To satisfy the Part 75 requirement that CEM data are reported for every operating hour that is required to report emissions, a complex process for reporting and filling in missing data has been defined. Many times, missing emissions are substituted with values that are much larger than the actual emissions that were emitted. In order to properly address the issues described above, four steps must be followed to correctly simulate the emissions from these sources.

- 1. Anomalous data points in the CEM database that resulted from the Part 75 substitution methodology must be identified and corrected.
- 2. Differences between the reported CEM emissions and annual emissions estimates reported by the states for the CEM units must be reconciled and simulated accordingly
- 3. Hourly emissions for the non-reporting periods need to be generated.
- 4. Annual NOx and SO2 inventories for CEM point sources should be reconciled with the annual total of the corrected CEM hourly data.

In some cases the Part 75 substitution methodology results in hourly emission spikes in the NOx and/or SO2 CEM data that are clearly anomalous relative to the surrounding hourly data. Figure 2-23 shows an example of anomalous SO2 emissions in the actual 2007 CEM database. UNC developed a method to

identify and replace anomalous data points in SMOKE-formatted CEM files. These corrections must be made before reconciling the CEM data with the annual emissions estimates.



Figure 2-23. Example of anomalous SO<sub>2</sub> emissions in the CEM data

UNC developed an approach to correct anomalous data points in the CEM data resulting from Part 75 substitutions. The approach was developed for SESARM and has been reviewed by EPA OAQPS and CAMD<sup>5</sup> and presented at technical conferences (Adelman et al., 2012).

Figure 2-24 and Figure 2-25 illustrate the CEM emissions for two sources that were impacted by the anomaly correction procedure. Two CEM datasets are plotted in these figures. The black line shows the original CEM data and the red line shows the corrected data after removal of the anomalous emissions. Figure 2-24 is a time series plot of the hourly CEM  $NO_X$  emissions for Dominion-Hopewell Power #2 in Virginia. The black lines seen early April in this plot are substituted data that are present in the original CEM data from CAMD. The red lines during the same period in early April are the corrected data.

<sup>&</sup>lt;sup>5</sup> <u>http://www.ie.unc.edu/cempd/projects/SEMAP/secure/documents/SEMAP\_EGU\_Modeling\_Approach\_11\_17\_20</u> 11.pdf



Figure 2-24. Virginia Dominion-Hopewell #2 2007 CEM  $NO_X$  emissions; illustration of anomalous data correction approach

Figure 2-25 is a time series plot of the hourly CEM SO<sub>2</sub> emissions for Mountaineer #1 in West Virginia. This plot shows a similar trend with the correction of anomalous emissions data in mid-February. These plots illustrate that the corrected data used to replace the anomalous emissions records for these two units is consistent with the overall magnitude of the CEM emissions during the rest of the year.



Figure 2-25. West Virginia Mountaineer #1 2007 CEM SO<sub>2</sub> emissions; illustration of anomalous data correction approach

UNC used the approach described above to identify and correct anomalies in the 2007 CAMD CEM database for the SESARM states. Table 2-12 shows for each SESARM state the total amount of anomalous NOx and SO2 emissions (tons) and heat input (HI, mmBTU) identified and removed from the 2007 CEM data. The values in parentheses in Table 2-12 are the total number of hours across the year that UNC scrubbed from the CEM data for each variable. Sources in Florida accounted for the most NOx anomalies in the SESARM region (1,777 tons and 2,291 hours), with three facilities (TAMPA ELECTIC COMPANY, FLORIDA POWER CORPDBAPROGRESS ENERGY FLA, and FLORIDA POWER & LIGHT (PSN)) contributing over 90% of these anomalies. Sources in West Virginia accounted for the most SO<sub>2</sub> anomalies in the SESARM region (2,288 tons and 453 hours), with two facilities (OHIO POWER – MITCHELL PLANT and APPALACHIAN POWER – MOUNTAINEER PLANT) contributing over 90% of these anomalies. Sources in North Carolina accounted for the most HI anomalies in the SESARM region (1,331 mmBTU and 420 hours), with two facilities (DUKE ENERGY CAROLINAS, LLC – MARSHALL ST. and PLANT ROWAN COUNTY) contributing over 90% of these anomalies.

| State | Tons NOx Anomaly (Hours) | Tons SO <sub>2</sub> Anomaly (Hours) | mmBTU HI Anomaly (Hours) |
|-------|--------------------------|--------------------------------------|--------------------------|
| AL    | 187.5 (1351)             | 31.1 (14)                            | 32.6 (69)                |
| FL    | 1777.0 (2291)            | 124.3 (233)                          | 279.0 (72)               |
| GA    | 77.3 (519)               | 2.4 (11)                             | 3.2 (4)                  |
| KY    | 132.6 (399)              | 1376.4 (271)                         | 10.8 (15)                |
| MS    | 76.3 (326)               | 284.6 (390)                          | 48.9 (106)               |
| NC    | 713.1 (1977)             | 895.3 (305)                          | 1331.4 (420)             |
| SC    | 14.3 (174)               | 3.3 (17)                             | 14.1 (38)                |
| TN    | 97.6 (728)               | 16.4 (3)                             | 0.7 (3)                  |
| VA    | 144.7 (507)              | 167.8 (416)                          | 99.2 (141)               |
| WV    | 765.9 (323)              | 2287.9 (453)                         | 0.0 (0)                  |

Table 2-12. SESARM state 2007 CEM anomaly correction summary

# 2.1.2.9.2 CEM partial year reporters

CEM sources can be classified as either full or partial reporters. In general, CEM data for full reporters contain nearly continuous hourly emissions throughout their operating year. Full reporters don't always operate for the entire calendar year, but they do report emissions continuously for the period that they operated. In general, the development of the annual point (PTINV) NO<sub>x</sub> and SO<sub>2</sub> inventories for CEM units is accomplished by summing the hourly CEM data to annual values. The CEM units are classified as partial reporters when both of the following criteria are met:

- The sum of the hourly CEM emissions is less than the annual value in the PTINV inventory
- CEM data are missing for at least one full month, including when a full month of reported CEM data have zero or null (-9) values

Identifying whether a source is a full or partial year reporter requires a comparison of the annual PTINV and CEM inventories for sources in the CEM database. Unique CEM sources are identified through a combination of the ORIS and boiler ID inventory fields. Once the CEM sources are matched with records in the PTINV file, UNC can classify the CEM sources as full or partial reporters.

After the partial reporters in the CEM database are identified, UNC used the following approach to estimate emissions for the reporting and non-reporting periods. The reporting period is defined as the period(s) for which the partial CEM reporters provide data; the non-reporting period is defined as the period(s) for which the partial CEM reporters do not provide data. Conceptually this approach will use full reporting sources to simulate the temporal patterns during the non-reporting period for the partial reporters. The details of this approach include estimating the total non-reporting period emissions for each partial reporter, identifying sources most similar to each partial reporter from the database of full reporters, estimating typical hourly emissions from these similar sources, and then using these typical hourly emissions to simulate the temporal patterns during the non-reporting period(s) for the partial reporter, eporter is provided at the temporal patterns during the non-reporting period emissions for each partial reporter, identifying sources most similar to each partial reporter from the database of full reporters, estimating typical hourly emissions from these similar sources, and then using these typical hourly emissions to simulate the temporal patterns during the non-reporting period(s) for the partial reporting CEM unit.

The first step in simulating the emissions from a particular unit for a partial reporter is to calculate the emissions for the reporting ( $E_{on}$ ) and non-reporting ( $E_{off}$ ) periods. Emissions for  $E_{on}$  are calculated by summing the hourly CEM values for the unit across the entire reporting period (Equation 1).

(Equation 1)  $E_{on} = \Sigma CEM_{hr}$ 

Emissions for  $E_{off}$  are calculated by subtracting  $E_{on}$  from the annual inventory value for a particular emissions unit (Equation 2).

(Equation 2)  $E_{off} = E_{ann} - E_{on}$ where if  $E_{off} < 0$ , then  $E_{off} = 0.0$ 

E<sub>off</sub> emissions will only be simulated under the following conditions:

- The source is partial reporter
- R > 5, where  $R = ABS(100 100*E_{on}/E_{ann})$ , and
- $E_{off} > 10 \text{ ton/yr}$

Since CEM data are available only for NOx and SO<sub>2</sub>, the CEM heat input (HI) field is used to calculate the temporal variability for the other inventory pollutants (i.e.  $PM_{2.5}$ ,  $NH_3$ , CO, etc). The heat input values for the reporting ( $HI_{on}$ ) and non-reporting ( $HI_{off}$ ) are calculated with Equations 3 and 4, respectively.

| (Equation 3) | $HI_{on} = \Sigma CEM_{hr,HI}$                                |
|--------------|---|
| (Equation 4) | $HI_{off} = HI_{on} * \Sigma HI_{off,MS} / \Sigma HI_{on,MS}$ |

The terms  $HI_{on,MS}$  and  $HI_{off,MS}$  in Equation 4 are summed total heat inputvalues for the reporting and nonreporting periods, respectively, calculated from matching sources (MS) in the same state that have similar source classification codes (SCCs). Section 6 of Adelman et al (2011) provides details on how similar sources are identified.

After calculating  $E_{on}$  and  $E_{off}$  for NO<sub>x</sub> and SO<sub>2</sub>, UNC can then use the CEM data to estimate the hourly temporal variability in the emissions. Because the partial reporters do not have CEM data for the non-reporting period, we've developed an approach for matching the partial reporters to similar full reporting CEM sources. The hourly temporal variability for these representative sources will be used to estimate the temporal profiles for the partial reporters during the non-reporting period.

UNC use a state and SCC-based matching system to identify the full reporting sources in the CEM database to use for calculating representative hourly emissions for the non-reporting periods. The code structure for an 8-digit point source SCC is:

#### (SCC Code Structure) A BB CCC DD

where, A = Tier 1, Process Type (e.g., External Combustion Boiler or Industrial Process)

- B = Tier 2, Application (e.g., Electricity Generation or Industrial)
  - C = Tier 3, Fuel (e.g., Anthracite Coal or Gasoline)
  - D = Tier 4, Technology Type (e.g., Turbine or Stoker)

After identifying the partial reporters, the ORIS and Boiler ID fields are cross-referenced to the annual PTINV inventory file to find the SCCs associated with each CEM unit. In some cases there may be multiple SCCs associated with a single ORIS and Boiler ID combination. UNC assigns the SCC to the unit that has the largest amount of emissions in the annual PTINV file. After assigning an SCC to each partial reporter in the CEM database UNC identify representative sources in the list of full reporters using the following hierarchy.

- (1) Match by State ID and Tier-4 SCC
- (2) If no match in (1), then match by State ID and Tier-3 SCC
- (3) If no match in (2), then match by State ID and Tier-2 SCC
- (4) If no match in (3), then match by State ID and Tier-1 SCC

If multiple representative sources are identified for a single partial reporting unit, the CEM data will be averaged across all of the sources for each month of the non-reporting period.

For each partial reporter in the CEM database, hourly heat input (HI) data from the group of representative sources are used to estimate the CEM emissions during the non-reporting periods. UNC calculates hourly average HI for all representative sources for the entire non-reporting period to create a single average representative source. Only valid HI fields (skip "-9") are used to in the calculation of the representative hourly HI values. Hourly emissions of NO<sub>x</sub> and SO<sub>2</sub> for the non-reporting period (CEM<sub>off,hr</sub>) are calculated using Equation 5. Equation 5 uses hourly HI from representative sources to estimate emissions on each hour of the non-reporting period. The term  $\Sigma HI_{hr,off,MS}$  in Equation 5 is the sum of the HI values from matching sources (MS) with similar SCCs for each hour of the non-reporting period; the term  $\Sigma HI_{off,MS}$  is the sum of the HI values for matching sources in the CEM database. The product of the total non-reporting period emissions (E<sub>off</sub>) and these hourly fractions produces an estimate of the hourly emissions for the non-reporting period (CEM<sub>off,hr</sub>).

(Equation 5) 
$$CEM_{off,hr,} = E_{off} * (\Sigma HI_{hr,off,MS} / \Sigma HI_{off,MS})$$

Equation 6 shows that substituting the non-reporting period emissions term in Equation 5 ( $E_{off}$ ) with total non-reporting period HI (from Equation 4) estimates non-reporting period hourly HI values to use for calculating hourly emissions for the pollutants other than NO<sub>x</sub> and SO<sub>2</sub>. Null hourly CEM records (-9) are excluded from Equations 5 and 6.

#### (Equation 6) $CEM_{off,hr} = HI_{off} * (\Sigma HI_{hr,off,MS} / \Sigma HI_{off,MS})$

The result of this step will be a SMOKE-formatted CEM file that contains hourly  $SO_2$ ,  $NO_x$ , and HI fields for the non-reporting periods for each partial reporter in the CEM database. These data will be combined with the CEM data for the reporting period to create a full set of annual CEM data for each partial reporter.

Figure 2-26 illustrates CEM emissions for a source in which hourly non-reporting period emissions were calculated using the approach described above. This plot shows two sets of data. The black line shows the CEM data after any anomalous data points were removed. The red line shows the full year CEM data that includes the hourly non-reporting period emissions. Figure 2-26 is a time series plot of CEM NOx emissions at a unit in Virginia. This unit reported an annual total of 711.10 tons of NOx and hourly CEM data for 5 months that sum to 276.87 tons. The non-reporting period emissions, calculated as the difference between the annual total and the sum of the CEM data, of 434.2 tons were distributed to the non-reporting months using hourly heat input profiles from similar sources. The red dashed line in Figure 2-26 shows the hourly emissions in the non-reporting period relative to the reporting period emissions (shows as the overlaid black and red lines). Table 2-13 shows the monthly total CEM NOx emissions before and after the distribution of the non-reporting period emissions. One feature to note in this table is that the emissions in the reporting months (May-September) are not changed by the distribution of the non-reporting period emissions were allocated to January-April and October-December, based on the heat input profiles from similar CEM sources.



Figure 2-26. Virginia Stone Container Enterprises #2 2007 CEM NOx emissions; illustration of distribution of non-reporting period data

 Table 2-13. Stone Container Enterprises #2 2007 CEM NOx emissions before and after distribution of non-reporting period data

| Month | CEM NOx before<br>distribution<br>(tons/month) | CEM NOx after<br>distribution<br>(tons/month) |
|-------|--|---|
| 1     | 0.00   | 61.40   |
| 2     | 0.00   | 68.45   |
| 3     | 0.00   | 60.93   |
| 4     | 0.00   | 52.48   |
| 5     | 16.56  | 16.56   |
| 6     | 58.86  | 58.86   |
| 7     | 62.04  | 62.04   |
| 8     | 73.25  | 73.25   |
| 9     | 66.17  | 66.17   |
| 10    | 0.00   | 67.16   |
| 11    | 0.00   | 57.99   |
| 12    | 0.00   | 65.82   |
| Total | 276.87   | 711.10  |

For both full and partial reporters, the hourly CEM data are used to directly simulate  $NO_x$  and  $SO_2$  emissions and the HI is used to estimate temporal profiles to convert the annual inventory for the other inventory pollutants to hourly emissions. Equations 7 and 8 show how the hourly CEM  $NO_x$  and  $SO_2$  emissions are modeled with SMOKE.

 $\begin{array}{ll} (Equation \ 7) & \mbox{If } {\rm CEM}_{\rm NOx,hr} \leq 0.0 \ \mbox{then } {\rm E}_{\rm hr} = 0.0 \ \mbox{for all pollutants} \\ & \mbox{If } {\rm CEM}_{\rm NOx,hr} > 0.0 \ \mbox{then } \\ & \mbox{\bf E}_{\rm NOx,hr} = ({\rm E}_{\rm NOx,SCC} / \Sigma {\rm E}_{\rm NOx,SCC}) \ ^{*} \ {\rm CEM}_{\rm NOx,hr} \ ^{*} \ \mbox{lb2ton} \\ & \mbox{Else } {\rm E}_{\rm NOx,hr} = 0.0 \end{array}$   $(Equation \ 8) \quad \mbox{If } {\rm CEM}_{\rm SO2,hr} > 0.0 \ \mbox{then } \\ & \mbox{\bf E}_{\rm SO2,hr} = ({\rm E}_{\rm SO2,SCC} / \Sigma {\rm E}_{\rm SO2,SCC}) \ ^{*} \ \mbox{CEM}_{\rm SO2,hr} \ ^{*} \ \mbox{lb2ton} \\ & \mbox{Else } {\rm E}_{\rm SO2,hr} = 0.0 \end{array}$   $(Equation \ 8) \quad \mbox{If } {\rm CEM}_{\rm SO2,hr} = 0.0 \\ & \mbox{where, } \ \ \mbox{CEM}_{\rm NOx,hr} = hourly \ \ \mbox{CEM } \ \ \ NO_x \ \ \ \ \ mbox{emissions at hour } hr \end{array}$ 

where,  $CEM_{NOx,hr}$  = hourly CEM NO<sub>x</sub> emissions at hour *hr*   $CEM_{SO2,hr}$  = hourly CEM SO<sub>2</sub> emissions at hour *hr*   $E_{NOx,SCC}$  = Annual NO<sub>x</sub> emissions for a particular SCC at the CEM unit from the annual inventory file (PTINV)

 $E_{SO2,SCC}$  = Annual SO<sub>2</sub> emissions for a particular SCC at the CEM unit from the annual inventory file (PTINV) lb2ton = 0.0005 short tons/lb

For the other inventory pollutants (i.e., VOC, NH<sub>3</sub>, PM<sub>2.5</sub>, PM<sub>10</sub>, CO) at units with CEM data, the hourly emissions fraction derived from the CEM heat input data will be used to allocate the annual emissions to the hourly estimates required for air quality modeling. Equation 9 shows how the hourly emissions will be calculated for the other inventory pollutants.

(Equation 9)  $E_{hr} = F_{hr} * E_{ann}$ If  $HI_{hr} > 0.0$ , then  $F_{hr} = HI_{hr}/\Sigma HI_{hr}$ If  $HI_{hr} = 0.0$ , then  $E_{hr} = 0.0$  for all pollutants where,  $HI_{hr} =$  hourly heat input value from CEM  $F_{hr} =$  fraction of emissions at hour hr

 $E_{hr} = Emissions$  at hour *hr*.

After calculating  $CEM_{off,hr}$  for the partial reporters, loop over all the sources and scale the CEM emissions so that the annual total CEM emissions are equal to the annual PTINV values for each unique CEM source (Equation 10). This scaling only applies to  $NO_x$  and  $SO_2$ . If the annual CEM value equals the annual PTINV value, the scaling factor will be 1.0.

(Equation 10)  $S_{CEM_{hr}} = CEM_{hr} * (E_{ann}/\Sigma CEM_{hr})$ where, S CEM = scaled hourly NO<sub>x</sub> and SO<sub>2</sub> CEM data

## 2.1.2.9.3 Point source emissions results

Table 2-25 includes the 2007 state total annual point source emissions used for the SEMAP modeling. These totals are the sum of the CEM and non-CEM point inventories and represent the total stationary point source emissions used for the SEMAP 2007 modeling.

Figure 2-27 and Figure 2-28 display the 2007 state total non-CEM and CEM point source emissions for the 10 SESARM states. Alabama is the largest source of non-CEM point NOx emissions in the region, contributing about 17.4% of the NOx emissions for the SESARM region non-CEM point sources. Other large regional sources of non-CEM point source NOx include Florida (12.6%), Mississippi (11.7%), and Georgia (10.7%). Alabama is also the largest source of non-CEM point SO<sub>2</sub> (16.5%), followed by Florida (15%), Georgia (11.6%), and North Carolina (11.6%). North Carolina is the largest source of non-CEM point VOC (13.4%), followed by Tennessee (13.3%), Kentucky (13.1%), and Alabama (10.7%). Florida is the largest sources of CEM NOx emissions in the region contributing 16.8% of the regional total NOx emissions for this sector. Other large sources of CEM source NOx in the region include Kentucky (16.1%), West Virginia (14.3%), and Alabama (11.5%). Georgia is the largest source of CEM point SO<sub>2</sub> emissions (19.4%), followed by Alabama (14%), West Virginia (12%), and Kentucky (11.5%), and North Carolina (11.4%).



Figure 2-27. SESARM state annual total 2007 non-CEM point source emissions



Figure 2-28. SESARM state annual total 2007 CEM point source emissions; note that the NOx emissions are divided by 2 and the SO2 emissions are divided by 5 to normalize their magnitudes.

| Region  | Data Source | <b>Final Version</b> | Notes  |
|---------|-------------|----------------------|--|
| SESARM  | TranSystems | March 2012           | NIF to ORL conversion by UNC; stack<br>parameters for aircraft based on FAA EDMS<br>airport data |
| MANE-VU | N/A         | N/A                  | The MANE-VU airport inventory is part of the non-point ALM sector                                |
| MWRPO   |             |                      | Downloaded from  |
| CENRAP  | US EPA      | NEI2008v2            | ftp://ftp.epa.gov/EmisInventory/2008dev/ in  |
| WRAP    |             |                      | ORL format   |

2.1.2.10 Airport points (airpt)

The airport point processing sector (**airpt**) is a subset of the ALM sector. It includes airport ground support equipment and aircraft in their landing/takeoff (LTO) cycles, up to 3,000 feet. The inventory for the airpt sources used for the SEMAP project is a point inventory, with latitude-longitude coordinates used to locate these sources on the modeling grid. Only the MANE-VU states are missing from this processing sector; the airport sources for MANE-VU are nonpoint sources and are contained in the ALM processing sector. UNC separated the SEMAP airpt sources from both the ALM and other point sectors to distinguish it as a point source nonroad mobile sector and to apply vertical profiles to the airports in the SESARM states.

TranSystems Corporation (2012a) developed the 2007 SESARM state airport point inventory for the SEMAP project. MARAMA included the airport sources, including LTO aircraft, in their nonpoint ALM inventory. UNC used the NEI2008v2 for the rest of the states in the U.S.

The airport point inventory was developed as a two-dimensional dataset with latitude-longitude coordinates and no stack information to support allocation of the emissions to the vertical layers. To properly model the aircraft component of the airport inventories, which represent emissions from the ground up to 3,000 feet, it was necessary to add vertical profiles to the inventory data before processing them using SMOKE. UNC developed an approach to add a vertical distribution to the aircraft SCCs in the airpt sector by adding stack heights for these sources. For the ground support equipment UNC imposed stack heights of 2.0 meters, effectively putting these emissions in the surface layer. For the aircraft SCCs, UNC used airport profile data associated with the Federal Aviation Administration (FAA) Emissions and Dispersion Modeling System (EDMS)<sup>6</sup> to distribute the emissions to different heights. UNC developed pollutant-specific vertical profiles for the 100 airports in the EDMS database. As the EDMS database only contains data for the 100 largest airports in the U.S., UNC had to create a generic "small airport" vertical profile to apply to the airports in the SEMAP inventory that didn't have matches in the database. UNC created this small airport profile as an average of the vertical profiles for all airports in the 4<sup>th</sup> guartile of column total CO emissions in the EDMS database. UNC then used the vertical profiles for the airports that had exact matches between the EDMS database and SEMAP inventory to create stack parameters for the airports in the SESARM states. UNC used the average small airport vertical profile to create stack parameters for the airports in the SEMAP inventory that didn't have exact matches in the EDMS database. UNC only added vertical distributions to the airports in the SESARM states; the airport inventory for the rest of the country was simulated as low-level (surface) point sources.

Figure 2-29 illustrates two example airport vertical profiles used for the SEMAP airpt inventory. The figure on the left shows the pollutant-specific vertical profile for the Atlanta Jackson-Hartsfield airport and the figure on the right shows the profile for the generic small airport. Both plots show that the majority of the LTO aircraft CO, VOC, and SO2 emissions occur below 40 feet. The NOx and PM2.5 emissions also peak below 40 feet, they are also significant sources aloft.



# Figure 2-29. Atlanta Jackson-Hartsfield (L) and average small airport (R) pollutant-specific vertical emissions profiles

Table 2-26 includes the 2007 state total annual airport point source emissions used for the SEMAP modeling. This table does not include the airport emissions in the MANE-VU states because these are contained in the nonpoint ALM sector.

Figure 2-30 displays the 2007 state total airport point source emissions for the 10 SESARM states. Florida is the largest source of airport emissions in the region, contributing about 37% of the airport NOx

<sup>&</sup>lt;sup>6</sup> <u>http://www.faa.gov/about/office\_org/headquarters\_offices/apl/research/models/edms\_model/</u>

emissions and 27% of the airport VOC emissions for the SESARM region. Virginia, Georgia, and North Carolina are also significant regional sources of airport emissions.



Figure 2-30. SESARM state annual total 2007 airport point source emissions

## 2.1.2.11 C2/C3 Commerical Marine (ptseca)

| Region   | Data Source | <b>Final Version</b> | Notes                                       |
|----------|-------------|----------------------|---|
| US and   | US EPA      | NEI2005v4.1          | In-port, near and offshore elevated sources |
| offshore |             |                      |   |

Large ships, such as container ships, tankers, bulk carriers and cruise ships, are significant contributors to air pollution in many of our nation's cities and ports. There are two types of diesel engines used on large ships: main propulsion and auxiliary engines. The main propulsion engines on most large ships are "Category 3" marine diesel engines, which can stand over three stories tall and run the length of two school buses. Auxiliary engines on large ships typically range in size from small portable generators to locomotive-size engines.

To account for these emissions, a separate set of SMOKE input files was developed for the 2005 NEIv4.1. Based on earlier 1996 and 2002 inventories, the current 2005 inventory was developed by ICF International<sup>7</sup> combining updated port and maneuvering estimation methods. These estimates are combined with detailed spatial information regarding port locations and shipping lanes. The sulfur emission control area point source (**ptseca**) emissions processing category includes shipping sources in-

<sup>&</sup>lt;sup>7</sup> <u>ftp://ftp.epa.gov/EmisInventory/2005\_nei/mobile/commercial\_marine\_vessels\_2002\_and\_2005.pdf</u>

port, near shore, and in commercial shipping lanes. These emissions are developed and carried as point sources, rather than the area-level files generally used for off-road mobiles sources, including marine emissions sources. Using the point source format allows for: (1) detailed location information for the emissions, rather than use of generalized spatial allocation profiles; and (2) processing of the emissions as elevated sources, rather than distributing all of Class 2/3 marine emissions into the lowest level of the model.

Details on the Off-Shore Shipping emissions are provided in a report "Documentation for the Commercial Marine Vessel Component of the National Emissions Inventory – Methodology" prepared by Eastern Research Group<sup>8</sup> dated March 30, 2010. It should be noted that the Off Shore Shipping emissions category discussed here only includes the Class 2 and 3 Commercial Marine source. Smaller vessels (Class 1) are included with the nonroad source processing sector.

The C2/C3 emissions estimates for the SESARM states are included in the ALM processing sector described in Section 2.1.2.7. The ptseca processing sector described here includes only emissions for inport sources outside of the SESARM region and for near and off-shore sources around the continental U.S. and Canada.

Table 2-28 shows the annual total near and offshore emissions for the commercial shipping sector. The state total emissions represent the in-port emissions, the near shore emissions are between 0-0.5 km from port, and the Sulfur Emissions Control Area (SECA) emissions are the offshore sources in commercial shipping lanes.

| Region      | Data Source | <b>Final Version</b> | Notes                                    |
|-------------|-------------|----------------------|--|
| SESARM      | AMEC        | July 2011            | NIF to ORL-fire conversion by UNC; daily |
| (except MS) |             |                      | inventories do not include MS            |
| MS          |             |                      |  |
| MANE-VU     |             |                      | SMADTEIDEr 1 downloaded from             |
| MWRPO       | US EPA      | 2007aq_07c           | SMARTFIREVI downloaded from              |
| CENRAP      |             |                      | <u>np.epa.gov</u> in OKL-me format       |
| WRAP        |             |                      |  |

# 2.1.2.12 Fires (sesarm\_ptf and ptfire)

Fires are significant local and regional sources of ozone precursor and PM emissions. The plumes from large fires can rise several kilometers high and travel hundreds of kilometers down wind. Inventories with high spatial and temporal resolution are required to capture the spatial heterogeneity and episodic nature of fire emissions. Contemporary fire inventory methods track these data as point sources, typically with either daily or hourly temporal resolution. SESARM provided daily point source fire inventories for all SESARM states other than Mississippi. UNC converted the NIF-formatted fire data to ORL-fire format for input to the SMOKE processor.

The **sesarm\_ptf** processing sector includes all of the 2007 prescribed and wildfires for nine of the SESARM states. AMEC developed the 2007 SESARM state (excluding Mississippi) fire inventory for the SEMAP project. UNC used the SMARTFIREv1 (SF1) 2007 inventory available from the EPA to represent fires in Mississippi and the rest of the U.S. outside of the SESARM region. The **ptfire** processing sector includes the SF1 inventories outside of the SESARM states. All of the fire inventories used for the SEMAP project include daily fire emissions. The SESARM inventories also include daily fuel loads and acres burned for each fire event while the SF1 inventories include daily heat flux and acres

<sup>&</sup>lt;sup>8</sup> <u>http://www.epa.gov/ttn/chief/net/nei08\_alm\_popup.html</u>

burned for each fire. The fuel loads, acres burned, and heat flux information is used by SMOKE to estimate plume rise for the fires and to distribute these emissions to the vertical model layers. To convert the daily fire emissions to hourly estimates, UNC applied the generic diurnal profile shown in Figure 2-31 to all fire emissions in the SEMAP project.



Figure 2-31. Diurnal distribution of the fire emissions used for the SEMAP modeling

Table 2-27 includes the 2007 state total annual fire source emissions used for the SEMAP modeling. This table includes the annual emissions for both the SEMAP and SF1 inventories used for this project.

Figure 2-32 displays the 2007 state total fire source emissions for the 10 SESARM states. In 2007, Georgia was the largest source of fire emissions in the region, contributing about 43% of the fire NOx emissions and 40% of the fire PM10 emissions for the SESARM region. Florida was the next largest source of fire emissions in the region in 2007 followed by Mississippi. Although Mississippi was the third highest source of fire CO, NOx, and PM emissions, it was the largest source of VOC emissions (48.5%) in the region. This disconnect in the VOC emissions for Mississippi relative to the rest of the SESARM states is likely due to the differences in inventory methodology between the SESARM and SF1 inventories.



Figure 2-32. SESARM state annual total 2007 fire emissions; note that the CO emissions are divided by 5 to normalize their magnitude

| Data      | Data Source | <b>Final Version</b> | Notes   |  |
|-----------|-------------|----------------------|---|--|
| Landcover | US EPA      | BELD3                | BELD3 tiles gridded to the SEMAP modeling domains |  |
| Emission  | US EPA      | Version 3.14         |   |  |
| Factors   |             | (14May2008)          |   |  |

2.1.2.13 Biogenic

Emissions from vegetation, mostly from the leaves of plants, are the largest source of volatile organic compounds (VOC) in the global atmosphere, although VOC emissions from cars, factories and fires dominate in urban and industrial areas. In the atmosphere, the oxidation of VOC can influence aerosol particles, precipitation acidity, and regional ozone distributions. Accurate predictions of biogenic VOC emissions are important for developing regulatory ozone and aerosol control strategies for at least some rural and urban areas. One of the great challenges associated with characterizing biogenic VOC (BVOC) is the large variety of compounds involved. Isoprene is the single most important BVOC with an emission that is about half of the global BVOC emission and is highly reactive so can be an important component of ozone formation. Many monoterpenes have been observed in the atmosphere but only a few, such as  $\alpha$ pinene, make a significant contribution to the global total emissions. The dominant sesquiterpenes, such as  $\beta$ -caryophyllene, have lifetimes of only minutes in the atmosphere and so are present at very low levels, but their reaction products may be an important source of secondary organic aerosol (SOA). Oxygenated BVOC include a wide range of alcohols, aldehydes, ketones, acids, ethers, and esters but are dominated by relatively low molecular weight compounds such as methanol, acetaldehyde and acetone. Other BVOC include alkanes (e.g., heptane), alkenes (e.g., ethene), aromatic hydrocarbons (e.g., toluene), sulfur compounds (e.g., dimethyl sulfide), and nitrogen compounds (e.g., hydrogen cyanide).

Observations of land–atmosphere interactions must include not only primary emissions but also the larger number of reaction products that impact atmospheric oxidants and particle formation and growth.

Soil emissions of nitric oxide (NO) are also treated by biogenic emissions models. Investigations

of NO emission from soils began in the 1960s with agronomists that were interested in the fate of fertilizer applied to soil, but the amount lost to the atmosphere was a relatively small part (a few percent) of the total fertilizer applied. NO emissions were later observed from unfertilized landscapes and it was recognized that this could be an important source of atmospheric NO in some regions. Early studies of the microbial and ecological processes and environmental controls over NO emissions led to what has been called the "hole-in-the-pipe" model, which conceptualizes NO emission regulation at two levels: (1) the rate of nitrogen cycling (the amount of nitrogen flowing through the pipe); and (2) factors influencing the ability of NO to escape from the soil into the atmosphere (the hole in the pipe). The nitrogen cycling includes two components: (1) nitrification (converting NH4 to NO3; and (2) denitrification (converting NO3 to N2). Nitrification is considered the main source of NO emission. Fertilizer, atmospheric nitrogen deposition, leaf litter, soil temperature and perhaps other factors can influence the rate of nitrogen cycling in the soil while soil properties and water content and perhaps other factors influence the amount that can leak into the atmosphere. Although NO emissions have been observed from a wide range of landscapes under various conditions, the implementation in regional to global models has been relatively simple due to the lack of suitable databases for scaling observations to regional scales.

For the SEMAP project, UNC tested both the Model of Emissions of Gases and Aerosols from Nature version 2.04 (MEGAN) and the Biogenic Emission Inventory System version 3 (BEIS3) to estimate emissions for the SESARM states. Based on the work of Hogrefe et al (2011) SESARM instructed UNC that the BEIS3 model was more appropriate for the southeast U.S. UNC regridded the BELD3 land use database to the SEMAP modeling grids using the Spatial Allocator and used version 3.14 of BEIS emission factors to estimate biogenic emissions for the SEMAP modeling.

Table 2-29 includes the 2007 state total annual biogenic source emissions used for the SEMAP modeling. This table includes annual emissions for all states in the CONUS 36-km modeling domain. Figure 2-33 displays the 2007 state total biogenic source emissions for the 10 SESARM states. In 2007, Georgia was the largest source of biogenic VOCs in the region (16.7%), followed by Alabama (15%), Florida (14.6%), and Mississippi (13.2%). Florida was the largest regional source of biogenic NO (26.3%), followed by Georgia (13.6%), Mississippi (10.4%), and Kentucky (9.7%). Florida is also the largest regional source of biogenic CO (17.4%), followed by Georgia (15.7%), Alabama (13.5%), and Mississippi (12.3%).



Figure 2-33. SESARM state annual total 2007 biogenic emissions

## 2.1.2.14 Canada and Mexico

| Region | Data Source        | <b>Final Version</b> | Notes                              |
|--------|--------------------|----------------------|------------------------------------|
| Canada | Environment Canada | 2006                 |                                    |
| Mexico | INE and ERG, Inc.  | 2008                 | Mexico National Emission Inventory |
|        |                    |                      | projected from 1999 to 2008        |

The SEMAP 2007 base case emissions for Canada are based on a 2006 emissions inventory from Environment Canada (EC). This national inventory contains provincial-level emissions for all source categories. The EC 2006 inventory is based on Canada's National Pollutant Release Inventory (NPRI<sup>9</sup>) for 2006. The database files are in SMOKE-ready ORL format. The database provides annual emissions of seven criteria air pollutants (CAPs): VOC, CO, NO<sub>x</sub>, PM<sub>10</sub>, PM<sub>2.5</sub>, SO<sub>2</sub>, and NH<sub>3</sub> for all of Canada. The EC 2006 CAP stationary point source inventory includes a separate file for speciated VOC emissions (Carbon Bond CB05 chemical species). The EC inventory also includes stationary area, mobile and upstream oil and gas point source emissions, as they include upset and accidental releases, the EC inventory is considered the most updated Canadian national inventory. EC applied a fugitive dust transport factor (FDTF) to account for fugitive dust emissions that are deposited locally and so are not transported downwind. More specifically, particulate matter (PM) dust emissions for road dust, construction and agriculture were reduced by 75% in the EC 2006 emissions inventory (i.e., a 0.25 FDTF).

<sup>&</sup>lt;sup>9</sup> <u>http://www.ec.gc.ca/inrp-npri/default.asp?lang=En&n=4A577BB9-1</u>

The EC 2006 inventory is based on the NPRI inventory so the documentation is on the NPRI website<sup>15</sup> which also has summary emissions for all of Canada<sup>10</sup>. The EC 2006 emissions inventory was processed by the SMOKE emissions model in three batches: (1) elevated point source; (2) on-road mobile sources; and (3) area sources, which also included non-road mobile sources. Temporal allocation of the annual EC inventory to month, day-of-week and hour-of-day used U.S. EPA profiles and assignments by inventory Source Classification Codes (SCC). Spatial aggregation of the Provincial area and mobile sources to the 36/12 km modeling domains was also based on SCCs using spatial surrogate distributions from the EC. Chemical speciation for the area and mobile sources was also based on SCCs. However, as noted above, the Canadian point sources in the EC 2006 emissions database were already speciated into the CB05 chemical species used by the photochemical grid models (PGMs).

Many of the Canadian point sources were classified using the same miscellaneous SCC code in order to keep the confidentiality of the process of the point source. This makes it difficult to isolate specific types of point sources (e.g., coal-fired power plants) and results in the application of flat temporal allocation profiles (i.e. the emissions don't change from month-to-month, day-to-day, or hour-to-hour). Table 2-14 shows the annual pollutant totals in the 36-km CONUS modeling domain for the Canadian inventory sectors.

| Sector | СО      | NOx     | VOC     | NH3    | SO2     | PM10    | PM2_5  |
|--------|---------|---------|---------|--------|---------|---------|--------|
| Area   | 1270565 | 857750  | 447490  | 21170  | 1664035 | 117165  | 68620  |
| Mobile | 4403725 | 524870  | 270830  | 21170  | 5475    | 14600   | 10220  |
| Point  | 3794540 | 733285  | 1282245 | 546040 | 94900   | 1665130 | 432160 |
| Total  | 9468830 | 2115905 | 2000565 | 588380 | 1764410 | 1796895 | 511000 |

Table 2-14. SEMAP 2007 Canada emissions in the 36-km CONUS domain (TPY)

For Mexico, the SEMAP 2007 modeling used year 2008 projections off of the 1999 Mexican National Emission Inventory (MNEI) to represent anthropogenic emissions sources for Mexico. The 1999 MNEI was finalized in the year 2006 and represented a joint effort between U.S. and Mexican government agencies.<sup>11</sup> The MNEI includes annual estimates of NO<sub>X</sub>, SO<sub>X</sub>, VOC, PM<sub>10</sub>, PM<sub>2.5</sub>, and NH<sub>3</sub> emissions for the entire country of Mexico at the municipality level from point, non-point/area, on-road mobile, off-road mobile and natural sources. As the first national-scale inventory for Mexico, the 1999 MNEI was designed to meet the following objectives:

• Comply with the Mexican Federal Environmental Law mandate to integrate and update a National Emissions Inventory for Mexico;

<sup>&</sup>lt;sup>10</sup> http://www.ec.gc.ca/pdb/websol/emissions/2006/2006\_canada\_e.cfm

<sup>&</sup>lt;sup>11</sup> <u>http://www.epa.gov/ttn/chief/net/mexico/1999\_mexico\_nei\_final\_report.pdf</u>

- Promote Mexican institutional capacity-building to compile, maintain, and update emissions inventories;
- Provide a technical basis for improved air quality and health impact analyses in Mexico and the U.S.;
- Assist with regional haze requirements in the U.S.; and
- Support the development of a tri-national emissions inventory of criteria pollutants for Mexico, the U.S. and Canada.

The year 1999 was selected as the inventory year because of data accessibility within Mexican government agencies and to correspond with the U.S. EPA triennial national emissions inventory (NEI) cycle. While the 1999 MNEI represented a significant improvement over previous emissions estimates for Mexico, there were several opportunities to improve the quality of the data and to increase the quantity of data used to estimate the emissions.

In the year 2009, the Western Governors' Association sponsored Eastern Research Group, Inc. (ERG) to project the 1999 MNEI to 2008, 2012, and 2030.<sup>12</sup> This work was used to support research at the National Institute of Ecology in Mexico and the National Renewable Energy Laboratory in the U.S. Continuing with the same spatial coverage (national, municipality-level) and pollutants in the 1999 MNEI, ERG derived growth and control factors from various sources of historical economic indicators and emissions trends and from forecasts of energy use, technology changes, and economic changes.

In the summary of the projections trends for the 1999 MNEI, ERG states the following:

"In general, the emissions from point sources, area sources, and non-road mobile sources are projected to increase in future years relative to the 1999 base year. The projection factors for these source types are primarily driven by population growth, growth in gross domestic product (GDP), and fuel growth. There are also a few source categories with decreasing emissions (i.e., area source  $SO_2$ ,  $PM_{10}$ , and  $PM_{2.5}$ ); these are due to projected decreases in certain fuel types and uses (e.g., commercial combustion of residual fuel oil and residential wood combustion). On-road motor vehicle  $NO_X$ ,  $SO_2$ , VOC, and CO emissions are projected to decrease in future years relative to the 1999 base year, while  $PM_{10}$ ,  $PM_{2.5}$ , and  $NH_3$  emissions increase. Although the demand for motor vehicle fuel will increase in the future, the decreases in  $NO_X$ ,  $SO_2$ , VOC, and CO emissions are due to effects of new control technologies that are gradually incorporated into the overall vehicle fleet due to turnover, as well as low sulfur fuels. Because new motor vehicle standards are not being implemented for  $PM_{10}$ ,  $PM_{2.5}$ , and  $NH_3$ , emissions are projected to increase in the future for these pollutants."

The 2008 MNEI was prepared for air quality modeling with the SMOKE emissions processor for area/non-point and off-road mobile sources, stationary point sources, and on-road mobile sources. Emissions from the active volcanoes in Mexico were not included in the SEMAP inventory because year 2008 data were not readily available for these sources. Temporal allocation of the MNEI annual inventories to month, day-of-week and hour-of-day used U.S. EPA profiles and assignments based on inventory Source Classification Codes (SCC). Spatial

<sup>&</sup>lt;sup>12</sup> http://www.wrapair.org/forums/ef/inventories/MNEI/2018\_Mexico/2009-01\_Mexico\_Projections\_2008-2012-2030\_Final\_Report\_01-09.pdf

distribution of the municipality non-point and mobile sources to the 36/12 km modeling domains was also based on SCCs using spatial surrogate distributions provided by the Mexican National Institute of Ecology. Chemical speciation for the MNEI was also based on speciation profiles and SCC assignments from the U.S. EPA.

Table 2-15 shows the annual pollutant totals in the 36-km CONUS modeling domain for the Mexican inventory sectors.

| Sector | СО      | NOx    | VOC     | NH3    | SO2     | PM10   | PM2_5  |
|--------|---------|--------|---------|--------|---------|--------|--------|
| Area   | 127020  | 375950 | 150015  | 0      | 968345  | 154395 | 107310 |
| Mobile | 907025  | 125560 | 129575  | 4015   | 8395    | 10585  | 9855   |
| Point  | 881475  | 292730 | 746425  | 285795 | 66430   | 168265 | 109865 |
| Total  | 1915520 | 794240 | 1026015 | 289810 | 1043170 | 333245 | 227030 |

Table 2-15. SEMAP 2007 Mexico emissions in the 36-km CONUS domain (TPY)

# 2.1.2.15 Ancillary data

Most of the ancillary data used to simulation emissions for the SEMAP project came from the EPA. The EPA's 2008 National Emissions Inventory version 2 (NEI08v2) EMP<sup>13</sup> was the primary source of the spatial, temporal and speciation data used for the SEMAP project. Source-specific improvements were made to these data; particularly the temporal profiles for the livestock and residential wood combustion sectors. UNC used the SMOKE program GenTPRO to estimate meteorology-dependent temporal variability for livestock and residential wood combustion sources for all of the SEMAP EMPs.

For air quality modeling studies prior to 2012, EPA used geospatial data primarily from the year 2000 and earlier for estimating the spatial surrogates that characterize the spatial distribution of non-point anthropogenic emissions sources. In November 2011 UNC initiated updates to the spatial surrogate and Shapefile database used by the EPA Office of Air Quality Planning and Standards for emissions modeling. By July 2012 many of the original surrogates were updated with weight Shapefiles that reflected North American geospatial data collected since the year 2006. UNC used these updated surrogates for the SEMAP project. Table 2-16 shows the vintage of the surrogate classes used for the SEMAP modeling (shown as the Current Year).

<sup>&</sup>lt;sup>13</sup> <u>http://www.epa.gov/ttn/chief/emch/index.html - 2008</u>

| Shapefile                       | Surrogates | Current Year | <b>Previous Year</b> |
|---------------------------------|------------|--------------|----------------------|
| Population and Housing          | 100-140    | 2010         | 2000                 |
| Home Heating                    | 150-165    | 2005-2010    | 2000                 |
| Road and Rail                   | 200-280    | 2010         | 2000                 |
| Land-use/Land Cover             | 300-350    | 2006         | 1992                 |
| Building Square Footage         | 500-595    | 2000-2006    | 1990                 |
| Gas Stations and oil & gas      | 600-699    | 2008-2011    | 2000                 |
| Shipping                        | 800-820    | 2010         | 1999-2003            |
| Other industrial and commercial | 850-890    | 2010         | 2000                 |

Table 2-16. SEMAP spatial surrogate data

# 2.1.3 SEMAP Typical 2007 Modeling Platform

The SEMAP Typical 2007 EMP differs from the Base 2007 EMP only in the fire inventories. The rest of the anthropogenic and natural emissions data for the SEMAP Typical 2007 simulation are exactly the same as in the Base 2007 simulation. The purpose of the Typical emissions estimates is to construct a baseline against which future year emissions can be compared. Typical year fire inventories smooth the episodic nature of fire emissions by averaging the emissions across multiple years.

This section present the details of how UNC developed the SEMAP typical year fire emissions, including the testing and analysis of different fire inventories.

Region **Final Version Data Source** Notes SESARM July 2011 AMEC NIF to ORL-fire conversion by UNC; daily inventories do not include MS (except MS) MS MANE-VU SMARTFIREv2 downloaded from US EPA **MWRPO** 02Jan2013 ftp.epa.gov in ORL-fire format and scaled by CENRAP GA EPD WRAP

2.1.3.1 Fires (sesarm\_ptf and ptfire)

The initial plan for creating typical year fires for the SEMAP project included combining the SESARM typical year fire inventory developed for this project by AMEC with 3-year averaged SMARTFIRE-based emissions estimates from the EPA Fire Averaging Tool (FAT). Analysis of the CMAQ results using the FAT emissions showed large positive biases for PM<sub>2.5</sub> species outside of the SESARM states, particularly in Southern Louisiana. UNC attributed these biases to a combination of the SMARTFIRE1 (SF1) inventories and FAT outputs, which result in the fire emissions all being allocated to the surface layer as area sources. Figure 2-34 shows year 2007 fire PM<sub>2.5</sub> estimates from the SF1, SF2, and SEMAP fire inventories for the SESARM and bordering states. For all SESARM states other than Georgia and Florida, the SF1 inventory is high relative to the SEMAP base 2007 fire inventory. The SF1 inventory is particularly high in Louisiana relative to the SESARM fire inventories for this project, the SEMAP base 2007 fire inventory is a better estimate of fire emissions than SF1. With SF1 biased high relative to the

SEMAP inventory, UNC suspected that it was high in the surrounding states as well. Using the FAT software to average 2006-2008 SF1 inventories to create typical fire estimates for the non-SESARM states made this high bias worse. Figure 2-35 shows monthly distributions of Louisiana fire  $PM_{2.5}$  emissions from the SF1 2007 inventory and the FAT average of SF1 2006-2008 inventories. For most months, the FAT inventory was higher than SF1 2007 in both the extremes and averages of the data.

These analyses confirmed our suspicion of the quality of the FAT and SF1 inventories for the non-SESARM states. UNC then sought to improve the typical year fire estimates outside of the SESARM region through using other sources of fire inventory data. GA DNR proposed a solution for the non-SESARM typical fire inventories that used SMARTFIRE2 (SF2) year 2007 inventories with caps on the emissions magnitudes based on the typical year SEMAP fire inventory. GA DNR calculated emissions ceilings by pollutant-month-SCC from the SEMAP typical year fire inventories for Alabama and Tennessee. The SF2 inventories outside of the SESARM states, including Mississippi, were capped if the magnitude of the monthly emissions in a state was larger then the ceiling calculated by GA DNR. UNC combined the scaled SF2 inventories with the base 2007 SF2 heat flux and acres burned parameters to calculate new typical year fires for the non-SESARM states and Mississippi.



Figure 2-34. Comparison of 2007 fire PM2.5 inventories for the SESARM and bordering states



Figure 2-35. Box plots of Louisiana year fire emissions from SMARTFIRE1 and FAT

Table 2-30 shows the state total annual typical year fire source emissions used for the SEMAP modeling. Figure 2-36 displays the typical year state total fire source emissions for the 10 SESARM states. Unlike in the 2007 base year, Georgia was not the largest source of fire emissions in the region in the typical year inventory. Florida surpasses Georgia as the largest source of typical fire emissions in the region. Figure 2-37 compares the base 2007 and typical year fires emissions for NOx, VOC, and PM2.5 for the SESARM states. This plot illustrates that for all pollutants and all states, the typical year fire inventory has a lower magnitude of emissions than the base year inventory.



Figure 2-36. SESARM state annual total typical year fire emissions; note that the CO emissions are divided by 5 to normalize their magnitude



Figure 2-37. SESARM base 2007 and typical annual total fire emissions of NOx, VOC, and PM2.5

# 2.1.4 SEMAP Base 2018 Modeling Platform

UNC developed the SEMAP Base 2018 EMP to estimate future year air quality in the SESARM region. The 2018 inventory data for the SESARM states were developed specifically for the SEMAP project and used the best available information on emissions growth projections and the impacts of emissions control strategies to estimate emissions for the year 2018. UNC used local or regional inventories to estimate emissions for the regions outside of SESARM states and defaulted to the NEI when other data were not available. UNC used the same biogenic emissions and ancillary data for the 2018 EMP as were used for the SEMAP 2007 base and typical EMPs.

This section presents the details of the data that UNC collected for the SEMAP 2018 EMP, including details of the processing with SMOKE and results for each inventory processing sector. Section 2.1.4.1 first presents the overall results of the 2018 EMP in terms of the annual total emissions for each of the 10 SESARM states. The subsequent sections begin with a table describing the sources, versions, and notes on the inventory data for each of the RPO regions. These sections are organized by inventory processing sector and include details on the sector and any special processing used to prepare these data for input the CMAQ model.

## 2.1.4.1 SESARM state 2018 emissions summary

The plots in this section illustrate the contribution of the different inventory processing sectors to the total annual 2018 criteria pollutant emissions. The stack bar plots show the total emissions for each pollutant by state with each segment in the stack representing a different emissions processing sector. Details of the processing and emissions totals for each sector are provided in the subsequent sections of this report.

#### Carbon Monoxide (CO)

In the 2018 SEMAP modeling, onroad mobile is projected to be the largest source of CO emissions in all of the SESARM states except Mississippi. Secondary important regional CO sources include nonroad mobile, fires, and biogenic sources. Overall Florida, Georgia, and North Carolina are projected to be the largest regional sources of CO. West Virginia is projected to be the smallest regional source of CO.

### Nitrogen Oxides (NOx)

Unlike in the base year, the 2018 NOx emissions are not dominated by any major sector. Onroad mobile and CEM point are projected to still be significant sources of NOx, other sectors have relatively large contributions as well. Other large contributors to NOx are projected to include nonroad mobile, non-CEM point, biogenic, and aircraft/locomotive/marine sources. Florida and Georgia are projected to be the largest regional of source of NOx. West Virginia is projected to be the smallest regional source of NOx.

#### Volatile Organic Compounds (VOCs)

Biogenic sources are projected to still be the dominant VOC source in all of the SESARM states. Significant anthropogenic sources of VOC include onroad mobile and nonpoint. Florida and Georgia are projected to be the largest sources of VOC in the region. West Virginia is projected to be the smallest regional source of VOC.

#### Ammonia (NH3)

Livestock is still projected to be the dominant source of NH3 in all of the SESARM states. Other significant sources of NH3 include fires, fertilizer, and onroad mobile sources. North Carolina and Georgia are projected to be the largest regional sources of NH3. West Virginia is projected to be the smallest regional source of NH3.

### Sulfur Dioxide (SO2)

While SO2 emissions are still projected to be dominated by CEM point sources in all of the SESARM states, the relative contribution of this sector to the total will decline. The non-CEM point sector is

projected to become a larger relative contributor to SO2 emissions. Florida and Tennessee are projected to be the largest regional contributors to SO2. Georgia is projected to be the smallest regional source.

#### Particulate Matter < 2.5 µm (PM2.5)

Fires and dust are projected to be the largest source of PM2.5 in many of the states. Other significant sources of PM2.5 include non-CEM point, CEM point, and nonpoint. Georgia and Florida are projected to be the largest regional sources of PM2.5, primarily because of large contributions from fires. West Virginia is the smallest regional source of PM2.5.



Figure 2-38. SESARM 2018 state total CO emissions by inventory sector



Figure 2-39. SESARM 2018 state total NOx emissions by inventory sector



Figure 2-40. SESARM 2018 state total VOC emissions by inventory sector



Figure 2-41. SESARM 2007 state total NH3 emissions by inventory sector


Figure 2-42. SESARM 2018 state total SO2 emissions by inventory sector



Figure 2-43. SESARM 2018 state total PM2.5 emissions by inventory sector

| Region  | Data Source | <b>Final Version</b> | Notes                                       |
|---------|-------------|----------------------|---|
| SESARM  | TranSystems | January 22, 2013     | NIF to ORL conversion by UNC                |
| MANE-VU | MARAMA      | 2017v3.3,            | Downloaded from ftp.marama.org in ORL       |
|         |             | existing controls    | format; VA removed by UNC                   |
| MWRPO   | LADCO       | BaseCv7              | NIF to ORL conversion by UNC                |
| CENRAP  | US EPA      | NEI2008v2            | Downloaded from                             |
| WRAP    | US EPA      | NEI2008v2            | ftp://ftp.epa.gov/EmisInventory/2008dev/ in |
|         |             |                      | ORL format                                  |

### 2.1.4.2 U.S. Nonpoint (nonpt)

The SEMAP 2018 nonpoint sector includes the same sources as the 2007 processing sector described in Section 2.1.2.2. UNC used future year (2018) nonpoint inventories for only the SESARM and MANE-VU states in the SEMAP 2018 modeling; UNC held the nonpoint emissions for the other RPOs constant at 2007 levels. UNC kept the emissions for these other RPOs constant because SESARM was not comfortable with the magnitudes of the differences between the base and future years. UNC and SESARM reviewed plots of the national 2018 emissions and noted steep spatial gradients between the RPOs. Figure 2-44 illustrates the nonpoint sector NOx emissions spatial gradients in the final and preliminary SEMAP 2018 modeling. The preliminary annual total nonpoint sector NOx plot on the top left of this figure shows a noticeable increase in emissions outside of the SESARM and MANE-VU states. The plot on the bottom pane of this figure, which shows January monthly total nonpoint sector NOx differences for the preliminary 2018 SEMAP emissions simulation, emphasizes these increases outside of the SESARM and MANE-VU states. The top right plot in the figure shows the final SEMAP 2018 annual total nonpoint NOx emissions, which include 2007 inventories for the regions outside of the SESARM and MANE-VU states. With the other inventory pollutants showing similar patterns, UNC consulted with SESARM and ultimately decided to hold the 2018 nonpoint emissions constant at 2007 levels for the states outside of the SESARM and MANE-VU regions.

TranSystems Corporation (2012b) developed the 2018 nonpoint inventory for the SEMAP project. UNC obtained inventories for the northeast states from MARAMA (2017) and for the Great Lakes region from LADCO (2007). UNC used the NEI2008v2 for the rest of the states in the U.S.

Table 2-31 shows the annual 2018 state total nonpoint source emissions used for the SEMAP modeling. Figure 2-45 displays the 2018 annual state total nonpoint emissions for the 10 SESARM states. Virginia is projected to be the largest emitter of nonpoint CO in the region, contributing 16.8% of the SESARM region total, followed by Kentucky (15.1%), Georgia (13.8%), and Tennessee (13.0%). Virginia is projected to be the largest emitter of nonpoint NOx (18.1%) in the region, followed by Georgia (13.4%), Kentucky (12.9%), and Tennessee (12.9%). Georgia is projected to be the largest emitter of nonpoint NOx (18.1%) in the region, followed by Georgia (11.9%). Kentucky is projected to be the largest emitter of nonpoint SO2 (19.7%) in the region, followed by Virginia (19.0%), Tennessee (18.2%), and Florida (13.3%). Florida is projected to be the largest emitter of nonpoint VOC (23.8%) in the region, followed by North Carolina (14.4%), Virginia (12.4%), and Georgia (12.0%). Tennessee is projected to be the largest emitter of PM10 (16.9%) in the region, followed by Kentucky (15.5%), Florida (13.7%), and South Carolina (13.4%). Kentucky is projected to be the largest emitter of PM10 (16.9%) in the region, followed by Kentucky (15.5%), Florida (13.7%), and South Carolina (13.4%). Kentucky is projected to be the largest emitter of PM10 (16.9%) in the region, followed by Kentucky (15.5%), Florida (13.7%), and South Carolina (13.4%). Kentucky is projected to be the largest emitter of PM10 (16.9%) in the region, followed by Kentucky (15.5%), Florida (13.7%), and South Carolina (13.4%). Kentucky is projected to be the largest emitter of PM10 (16.9%) in the region, followed by Kentucky (15.5%), Florida (13.7%), and South Carolina (13.4%). Kentucky is projected to be the largest emitter of PM2.5 (14.9%) in the region, followed by South Carolina (14.4%), Virginia (13.2%), and Georgia (12.8%).



Figure 2-44. SEMAP 2018 modeling emissions with 2007 data for the MWRPO, CENRAP and WRAP states (left); 2018 emissions for the entire country (right); difference in January monthly total preliminary 2018 NOx (bottom)



Figure 2-45. SESARM state annual total 2018 nonpoint source emissions; note that the VOC emissions are divided by 10 to normalize their magnitude

| 2.1.4.3 | Residential | wood | combustion | (RWC) |
|---------|-------------|------|------------|-------|
|---------|-------------|------|------------|-------|

| Region  | Data Source | <b>Final Version</b> | Notes                                       |
|---------|-------------|----------------------|---|
| SESARM  | TranSystems | January 22,          | NIF to ORL conversion by UNC                |
|         |             | 2013                 |   |
| MANE-VU | MARAMA      | 2017v3.3,            | Downloaded from ftp.marama.org in ORL       |
|         |             | existing             | format; VA removed by UNC                   |
|         |             | controls             |   |
| MWRPO   | LADCO       | BaseCv7              | NIF to ORL conversion by UNC                |
| CENRAP  | US EPA      | NEI2008v2            | Downloaded from                             |
| WRAP    | US EPA      | NEI2008v2            | ftp://ftp.epa.gov/EmisInventory/2008dev/ in |
|         |             |                      | ORL format                                  |

The SEMAP 2018 RWC sector includes the same sources as the 2007 processing sector described in Section 2.1.2.3. As a subsector of the nonpoint inventory, UNC used future year (2018) inventories for only the SESARM and MANE-VU states in the SEMAP 2018 modeling; UNC held the RWC emissions for the other RPOs constant at 2007 levels.

TranSystems Corporation (2012b) developed the 2018 RWC inventory for the SEMAP project. UNC obtained inventories for the northeast states from MARAMA and for the Great Lakes region from LADCO. UNC used the NEI2008v2 for the rest of the states in the U.S.

Table 2-32 shows the annual 2018 state total RWC source emissions used for the SEMAP modeling. Figure 2-46 displays the 2018 state total RWC emissions for the 10 SESARM states. The distribution of RWC emissions is consistent across pollutants with Virginia projected to contribute the highest emissions



in the region with 18.5% of the 10-state total for all pollutants. Virginia is followed by North Carolina (15.5%), Kentucky (14.3%), and Tennessee (10.3%) as the next largest sources of regional total RWC emissions for all pollutants.

Figure 2-46. SESARM state annual total 2018 RWC source emissions; note that the CO emissions are divided by 5 to normalize their magnitude

| Region  | Data Source | <b>Final Version</b> | Notes                                       |
|---------|-------------|----------------------|---|
| SESARM  | TranSystems | January 22,          | NIF to ORL conversion by UNC                |
|         |             | 2013                 |   |
| MANE-VU | MARAMA      | 2017v3.3,            | Downloaded from ftp.marama.org in ORL       |
|         |             | existing controls    | format; VA removed by UNC                   |
| MWRPO   | LADCO       | BaseCv7              | NIF to ORL conversion by UNC                |
| CENRAP  | US EPA      | NEI2008v2            | Downloaded from                             |
| WRAP    | US EPA      | NEI2008v2            | ftp://ftp.epa.gov/EmisInventory/2008dev/ in |
|         |             |                      | ORL format                                  |

The SEMAP 2018 dust sectors include the same sources as the 2007 processing sector described in Section 2.1.2.4. As a subsector of the nonpoint inventory, UNC used future year (2018) inventories for only the SESARM and MANE-VU states in the SEMAP 2018 modeling; UNC held the dust emissions for the other RPOs constant at 2007 levels.

TranSystems Corporation (2012b) developed the 2018 fugitive and road dust inventory for the SEMAP project. UNC obtained inventories for the northeast states from MARAMA and for the Great Lakes region from LADCO. UNC used the NEI2008v2 for the rest of the states in the U.S.

Table 2-33 shows the annual 2018 state total dust source emissions used for the SEMAP modeling. Figure 2-47 displays the 2007 state total dust emissions for the 10 SESARM states. Georgia is the largest emitter of road and fugitive dust PM10 in the region, contributing 24.5% of the SESARM region total, followed by Alabama (13.4%), Florida (12.6%), and Mississippi (12.4%).



Figure 2-47. SESARM state annual total 2018 road and fugitive dust source emissions; note that these values do not reflect the application of any adjustment factors

| Region  | Data Source | <b>Final Version</b> | Notes                                       |
|---------|-------------|----------------------|---|
| SESARM  | TranSystems | January 22,          | NIF to ORL conversion by UNC                |
|         |             | 2013                 |   |
| MANE-VU | MARAMA      | 2017v3.3,            | Downloaded from ftp.marama.org in ORL       |
|         |             | existing controls    | format; VA removed by UNC                   |
| MWRPO   | LADCO       | BaseCv7              | NIF to ORL conversion by UNC                |
| CENRAP  | US EPA      | NEI2008v2            | Downloaded from                             |
| WRAP    | US EPA      | NEI2008v2            | ftp://ftp.epa.gov/EmisInventory/2008dev/ in |
|         |             |                      | ORL format                                  |

| 2.1.4.5 | Agricultural | ammonia     | (Iv and | ft) |
|---------|--------------|-------------|---------|-----|
|         |              | ••••••••••• |         | /   |

The SEMAP 2018 agricultural ammonia sector includes the same sources as the 2007 processing sector described in Section 2.1.2.5. As a subsector of the nonpoint inventory, UNC used future year (2018) inventories for only the SESARM and MANE-VU states in the SEMAP 2018 modeling; UNC held the agricultural ammonia emissions for the other RPOs constant at 2007 levels.

TranSystems Corporation (2012b) developed the 2018 agricultural ammonia inventory for the SEMAP project. UNC obtained inventories for the northeast states from MARAMA and for the Great Lakes region from LADCO. UNC used the NEI2008v2 for the rest of the states in the U.S.

Table 2-34 shows the annual 2018 state total agricultural ammonia emissions used for the SEMAP modeling. Figure 2-48 displays the 2018 state total agricultural ammonia emissions for the 10 SESARM states. North Carolina is projected to be the largest emitter of livestock NH<sub>3</sub> in the region, contributing 31.2% of the SESARM region total, followed by Georgia (15%), Alabama (12.1%), and Mississippi (10.0%). Kentucky is projected to be the largest emitter of fertilizer NH<sub>3</sub> in the region, contributing 18.1% of the SESARM region total, followed by North Carolina (15.5%), Mississippi (12.7%), and Georgia (11.4%).



Figure 2-48. SESARM state annual total 2018 fertilizer and livestock source emissions

| Region  | Data Source | <b>Final Version</b> | Notes  |
|---------|-------------|----------------------|--|
| SESARM  | TranSystems | October 2012         | Monthly ORL-formatted files provided by      |
|         |             |                      | TranSystems                                  |
| MANE-VU | MARAMA      | 2017v3.3, existing   | Downloaded from ftp.marama.org in ORL        |
|         |             | controls             | format; VA removed by UNC                    |
| MWRPO   | US EPA      | NEI2005v4.3          |  |
|         |             | 2017ct_ref_05b       | Downloaded from                              |
| CENRAP  | US EPA      | NEI2005v4.3          | ftp://ftp.epa.gov/EmisInventory/2005v4_3/mat |
|         |             | 2017ct_ref_05b       | s/2017emis/ in ORL format                    |
| WRAP    | US EPA      | NEI2005v4.3          |  |
|         |             | 2017ct ref 05b       |  |

## 2.1.4.6 Offroad mobile (nonroad)

The SEMAP 2018 offroad mobile (nonroad) sector includes the same sources as the 2007-processing sector described in Section 2.1.2.6. UNC used future year nonroad inventories for all areas of the U.S. TranSystems (2012b) provided 2018 monthly nonroad inventories in ORL, SMOKE-ready format. MARAMA provided 2017 monthly nonroad projection inventories for the MANE-VU states. UNC used the NEI2005v4.3 modeling platform for 2017 projected monthly nonroad inventories for the rest of the country. UNC moved all aircraft, locomotive, and marine sources, including pleasure craft, from the nonroad to the ALM sector before processing these data with SMOKE.

Table 2-35 shows the annual 2018 state total nonroad mobile emissions used for the SEMAP modeling. Figure 2-49 displays the 2018 state total nonroad emissions for the 10 SESARM states. Florida is projected to be the largest emitter of nonroad emissions in the region, contributing about 27% of the SESARM region total nonroad emissions for all pollutants, followed by Georgia and North Carolina (13.5%), Virginia (10.5%), and Tennessee (9.0%).



Figure 2-49. SESARM state annual total 2018 nonroad mobile source emissions; note that the CO emissions are divided by 10 to normalize their magnitude

| Region  | Data Source | Final Version     | Notes  |
|---------|-------------|-------------------|--|
| SESARM  | TranSystems | October 2012      | NIF to ORL conversion by UNC                         |
| MANE-VU | MARAMA      | 2017v3.3,         | Downloaded from <u>ftp.marama.org</u> in ORL format; |
|         |             | existing controls | VA removed by UNC                                    |
| MWRPO   | US EPA      | NEI2005v4.3       |  |
|         |             | 2017ct_ref_05b    | Downloaded from                                      |
| CENRAP  | US EPA      | NEI2005v4.3       | ftp://ftp.epa.gov/EmisInventory/2005v4_3/mats/201    |
|         |             | 2017ct_ref_05b    | 7emis/ in ORL format                                 |
| WRAP    | US EPA      | NEI2005v4.3       |  |
|         |             | 2017ct_ref_05b    |  |

## 2.1.4.7 Aircraft locomotive marine (ALM)

The SEMAP 2018 Aircraft, Locomotive, Marine (ALM) sector includes the same sources as the 2007-processing sector described in Section 2.1.2.7. UNC obtained the 2018 ALM inventories from the same sources as the 2018 nonpoint inventories.

Table 2-36 shows the annual 2018 state total ALM emissions used for the SEMAP modeling. Figure 2-50 displays the 2018 state total ALM emissions for the 10 SESARM states. Florida is the projected to be largest emitter of ALM emissions in the region, contributing about 24% of the NOx and 36% of the VOC emissions for the SESARM region ALM sources. Other large regional sources of ALM NOx are projected to include Virginia (12.6%), Alabama (10.8%), and Georgia (10.2%). The other large regional sources of ALM VOC are projected to include North Carolina (9.2%) and Alabama (8.3%).



Figure 2-50. SESARM state annual total 2018 ALM source emissions; note that the CO emissions are divided by 2 to normalize their magnitude

| Region       | Data Source    | Final Version             | Notes                              |
|--------------|----------------|---------------------------|------------------------------------|
| SESARM       | AMEC/Alpine    | September 11, 2011 with   | 2018/2007 ratios from MOVES        |
| (without VA) | Geophysics and | ratios from SESARM states | 2010a emissions inventory mode     |
|              | SESARM states  |                           | runs used to scale the 2007        |
|              |                |                           | SEMAP emissions to 2018            |
| VA           | AMEC/Alpine    | February 7, 2012 EI and   | 2018/2007 ratios from MOVES        |
|              | Geophysics/VA  | September 11, 2011        | 2010a emissions inventory mode     |
|              | DEQ            | MOVES with ratios from    | runs used to scale the 2007        |
|              |                | VA DEQ                    | SEMAP emissions to 2018            |
| MANE-VU      | MARAMA         | 2007→2018 Projection      | Document titled "Creating Tier 3   |
| (without VA) |                | factors received July 19, | 2017 Mobile Emissions" used as     |
|              |                | 2013 from UMD             | guidance.                          |
| MWRPO        | US EPA         | NEI2005v4.3               | MOVES2010a run in emissions        |
|              |                | 2017ct_ref_05b            | inventory mode, monthly            |
| CENRAP       | US EPA         | NEI2005v4.3               | inventories with adjustments for   |
|              |                | 2017ct_ref_05b            | running and start PM emissions;    |
| WRAP         | US EPA         | NEI2005v4.3               | downloaded from                    |
|              |                | 2017ct_ref_05b            | ftp://ftp.epa.gov/EmisInventory/20 |
|              |                |                           | 05v4_3/mats/2017emis/              |

## 2.1.4.8 Onroad mobile

UNC used information provided by each of the SESARM states to project the MOVES onroad mobile emissions from the base year 2007 to the future year 2018. With guidance and scripts from GA DNR, each of the SESARM states ran MOVES in emission inventory mode for 2007 and 2018. They then provided UNC with either ratios of 2018/2007 emissions or their 2007 and 2018 MOVES inventories to use in calculating ratios. UNC used these ratios to develop a SMOKE onroad mobile emissions control factor input file (CFPRO). UNC then used SMOKE to apply the factors in the CFPRO file to generate 2018 onroad mobile emissions estimates for the SESARM states from the 2007 MOVES emissions factor mode tables. Using these projection ratios avoided the resource-intensive processes of running MOVES and SMOKE-MOVES in emission factor mode.

The SESARM states sent data to UNC in a few different forms, which UNC then had to process to get them in the CFPRO format for SMOKE. Each of the 10 SESARM states provided the following information for estimating future year 2018 onroad mobile emissions:

- Alabama annual, state-wide ratios for all criteria pollutants (CO, NO, NO2, NOx, VOC, SO2, NH3, PM10 exhaust, PM10 brakewear, PM10 tirewear, PM2.5 exhaust, PM2.5 brakewear, PM.5 tirewear) with no-SCC level assignments. UNC applied a single annual ratio for each pollutant to all counties, all SCCs, for all days of the year to estimate future year onroad emissions for AL.
- Florida annual, state-wide ratios for all criteria pollutants with no SCC-level assignments. UNC applied a single annual ratio for each pollutant to all counties, all SCCs, for all days of the year to estimate future year onroad emissions for FL.
- Georgia annual 2007 and 2018 inventories for 20 Atlanta counties and 2 counties to be used for the rest of the counties in the state. The inventories included all of the criteria pollutants with no SCC-level assignments. UNC used the inventories to develop annual 2018/2007 ratios, which UNC then applied for each pollutant and representative county to all counties, all SCCs, for all days of the year to estimate future year onroad emissions for GA.
- Kentucky monthly 2007 and 2018 inventories for 5 representative counties for all criteria pollutants with SCC-level assignments. UNC used the inventories to develop monthly 2018/2007

ratios, which UNC then applied for each pollutant, representative county, and SCC to all counties, all SCCs, for all days in each month to estimate future year onroad emissions for KY.

- Mississippi state-wide annual inventories and ratios for all criteria pollutants with SCC-level assignments. UNC used the inventories to develop annual 2018/2007 ratios, which UNC then applied for each pollutant and SCC to all counties, all SCCs, for all days of the year to estimate future year onroad emissions for MS.
- North Carolina annual, state-wide ratios for all criteria pollutants with no-SCC level assignments. UNC applied a single annual ratio for each pollutant to all counties, all SCCs, for all days of the year to estimate future year onroad emissions for NC.
- South Carolina annual, state-wide ratios for all criteria pollutants with no-SCC level assignments. UNC applied a single annual ratio for each pollutant to all counties, all SCCs, for all days of the year to estimate future year onroad emissions for SC.
- Tennessee monthly, county-level ratios for all criteria pollutants with no-SCC level assignments. UNC applied monthly ratios for each pollutant and county to all counties, all SCCs, for all days in each month to estimate future year onroad emissions for TN.
- Virginia monthly 2007 and 2018 inventories for 4 representative counties for all criteria pollutants with SCC-level assignments. UNC used the inventories to develop monthly 2018/2007 ratios, which UNC then applied for each pollutant, representative county, and SCC to all counties, all SCCs, for all days in each month to estimate future year onroad emissions for VA.
- West Virginia monthly 2007 and 2018 inventories for 1 representative county for all criteria pollutants with SCC-level assignments. UNC used the inventories to develop monthly 2018/2007 ratios, which UNC then applied for each pollutant and SCC to all counties, all SCCs, for all days in each month to estimate future year onroad emissions for WV.

UNC created a series of analysis products to help the states verify the projected emissions using the state-provided ratios. UNC developed an interactive spreadsheet that allowed the states to display annual county-total 2007 emissions, 2018 emissions, and ratios by pollutant. Figure 2-51 and Figure 2-52 are example scatter and bar plots for Georgia NO emissions extracted from the spreadsheet. The final version of the spreadsheet

(ftp://ftp.unc.edu/pub/empd/SEMAP/MOVES/SEMAP\_MOVES\_Projections.Counties.Aug.vMay20 13.xlsx) is provided as an electronic docket to this report. UNC also generated thematic maps of the emissions and ratios. Figure 2-53 includes county maps of the annual total 2007 and 2018 emission and the 2018/2007 county emissions ratios that UNC developed from the data provided by the SESARM states.

UNC used a combination of MOVES projection factors and MOVES future year emissions factors to estimate onroad mobile emission outside of the SESARM states. For the MANE-VU states, excluding Virginia, UNC developed projection factors by pollutant from a guidance document provided by the University of Maryland<sup>14</sup>. UNC applied these projection factors to the 2007 base-year, gridded MOVES outputs from MARAMA to create 2018 onroad emissions. For the MWRPO, CENRAP, and WRAP states, UNC used the year 2017 SMOKE-MOVES projections from the NEI 2005v4.3 modeling platform. UNC ran SMOKE-MOVES in emissions factor mode to estimate gridded onroad mobile emissions in these states.

<sup>&</sup>lt;sup>14</sup> Creating Tier 3 2017 Mobile Emissions



Figure 2-51. Scatter plot of 2018 vs 2007 onroad mobile NO emissions; each point represents a different county



Figure 2-52. Bar plot showing the 2007, 2018 and 2018/2007 ratios for onroad mobile NO emissions for each county in Georgia











Figure 2-53. County maps of SEMAP 2007, 2018, and 2018/2007 ratios of MOVES emissions

Table 2-37 shows the annual 2018 state total onroad mobile emissions used in the SEMAP modeling. Figure 2-54 displays the 2018 state total onroad mobile emissions for the 10 SESARM states. Florida is projected to be the largest emitter of onroad mobile CO and NOx emissions in the region, contributing about 20% of the CO and 22% of the NOx emissions for the SESARM region onroad sources. Georgia is projected to be the largest emitter of onroad mobile VOC (30%) Other large regional sources of onroad mobile NOx include Georgia (17%), North Carolina (12%), and Tennessee (11%). The other large regional sources of onroad mobile VOC include Florida (20%) and North Carolina (11%).



Figure 2-54. SESARM state annual total 2018 onroad mobile source emissions; note that the CO emissions are divided by 5 to normalize their magnitude

| Region  | <b>Data Source</b> | <b>Final Version</b> | Notes                                      |
|---------|--------------------|----------------------|--|
| SESARM  | AMEC               | 2018 v1c             | NIF to ORL conversion by UNC; 2007         |
|         |                    | (19Oct2013)          | hourly CEM scaled to 2018 using annual     |
|         |                    |                      | inventory ratios                           |
| MANE-VU | MARAMA             | 2020 hourly CEM and  | Downloaded from ftp.marama.org in ORL      |
|         |                    | 2017v3.3 existing    | format and hourly EMS-95 format; VA        |
|         |                    | controls             | removed by UNC                             |
| MWRPO   | US EPA             | NEI2005v4.3          | Downloaded from                            |
| CENRAP  |                    | 2017ct_ref_05b       | ftp://ftp.epa.gov/EmisInventory/2005v4_3/m |
| WRAP    |                    |                      | ats/2017emis/ in ORL format                |

## 2.1.4.9 EGU and Non-EGU point

UNC received the 2018 point inventory from SESARM (AMEC, 2014) as an Access database and converted the data to ORL format for SMOKE. As described in Section 2.1.2.9, UNC split the point inventories into CEM/non-CEM and EGU/non-EGU processing sectors. For the CEM sources, UNC created annual totals for each ORIS+Boiler ID combination in the 2018 and 2007 SESARM inventories and computed 2018/2007 ratios for each unique combination. UNC used these ratios to scale the 2007 hourly CEM data to 2018.

UNC gave special consideration to SESARM-state CEM sources that are projected to experience operational changes to the emissions control device from the base to future year. Table 2-17 lists the sources that transitioned from seasonal to annual controls between the base and future modeling years. UNC only applied the  $2007 \rightarrow 2018$  projection ratios for these sources to the period(s) when the control device was not operating in the base year. The rationale for this approach is that the reductions reflected in the projection ratios are due to the additional operating time of the control device in the future year. UNC did not want to further reduce the future emissions during the period when the control device was already in operation during the base year.

Figure 2-55 illustrates how UNC only applied the projection ratios to the uncontrolled periods of the base year CEM inventory. In this figure the black line shows the hourly 2007 NOx emissions and the green line shows the hourly 2018 NOx emissions. The 2007 and 2018 emissions are the same during the ozone season; the reductions from 2007 to 2018 are realized outside of the ozone season, as shown by the differences in the black and green lines.

| ORIS ID | Unit ID | State | Facility Name                                       |
|---------|---------|-------|---|
| 703     | 1BLR    | GA    | Bowen   |
| 703     | 2BLR    | GA    | Bowen   |
| 703     | 3BLR    | GA    | Bowen   |
| 703     | 4BLR    | GA    | Bowen   |
| 708     | 4       | GA    | Hammond   |
| 3935    | 1       | WV    | John Amos   |
| 3935    | 2       | WV    | John Amos   |
| 3935    | 3       | WV    | John Amos   |
| 3944    | 1       | WV    | Harrison Power Station                              |
| 3944    | 2       | WV    | Harrison Power Station                              |
| 3944    | 3       | WV    | Harrison Power Station                              |
| 3948    | 1       | WV    | Mitchell (WV)                                       |
| 3948    | 2       | WV    | Mitchell (WV)                                       |
| 6004    | 1       | WV    | Pleasants Power Station                             |
| 6004    | 2       | WV    | Pleasants Power Station                             |
| 6052    | 1       | GA    | Wansley (6052)                                      |
| 6052    | 2       | GA    | Wansley (6052)                                      |
| 6264    | 1       | WV    | Mountaineer (1301)                                  |
| 1356    | 1       | KY    | KY Utilities Co - Ghent Station                     |
| 1356    | 3       | KY    | KY Utilities Co - Ghent Station                     |
| 1356    | 4       | KY    | KY Utilities Co - Ghent Station                     |
| 1364    | 3       | KY    | LOU GAS & ELEC, MILL CREEK                          |
| 1364    | 4       | KY    | LOU GAS & ELEC, MILL CREEK                          |
| 1374    | 1       | KY    | Owensboro Municipal Utilities - Elmer Smith Station |
| 1374    | 2       | KY    | Owensboro Municipal Utilities - Elmer Smith Station |
| 1378    | 1       | KY    | Tennessee Valley Authority - Paradise Fossil Plant  |

Table 2-17. SESARM CEM sources with seasonal controls in 2007 and annual controls in 2018

| 1378 | 2  | KY | Tennessee Valley Authority - Paradise Fossil Plant   |
|------|----|----|--|
| 1378 | 3  | KY | Tennessee Valley Authority - Paradise Fossil Plant   |
| 1382 | H1 | KY | Western KY Energy Corp - Reid HMP&L Station 2        |
| 1382 | H2 | KY | Western KY Energy Corp - Reid HMP&L Station 2        |
| 47   | 5  | AL | TVA  |
| 50   | 7  | AL | TVA  |
| 50   | 8  | AL | TVA  |
|      |    |    | ALABAMA POWER COMPANY (MILLER POWER                  |
| 6002 | 1  | AL | PLANT)   |
|      |    |    | ALABAMA POWER COMPANY (MILLER POWER                  |
| 6002 | 2  | AL | PLANT)   |
|      |    |    | ALABAMA POWER COMPANY (MILLER POWER                  |
| 6002 | 3  | AL | PLANT)   |
|      |    |    | ALABAMA POWER COMPANY (MILLER POWER                  |
| 6002 | 4  | AL | PLANT)   |
| 6018 | 2  | KY | Duke Energy KY East Bend                             |
| 6041 | 1  | KY | East KY Power Coop - Spurlock Station                |
| 6041 | 2  | KY | East KY Power Coop - Spurlock Station                |
|      |    |    | Louisville Gas & Electric Co - Trimble Co Generating |
| 6071 | 1  | KY | Station  |
| 6823 | W1 | KY | Western KY Energy Corp - Wilson Station              |
| 3803 | 4  | VA | VIRGINIA POWER CHESAPEAKE                            |
| 3944 | 2  | WV | MONONGAHELA POWER CO-HARRISON                        |
| 3944 | 3  | WV | MONONGAHELA POWER CO-HARRISON                        |
| 3954 | 1  | WV | MOUNT STORM POWER PLANT                              |
| 3954 | 2  | WV | MOUNT STORM POWER PLANT                              |
| 3954 | 3  | WV | MOUNT STORM POWER PLANT                              |



Figure 2-55. Timeseries of 2007 and 2018 hourly CEM NOx at Bowen Power Plant in Georgia

UNC collected future year point inventories for sources outside of the SESARM region from MARAMA and EPA. MARAMA provided both annual and hourly 2020 point source inventories in formats similar to their base-year inventories. For the MWRPO, CENRAP, and WRAP states UNC used the EPA 2005v4.3 modeling platform projections to 2017.

Table 2-38 shows the annual 2018 state total point source emissions used for the SEMAP modeling. These totals are the sum of the CEM and non-CEM point inventories and represent the total stationary point source emissions used for the SEMAP 2018 modeling. Figure 2-56 and Figure 2-57 display the 2018 state total non-CEM and CEM point source emissions for the 10 SESARM states. Alabama is projected to be the largest source of non-CEM point NOx emissions in the region, contributing about

15.6% of the NOx emissions for the SESARM region. Other large regional sources of non-CEM point NOx are projected to include Florida (11.8%), Mississippi (12.3%), and Georgia (10.5%). Alabama is also projected to be the largest source of non-CEM point SO<sub>2</sub> (17.7%), followed by Florida (15.7%), Georgia (10.3%), and North Carolina (11.8%). Tennessee is projected to be the largest source of non-CEM point VOC (13.3%), followed by North Carolina (13.3%), Kentucky (13.0%), and Alabama (10.6%).

Tennessee is projected to be the largest regional emitter of CEM point NOx (17.1%) and SO2 (17.9%). Other large regional CEM point sources are projected to include Florida for CO (23.4%), NOx (14.9%), VOC (22.5%), and NH3 (69.3%); and North Carolina for PM10 (21.3%) and PM2.5 (21.4%).



Figure 2-56. SESARM state annual total 2018 non-CEM point source emissions; note that the CO emissions are divided by 2 to normalize their magnitude.



Figure 2-57. SESARM state annual 2018 CEM point source emissions; note that the NOx and SO2 emissions are divided by 2 to normalize their magnitudes.

| 2.1.4.10 | Airport points | (airpt) |
|----------|----------------|---------|
|----------|----------------|---------|

| Region  | Data Source | <b>Final Version</b> | Notes   |
|---------|-------------|----------------------|---|
| SESARM  | TranSystems | 22 January 2013      | NIF to ORL conversion by UNC; stack             |
|         |             |                      | parameters for aircraft based on FAA EDMS       |
|         |             |                      | airport data                                    |
| MANE-VU | N/A         | N/A                  | The MANE-VU airport inventory is part of the    |
|         |             |                      | non-point ALM sector                            |
| MWRPO   |             | NEI2005v4.3          | Downloaded from                                 |
| CENRAP  | US EPA      | 2017ct_ref_05b       | ftp://ftp.epa.gov/EmisInventory/2005v4_3/mats/2 |
| WRAP    |             |                      | <u>017emis/</u> in ORL format                   |
|         |             |                      |   |

The SEMAP 2018 airport point sector includes the same sources as the 2007 processing sector described in Section 2.1.2.10. Like in the base year inventory, UNC converted the 2-d LTO sources in the SESARM states to 3-d sources using vertical profiles derived from the FAA EDMS model. There are not sources in the MANE-VU region under the airpt sector; these sources are included in the MANE-VU nonpoint inventory.

Table 2-39 shows the 2018 state total annual airport point source emissions used for the SEMAP modeling. This table does not include the airport emissions in the MANE-VU states because these are contained in the nonpoint ALM sector. Figure 2-58 displays the 2018 state total airport point source emissions for the 10 SESARM states. Florida is the largest source of airport emissions in the region, contributing about 35% of the airport NOx emissions and 27% of the airport VOC emissions for the



SESARM region. Virginia, Georgia, and North Carolina are also significant regional sources of airport emissions.

Figure 2-58. SESARM state annual total 2018 airport point source emissions

## 2.1.4.11 C2/C3 Commerical Marine (ptseca)

| Region          | Data Source | <b>Final Version</b> | Notes                                |
|-----------------|-------------|----------------------|--------------------------------------|
| US and offshore | US EPA      | NEI2005v4.3          | In-port, near, and offshore elevated |
|                 |             | 2017ct_ref_05b       | sources                              |

EPA projected the near-shore/offshore C1/C2 commercial marine inventories to 2017 in the NEI2005v4.3 modeling platform. UNC gridded these point source inventories directly to the SEMAP 36 and 12km modeling grids.

Table 2-40 shows the annual total near and offshore emissions for the commercial shipping sector. The state total emissions represent the in-port emissions, the near shore emissions are between 0-0.5 km from port, and the SECA emissions are the offshore sources in commercial shipping lanes. UNC used the point SECA emissions from the EPA for all in-port, near-short, and commercial shipping sources, including the in-port emissions for the SESARM states, in the 2018 SEMAP modeling.

| Region | Data Source        | <b>Final Version</b> | Notes                              |
|--------|--------------------|----------------------|------------------------------------|
| Canada | Environment Canada | 2006                 |                                    |
| Mexico | INE and ERG, Inc.  | 2008                 | Mexico National Emission Inventory |
|        |                    |                      | projected from 1999 to 2008        |

## 2.1.4.12 Canada and Mexico

The SEMAP future year simulation used the same inventories for Canada and Mexico as the base year simulation. Future year projections for these inventories were not available during the SEMAP project period.

# 2.2 Errata

Emission inventories are best-guess approximations of the actual pollution fluxes from air pollution sources. Most of the inventories used for the SEMAP project were developed from the "bottom-up", meaning that they were derived from the product of an average emissions factor and an estimate of the activity of an emissions sources in a county. Uncertainty arises from both parameters in the inventory equation. The practice of developing inventories, compiling ancillary emissions data, and preparing the emissions for input to air quality models is enormously complex. There are many places in this process where uncertainty and errors may be introduced. It is the job of the modelers using these data to employ as many QA steps as practically possible to reveal multiple facets of the data. By seeing the data from many different angles (temporal, spatial, chemical), the hope is that one may be able to identify and correct major uncertainties and/or errors. Despite the best efforts of emissions modelers, errors persist in the data and modeling. This section describes known omissions or discrepancies in the SEMAP emissions data and/or modeling.

- US EPA C2/C3 in-port commercial marine inventories were used for the SESARM states in the 2018 simulation. While SESARM provided in-port C2/C3 inventories for both the base and future years, UNC used the SESARM inventories in only the base year simulation. There is no double counting or omission of these sources in the future year simulation.
- UNC corrected an error in the MANE-VU future year on-road MOVES emissions in which the future year projection factors were double counted. UNC received from the OTC both projected gridded MOVES emissions files and state projection factors. When UNC were instructed by SESARM to apply the projection factors to the base year gridded MOVES data, UNC mistakenly applied them to the future year gridded MOVES data, effectively double counting the projection. UNC corrected this error in version B of the SEMAP 2018 emissions simulation.

#### State Emissions Summaries 2.3

## 2.3.1 2007 Base

|    | Table 2-18. SEMAP 2007 nonpoint source emissions state totals (TPY) |       |        |       |       |       |       |
|----|---|-------|--------|-------|-------|-------|-------|
|    | CO  | NOX   | VOC    | NH3   | SO2   | PM10  | PM2.5 |
| AL | 5817  | 3789  | 77313  | 387   | 411   | 2713  | 2363  |
| AZ | 36371   | 15594 | 91491  | 8884  | 3393  | 14752 | 12832 |
| AR | 92376   | 12901 | 77452  | 330   | 1157  | 13930 | 12348 |
| CA | 161900  | 68074 | 281610 | 62981 | 6088  | 58210 | 44615 |
| CO | 5602  | 6469  | 46543  | 1222  | 125   | 1623  | 1611  |
| СТ | 6298  | 11828 | 50642  | 1647  | 15991 | 2237  | 2102  |
| DE | 3555  | 2157  | 8608   | 508   | 1131  | 2175  | 910   |
| DC | 999   | 1477  | 4740   | 145   | 1232  | 208   | 196   |
| FL | 19134   | 5823  | 293960 | 246   | 10313 | 15933 | 10026 |
| GA | 32720   | 12143 | 141190 | 1202  | 4831  | 12172 | 10948 |
| ID | 85226   | 11343 | 90460  | 2222  | 8865  | 6317  | 5468  |
| IL | 46416   | 44581 | 193300 | 5112  | 4481  | 10825 | 10410 |
| IN | 19458   | 21068 | 140870 | 1043  | 15859 | 7413  | 6791  |
| IA | 27483   | 5255  | 64911  | 695   | 2143  | 5394  | 5076  |
| KS | 65497   | 19025 | 71627  | 4961  | 7440  | 16039 | 9191  |
| KY | 37204   | 12400 | 71730  | 531   | 15549 | 18989 | 13592 |
| LA | 126120  | 30012 | 136600 | 27343 | 2540  | 17365 | 16123 |
| ME | 21137   | 6212  | 26735  | 747   | 9710  | 3013  | 2869  |
| MD | 37561   | 9765  | 57803  | 956   | 5861  | 6376  | 5085  |
| MA | 30146   | 19424 | 76978  | 9998  | 19721 | 6565  | 5822  |
| MI | 19463   | 31311 | 147330 | 3611  | 12227 | 0     | 0     |
| MN | 80915   | 17952 | 98514  | 1777  | 8114  | 15506 | 13403 |
| MS | 16444   | 5995  | 73663  | 267   | 331   | 5991  | 5476  |
| MO | 67561   | 18157 | 113580 | 1348  | 44313 | 11036 | 10338 |
| MT | 11443   | 1897  | 14970  | 218   | 321   | 1842  | 1620  |
| NE | 12603   | 2682  | 38591  | 372   | 200   | 2733  | 2641  |
| NV | 5341  | 4077  | 36104  | 250   | 4459  | 2983  | 1900  |
| NH | 20525   | 4445  | 19015  | 190   | 5210  | 2704  | 2175  |
| NJ | 37343   | 23537 | 90305  | 12080 | 8711  | 10455 | 7255  |
| NM | 18296   | 2710  | 32217  | 323   | 53    | 3021  | 2583  |
| NY | 89565   | 70698 | 186020 | 4913  | 69814 | 22978 | 18991 |
| NC | 27646   | 12394 | 149180 | 744   | 8322  | 11339 | 10239 |
| ND | 19865   | 1734  | 20319  | 119   | 658   | 2402  | 2344  |
| OH | 71706   | 35234 | 152460 | 3063  | 12152 | 13481 | 12580 |
| OK | 104080  | 84275 | 246080 | 781   | 4514  | 13355 | 9867  |
| OR | 25565   | 3201  | 45126  | 444   | 691   | 4449  | 3897  |

| PA | 116330 | 45937  | 157340  | 930  | 66311 | 27831 | 21306 |
|----|--------|--------|---------|------|-------|-------|-------|
| RI | 4098   | 3276   | 22077   | 274  | 3866  | 1011  | 862   |
| SC | 25183  | 9239   | 75542   | 385  | 6033  | 15986 | 12860 |
| SD | 6719   | 1733   | 25561   | 137  | 299   | 1478  | 1363  |
| TN | 31560  | 12211  | 108690  | 960  | 14386 | 20461 | 9230  |
| ТХ | 215430 | 322650 | 1713600 | 2093 | 1452  | 27780 | 22179 |
| UT | 33138  | 8411   | 70332   | 5531 | 1243  | 6612  | 4810  |
| VT | 16057  | 3522   | 8615    | 156  | 3571  | 3335  | 2869  |
| VA | 40395  | 17356  | 129620  | 1247 | 16970 | 13269 | 11782 |
| WA | 48360  | 6134   | 80418   | 807  | 1223  | 7863  | 6866  |
| WV | 14760  | 3434   | 30475   | 359  | 6484  | 5915  | 5043  |
| WI | 58760  | 24954  | 106210  | 1787 | 5484  | 10918 | 10365 |
| WY | 13102  | 17156  | 113670  | 125  | 1675  | 792   | 690   |

Table 2-19. SEMAP 2007 RWC source emissions state totals (TPY)

|    | CO     | NOX  | VOC   | NH3  | SO2 | PM10  | PM2.5 |
|----|--------|------|-------|------|-----|-------|-------|
| AL | 9335   | 151  | 1717  | 79   | 20  | 1359  | 1357  |
| AZ | 18127  | 310  | 3244  | 154  | 48  | 2642  | 2638  |
| AR | 9904   | 162  | 1823  | 84   | 22  | 1432  | 1430  |
| CA | 274630 | 3528 | 17968 | 2044 | 530 | 39296 | 37829 |
| CO | 91792  | 1414 | 16522 | 744  | 224 | 13146 | 13137 |
| СТ | 35199  | 594  | 6611  | 281  | 92  | 4983  | 4979  |
| DE | 4711   | 79   | 874   | 38   | 13  | 669   | 668   |
| DC | 4489   | 70   | 828   | 38   | 10  | 650   | 649   |
| FL | 9414   | 160  | 1671  | 84   | 21  | 1400  | 1397  |
| GA | 12517  | 207  | 2280  | 108  | 27  | 1840  | 1837  |
| ID | 15629  | 264  | 3131  | 119  | 40  | 2252  | 2250  |
| IL | 45995  | 654  | 8425  | 393  | 100 | 6531  | 6531  |
| IN | 31764  | 444  | 5950  | 263  | 68  | 4472  | 4472  |
| IA | 24230  | 384  | 4438  | 197  | 67  | 3456  | 3452  |
| KS | 16441  | 265  | 3012  | 134  | 44  | 2355  | 2352  |
| KY | 18245  | 293  | 3371  | 152  | 42  | 2644  | 2641  |
| LA | 16563  | 234  | 5504  | 59   | 30  | 2313  | 2311  |
| ME | 29359  | 444  | 5231  | 243  | 102 | 4201  | 4197  |
| MD | 36626  | 547  | 6627  | 304  | 98  | 5257  | 5251  |
| MA | 49080  | 828  | 8892  | 405  | 139 | 7049  | 7042  |
| MI | 55839  | 797  | 10347 | 500  | 120 | 7967  | 7967  |
| MN | 81970  | 1199 | 14458 | 667  | 248 | 11941 | 11940 |
| MS | 5933   | 95   | 1092  | 50   | 13  | 863   | 861   |
| MO | 37831  | 606  | 6898  | 311  | 103 | 5425  | 5419  |
| MT | 9516   | 161  | 1699  | 80   | 27  | 1377  | 1375  |
| NE | 13160  | 211  | 2413  | 107  | 36  | 1879  | 1877  |

| Final Report: | Emissions and Air | <b>Oualitv</b> | Modeling | for SEMAP |
|---------------|-------------------|----------------|----------|-----------|
|               |                   | 2              |          | /         |

| -  |        |      |       |     |     |       |       |
|----|--------|------|-------|-----|-----|-------|-------|
| NV | 12029  | 232  | 3309  | 93  | 317 | 1700  | 1697  |
| NH | 19152  | 293  | 3328  | 160 | 73  | 2745  | 2747  |
| NJ | 40344  | 638  | 7816  | 318 | 100 | 5683  | 5678  |
| NM | 14256  | 243  | 2561  | 120 | 39  | 2062  | 2060  |
| NY | 115490 | 1355 | 9957  | 827 | 230 | 12817 | 12817 |
| NC | 19733  | 321  | 3648  | 166 | 43  | 2872  | 2867  |
| ND | 4957   | 80   | 910   | 40  | 14  | 708   | 707   |
| OH | 64992  | 903  | 12271 | 532 | 138 | 9123  | 9123  |
| OK | 9370   | 151  | 1723  | 80  | 21  | 1356  | 1355  |
| OR | 86810  | 1544 | 15091 | 724 | 243 | 12917 | 12906 |
| PA | 100750 | 1608 | 19438 | 811 | 274 | 14183 | 14195 |
| RI | 11321  | 193  | 2137  | 89  | 31  | 1592  | 1591  |
| SC | 7025   | 114  | 1297  | 59  | 15  | 1022  | 1020  |
| SD | 5632   | 91   | 1034  | 46  | 15  | 804   | 804   |
| TN | 13111  | 211  | 2437  | 108 | 29  | 1901  | 1895  |
| ТХ | 46739  | 790  | 8237  | 419 | 105 | 6939  | 6928  |
| UT | 14603  | 270  | 2495  | 128 | 46  | 2149  | 2146  |
| VT | 35052  | 474  | 5494  | 289 | 180 | 5032  | 5030  |
| VA | 23442  | 384  | 4316  | 197 | 53  | 3419  | 3413  |
| WA | 102740 | 1590 | 18437 | 822 | 239 | 14564 | 14564 |
| WV | 8729   | 140  | 1615  | 73  | 20  | 1266  | 1264  |
| WI | 64571  | 901  | 12262 | 513 | 141 | 9178  | 9178  |
| WY | 5327   | 90   | 952   | 45  | 15  | 771   | 770   |

 

 Table 2-20. SEMAP 2007 road and fugitive dust source emissions state totals (TPY); note that only the MANE-VU states include vegetative adjustment factors

|    | PM10   | PM2.5  |
|----|--------|--------|
| AL | 345910 | 37867  |
| AZ | 257610 | 36317  |
| AR | 369000 | 54140  |
| CA | 695090 | 84793  |
| CO | 285880 | 45894  |
| СТ | 8371   | 1315   |
| DE | 4365   | 829    |
| DC | 1587   | 275    |
| FL | 303450 | 26815  |
| GA | 626540 | 70809  |
| ID | 383230 | 61947  |
| IL | 715050 | 114840 |
| IN | 493800 | 67155  |
| IA | 513550 | 87591  |
| KS | 770150 | 117710 |

| -  |         |        |
|----|---------|--------|
| KY | 205200  | 24109  |
| LA | 190760  | 22034  |
| ME | 13013   | 1679   |
| MD | 26888   | 4373   |
| MA | 44766   | 5758   |
| MI | 345010  | 49828  |
| MN | 647080  | 95043  |
| MS | 319500  | 36421  |
| MO | 781810  | 101580 |
| MT | 330020  | 45470  |
| NE | 488000  | 74247  |
| NV | 221530  | 24527  |
| NH | 5201    | 910    |
| NJ | 8663    | 2010   |
| NM | 799970  | 84087  |
| NY | 104970  | 15215  |
| NC | 37467   | 3722   |
| ND | 407480  | 71066  |
| OH | 434810  | 56711  |
| OK | 711740  | 90618  |
| OR | 209430  | 26379  |
| PA | 96556   | 15354  |
| RI | 2949    | 504    |
| SC | 249740  | 25657  |
| SD | 248400  | 43419  |
| TN | 193320  | 22827  |
| TX | 2300200 | 289610 |
| UT | 210350  | 25839  |
| VT | 10730   | 1536   |
| VA | 159580  | 23839  |
| WA | 194560  | 25946  |
| WV | 93249   | 10556  |
| WI | 237410  | 40031  |
| WY | 476820  | 52628  |

|    | Eardillan NILL2 | I incode al- NITO |  |  |
|----|-----------------|-------------------|--|--|
|    | Fertilizer NH3  | LIVESTOCK NH3     |  |  |
| AL | 6517            | 55443             |  |  |
| AZ | 6356            | 22327             |  |  |
| AR | 42570           | 77632             |  |  |
| CA | 65914           | 192380            |  |  |
| СО | 14537           | 53940             |  |  |
| СТ | 429             | 2063              |  |  |
| DE |                 | 11232             |  |  |
| FL | 7157            | 26179             |  |  |
| GA | 10569           | 74088             |  |  |
| ID | 25721           | 76041             |  |  |
| IL | 69613           | 46914             |  |  |
| IN | 42503           | 59125             |  |  |
| IA | 89461           | 206090            |  |  |
| KS | 59036           | 92101             |  |  |
| КҮ | 17645           | 34003             |  |  |
| LA | 18925           | 18048             |  |  |
| ME | 1708            | 3038              |  |  |
| MD | 4823            | 1992              |  |  |
| MA | 731             | 1426              |  |  |
| MI | 24271           | 36522             |  |  |
| MN | 72561           | 111050            |  |  |
| MS | 12377           | 46080             |  |  |
| мо | 44848           | 79482             |  |  |
| MT | 33715           | 21230             |  |  |
| NE | 64673           | 111500            |  |  |
| NV | 786             | 4585              |  |  |
| NH | 113             | 1037              |  |  |
| NJ | 1365            | 1973              |  |  |
| NM | 13996           | 31895             |  |  |
| NY | 4231            | 35722             |  |  |
| NC | 14341           | 154190            |  |  |
| ND | 63948           | 14742             |  |  |
| ОН | 31318           | 52213             |  |  |
| ОК | 25037           | 72133             |  |  |
| OR | 24687           | 17952             |  |  |
| ΡΑ | 9565            | 61263             |  |  |
| RI | 93              | 170               |  |  |
| SC | 5181            | 24622             |  |  |
| SD | 84902           | 46529             |  |  |

Table 2-21. SEMAP 2007 livestock and fertilizer source emissions state totals (TPY)

| Final Report: | Emissions | and Air | Quality | Modeling | for SEMAP |
|---------------|-----------|---------|---------|----------|-----------|
|               |           |         |         |          |           |

| -  |       |        |
|----|-------|--------|
| TN | 8830  | 25381  |
| ΤХ | 86218 | 202030 |
| UT | 1702  | 34105  |
| VT | 758   | 6810   |
| VA | 8414  | 33179  |
| WA | 17920 | 24800  |
| WV | 3631  | 8795   |
| WI | 32876 | 82453  |
| WY | 6877  | 12382  |

Table 2-22. SEMAP 2007 nonroad source emissions state totals (TPY)

|    | CO      | NOX    | VOC    | NH3 | SO2  | PM10  | PM2.5 |
|----|---------|--------|--------|-----|------|-------|-------|
| AL | 259995  | 23938  | 29099  | 24  | 1392 | 2454  | 2339  |
| AZ | 338650  | 32347  | 32160  | 37  | 656  | 3304  | 3154  |
| AR | 170842  | 23422  | 22356  | 22  | 447  | 2412  | 2308  |
| CA | 1859978 | 155642 | 161279 | 175 | 169  | 15116 | 14398 |
| CO | 282835  | 30691  | 30216  | 34  | 602  | 3143  | 3002  |
| СТ | 167319  | 13895  | 14190  | 14  | 634  | 1140  | 1087  |
| DE | 41976   | 4030   | 3524   | 4   | 216  | 363   | 343   |
| DC | 13788   | 2639   | 1113   | 3   | 166  | 215   | 208   |
| FL | 1153970 | 96595  | 91403  | 106 | 6287 | 9872  | 9443  |
| GA | 571979  | 49087  | 50488  | 51  | 2991 | 4977  | 4754  |
| ID | 100231  | 13376  | 17445  | 15  | 268  | 1538  | 1468  |
| IL | 650896  | 95003  | 65671  | 87  | 5726 | 8714  | 8369  |
| IN | 343662  | 52527  | 36331  | 46  | 3057 | 4620  | 4435  |
| IA | 181834  | 53171  | 24240  | 46  | 1031 | 4996  | 4819  |
| KS | 169036  | 41912  | 15979  | 36  | 810  | 3866  | 3732  |
| KY | 205407  | 26919  | 24259  | 24  | 1571 | 2655  | 2544  |
| LA | 216450  | 22029  | 26070  | 24  | 431  | 2272  | 2168  |
| ME | 110013  | 5939   | 22953  | 11  | 358  | 972   | 918   |
| MD | 260942  | 22039  | 23112  | 25  | 1221 | 2172  | 2063  |
| MA | 300362  | 23162  | 25325  | 25  | 1098 | 1931  | 1841  |
| MI | 634763  | 58714  | 104763 | 68  | 3353 | 6385  | 6060  |
| MN | 321232  | 56143  | 59951  | 57  | 1062 | 5841  | 5592  |
| MS | 147902  | 18198  | 19531  | 17  | 1085 | 1884  | 1802  |
| MO | 308848  | 44583  | 32181  | 42  | 847  | 4291  | 4117  |
| MT | 69625   | 16526  | 10448  | 15  | 331  | 1710  | 1646  |
| NE | 104913  | 35443  | 12168  | 30  | 694  | 3317  | 3204  |
| NV | 149855  | 16476  | 15027  | 19  | 316  | 1717  | 1640  |
| NH | 78087   | 6043   | 13036  | 8   | 307  | 693   | 655   |
| NJ | 415529  | 31876  | 34180  | 35  | 1520 | 2743  | 2613  |
| NM | 82749   | 8071   | 8742   | 9   | 161  | 821   | 784   |

| NY | 828687  | 62147  | 84204 | 72  | 3187 | 5851  | 5594  |
|----|---------|--------|-------|-----|------|-------|-------|
| NC | 526733  | 52163  | 50060 | 51  | 3005 | 4988  | 4769  |
| ND | 63854   | 34302  | 10064 | 28  | 682  | 3280  | 3173  |
| OH | 687488  | 72633  | 65166 | 70  | 4135 | 6540  | 6254  |
| OK | 202772  | 25987  | 19364 | 25  | 499  | 2517  | 2415  |
| OR | 206533  | 21777  | 23440 | 23  | 414  | 2227  | 2124  |
| PA | 664375  | 49345  | 65070 | 54  | 2518 | 4728  | 4505  |
| RI | 44100   | 3411   | 3231  | 4   | 167  | 279   | 267   |
| SC | 274140  | 24526  | 23676 | 24  | 1449 | 2350  | 2247  |
| SD | 56098   | 24391  | 8727  | 20  | 482  | 2346  | 2267  |
| TN | 335680  | 34216  | 35159 | 32  | 1798 | 3310  | 3164  |
| ТХ | 1134327 | 126351 | 98320 | 130 | 2474 | 11841 | 11347 |
| UT | 129435  | 12471  | 19179 | 14  | 243  | 1399  | 1331  |
| VT | 46076   | 3196   | 8304  | 4   | 188  | 429   | 408   |
| VA | 370899  | 38550  | 35982 | 39  | 2246 | 3791  | 3621  |
| WA | 333154  | 35098  | 34783 | 38  | 672  | 3499  | 3342  |
| WV | 96726   | 7026   | 13986 | 8   | 392  | 893   | 846   |
| WI | 383012  | 43118  | 65850 | 46  | 2482 | 4544  | 4327  |
| WY | 39648   | 4540   | 7598  | 5   | 91   | 544   | 517   |

Table 2-23. SEMAP 2007 alm source emissions state totals (TPY)

|    | CO     | NOX    | VOC    | NH3 | SO2   | PM10 | PM2.5 |
|----|--------|--------|--------|-----|-------|------|-------|
| AL | 62407  | 39210  | 22240  | 22  | 2026  | 1675 | 1576  |
| AZ | 30742  | 25062  | 11370  | 14  | 260   | 954  | 879   |
| AR | 36093  | 25301  | 11276  | 15  | 588   | 981  | 916   |
| CA | 164885 | 97866  | 59483  | 51  | 3300  | 3952 | 3728  |
| CO | 14356  | 15763  | 4819   | 8   | 163   | 579  | 533   |
| СТ | 19056  | 10455  | 6669   | 6   | 1612  | 537  | 493   |
| DE | 14915  | 7021   | 4229   | 2   | 2154  | 422  | 386   |
| DC | 441    | 591    | 160    | 0   | 42    | 16   | 15    |
| FL | 285996 | 72520  | 104423 | 61  | 18747 | 4998 | 4653  |
| GA | 62667  | 37084  | 20985  | 21  | 2384  | 1615 | 1508  |
| ID | 14818  | 9275   | 4889   | 5   | 95    | 366  | 337   |
| IL | 63635  | 70499  | 20972  | 40  | 2641  | 2402 | 2215  |
| IN | 45977  | 30393  | 14460  | 18  | 883   | 1116 | 1031  |
| IA | 53513  | 30395  | 14432  | 19  | 396   | 1127 | 1041  |
| KS | 15359  | 36530  | 5347   | 17  | 382   | 1255 | 1151  |
| KY | 40352  | 34278  | 13609  | 22  | 1247  | 1348 | 1272  |
| LA | 102139 | 153103 | 30525  | 73  | 8337  | 5712 | 5503  |
| ME | 53218  | 4067   | 6784   | 2   | 325   | 615  | 551   |
| MD | 47448  | 25078  | 12791  | 11  | 2547  | 1078 | 952   |
| MA | 39730  | 14793  | 11218  | 5   | 1098  | 950  | 818   |

| MI | 162899 | 29583  | 40322 | 24 | 4816  | 1450 | 1338 |
|----|--------|--------|-------|----|-------|------|------|
| MN | 75445  | 39971  | 27558 | 23 | 1207  | 1663 | 1561 |
| MS | 44018  | 29905  | 15119 | 18 | 1977  | 1256 | 1187 |
| MO | 64107  | 50424  | 21319 | 28 | 1203  | 1962 | 1832 |
| MT | 10328  | 24210  | 3139  | 12 | 250   | 827  | 762  |
| NE | 18352  | 72343  | 6554  | 34 | 752   | 2480 | 2283 |
| NV | 11701  | 7643   | 4149  | 4  | 75    | 297  | 274  |
| NH | 13397  | 3444   | 3796  | 2  | 639   | 160  | 144  |
| NJ | 50417  | 25034  | 15091 | 15 | 7413  | 1174 | 1073 |
| NM | 11335  | 25313  | 3880  | 12 | 263   | 878  | 808  |
| NY | 99228  | 62986  | 32276 | 13 | 11029 | 2980 | 2772 |
| NC | 72900  | 19405  | 27238 | 14 | 2081  | 1046 | 971  |
| ND | 7098   | 15874  | 2562  | 8  | 162   | 540  | 498  |
| ОН | 74110  | 47373  | 22723 | 28 | 1719  | 1823 | 1685 |
| OK | 35634  | 21520  | 12536 | 12 | 248   | 847  | 781  |
| OR | 32118  | 21185  | 10648 | 11 | 625   | 822  | 775  |
| PA | 77555  | 38668  | 22839 | 27 | 3850  | 1963 | 1742 |
| RI | 11541  | 3949   | 3427  | 2  | 693   | 193  | 180  |
| SC | 55949  | 13129  | 19205 | 10 | 1462  | 745  | 684  |
| SD | 6062   | 4583   | 2289  | 2  | 44    | 167  | 154  |
| TN | 57694  | 29565  | 20778 | 18 | 1184  | 1480 | 1363 |
| ТХ | 137508 | 110413 | 46606 | 45 | 7482  | 4330 | 4119 |
| UT | 16813  | 9952   | 5368  | 7  | 709   | 386  | 350  |
| VT | 7769   | 1081   | 1926  | 1  | 25    | 94   | 78   |
| VA | 52220  | 46664  | 20886 | 25 | 4620  | 2035 | 1915 |
| WA | 60284  | 46537  | 18889 | 25 | 1820  | 1824 | 1729 |
| WV | 14719  | 29428  | 4366  | 14 | 1256  | 1069 | 1013 |
| WI | 99705  | 21229  | 37060 | 18 | 1212  | 1207 | 1114 |
| WY | 9961   | 37003  | 3298  | 17 | 387   | 1280 | 1178 |

Table 2-24. SEMAP 2007 onroad mobile source emissions state totals (TPY)

|    | СО      | NOX    | VOC    | NH3   | SO2  | PM2.5 |
|----|---------|--------|--------|-------|------|-------|
| AL | 909848  | 172674 | 77122  | 2823  | 1509 | 5888  |
| AZ | 705781  | 197933 | 74094  | 2973  | 1201 | 6258  |
| AR | 461467  | 96388  | 41768  | 1537  | 779  | 2952  |
| CA | 2339866 | 577924 | 255866 | 34289 | 3386 | 20521 |
| CO | 604386  | 128832 | 59801  | 2241  | 1184 | 4320  |
| СТ | 383443  | 54821  | 34949  | 1360  | 415  | 2067  |
| DE | 94312   | 17153  | 8037   | 295   | 145  | 550   |
| DC | 17151   | 3070   | 1557   | 77    | 26   | 112   |
| FL | 2565466 | 498934 | 222898 | 9676  | 5151 | 14481 |
| GA | 1909807 | 396844 | 160962 | 5416  | 6407 | 13682 |

| ID | 208516  | 42254  | 19036  | 650   | 406  | 1461  |
|----|---------|--------|--------|-------|------|-------|
| IL | 1556441 | 323575 | 157678 | 5181  | 2679 | 11422 |
| IN | 949063  | 208151 | 93414  | 3274  | 1693 | 6470  |
| IA | 492064  | 94726  | 47431  | 1530  | 825  | 3190  |
| KS | 383243  | 84487  | 36913  | 1397  | 778  | 2563  |
| KY | 704306  | 133430 | 55923  | 2172  | 1022 | 4365  |
| LA | 541618  | 124974 | 53436  | 2119  | 1065 | 3776  |
| ME | 224820  | 37704  | 15953  | 661   | 381  | 1467  |
| MD | 639880  | 119948 | 58926  | 2468  | 965  | 4137  |
| MA | 569774  | 72885  | 48529  | 2084  | 734  | 2801  |
| MI | 1509734 | 292799 | 143454 | 4597  | 2996 | 10564 |
| MN | 828165  | 155580 | 79078  | 2553  | 1164 | 5665  |
| MS | 525670  | 117231 | 45136  | 1809  | 920  | 4062  |
| MO | 879899  | 187661 | 84722  | 2978  | 1719 | 5928  |
| MT | 160938  | 37191  | 14159  | 513   | 312  | 1230  |
| NE | 238299  | 61038  | 24330  | 835   | 473  | 2089  |
| NV | 205385  | 41799  | 22287  | 932   | 289  | 1073  |
| NH | 204365  | 33469  | 14860  | 570   | 288  | 1370  |
| NJ | 820749  | 149986 | 79052  | 3429  | 1035 | 5519  |
| NM | 352296  | 94933  | 35178  | 1345  | 734  | 2926  |
| NY | 1930531 | 291087 | 155595 | 6699  | 2105 | 13160 |
| NC | 2111242 | 280672 | 137084 | 5053  | 2534 | 7382  |
| ND | 106359  | 22527  | 10177  | 324   | 172  | 755   |
| OH | 1546417 | 297954 | 137326 | 5072  | 2848 | 9762  |
| OK | 621094  | 129700 | 57927  | 2228  | 1175 | 4017  |
| OR | 445332  | 87721  | 40252  | 1496  | 669  | 2590  |
| PA | 1911032 | 348665 | 159478 | 5265  | 2479 | 12378 |
| RI | 126441  | 16485  | 9226   | 423   | 145  | 638   |
| SC | 745572  | 144481 | 54030  | 2303  | 1313 | 4995  |
| SD | 116213  | 28063  | 11693  | 403   | 217  | 903   |
| TN | 1198308 | 248811 | 86874  | 3322  | 1857 | 7784  |
| ТХ | 2525929 | 690334 | 267639 | 10847 | 5286 | 23642 |
| UT | 375141  | 70635  | 34346  | 1268  | 751  | 2345  |
| VT | 109376  | 16898  | 8985   | 335   | 162  | 678   |
| VA | 357736  | 60062  | 25237  | 875   | 488  | 1928  |
| WA | 1161832 | 194724 | 93056  | 3881  | 1423 | 6443  |
| WV | 831852  | 167358 | 72384  | 2684  | 1291 | 6026  |
| WI | 1188925 | 196779 | 96303  | 4041  | 1429 | 6513  |
| WY | 124339  | 31643  | 11510  | 421   | 256  | 1033  |

|    |        |        |       |       |         | ,     | /     |
|----|--------|--------|-------|-------|---------|-------|-------|
|    | CO     | NOX    | VOC   | NH3   | SO2     | PM10  | PM2.5 |
| AL | 119344 | 197965 | 38877 | 2191  | 526616  | 34777 | 24929 |
| AZ | 16928  | 56475  | 2614  | 973   | 78272   | 11317 | 5975  |
| AR | 37897  | 74686  | 27738 | 1189  | 87262   | 10924 | 7647  |
| CA | 72401  | 78943  | 39442 | 11593 | 25914   | 38543 | 23187 |
| CO | 37770  | 109930 | 71428 | 469   | 64717   | 20478 | 8961  |
| СТ | 4541   | 11125  | 1550  | 0     | 10090   | 1513  | 1395  |
| DE | 8408   | 18034  | 3279  | 105   | 45264   | 3927  | 3569  |
| DC | 384    | 911    | 64    | 0     | 613     | 66    | 59    |
| FL | 111280 | 237473 | 33682 | 1661  | 379594  | 35795 | 28418 |
| GA | 82547  | 154038 | 36718 | 6046  | 683362  | 30226 | 22296 |
| ID | 21142  | 12379  | 1028  | 1100  | 7462    | 3000  | 2350  |
| IL | 75920  | 198670 | 50091 | 1486  | 376550  | 28795 | 19123 |
| IN | 345190 | 262840 | 39116 | 1188  | 672340  | 74108 | 58005 |
| IA | 53220  | 89420  | 22304 | 3419  | 160880  | 17017 | 11422 |
| KS | 28046  | 105540 | 18521 | 1935  | 103180  | 8110  | 5356  |
| KY | 82554  | 210215 | 47679 | 113   | 410418  | 30678 | 21111 |
| LA | 129540 | 188390 | 68272 | 7710  | 226190  | 58667 | 49959 |
| ME | 14446  | 17684  | 4710  | 664   | 17174   | 4868  | 3828  |
| MD | 62669  | 75544  | 4132  | 55    | 324520  | 19278 | 15859 |
| MA | 10167  | 24054  | 4560  | 665   | 63663   | 5716  | 4930  |
| MI | 77885  | 180990 | 28299 | 920   | 389290  | 25132 | 15601 |
| MN | 27215  | 116740 | 22566 | 2056  | 99013   | 28730 | 16304 |
| MS | 40295  | 98183  | 34586 | 1640  | 94978   | 12368 | 8731  |
| MO | 92463  | 131830 | 17537 | 1656  | 367380  | 18551 | 11417 |
| MT | 27608  | 42328  | 4542  | 55    | 26659   | 5788  | 2202  |
| NE | 10995  | 56644  | 4061  | 1212  | 78223   | 5416  | 3932  |
| NV | 4638   | 26566  | 2429  | 302   | 10991   | 5605  | 3357  |
| NH | 3158   | 7409   | 913   | 128   | 45210   | 1922  | 1661  |
| NJ | 9472   | 29528  | 10284 | 684   | 40728   | 7426  | 6635  |
| NM | 32878  | 56904  | 8953  | 274   | 22810   | 2874  | 1734  |
| NY | 66894  | 93180  | 11688 | 2602  | 180990  | 9656  | 6061  |
| NC | 66811  | 100379 | 48349 | 1706  | 420434  | 42995 | 33444 |
| ND | 15347  | 78599  | 3790  | 6372  | 142080  | 4423  | 2574  |
| OH | 248770 | 301970 | 31785 | 3077  | 858750  | 73688 | 64874 |
| OK | 47178  | 142500 | 25551 | 3059  | 137050  | 14399 | 8951  |
| OR | 29273  | 22327  | 8245  | 255   | 15811   | 11414 | 9040  |
| PA | 102188 | 262346 | 27926 | 2388  | 1038778 | 50176 | 32821 |
| RI | 1653   | 1444   | 824   | 74    | 1516    | 189   | 140   |
| SC | 60375  | 81221  | 29281 | 1125  | 216127  | 30605 | 23493 |

Table 2-25. SEMAP 2007 total point source emissions state totals (TPY)

| SD | 572    | 13851  | 126    | 34   | 13537  | 242   | 229   |
|----|--------|--------|--------|------|--------|-------|-------|
| TN | 51185  | 144762 | 48103  | 1429 | 287668 | 26134 | 20403 |
| ТХ | 395800 | 371810 | 113790 | 6646 | 601750 | 58169 | 41417 |
| UT | 16769  | 84673  | 6942   | 568  | 28185  | 9250  | 4005  |
| VT | 2146   | 811    | 395    | 0    | 322    | 146   | 114   |
| VA | 72029  | 112938 | 35618  | 1830 | 243046 | 19202 | 14875 |
| WA | 54479  | 35632  | 12033  | 442  | 15500  | 5025  | 4329  |
| WV | 65230  | 188629 | 12502  | 366  | 428348 | 13736 | 9173  |
| WI | 43521  | 88123  | 27598  | 923  | 193140 | 12376 | 3420  |
| WY | 45007  | 114610 | 18227  | 722  | 106960 | 44501 | 24200 |

 Table 2-26. SEMAP 2007 total airport point source emissions state totals (TPY)

|    | CO    | NOX   | VOC  | NH3  | SO2  | PM10 | PM2.5 |
|----|-------|-------|------|------|------|------|-------|
| AL | 14778 | 440   | 891  | 51   | 294  | 205  | 14778 |
| AZ | 18174 | 3532  | 876  | 346  | 378  | 119  | 18174 |
| AR | 6445  | 358   | 226  | 46   | 135  | 24   | 6445  |
| CA | 52260 | 15405 | 2863 | 1404 | 1057 | 479  | 52260 |
| CO | 13229 | 3303  | 764  | 322  | 226  | 88   | 13229 |
| FL | 57330 | 10746 | 5060 | 992  | 1028 | 772  | 57330 |
| GA | 28081 | 4759  | 2772 | 608  | 433  | 346  | 28081 |
| ID | 4357  | 302   | 161  | 38   | 94   | 17   | 4357  |
| IL | 19004 | 7118  | 1171 | 684  | 333  | 166  | 19004 |
| IN | 7188  | 1392  | 423  | 132  | 144  | 44   | 7188  |
| IA | 3051  | 315   | 133  | 40   | 62   | 15   | 3051  |
| KS | 4540  | 224   | 190  | 30   | 94   | 17   | 4540  |
| KY | 11555 | 2257  | 918  | 219  | 204  | 154  | 11555 |
| LA | 7319  | 886   | 318  | 99   | 163  | 37   | 7319  |
| MI | 12743 | 2830  | 788  | 299  | 255  | 97   | 12743 |
| MN | 9228  | 2408  | 518  | 239  | 177  | 66   | 9228  |
| MS | 8519  | 219   | 665  | 26   | 168  | 117  | 8519  |
| MO | 7491  | 1984  | 508  | 217  | 134  | 61   | 7491  |
| MT | 3055  | 252   | 149  | 33   | 68   | 15   | 3055  |
| NE | 2849  | 394   | 156  | 45   | 56   | 17   | 2849  |
| NV | 7789  | 3338  | 523  | 305  | 145  | 77   | 7789  |
| NM | 4062  | 557   | 188  | 58   | 80   | 20   | 4062  |
| NC | 22481 | 3499  | 2487 | 370  | 521  | 423  | 22481 |
| ND | 2141  | 143   | 87   | 20   | 53   | 10   | 2141  |
| OH | 14477 | 2327  | 748  | 256  | 310  | 88   | 14477 |
| OK | 7068  | 574   | 270  | 67   | 142  | 29   | 7068  |
| OR | 7109  | 1176  | 309  | 120  | 136  | 37   | 7109  |
| SC | 11116 | 586   | 930  | 68   | 210  | 149  | 11116 |
| SD | 2285  | 165   | 98   | 21   | 50   | 10   | 2285  |
| Final Roport. | Emissions  | and Air | Quality | Modeling | for SEMAP |
|---------------|------------|---------|---------|----------|-----------|
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| TN | 16318 | 4055  | 1623 | 354  | 292  | 227  | 16318 |
|----|-------|-------|------|------|------|------|-------|
| ТХ | 87665 | 21870 | 9192 | 2272 | 1795 | 1360 | 87665 |
| UT | 5112  | 1300  | 276  | 134  | 91   | 38   | 5112  |
| VA | 23031 | 5385  | 2842 | 410  | 844  | 594  | 23031 |
| WA | 14018 | 2901  | 674  | 273  | 281  | 81   | 14018 |
| WV | 3607  | 59    | 257  | 7    | 72   | 50   | 3607  |
| WI | 32060 | 1310  | 3869 | 181  | 301  | 215  | 32060 |
| WY | 1413  | 99    | 79   | 12   | 28   | 6    | 1413  |

|    | Table 2-27. SEMAP 2007 total fire emissions state totals (TPY) |       |         |        |       |        |        |  |  |  |  |
|----|--|-------|---------|--------|-------|--------|--------|--|--|--|--|
|    | CO   | NOX   | VOC     | NH3    | SO2   | PM10   | PM2.5  |  |  |  |  |
| AL | 226950   | 7944  | 15861   | 1687   | 2137  | 31473  | 27666  |  |  |  |  |
| AZ | 166730   | 3091  | 39565   | 2752   | 1502  | 17690  | 14992  |  |  |  |  |
| AR | 927270   | 11989 | 218590  | 15206  | 6766  | 93738  | 79439  |  |  |  |  |
| CA | 2503400  | 31127 | 589770  | 41028  | 17886 | 251960 | 213520 |  |  |  |  |
| CO | 42683  | 761   | 10120   | 704    | 376   | 4502   | 3815   |  |  |  |  |
| СТ | 299  | 5     | 71      | 5      | 3     | 32     | 27     |  |  |  |  |
| DE | 1157   | 21    | 274     | 19     | 10    | 122    | 104    |  |  |  |  |
| FL | 857630   | 30157 | 64526   | 7400   | 7923  | 127610 | 113420 |  |  |  |  |
| GA | 1121800  | 45254 | 88902   | 9113   | 11619 | 175460 | 154220 |  |  |  |  |
| ID | 9474700  | 90718 | 2224600 | 154760 | 59411 | 929410 | 787640 |  |  |  |  |
| IL | 32847  | 524   | 7771    | 541    | 270   | 3409   | 2889   |  |  |  |  |
| IN | 14486  | 282   | 3441    | 239    | 135   | 1549   | 1313   |  |  |  |  |
| IA | 7840   | 148   | 1861    | 129    | 71    | 834    | 707    |  |  |  |  |
| KS | 107130   | 2356  | 25526   | 1776   | 1079  | 11697  | 9913   |  |  |  |  |
| KY | 16091  | 657   | 1272    | 139    | 180   | 2573   | 2235   |  |  |  |  |
| LA | 1645100  | 13215 | 385550  | 26821  | 9540  | 159110 | 134840 |  |  |  |  |
| ME | 3219   | 53    | 762     | 53     | 27    | 336    | 284    |  |  |  |  |
| MD | 11890  | 221   | 2822    | 196    | 107   | 1262   | 1069   |  |  |  |  |
| MA | 1309   | 25    | 311     | 22     | 12    | 139    | 118    |  |  |  |  |
| MI | 225230   | 2208  | 52899   | 3680   | 1428  | 22140  | 18763  |  |  |  |  |
| MN | 609730   | 6622  | 143380  | 9974   | 4063  | 60511  | 51281  |  |  |  |  |
| MS | 753720   | 12454 | 178430  | 12413  | 6328  | 78612  | 66621  |  |  |  |  |
| MO | 285840   | 4951  | 67731   | 4712   | 2470  | 30017  | 25438  |  |  |  |  |
| MT | 4969200  | 54558 | 1168700 | 81301  | 33293 | 493690 | 418380 |  |  |  |  |
| NE | 33852  | 300   | 7942    | 552    | 205   | 3299   | 2796   |  |  |  |  |
| NV | 130910   | 3320  | 31314   | 2178   | 1453  | 14686  | 12446  |  |  |  |  |
| NH | 1691   | 27    | 400     | 28     | 14    | 176    | 149    |  |  |  |  |
| NJ | 56198  | 536   | 13194   | 918    | 352   | 5511   | 4670   |  |  |  |  |
| NM | 147990   | 2187  | 34963   | 2432   | 1163  | 15205  | 12885  |  |  |  |  |
| NY | 11181  | 214   | 2655    | 185    | 103   | 1192   | 1010   |  |  |  |  |

NC

| ND | 34796   | 276   | 8154   | 567   | 201   | 3362   | 2850   |
|----|---------|-------|--------|-------|-------|--------|--------|
| OH | 11252   | 186   | 2664   | 185   | 94    | 1173   | 994    |
| OK | 346600  | 5815  | 82076  | 5710  | 2937  | 36229  | 30702  |
| OR | 2669800 | 25910 | 626940 | 43613 | 16847 | 262200 | 222200 |
| PA | 15128   | 245   | 3580   | 249   | 126   | 1574   | 1334   |
| RI | 93      | 2     | 22     | 2     | 1     | 10     | 8      |
| SC | 147030  | 6171  | 12789  | 1486  | 1616  | 25334  | 22984  |
| SD | 171300  | 1114  | 40074  | 2788  | 913   | 16334  | 13842  |
| TN | 23097   | 792   | 1576   | 167   | 217   | 3195   | 2753   |
| ТХ | 614250  | 9577  | 145250 | 10105 | 4982  | 63555  | 53860  |
| UT | 292460  | 4534  | 69152  | 4811  | 2364  | 30236  | 25624  |
| VT | 1105    | 20    | 262    | 18    | 10    | 117    | 99     |
| VA | 10329   | 362   | 722    | 77    | 99    | 1462   | 1272   |
| WA | 956530  | 8524  | 224410 | 15611 | 5804  | 93264  | 79037  |
| WV | 1516    | 62    | 119    | 13    | 17    | 241    | 208    |
| WI | 45056   | 745   | 10666  | 742   | 378   | 4699   | 3983   |
| WY | 834290  | 7356  | 195710 | 13615 | 5038  | 81275  | 68877  |

Table 2-28. SEMAP 2007 near and offshore shipping totals (TPY)

|        | 1 4010 - |         | 2007 neur un | a offenore si | upping ion |        |        |
|--------|----------|---------|--------------|---------------|------------|--------|--------|
|        | CO       | NOX     | VOC          | NH3           | SO2        | PM10   | PM2.5  |
| CA     | 1235     | 11208   | 339          | 7118          | 794        | 729    | 1235   |
| IL     | 8        | 102     | 3            | 64            | 8          | 8      | 8      |
| IN     | 4        | 45      | 2            | 31            | 4          | 4      | 4      |
| LA     | 1686     | 17774   | 613          | 11762         | 1538       | 1412   | 1686   |
| MI     | 861      | 10822   | 366          | 6396          | 862        | 793    | 861    |
| MN     | 25       | 306     | 10           | 196           | 26         | 24     | 25     |
| ОН     | 200      | 2499    | 85           | 1499          | 201        | 185    | 200    |
| OR     | 218      | 2175    | 114          | 1248          | 198        | 182    | 218    |
| ТХ     | 1040     | 9057    | 346          | 9516          | 1246       | 1143   | 1040   |
| WA     | 1604     | 18713   | 747          | 11280         | 1643       | 1490   | 1604   |
| WI     | 61       | 772     | 26           | 465           | 62         | 57     | 61     |
| Near-  |          |         |              |               |            |        |        |
| shore  | 50171    | 618630  | 21320        | 376180        | 50385      | 46307  | 50171  |
| SECA   | 147220   | 1816500 | 62564        | 1094800       | 147310     | 135730 | 147220 |
| Canada | 13792    | 169824  | 5858         | 102543        | 13827      | 12671  | 13792  |

|    |        | genic source | e emissions si |
|----|--------|--------------|----------------|
|    | CO     | NOX          | VOC            |
| AL | 177338 | 15052        | 1710315        |
| AZ | 372403 | 28838        | 1745470        |
| AR | 148167 | 25780        | 1196200        |
| CA | 443660 | 58754        | 2878423        |
| CO | 156469 | 38653        | 813819         |
| СТ | 7164   | 608          | 45825          |
| DE | 3690   | 980          | 29447          |
| DC | 134    | 18           | 1354           |
| FL | 229020 | 47773        | 1670058        |
| GA | 205821 | 24779        | 1909704        |
| ID | 191117 | 18659        | 933657         |
| IL | 91914  | 40988        | 498253         |
| IN | 59237  | 23002        | 328383         |
| IA | 77835  | 39867        | 342040         |
| KS | 138739 | 78281        | 493332         |
| KY | 80573  | 17652        | 588613         |
| LA | 145624 | 23350        | 1188400        |
| ME | 59315  | 2405         | 269255         |
| MD | 18248  | 3462         | 146514         |
| MA | 10925  | 1235         | 71506          |
| MI | 92045  | 18684        | 557100         |
| MN | 121644 | 35016        | 799671         |
| MS | 162064 | 18848        | 1508176        |
| MO | 134674 | 35781        | 1134279        |
| MT | 258440 | 66233        | 1184863        |
| NE | 114114 | 63262        | 449645         |
| NV | 218927 | 15583        | 935198         |
| NH | 14625  | 630          | 80710          |
| NJ | 13006  | 1921         | 115180         |
| NM | 253239 | 43743        | 1089017        |
| NY | 64785  | 9139         | 310364         |
| NC | 133292 | 16055        | 1126955        |
| ND | 79601  | 48209        | 272168         |
| OH | 63858  | 20274        | 331671         |
| OK | 138875 | 58222        | 846239         |
| OR | 234223 | 17465        | 1139088        |
| PA | 64135  | 9831         | 425753         |
| RI | 1533   | 167          | 11371          |
| SC | 98976  | 11864        | 908485         |

Table 2-29. SEMAP 2007 total biogenic source emissions state totals (TPY)

| SD | 111279 | 55723  | 468773  |
|----|--------|--------|---------|
| TN | 98607  | 16030  | 868972  |
| TX | 719359 | 276603 | 3154149 |
| UT | 162402 | 13618  | 743872  |
| VT | 14172  | 1123   | 63772   |
| VA | 86868  | 10070  | 773553  |
| WA | 157221 | 18411  | 613604  |
| WV | 40390  | 3608   | 354681  |
| WI | 78821  | 24639  | 501936  |
| WY | 142027 | 17806  | 705019  |

#### 2.3.2 2007 Typical

 Table 2-30. SEMAP typical year total fire emissions state totals (TPY)

|    |        |       | <u> </u> | 5    |      | ( )    |       |
|----|--------|-------|----------|------|------|--------|-------|
|    | CO     | NOX   | VOC      | NH3  | SO2  | PM10   | PM2.5 |
| AL | 230240 | 8019  | 16011    | 1701 | 2157 | 31785  | 27951 |
| AZ | 86791  | 1581  | 13223    | 1140 | 744  | 10185  | 8705  |
| AR | 579680 | 10760 | 86705    | 7777 | 5087 | 67884  | 58252 |
| CA | 396260 | 8861  | 60373    | 5177 | 3672 | 47877  | 40844 |
| CO | 49551  | 813   | 8081     | 690  | 408  | 5550   | 4737  |
| СТ | 780    | 16    | 140      | 11   | 8    | 95     | 80    |
| DE | 1212   | 24    | 247      | 18   | 11   | 130    | 111   |
| FL | 721450 | 23429 | 52696    | 6156 | 6006 | 103410 | 93131 |
| GA | 528320 | 19424 | 39877    | 3709 | 4491 | 76011  | 68750 |
| ID | 626470 | 16922 | 64132    | 6389 | 6256 | 87609  | 75130 |
| IL | 56406  | 945   | 10787    | 864  | 478  | 6098   | 5181  |
| IN | 24038  | 388   | 4118     | 344  | 199  | 2645   | 2252  |
| IA | 35017  | 694   | 7605     | 558  | 328  | 3789   | 3211  |
| KS | 335130 | 8743  | 70399    | 5256 | 3723 | 38519  | 32702 |
| KY | 13247  | 552   | 1064     | 116  | 151  | 2154   | 1873  |
| LA | 382040 | 6373  | 68325    | 5540 | 3264 | 42648  | 36350 |
| ME | 2999   | 33    | 512      | 43   | 20   | 300    | 254   |
| MD | 15366  | 282   | 2786     | 222  | 135  | 1736   | 1483  |
| MA | 2092   | 43    | 394      | 32   | 20   | 238    | 204   |
| MI | 26654  | 541   | 3775     | 330  | 240  | 3294   | 2814  |
| MN | 246580 | 4174  | 33178    | 2997 | 2046 | 29811  | 25449 |
| MS | 305180 | 6821  | 59615    | 4596 | 3035 | 34533  | 29353 |
| MO | 521970 | 7750  | 79943    | 7344 | 4122 | 58541  | 50082 |
| MT | 405540 | 10298 | 45808    | 4353 | 3948 | 55956  | 47928 |
| NE | 60945  | 1265  | 12369    | 941  | 584  | 6751   | 5734  |
| NV | 21650  | 706   | 2594     | 234  | 232  | 2976   | 2541  |
| NH | 1612   | 25    | 334      | 25   | 13   | 167    | 141   |
| NJ | 32042  | 588   | 4231     | 394  | 260  | 3861   | 3295  |

| NM | 47560  | 972  | 7821  | 639  | 434  | 5613  | 4777  |
|----|--------|------|-------|------|------|-------|-------|
| NY | 11368  | 207  | 1632  | 141  | 103  | 1376  | 1177  |
| NC | 23144  | 977  | 1861  | 205  | 268  | 3792  | 3304  |
| ND | 111940 | 2244 | 22196 | 1705 | 1052 | 12480 | 10604 |
| OH | 17273  | 335  | 3114  | 250  | 162  | 1982  | 1687  |
| OK | 429020 | 9199 | 77469 | 6222 | 4146 | 49386 | 42139 |
| OR | 484980 | 7211 | 66566 | 6084 | 3786 | 57016 | 48789 |
| PA | 21679  | 364  | 4078  | 323  | 186  | 2393  | 2033  |
| RI | 185    | 4    | 44    | 3    | 2    | 20    | 17    |
| SC | 144800 | 6072 | 12642 | 1473 | 1586 | 25012 | 22732 |
| SD | 84244  | 1260 | 14662 | 1192 | 656  | 9270  | 7903  |
| TN | 14238  | 479  | 956   | 101  | 131  | 1941  | 1672  |
| ТХ | 383400 | 8731 | 77498 | 5828 | 3912 | 43925 | 37363 |
| UT | 47199  | 1238 | 6466  | 567  | 463  | 6225  | 5326  |
| VT | 956    | 16   | 168   | 14   | 8    | 108   | 92    |
| VA | 9862   | 379  | 743   | 80   | 103  | 1504  | 1309  |
| WA | 184760 | 3177 | 27336 | 2380 | 1528 | 21856 | 18682 |
| WV | 577    | 22   | 44    | 5    | 6    | 88    | 76    |
| WI | 41341  | 656  | 8221  | 623  | 337  | 4449  | 3780  |
| WY | 106580 | 2067 | 15454 | 1370 | 918  | 12934 | 11052 |

#### 2.3.3 2018 Base

Table 2-31. SEMAP 2018 nonpoint source emissions state totals (TPY)

|    | CO     | NOX   | VOC    | NH3   | SO2   | <b>PM10</b> | PM2.5 |
|----|--------|-------|--------|-------|-------|-------------|-------|
| AL | 6135   | 3689  | 71654  | 379   | 338   | 3182        | 2785  |
| AZ | 36371  | 15594 | 91491  | 8884  | 3393  | 14752       | 12832 |
| AR | 92376  | 12901 | 77452  | 330   | 1157  | 13930       | 12348 |
| CA | 161900 | 68074 | 281610 | 62981 | 6088  | 58210       | 44615 |
| CO | 5602   | 6469  | 46543  | 1222  | 125   | 1623        | 1611  |
| СТ | 6111   | 10516 | 40639  | 1584  | 12856 | 2080        | 1963  |
| DE | 3594   | 2131  | 7873   | 519   | 934   | 2173        | 910   |
| DC | 998    | 1491  | 4579   | 151   | 986   | 215         | 204   |
| FL | 20872  | 6052  | 233020 | 253   | 10273 | 17408       | 11423 |
| GA | 35126  | 12669 | 117550 | 1272  | 3935  | 13536       | 12183 |
| ID | 85226  | 11343 | 90460  | 2222  | 8865  | 6317        | 5468  |
| IL | 46416  | 44581 | 193300 | 5112  | 4481  | 10825       | 10410 |
| IN | 19458  | 21068 | 140870 | 1043  | 15859 | 7413        | 6791  |
| IA | 27483  | 5255  | 64911  | 695   | 2143  | 5394        | 5076  |
| KS | 65497  | 19025 | 71627  | 4961  | 7440  | 16039       | 9191  |
| KY | 38616  | 12235 | 63531  | 524   | 15228 | 19636       | 14223 |
| LA | 126120 | 30012 | 136600 | 27343 | 2540  | 17365       | 16123 |
| ME | 21222  | 5541  | 21609  | 711   | 7781  | 2835        | 2708  |

| MD | 38793  | 10420  | 51191   | 1050  | 1582  | 6898  | 5534  |
|----|--------|--------|---------|-------|-------|-------|-------|
| MA | 30245  | 18163  | 58390   | 10075 | 15865 | 6448  | 5719  |
| MI | 19463  | 31311  | 147330  | 3611  | 12227 | 0     | 0     |
| MN | 80915  | 17952  | 98514   | 1777  | 8114  | 15506 | 13403 |
| MS | 17092  | 6081   | 59674   | 264   | 324   | 6404  | 5856  |
| MO | 67561  | 18157  | 113580  | 1348  | 44313 | 11036 | 10338 |
| MT | 11443  | 1897   | 14970   | 218   | 321   | 1842  | 1620  |
| NE | 12603  | 2682   | 38591   | 372   | 200   | 2733  | 2641  |
| NV | 5341   | 4077   | 36104   | 250   | 4459  | 2983  | 1900  |
| NH | 20276  | 3890   | 17917   | 191   | 4111  | 2671  | 2147  |
| NJ | 37427  | 22718  | 83268   | 12667 | 613   | 10685 | 7336  |
| NM | 18296  | 2710   | 32217   | 323   | 53    | 3021  | 2583  |
| NY | 88488  | 62174  | 172970  | 4755  | 11389 | 22012 | 18393 |
| NC | 19369  | 11749  | 140740  | 769   | 7024  | 7854  | 7063  |
| ND | 19865  | 1734   | 20319   | 119   | 658   | 2402  | 2344  |
| ОН | 71706  | 35234  | 152460  | 3063  | 12152 | 13481 | 12580 |
| OK | 104080 | 84275  | 246080  | 781   | 4514  | 13355 | 9867  |
| OR | 25565  | 3201   | 45126   | 444   | 691   | 4449  | 3897  |
| PA | 114430 | 44390  | 148310  | 975   | 55630 | 26661 | 20596 |
| RI | 4126   | 3112   | 18461   | 276   | 3193  | 998   | 853   |
| SC | 27027  | 9456   | 58713   | 402   | 6002  | 16964 | 13764 |
| SD | 6719   | 1733   | 25561   | 137   | 299   | 1478  | 1363  |
| TN | 33117  | 12252  | 89190   | 945   | 14116 | 21447 | 10284 |
| ТХ | 215430 | 322650 | 1713600 | 2093  | 1452  | 27780 | 22179 |
| UT | 33138  | 8411   | 70332   | 5531  | 1243  | 6612  | 4810  |
| VT | 16473  | 3210   | 7681    | 150   | 3007  | 3435  | 2964  |
| VA | 42820  | 17121  | 121170  | 1267  | 14714 | 14180 | 12636 |
| WA | 48360  | 6134   | 80418   | 807   | 1223  | 7863  | 6866  |
| WV | 15173  | 3329   | 25427   | 375   | 5435  | 6109  | 5213  |
| WI | 58760  | 24954  | 106210  | 1787  | 5484  | 10918 | 10365 |
| WY | 13102  | 17156  | 113670  | 125   | 1675  | 792   | 690   |

Table 2-32. SEMAP 2018 RWC source emissions state totals (TPY)

|    | CO     | NOX  | VOC   | NH3  | SO2 | PM10  | PM2.5 |
|----|--------|------|-------|------|-----|-------|-------|
| AL | 8820   | 146  | 1537  | 77   | 20  | 1300  | 1298  |
| AZ | 18127  | 310  | 3244  | 154  | 48  | 2641  | 2638  |
| AR | 9904   | 162  | 1823  | 84   | 22  | 1432  | 1430  |
| CA | 274629 | 3528 | 17968 | 2044 | 530 | 39296 | 37829 |
| CO | 91792  | 1414 | 16522 | 744  | 224 | 13146 | 13137 |
| СТ | 32049  | 585  | 5725  | 260  | 87  | 4602  | 4598  |
| DE | 4287   | 78   | 758   | 35   | 12  | 617   | 617   |
| DC | 4249   | 69   | 745   | 37   | 10  | 625   | 624   |

| FL | 9171   | 161  | 1553  | 83  | 21  | 1385  | 1382  |
|----|--------|------|-------|-----|-----|-------|-------|
| GA | 12007  | 206  | 2084  | 105 | 27  | 1793  | 1790  |
| ID | 15629  | 264  | 3131  | 119 | 40  | 2252  | 2250  |
| IL | 45995  | 654  | 8425  | 393 | 100 | 6531  | 6531  |
| IN | 31764  | 444  | 5950  | 263 | 68  | 4472  | 4472  |
| IA | 24230  | 384  | 4438  | 197 | 67  | 3456  | 3452  |
| KS | 16441  | 265  | 3012  | 134 | 44  | 2355  | 2352  |
| KY | 17093  | 280  | 2994  | 146 | 41  | 2508  | 2504  |
| LA | 16563  | 234  | 5504  | 59  | 30  | 2313  | 2311  |
| ME | 26045  | 420  | 4505  | 218 | 90  | 3775  | 3770  |
| MD | 33838  | 528  | 5853  | 285 | 91  | 4924  | 4918  |
| MA | 45237  | 821  | 7821  | 379 | 130 | 6592  | 6584  |
| MI | 55839  | 797  | 10347 | 500 | 120 | 7967  | 7967  |
| MN | 81970  | 1199 | 14458 | 667 | 248 | 11941 | 11940 |
| MS | 5603   | 92   | 977   | 49  | 13  | 825   | 824   |
| MO | 37831  | 606  | 6898  | 311 | 103 | 5425  | 5419  |
| MT | 9516   | 161  | 1699  | 80  | 27  | 1377  | 1375  |
| NE | 13160  | 211  | 2413  | 107 | 36  | 1879  | 1877  |
| NV | 12029  | 232  | 3309  | 93  | 317 | 1700  | 1697  |
| NH | 17129  | 262  | 2977  | 143 | 65  | 2455  | 2457  |
| NJ | 36135  | 613  | 6704  | 288 | 93  | 5162  | 5157  |
| NM | 14256  | 243  | 2561  | 120 | 39  | 2062  | 2060  |
| NY | 129885 | 1537 | 11298 | 930 | 262 | 14567 | 14567 |
| NC | 18703  | 315  | 3291  | 160 | 43  | 2765  | 2760  |
| ND | 4957   | 80   | 910   | 40  | 14  | 708   | 707   |
| OH | 64992  | 903  | 12271 | 532 | 138 | 9122  | 9122  |
| OK | 9370   | 151  | 1723  | 80  | 21  | 1356  | 1355  |
| OR | 86810  | 1544 | 15091 | 724 | 243 | 12917 | 12906 |
| PA | 89064  | 1535 | 16555 | 728 | 248 | 12706 | 12719 |
| RI | 10182  | 190  | 1830  | 81  | 29  | 1452  | 1450  |
| SC | 6662   | 112  | 1170  | 57  | 15  | 984   | 983   |
| SD | 5632   | 91   | 1034  | 46  | 15  | 804   | 804   |
| TN | 12351  | 203  | 2175  | 105 | 28  | 1813  | 1807  |
| TX | 46739  | 790  | 8237  | 419 | 105 | 6939  | 6927  |
| UT | 14603  | 270  | 2495  | 128 | 46  | 2149  | 2146  |
| VT | 30078  | 432  | 4630  | 247 | 152 | 4360  | 4358  |
| VA | 22268  | 378  | 3902  | 191 | 52  | 3299  | 3293  |
| WA | 102740 | 1590 | 18437 | 822 | 239 | 14564 | 14564 |
| WV | 8245   | 137  | 1450  | 70  | 20  | 1214  | 1212  |
| WI | 64571  | 901  | 12262 | 513 | 141 | 9178  | 9178  |
| WY | 5327   | 90   | 952   | 45  | 15  | 771   | 770   |

|    | PM10   | PM2.5  |  |  |
|----|--------|--------|--|--|
| AL | 338680 | 36565  |  |  |
| AZ | 257610 | 36317  |  |  |
| AR | 369000 | 54140  |  |  |
| CA | 695090 | 84793  |  |  |
| CO | 285880 | 45894  |  |  |
| СТ | 8698   | 1379   |  |  |
| DE | 4777   | 915    |  |  |
| DC | 1675   | 289    |  |  |
| FL | 318490 | 26751  |  |  |
| GA | 619270 | 68672  |  |  |
| ID | 383230 | 61947  |  |  |
| IL | 715050 | 114840 |  |  |
| IN | 493800 | 67155  |  |  |
| IA | 513550 | 87591  |  |  |
| KS | 770150 | 117710 |  |  |
| KY | 205290 | 23643  |  |  |
| LA | 190760 | 22034  |  |  |
| ME | 13212  | 1717   |  |  |
| MD | 29338  | 4790   |  |  |
| MA | 44939  | 5800   |  |  |
| MI | 345010 | 49828  |  |  |
| MN | 647080 | 95043  |  |  |
| MS | 314100 | 35320  |  |  |
| MO | 781810 | 101580 |  |  |
| MT | 330020 | 45470  |  |  |
| NE | 488000 | 74247  |  |  |
| NV | 221530 | 24527  |  |  |
| NH | 5532   | 976    |  |  |
| NJ | 9631   | 2252   |  |  |
| NM | 799970 | 84087  |  |  |
| NY | 113210 | 16742  |  |  |
| NC | 34534  | 3428   |  |  |
| ND | 407480 | 71066  |  |  |
| OH | 434810 | 56711  |  |  |
| OK | 711740 | 90618  |  |  |
| OR | 209430 | 26379  |  |  |
| PA | 100300 | 16030  |  |  |
| RI | 3300   | 573    |  |  |

 

 Table 2-33. SEMAP 2018 road and fugitive dust source emissions state totals (TPY); note that only the MANE-VU states include vegetative adjustment factors

| SC | 244890  | 24749  |
|----|---------|--------|
| SD | 248400  | 43419  |
| TN | 204900  | 23277  |
| ТХ | 2300200 | 289610 |
| UT | 210350  | 25839  |
| VT | 10500   | 1492   |
| VA | 160240  | 24787  |
| WA | 194560  | 25946  |
| WV | 92394   | 10395  |
| WI | 237410  | 40031  |
| WY | 476820  | 52628  |

Table 2-34. SEMAP 2018 livestock and fertilizer source emissions state totals (TPY)

|    | Fertilizer NH3 | Livestock NH3 |
|----|----------------|---------------|
| AL | 6918           | 58994         |
| AZ | 6356           | 22327         |
| AR | 42570          | 77632         |
| CA | 65914          | 192380        |
| CO | 14537          | 53940         |
| СТ | 405            | 2203          |
| DE | 429            | 14250         |
| FL | 8009           | 25939         |
| GA | 11828          | 73407         |
| ID | 25721          | 76041         |
| IL | 69613          | 46914         |
| IN | 42503          | 59125         |
| IA | 89461          | 206090        |
| KS | 59036          | 92101         |
| KY | 18730          | 36181         |
| LA | 18925          | 18048         |
| ME | 1986           | 3288          |
| MD | 4823           | 19923         |
| MA | 731            | 2727          |
| MI | 24271          | 36522         |
| MN | 72561          | 111050        |
| MS | 13138          | 49031         |
| MO | 44848          | 79482         |
| MT | 33715          | 21230         |
| NE | 64673          | 111500        |
| NV | 786            | 4585          |
| NH | 116            | 1078          |
| NJ | 1403           | 2017          |

| NM | 13996 | 31895  |
|----|-------|--------|
| NY | 4131  | 36404  |
| NC | 16050 | 152770 |
| ND | 63948 | 14742  |
| OH | 31318 | 52213  |
| OK | 25037 | 72133  |
| OR | 24687 | 17952  |
| PA | 9695  | 65985  |
| RI | 92    | 180    |
| SC | 5798  | 24396  |
| SD | 84902 | 46529  |
| TN | 9373  | 27006  |
| ТХ | 86218 | 202030 |
| UT | 1702  | 34105  |
| VT | 758   | 6858   |
| VA | 9417  | 32874  |
| WA | 17920 | 24800  |
| WV | 4063  | 8715   |
| WI | 32876 | 82453  |
| WY | 6877  | 12382  |

Table 2-35. SEMAP 2018 nonroad source emissions state totals (TPY)

|    | CO      | NOX   | VOC    | NH3 | SO2 | PM10  | PM2.5 |
|----|---------|-------|--------|-----|-----|-------|-------|
| AL | 184263  | 11544 | 18238  | 30  | 31  | 1493  | 1411  |
| AZ | 256634  | 18253 | 22015  | 44  | 45  | 2305  | 2184  |
| AR | 121022  | 13692 | 15170  | 26  | 28  | 1473  | 1403  |
| CA | 1470933 | 87045 | 107290 | 208 | 185 | 11120 | 10513 |
| CO | 226991  | 18096 | 21351  | 40  | 42  | 2149  | 2039  |
| СТ | 131700  | 6689  | 8914   | 17  | 25  | 826   | 785   |
| DE | 30924   | 2108  | 2162   | 5   | 5   | 246   | 232   |
| DC | 9845    | 1396  | 633    | 3   | З   | 121   | 117   |
| FL | 809861  | 50336 | 58411  | 132 | 119 | 6283  | 5950  |
| GA | 378180  | 24737 | 30964  | 63  | 62  | 3087  | 2921  |
| ID | 76403   | 8359  | 12342  | 17  | 18  | 987   | 936   |
| IL | 481546  | 53296 | 42443  | 111 | 116 | 5164  | 4926  |
| IN | 250091  | 28070 | 23309  | 58  | 65  | 2708  | 2583  |
| IA | 144220  | 32892 | 16576  | 54  | 50  | 2881  | 2770  |
| KS | 125075  | 25921 | 10579  | 42  | 40  | 2230  | 2146  |
| KY | 147336  | 13771 | 14645  | 30  | 30  | 1485  | 1413  |
| LA | 165404  | 12514 | 17709  | 28  | 31  | 1463  | 1387  |
| ME | 77890   | 3658  | 16207  | 13  | 13  | 736   | 685   |
| MD | 220181  | 11847 | 15373  | 31  | 30  | 1564  | 1482  |

| MA | 222308 | 11575 | 15789 | 30  | 34  | 1387 | 1314 |
|----|--------|-------|-------|-----|-----|------|------|
| MI | 441431 | 32052 | 70784 | 85  | 100 | 4218 | 3972 |
| MN | 253585 | 32811 | 43721 | 63  | 64  | 3588 | 3416 |
| MS | 103692 | 9085  | 12300 | 21  | 21  | 1040 | 987  |
| MO | 241333 | 26302 | 21914 | 50  | 53  | 2689 | 2566 |
| MT | 49010  | 10810 | 7098  | 18  | 16  | 987  | 947  |
| NE | 84604  | 22227 | 8205  | 35  | 31  | 1875 | 1806 |
| NV | 118964 | 9422  | 10383 | 22  | 21  | 1182 | 1121 |
| NH | 63125  | 3142  | 9070  | 10  | 11  | 510  | 481  |
| NJ | 337307 | 16403 | 21630 | 43  | 46  | 2017 | 1903 |
| NM | 64889  | 4716  | 6030  | 11  | 11  | 550  | 522  |
| NY | 650282 | 33951 | 54035 | 87  | 93  | 3993 | 3780 |
| NC | 371460 | 25339 | 29696 | 62  | 66  | 3051 | 2891 |
| ND | 49938  | 22322 | 6764  | 33  | 27  | 1801 | 1739 |
| ОН | 472792 | 33867 | 39206 | 78  | 90  | 3870 | 3666 |
| OK | 150304 | 15532 | 13157 | 30  | 31  | 1591 | 1517 |
| OR | 160476 | 12338 | 16231 | 28  | 31  | 1496 | 1418 |
| PA | 494127 | 25534 | 42147 | 66  | 75  | 3265 | 3090 |
| RI | 31868  | 1640  | 1897  | 4   | 5   | 196  | 187  |
| SC | 221277 | 11367 | 14742 | 30  | 31  | 1448 | 1371 |
| SD | 44560  | 15708 | 5978  | 24  | 20  | 1306 | 1259 |
| TN | 228021 | 16840 | 21417 | 40  | 43  | 1961 | 1859 |
| TX | 835847 | 72140 | 64597 | 154 | 164 | 7760 | 7388 |
| UT | 95630  | 7279  | 13239 | 17  | 19  | 940  | 889  |
| VT | 31653  | 1859  | 5759  | 5   | 6   | 305  | 284  |
| VA | 333903 | 18719 | 23519 | 48  | 47  | 2428 | 2296 |
| WA | 252505 | 20131 | 24040 | 45  | 49  | 2357 | 2236 |
| WV | 72202  | 3743  | 9066  | 10  | 10  | 551  | 518  |
| WI | 251943 | 22321 | 40007 | 53  | 59  | 2678 | 2532 |
| WY | 30712  | 2902  | 5406  | 6   | 7   | 352  | 333  |

Table 2-36. SEMAP 2018 alm source emissions state totals (TPY)

|    | CO     | NOX    | VOC   | NH3 | SO2  | PM10 | PM2.5 |
|----|--------|--------|-------|-----|------|------|-------|
| AL | 43177  | 30914  | 10197 | 22  | 1145 | 934  | 887   |
| AZ | 22467  | 18688  | 6133  | 19  | 14   | 495  | 489   |
| AR | 25725  | 25881  | 6245  | 27  | 94   | 682  | 638   |
| CA | 139834 | 112436 | 32235 | 226 | 2619 | 4393 | 4178  |
| CO | 10810  | 12258  | 2457  | 7   | 8    | 315  | 311   |
| СТ | 15973  | 7427   | 3040  | 6   | 245  | 265  | 240   |
| DE | 10894  | 5083   | 2304  | 2   | 281  | 152  | 138   |
| DC | 340    | 438    | 84    | 0   | 1    | 9    | 9     |
| FL | 186861 | 69490  | 50631 | 69  | 2625 | 1955 | 1842  |

| GA | 40209  | 29146  | 9714  | 21 | 675  | 799  | 751  |
|----|--------|--------|-------|----|------|------|------|
| ID | 10422  | 5362   | 2249  | 6  | 5    | 249  | 249  |
| IL | 56682  | 77825  | 10868 | 66 | 176  | 2039 | 1957 |
| IN | 38180  | 37823  | 7633  | 31 | 84   | 965  | 907  |
| IA | 46089  | 23790  | 4558  | 17 | 36   | 574  | 578  |
| KS | 13182  | 27892  | 2985  | 15 | 18   | 719  | 726  |
| KY | 28097  | 26170  | 5899  | 21 | 991  | 787  | 749  |
| LA | 83540  | 128129 | 15694 | 57 | 825  | 3407 | 3449 |
| ME | 46151  | 3634   | 3030  | 2  | 36   | 291  | 254  |
| MD | 37882  | 17911  | 6508  | 12 | 478  | 530  | 454  |
| MA | 32928  | 11442  | 5502  | 6  | 297  | 615  | 517  |
| MI | 99677  | 19938  | 19288 | 19 | 72   | 610  | 594  |
| MN | 63244  | 38644  | 13060 | 24 | 147  | 1063 | 1062 |
| MS | 29945  | 24093  | 7009  | 18 | 1101 | 743  | 708  |
| MO | 50355  | 51762  | 11302 | 30 | 138  | 1379 | 1387 |
| MT | 7454   | 14518  | 1568  | 9  | 9    | 382  | 385  |
| NE | 16135  | 44713  | 3486  | 25 | 27   | 1148 | 1160 |
| NV | 8909   | 7129   | 2142  | 5  | 6    | 198  | 198  |
| NH | 10831  | 3310   | 1780  | 2  | 86   | 105  | 92   |
| NJ | 46220  | 23278  | 7948  | 17 | 946  | 607  | 550  |
| NM | 10521  | 24054  | 2384  | 13 | 14   | 620  | 627  |
| NY | 83668  | 46497  | 14834 | 13 | 1654 | 1473 | 1385 |
| NC | 49554  | 16169  | 11316 | 15 | 305  | 449  | 420  |
| ND | 7115   | 14834  | 1498  | 9  | 9    | 383  | 387  |
| OH | 62792  | 64869  | 11033 | 48 | 218  | 1677 | 1605 |
| OK | 26214  | 19042  | 6762  | 12 | 17   | 513  | 513  |
| OR | 25313  | 28248  | 5454  | 14 | 99   | 705  | 684  |
| PA | 62865  | 28428  | 10923 | 27 | 808  | 1075 | 928  |
| RI | 6140   | 2705   | 1011  | 2  | 97   | 109  | 98   |
| SC | 43578  | 10264  | 8197  | 10 | 585  | 309  | 283  |
| SD | 4895   | 2934   | 1113  | 2  | 3    | 80   | 80   |
| TN | 38769  | 22573  | 9403  | 17 | 759  | 824  | 763  |
| ТХ | 104207 | 140653 | 27368 | 82 | 502  | 4617 | 4294 |
| UT | 12242  | 9498   | 2711  | 9  | 7    | 80   | 74   |
| VT | 5590   | 1136   | 923   | 1  | 14   | 66   | 53   |
| VA | 49661  | 36122  | 8785  | 26 | 1289 | 1031 | 979  |
| WA | 43035  | 35964  | 9142  | 30 | 187  | 813  | 789  |
| WV | 11262  | 22029  | 2054  | 14 | 993  | 675  | 645  |
| WI | 70174  | 22256  | 17498 | 24 | 42   | 668  | 618  |
| WY | 7576   | 19941  | 1587  | 11 | 12   | 512  | 517  |

|    | CO      | NOX    | VOC    | NH3   | SO2  | PM2.5 |
|----|---------|--------|--------|-------|------|-------|
| AL | 508548  | 70068  | 36082  | 1772  | 533  | 2663  |
| AZ | 573197  | 106555 | 32603  | 3225  | 941  | 5549  |
| AR | 201059  | 35718  | 15002  | 907   | 339  | 1390  |
| CA | 2362995 | 478752 | 116181 | 16794 | 3206 | 29876 |
| CO | 365686  | 60028  | 26317  | 1528  | 568  | 2616  |
| СТ | 268239  | 26665  | 18669  | 1180  | 359  | 1353  |
| DE | 65875   | 8337   | 4269   | 256   | 126  | 360   |
| DC | 7218    | 1055   | 524    | 39    | 17   | 55    |
| FL | 1368494 | 191926 | 105343 | 6022  | 1729 | 6832  |
| GA | 1037134 | 152195 | 160914 | 3392  | 3439 | 5601  |
| ID | 126124  | 19433  | 7628   | 518   | 186  | 798   |
| IL | 748596  | 123224 | 51458  | 3179  | 1193 | 5360  |
| IN | 541534  | 85018  | 36302  | 2145  | 795  | 3572  |
| IA | 247280  | 37395  | 16392  | 957   | 333  | 1536  |
| KS | 206834  | 33666  | 14435  | 839   | 316  | 1387  |
| KY | 414019  | 57657  | 27271  | 1373  | 375  | 1965  |
| LA | 269089  | 47959  | 20452  | 1249  | 473  | 1833  |
| ME | 148121  | 17635  | 7924   | 514   | 317  | 940   |
| MD | 405901  | 54527  | 28818  | 1950  | 787  | 2545  |
| MA | 398893  | 35478  | 25890  | 1810  | 637  | 1835  |
| MI | 857335  | 134988 | 48801  | 4051  | 1286 | 5482  |
| MN | 497136  | 70576  | 28586  | 1856  | 655  | 3174  |
| MS | 290728  | 49097  | 21502  | 1102  | 323  | 1680  |
| MO | 446790  | 75618  | 31031  | 1927  | 725  | 3134  |
| MT | 193186  | 24876  | 5292   | 581   | 219  | 789   |
| NE | 139497  | 21405  | 9461   | 538   | 200  | 921   |
| NV | 118991  | 22184  | 10170  | 555   | 208  | 908   |
| NH | 141642  | 16167  | 7774   | 487   | 247  | 892   |
| NJ | 572884  | 72840  | 42050  | 2967  | 896  | 3605  |
| NM | 213616  | 39777  | 13637  | 1116  | 340  | 2023  |
| NY | 1314465 | 138809 | 80369  | 5505  | 1770 | 8546  |
| NC | 1259227 | 106182 | 59021  | 3132  | 849  | 2988  |
| ND | 131901  | 16352  | 3566   | 363   | 140  | 553   |
| OH | 8872    | 2066   | 552    | 3066  | 1135 | 51    |
| OK | 341361  | 56121  | 24454  | 1424  | 538  | 2221  |
| OR | 225977  | 40450  | 15805  | 998   | 369  | 1694  |
| PA | 1308558 | 166488 | 82958  | 4484  | 2103 | 7901  |
| RI | 88431   | 8016   | 4920   | 366   | 126  | 417   |
| SC | 451974  | 56589  | 24622  | 1456  | 430  | 2160  |

 Table 2-37. SEMAP 2018 onroad mobile source emissions state totals (TPY)

| Final Report: | Emissions  | and Air | <b>O</b> uality | Modeling | for SEMAP |
|---------------|------------|---------|-----------------|----------|-----------|
| 1 mai nepon.  | Linissions | unu mi  | Quanty          | mouching | JOI SLIMM |

|    |         |        | 0      |       |      |       |
|----|---------|--------|--------|-------|------|-------|
| SD | 64337   | 9639   | 4358   | 239   | 89   | 434   |
| TN | 633649  | 95973  | 40676  | 2088  | 582  | 3251  |
| ТХ | 2940409 | 549293 | 105546 | 18693 | 4408 | 37236 |
| UT | 187841  | 31475  | 13592  | 802   | 284  | 1277  |
| VT | 75154   | 8114   | 4672   | 282   | 139  | 441   |
| VA | 673648  | 70499  | 42414  | 2575  | 793  | 2547  |
| WA | 785801  | 117871 | 29180  | 3443  | 1069 | 3908  |
| WV | 234835  | 28648  | 13263  | 567   | 158  | 889   |
| WI | 472457  | 74339  | 32408  | 1826  | 686  | 3440  |
| WY | 63919   | 9614   | 4348   | 244   | 91   | 419   |

 Table 2-38. SEMAP 2018 total point source emissions state totals (TPY)

|    | CO     | NOX    | VOC   | NH3   | SO2    | PM10  | PM2.5 |
|----|--------|--------|-------|-------|--------|-------|-------|
| AL | 124934 | 114553 | 38842 | 2339  | 165129 | 31344 | 23225 |
| AZ | 35054  | 48414  | 5893  | 1303  | 60983  | 11426 | 7536  |
| AR | 71938  | 68360  | 32257 | 2608  | 104942 | 18073 | 13331 |
| CA | 162908 | 100084 | 48114 | 14320 | 25998  | 36765 | 20900 |
| CO | 28144  | 68197  | 15515 | 520   | 75463  | 18398 | 10729 |
| СТ | 5007   | 12407  | 1779  | 0     | 10140  | 1462  | 1347  |
| DE | 8656   | 16239  | 2704  | 101   | 43599  | 3703  | 3361  |
| DC | 411    | 957    | 66    | 0     | 522    | 49    | 45    |
| FL | 108288 | 128630 | 35751 | 2700  | 187152 | 34439 | 28491 |
| GA | 80227  | 80628  | 35448 | 6192  | 65827  | 22663 | 17720 |
| ID | 27604  | 10199  | 1603  | 1287  | 17296  | 3197  | 2089  |
| IL | 122028 | 119213 | 51422 | 2660  | 199244 | 32999 | 21731 |
| IN | 376597 | 169724 | 52173 | 2321  | 274837 | 58602 | 35863 |
| IA | 29664  | 73532  | 30112 | 1506  | 108021 | 19993 | 11268 |
| KS | 36056  | 87346  | 23068 | 61478 | 56019  | 16279 | 10078 |
| KY | 86327  | 112772 | 47019 | 120   | 162424 | 28986 | 19744 |
| LA | 161886 | 179469 | 67951 | 6909  | 272110 | 43132 | 33892 |
| ME | 21401  | 21094  | 4920  | 645   | 14355  | 4623  | 3783  |
| MD | 72529  | 76951  | 5348  | 137   | 324007 | 19462 | 15809 |
| MA | 11530  | 25370  | 4265  | 645   | 62636  | 5590  | 4840  |
| MI | 105657 | 143915 | 35267 | 1957  | 211648 | 28965 | 19602 |
| MN | 37347  | 99196  | 24507 | 28402 | 76922  | 23009 | 12450 |
| MS | 41845  | 100770 | 35441 | 1806  | 80174  | 12796 | 9271  |
| MO | 91381  | 94567  | 21500 | 2084  | 211664 | 20641 | 13278 |
| MT | 28900  | 26052  | 6966  | 411   | 31212  | 12112 | 6411  |
| NE | 14642  | 41748  | 10156 | 1820  | 77770  | 9499  | 5168  |
| NV | 31193  | 29013  | 3158  | 1314  | 16088  | 9745  | 6426  |
| NH | 5883   | 7396   | 929   | 134   | 45174  | 2042  | 1771  |
| NJ | 9539   | 27562  | 9888  | 475   | 39871  | 7704  | 6818  |

| NM | 35151  | 105434 | 11029  | 598  | 17984   | 5669  | 4556  |
|----|--------|--------|--------|------|---------|-------|-------|
| NY | 69231  | 85444  | 12293  | 2463 | 179722  | 9639  | 6089  |
| NC | 63867  | 67503  | 47960  | 1717 | 73762   | 34520 | 26978 |
| ND | 13106  | 61581  | 2773   | 536  | 115246  | 8070  | 6655  |
| OH | 257951 | 154745 | 34615  | 7067 | 274393  | 42811 | 31137 |
| OK | 71631  | 115119 | 43444  | 4256 | 169258  | 13676 | 9162  |
| OR | 55321  | 32785  | 16150  | 1154 | 22926   | 12795 | 9182  |
| PA | 103390 | 251484 | 29515  | 2429 | 1030499 | 48368 | 31900 |
| RI | 1471   | 1348   | 994    | 71   | 1431    | 191   | 140   |
| SC | 60577  | 55927  | 27452  | 1277 | 101527  | 17123 | 13404 |
| SD | 9073   | 20014  | 4558   | 276  | 31358   | 4890  | 3124  |
| TN | 47766  | 119858 | 47846  | 1501 | 166629  | 28121 | 23137 |
| ТХ | 305007 | 383970 | 134805 | 8937 | 378740  | 74290 | 55757 |
| UT | 52495  | 84689  | 5897   | 716  | 41423   | 13606 | 7994  |
| VT | 2686   | 1161   | 338    | 0    | 253     | 128   | 98    |
| VA | 80975  | 96378  | 36976  | 1787 | 126230  | 17125 | 13510 |
| WA | 59886  | 34503  | 12536  | 1159 | 25198   | 7536  | 5741  |
| WV | 67134  | 76624  | 12398  | 357  | 77952   | 9918  | 6331  |
| WI | 71718  | 74120  | 30749  | 1106 | 111793  | 18651 | 13105 |
| WY | 26929  | 99785  | 13490  | 950  | 68686   | 20878 | 15881 |

|--|

|    | СО    | NOX   | VOC  | SO2  | PM10 | PM2.5 |
|----|-------|-------|------|------|------|-------|
| AL | 15032 | 474   | 915  | 55   | 299  | 209   |
| AZ | 5223  | 2008  | 412  | 205  | 179  | 162   |
| AR | 984   | 183   | 79   | 21   | 39   | 34    |
| CA | 6821  | 4222  | 631  | 394  | 283  | 267   |
| CO | 3536  | 2208  | 337  | 207  | 161  | 153   |
| FL | 56979 | 12755 | 5019 | 1165 | 1009 | 770   |
| GA | 29653 | 5972  | 2849 | 750  | 426  | 349   |
| ID | 427   | 169   | 25   | 19   | 24   | 23    |
| IL | 8047  | 10183 | 1354 | 658  | 339  | 327   |
| IN | 1316  | 614   | 170  | 63   | 66   | 61    |
| IA | 478   | 186   | 61   | 21   | 31   | 29    |
| KS | 625   | 77    | 43   | 9    | 20   | 17    |
| KY | 10228 | 1963  | 820  | 191  | 181  | 136   |
| LA | 1765  | 657   | 163  | 69   | 73   | 66    |
| MI | 4005  | 1999  | 662  | 219  | 197  | 188   |
| MN | 2592  | 2008  | 396  | 200  | 17   | 15    |
| MS | 8631  | 190   | 671  | 23   | 171  | 119   |
| MO | 3120  | 2298  | 546  | 233  | 172  | 166   |
| MT | 537   | 155   | 81   | 18   | 24   | 22    |

| NE | 612   | 216  | 72   | 25  | 26  | 24  |
|----|-------|------|------|-----|-----|-----|
| NV | 2856  | 1899 | 259  | 184 | 116 | 111 |
| NM | 1401  | 371  | 102  | 40  | 45  | 39  |
| NC | 23500 | 4356 | 2567 | 455 | 527 | 433 |
| ND | 279   | 76   | 43   | 9   | 11  | 10  |
| OH | 2792  | 1290 | 443  | 137 | 144 | 136 |
| OK | 2553  | 395  | 166  | 45  | 77  | 63  |
| OR | 1348  | 761  | 116  | 75  | 71  | 68  |
| SC | 10235 | 554  | 825  | 64  | 194 | 138 |
| SD | 243   | 60   | 32   | 7   | 12  | 11  |
| TN | 15390 | 4036 | 1542 | 349 | 276 | 215 |
| ТХ | 13008 | 6521 | 1360 | 671 | 615 | 568 |
| UT | 1455  | 945  | 129  | 88  | 63  | 59  |
| VA | 22735 | 5883 | 2843 | 455 | 832 | 589 |
| WA | 2614  | 1587 | 269  | 151 | 129 | 123 |
| WV | 3381  | 77   | 237  | 9   | 67  | 46  |
| WI | 1325  | 542  | 216  | 63  | 75  | 71  |
| WY | 174   | 27   | 16   | 3   | 7   | 6   |

Table 2-40. SEMAP 2018 in-port, near and offshore shipping totals (TPY)

|    | СО   | NOX   | VOC  | SO2 | PM10 | PM2.5 |
|----|------|-------|------|-----|------|-------|
| AL | 459  | 917   | 42   | 29  | 14   | 13    |
| CA | 2225 | 15667 | 613  | 506 | 200  | 182   |
| CO | 175  | 1648  | 72   | 51  | 24   | 22    |
| DE | 272  | 2288  | 114  | 474 | 35   | 32    |
| DC | 0    | 2     | 0    | 0   | 0    | 0     |
| FL | 2694 | 25412 | 1057 | 921 | 421  | 385   |
| GA | 246  | 2170  | 109  | 83  | 33   | 30    |
| IL | 10   | 108   | 4    | 3   | 1    | 1     |
| IN | 5    | 48    | 2    | 1   | 1    | 1     |
| LA | 2377 | 19138 | 863  | 593 | 297  | 270   |
| ME | 136  | 1262  | 54   | 43  | 19   | 18    |
| MD | 578  | 5384  | 243  | 163 | 82   | 75    |
| MA | 448  | 4154  | 184  | 162 | 64   | 59    |
| MI | 1054 | 11460 | 447  | 277 | 140  | 127   |
| MN | 30   | 324   | 13   | 8   | 4    | 4     |
| MS | 127  | 1173  | 51   | 38  | 18   | 17    |
| NJ | 905  | 7801  | 387  | 457 | 125  | 114   |
| NY | 607  | 5659  | 268  | 152 | 79   | 72    |
| NC | 184  | 1685  | 76   | 94  | 25   | 23    |
| ОН | 244  | 2646  | 104  | 65  | 33   | 30    |
| OR | 393  | 3040  | 206  | 89  | 50   | 45    |

| Final       | Danaute | Emissions | and Ain | Quality | Madalina | for CEMAD |
|-------------|---------|-----------|---------|---------|----------|-----------|
| <i>г та</i> | керон.  | Emissions | una Air | Quany   | modeling | JUI SEMAR |

| PA     | 382    | 3718    | 151    | 154     | 54     | 49     |
|--------|--------|---------|--------|---------|--------|--------|
| RI     | 27     | 247     | 11     | 26      | 4      | 3      |
| SC     | 414    | 3648    | 176    | 218     | 57     | 52     |
| ТХ     | 1466   | 9752    | 487    | 480     | 240    | 219    |
| VA     | 371    | 3453    | 157    | 126     | 52     | 47     |
| WA     | 2368   | 21630   | 1102   | 645     | 334    | 302    |
| WV     | 3      | 33      | 1      | 1       | 0      | 0      |
| WI     | 75     | 818     | 32     | 20      | 10     | 9      |
| Near-  |        |         |        |         |        |        |
| shore  | 80379  | 785660  | 34170  | 108590  | 21484  | 19696  |
| SECA   | 243840 | 2622600 | 103500 | 1812700 | 243970 | 225280 |
| Canada | 22194  | 211165  | 9427   | 6045    | 3036   | 2763   |



## 2.4 2018 vs 2007 (Actual) State Total Comparisons

Figure 2-59. 2007 actual and 2018 annual total CO emissions by SESARM state



Figure 2-60. 2007 actual and 2018 annual total NOx emissions by SESARM state



Figure 2-61. 2007 actual and 2018 annual total VOC emissions by SESARM state



Figure 2-62. 2007 actual and 2018 annual total NH3 emissions by SESARM state



Figure 2-63. 2007 actual and 2018 annual total SO<sub>2</sub> emissions by SESARM state



Figure 2-64. 2007 actual and 2018 annual total PM2.5 emissions by SESARM state







Figure 2-66. Florida annual emissions differences (2018-2007 actual) by pollutant



Figure 2-67. Georgia annual emissions differences (2018-2007 actual) by pollutant



Figure 2-68. Kentucky annual emissions differences (2018-2007 actual) by pollutant



Figure 2-69. Mississippi annual emissions differences (2018-2007 actual) by pollutant



Figure 2-70. North Carolina annual emissions differences (2018-2007 actual) by pollutant



Figure 2-71. South Carolina annual emissions differences (2018-2007 actual) by pollutant



Figure 2-72. Tennessee annual emissions differences (2018-2007 actual) by pollutant



Figure 2-73. Virgina annual emissions differences (2018-2007 actual) by pollutant



Figure 2-74. West Virginia annual emissions differences (2018-2007 actual) by pollutant

## 2.5 References

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# Chapter 3: Air Quality Model Performance Evaluation

## 3.1 Introduction

This chapter is devoted to the performance evaluation of the CMAQ model as applied to the SEMAP project. First the evaluation methodology is described. This is followed by a definition of the performance metrics and performance goals. Then, the observational data used in model evaluations are described. A comprehensive list of the performance evaluation products follows the data description. The discussion of the performance starts with the initial "Actual 2007" simulation. Ozone, PM<sub>2.5</sub> and wet deposition performances are evaluated. This is followed by the diagnostic tests performed to improve the initial model performance and the model configuration recommended for use. Then the model performance discussion continues with the final "Actual 2007" simulation and ends with the "Typical 2007" simulation. In the conclusion section the findings of the comprehensive performance evaluation are summarized.

# 3.2 Evaluation Methodology

EPA's integrated ozone,  $PM_{2.5}$  and regional haze modeling guidance calls for a comprehensive, multilayered approach to model performance testing, consisting of the four major components: operational, diagnostic, mechanistic (or scientific) and probabilistic (EPA, 2007a). The CMAQ model performance evaluation effort for  $PM_{2.5}$  and ozone discussed in this Chapter focused on the first two components of the EPA's recommended evaluation approach: statistical evaluation and diagnostic evaluation.

#### 3.2.1 Statistical Evaluation

Statistical evaluation tests the ability of the model to estimate ozone and  $PM_{2.5}$  mass concentrations and the components of  $PM_{2.5}$ , i.e., sulfate, nitrate, ammonium, organic carbon matter, elemental carbon, and other inorganic  $PM_{2.5}$ . This evaluation examines whether the measurements are properly represented by the model predictions but does not necessarily ensure that the model is getting "the right answer for the right reason"; and

## 3.2.2 Diagnostic Evaluation

Diagnostic evaluation tests the ability of the model to predict visibility and extinction, PM chemical composition including PM and ozone precursors (e.g., SOx, NOx, VOC, and NH<sub>3</sub>) and associated oxidants (e.g., nitric acid); PM size distribution; temporal variation; spatial variation; mass fluxes; and components of light extinction (i.e., scattering and absorption).

The diagnostic evaluation also includes the performance of diagnostic tests to better understand model performance and identify potential flaws in the modeling system that can be corrected. In this final model performance evaluation, the statistical evaluation has been given the greatest attention since this is the primary thrust of EPA's modeling guidance. However, we have also examined certain diagnostic features dealing with the model's ability to simulate sub-regional and monthly/diurnal gas phase and aerosol concentration distributions. In the course of the SEMAP studies numerous diagnostic sensitivity tests were performed to investigate and improve model performance and test the model assumptions that are available on the SEMAP modeling website.

# 3.3 Performance Metrics and Goals

To quantify model performance, several statistical measures were calculated and evaluated for all the IMPROVE, CSN, CASTNet, SEARCH, FRM, NADP and AQS monitors within the SEMAP region

individually for each monitoring network and for each SEMAP state. The statistical measures selected were based on the recommendations outlined in section 18.4 of the USEPA's <u>Guidance on the Use of</u> <u>Models and Other Analyses for Demonstrating Attainment of Air Quality Goals for Ozone,  $PM_{2.5}$ , and Regional Haze (EPA, 2007a).</u>

Although numerous model performance statistics measures are routinely calculated, SEMAP have found that the fractional bias and fractional gross error provide the best descriptive power over a wide range of concentrations. The fractional bias and error are expressed as a percentage and are normalized by the average of the predicted and gross observed values. Consequently, they are bounded statistics, with the fractional bias bounded by -200% to +200% and the fractional gross error bounded by 0 to 200%. Table 3-1 summarized the formulas for the fractional bias and gross error statistics. The SEMAP model performance goals and criteria are given in Table 3-2. Note that for ozone model performance the traditional (EPA, 1991)  $\leq \pm 15\%$  and  $\leq 35\%$  performance goals for mean normalized bias (MNB) and mean normalized gross error (MNGE) using hourly predicted and observed ozone pairs with the observed ozone value greater than 60 ppb are used. The MNB and MNGE statistics are similar to the fractional statistics given in Table 3-1; only the normalized statistics are divided by just the observed value rather than the average of the predicted and observed values.

Table 3-1. Definitions of the fractional bias and fractional error statistical model performance metrics

| Statistical Measure                               | Shorthand<br>Notation | Mathematical Expression   | Notes         |
|---|-----------------------|---|---------------|
| Mean Fractional Gross Error<br>(Fractional Error) | MFE                   | $\frac{2}{N} \sum_{i=1}^{N} \left  \frac{P_i - O_i}{P_i + O_i} \right $ | Reported as % |
| Mean Fractionalized Bias<br>(Fractional Bias)     | MFB                   | $\frac{2}{N}\sum_{i=1}^{N} \left(\frac{P_i - O_i}{P_i + O_i}\right)$    | Reported as % |

| Fractional Bias  | Fractional Error | Comment  |
|------------------|------------------|--|
| <u>&lt;±</u> 15% | <u>&lt;</u> 35%  | Goal for PM model performance based on ozone model performance, considered good performance  |
| <u>&lt;±</u> 30% | <u>&lt;</u> 50%  | Goal for PM model performance, considered average performance  |
| <u>&lt;±</u> 60% | <u>≤</u> 75%     | Criteria for PM model performance, considered poor<br>performance. Exceeding this level of performance indicates<br>fundamental concerns with the modeling system. |

Table 3-2. SEMAP model performance goals and criteria for components of fine particle mass

# 3.4 Observational Networks

We collected the available surface air quality measurement data, measured atmospheric deposition data, and satellite data for the 2007 SEMAP modeling periods and domains. Particularly, we collected surface measurement data of air quality from the following sources: EPA's AIRS database including CSN, PAMS, SLAMS and Air Toxics networks; CASTNet, IMPROVE and SEARCH networks; and

atmospheric deposition data from the NADP network. The ambient air quality measurement data that are used for evaluating model performance are summarized in Table 3-3. The following sections describe the observational networks providing the data.

| Variable                                | Database/Networks                    | Averaging Times       |
|---|--------------------------------------|-----------------------|
| PM <sub>10</sub>                        | AIRS, IMPROVE, SEARCH                | daily, hourly         |
| PM <sub>2.5</sub>                       | AIRS, IMPROVE, SEARCH                | daily, hourly         |
| Sulfate                                 | AIRS, IMPROVE, SEARCH, CASTNet       | daily, hourly, weekly |
| Nitrate                                 | AIRS, IMPROVE, SEARCH                | daily, hourly         |
| Ammonium                                | AIRS, SEARCH, CASTNet <sup>(a)</sup> | daily, hourly, weekly |
| EC (BC)                                 | AIRS, IMPROVE, SEARCH                | daily, hourly         |
| ос                                      | AIRS, IMPROVE, SEARCH                | daily, hourly         |
| Trace Metals in PM <sub>2.5</sub>       | AIRS, IMPROVE, SEARCH                | daily                 |
| NO, NO <sub>2</sub> and NO <sub>y</sub> | AIRS, SEARCH                         | hourly                |
| SO <sub>2</sub>                         | AIRS, CASTNet, IMPROVE, SEARCH       | hourly, daily, weekly |
| VOCs, HAPs                              | AIRS, SEARCH <sup>(b)</sup>          | hourly                |
| Total Nitrate <sup>(c)</sup>            | CASTNet, SEARCH                      | daily, weekly         |

Table 3-3. Observational data used for model performance evaluation

(a) Ammonium data from IMPROVE are estimated from sulfate and nitrate based on complete neutralization of those ions. Independent measurements from CASTNet are more appropriate for model evaluation purposes

(b) ARIES program measures HAPs and other VOCs at the SEARCH sites in Atlanta, GA area.

(c) CASTNet weekly measurements of PM nitrate and HNO<sub>3</sub> will be evaluated as total nitrate due to issues relating to filter-based methods to collect volatile nitrate species.

## 3.4.1 AIRS

AIRS compiles and provides access to datasets from multiple national observational networks/programs including CSN, PAMS, SLAMS and Air Toxics. The CSN network provides 24-hr (midnight to midnight) measurements of PM<sub>2.5</sub> and its composition including trace metals at every 3<sup>rd</sup> day or every 6<sup>th</sup> day. The SLAMS network provides hourly measurements of criteria air pollutants including PM<sub>2.5</sub>, PM<sub>10</sub>, O<sub>3</sub>, SO<sub>2</sub>, NO<sub>2</sub>, CO etc. The PAMS network measures photochemical smog related species such as O<sub>3</sub>, NO, NO<sub>2</sub>, NO<sub>y</sub>, Total NMOC, and 60 PAMS target VOC compounds in non-attainment areas. The AIRS datasets are spatially dense in populated areas with intensive sampling frequency in the SEMAP states and is the backbone for model performance evaluation and receptor modeling. In addition the monitoring data from the Air Toxics program provides a critically important role by characterizing HAPs concentrations to support exposure assessments, and can be a supplement for air quality model evaluation and input for receptor modeling. The AMET evaluation tool developed at UNC can take all AIRS datasets in their original AQS engineering format directly.

In addition, AIRS includes meteorological data at CSN and PAMS sites that can be used for quality assurance of the MCIP files and as an independent evaluation of WRF performance, especially if the meteorological modeling contractor is not using this dataset.

## 3.4.2 IMPROVE

The IMPROVE network was developed to monitor visibility degradation at wildness and remote areas in the nation. IMRPOVE includes measurements of chemical constituents including trace metals of  $PM_{2.5}$  as well as related gaseous species at each site. From these measurements, light extinction values are also calculated and provided.

## 3.4.3 CASTNet

CASTNet was developed to monitor dry and wet acid deposition. Monitoring site locations are predominantly rural by design to assess the relationship between regional pollution and changes in regional patterns in deposition. CASTNet also includes measurements of rural ozone and the chemical constituents of PM<sub>2.5</sub>.

## 3.4.4 NADP

NADP provides atmospheric deposition data. The weekly cumulative deposition data was extracted from CMAQ outputs between the hours of data collection and assigned to the measured species.

## 3.4.5 SEARCH

SEARCH provides continuous and speciated PM data in one urban and one rural location in each one of the following four SEMAP states: Alabama, Georgia, Florida and Mississippi. In addition to 24-hr particulate matter mass (fine and coarse) and composition (EC, OC, sulfate, nitrate, ammonium and metals) SEARCH also measures hourly PM mass and ion components (BC, OC, sulfate, nitrate, ammonium) and a wide range of complementary gaseous species (O<sub>3</sub>, NO, NO<sub>2</sub>, NO<sub>y</sub>, HNO<sub>3</sub>, SO<sub>2</sub>, CO, CO<sub>2</sub>). This dataset is extremely useful to evaluate how well the models reproduce the diurnal variability (which is not possible with the daily averaged data), spatial variability (urban versus rural), and if the secondary PM formation processes were simulated correctly. Speciated the SEARCH OC data (and OC data from Assessment of Spatial Aerosol Composition in Atlanta (ASACA) sites which are operated by Georgia Tech) into individual compounds for use as molecular markers for periods of the February 2007 prescribed burning event and the May-June 2007 Florida-Georgia wildfire episodes (Yan, Zheng et al. 2008). These additional datasets are very useful for evaluating the model performance in capturing the important Southeastern fire events during 2007. In addition, the HAP and other VOC data collected at the SEARCH sites in the Atlanta, GA metropolitan area are valuable for both model performance evaluation and receptor modeling.

#### 3.4.6 Quality Assurance

As existing data, surface measurements from the above specific networks or from EPA AIRS database are already quality-checked and well documented. Use of these existing data is fully documented with data's original documentation archived. In addition we use the provided measuring uncertainty information to further screen the datasets and to decide excluding particular data points. Spatial plots and time series plots are made for visual check of outliers that seems less reasonable. Also, descriptive statistics (mean, standard deviation, frequency distributions, etc.) are calculated and used for data presentation and cross comparison and to facilitate peer review. Cross-checking among the networks are made too if applicable for further assurance of the data reliability.

## 3.5 Evaluation Products

A variety of evaluation products are available for download at <u>http://semap.ce.gatech.edu/node/1835</u>. Tables 4-11 contain a summary of the available products on the website.

| Spatial      | Network-wide | By region         | By state          | By site |
|--------------|--------------|-------------------|-------------------|---------|
| Temporal     |              |                   |                   |         |
| Annual       |              |                   |                   |         |
| Ozone season |              |                   |                   |         |
| By month     |              | (& multi-network) | (& multi-network) |         |
| By Day       |              |                   |                   |         |

Table 3-4. Bugle Plots (PM<sub>2.5</sub>)

Table 3-5. Quantile-Quantile Plots

| Spatial      | Network-wide | By region | By state | By site          |
|--------------|--------------|-----------|----------|------------------|
| Temporal     |              |           |          |                  |
| Annual       |              |           |          | Other than ozone |
| Ozone season |              |           |          | Ozone networks   |
| By month     |              |           |          |                  |
| By Day       |              |           |          |                  |

#### Table 3-6. Scatter Plots

| Spatial      | Network-wide | By region | By state | By site |
|--------------|--------------|-----------|----------|---------|
| Temporal     |              |           |          |         |
| Annual       |              |           |          |         |
| Ozone season |              |           |          |         |
| By month     |              |           |          |         |
| By Day       |              |           |          |         |

| Spatial      | Spatial Network-wide |                   | By state          | By site |
|--------------|----------------------|-------------------|-------------------|---------|
| Temporal     |                      |                   |                   |         |
| Annual       |                      |                   |                   |         |
| Ozone season |                      |                   |                   |         |
| By month     |                      | (& multi-network) | (& multi-network) |         |
| By Day       |                      |                   |                   |         |

*Table 3-7. Soccer Plots (PM<sub>2.5</sub>)* 

Table 3-8. Stacked Bar Charts

| Spatial      | Network-wide | By region | By state | By site       |
|--------------|--------------|-----------|----------|---------------|
| Temporal     |              |           |          |               |
| Annual       |              |           |          |               |
| Ozone season |              |           |          |               |
| By month     |              |           |          | CSN & IMPROVE |
| By Day       |              |           |          |               |

Table 3-9. Tables of Statistics

| Spatial      | Network-wide | By region | By state | By site |
|--------------|--------------|-----------|----------|---------|
| Temporal     |              |           |          |         |
| Annual       |              |           |          |         |
| Ozone season |              |           |          |         |
| By month     |              |           |          |         |
| By Day       |              |           |          |         |

Table 3-10. Tile Plots

| Spatial      | Network-wide                                | By region | By state | By site |
|--------------|---|-----------|----------|---------|
| Temporal     |   |           |          |         |
| Annual       |   |           |          |         |
| Ozone season |   |           |          |         |
| By month     | 8-hr max O <sub>3</sub> , PM <sub>2.5</sub> |           |          |         |
| By Day       | 8-hr max O <sub>3</sub> , PM <sub>2.5</sub> |           |          |         |

| Spatial      | Network-wide | By region | By state | By site          |
|--------------|--------------|-----------|----------|------------------|
| Temporal     |              |           |          |                  |
| Annual       |              |           |          | Other than ozone |
| Ozone season |              |           |          |                  |
| By month     |              |           |          | Ozone networks   |
| By Day       |              |           |          |                  |

Table 3-11. Time Series Plots

# 3.6 Initial Model Performance

The goal of the initial model performance evaluation was to get a first assessment of the model's ability to predict ozone,  $PM_{2.5}$  and acid deposition through comparison with the observations.

#### 3.6.1 Ozone

AQS is the most extensive ozone observing network. Network-wide, MB for annual ozone with no cut-off is +3.1 ppb for an observed mean 8-hr ozone of 31 ppb (NMB=10%) and ME is 13 ppb (NME = 40%). Using a cut-off of 60 ppb, the network-wide, MB is -1.9 ppb (out of 69 ppb) and ME is 12 ppb. MFB is -5.8% and MFE is 19%. Bias and error are smallest for coastal SEMAP states (MFB = -2.0%; MFE= 18%) and larger for interior SEMAP (KY, TN and WV; MFB = -9.3% and MFE = 20%) or neighboring states. In some SEMAP states the bias is positive, most notably in GA (MB +3.6 ppb; MFB +2.2%).

The AQS network-wide 8-hr ozone MB with no cut-off is +7.1 ppb (out of 47 ppb). MFB is +12%. ME is 11 ppb and MFE is 23%. Annual, network-wide MB with a 60 ppb cut-off is +1.8 ppb (out of 69 ppb). MFB is +1.4%. ME is 9.3 ppb and MFE is 13%. The bias and error are smallest for the interior SEMAP states and larger for coastal SEMAP and neighboring states. In WW, TN, KY, MBs are -1.3 to +1.0ppb and MEs are 7.5 to 9.1 ppb (MFEs are 11% to 13%). In VA and GA bias and error are the largest. MBs are +5.6 and +6.9 ppb (MFBs are +6.6 and +8.0%) and MEs are 10 and 11 ppb (MFEs are 14 and 15%). In Georgia, August monthly MB is +18 ppb (out of 73 ppb; MFB is +21%) and ME is 19 ppb (MFE is 23%). Site 130590002 in Georgia has observations on 14 days in August. At this site, MB is +25 ppb (out of 70 ppb; MFB = +30%) and ME is 25 ppb (MFE = 30%).

#### 3.6.2 PM<sub>2.5</sub>

The AQS 24-hr network-wide  $PM_{2.5}$  annual MB is +1.5 µg/m<sup>3</sup> (out of 13 µg/m<sup>3</sup>; MFB is 8%) and ME is 5.5 µg/m<sup>3</sup> (MFE = 38%). For the CSN network, annual MB is +0.41 µg/m<sup>3</sup> (out of 15 µg/m<sup>3</sup> NMB is 2.7%) and ME is 6.0 µg/m<sup>3</sup> (NME = 40%). MB is negative (about 3 mg/m3; MFB is about -20%) for SEMAP states and positive for neighboring states (MB is +2.2 mg/m3 out of 15 µg/m<sup>3</sup>). Annual bias is largest in West Virginia (MB = -5.8 µg/m<sup>3</sup>; MFB = -37%). In Georgia, annual MB is -2.9 µg/m<sup>3</sup> (out of 17 µg/m<sup>3</sup>; MFB is -16%) and ME is 5.5 µg/m<sup>3</sup> (MFE = 34%). The largest monthly MBs are in May (recall that FL-GA fires were in May) and in Alabama (-14 µg/m<sup>3</sup> out of 27 µg/m<sup>3</sup>), Florida (-14 µg/m<sup>3</sup> out of 23 µg/m<sup>3</sup>) and Georgia (-13 µg/m<sup>3</sup> out of 24 µg/m<sup>3</sup>). Bias is high in NC in August (Table 3-12). MB is -11 µg/m<sup>3</sup> (out of 26 µg/m<sup>3</sup>; MFB is -54%). Note that according to the criteria in Table 3-2 two of the NC CSN sites, Asheville (37-021-0034) and Kinston (37-107-0004) exceed the performance criteria indicating fundamental concerns with the modeling.

| Site      | Model mean | CSN mean | # of Pairs | Cor  | ME    | MB     | NME   | NMB    | MNE   | MNB    | MFB    | MFE   | RMSE  |
|-----------|------------|----------|------------|------|-------|--------|-------|--------|-------|--------|--------|-------|-------|
| 370210034 | 9.75       | 25       | 5          | 0.67 | 15.25 | -15.25 | 61.01 | -61.01 | 58.63 | -58.63 | -84.12 | 84.12 | 16.44 |
| 370350004 | 14.34      | 26.22    | 5          | 0.79 | 11.88 | -11.88 | 45.31 | -45.31 | 43.72 | -43.72 | -56.6  | 56.6  | 12.97 |
| 370570002 | 14.84      | 27.22    | 5          | 0.81 | 12.38 | -12.38 | 45.47 | -45.47 | 44    | -44    | -57.3  | 57.3  | 13.55 |
| 370670022 | 16.02      | 27.92    | 5          | 0.62 | 11.9  | -11.9  | 42.63 | -42.63 | 39.65 | -39.65 | -51.19 | 51.19 | 14.38 |
| 371070004 | 9.02       | 21.12    | 5          | 0.6  | 12.1  | -12.1  | 57.28 | -57.28 | 55.61 | -55.61 | -78.87 | 78.87 | 13.22 |
| 371190041 | 19.06      | 27.25    | 10         | 0.71 | 8.19  | -8.19  | 30.07 | -30.07 | 29.41 | -29.41 | -35.76 | 35.76 | 9.15  |
| 371590021 | 13.42      | 23.9     | 4          | 0.58 | 10.49 | -10.49 | 43.91 | -43.91 | 42.07 | -42.07 | -54.29 | 54.29 | 11.4  |
| 371830014 | 16.59      | 24.74    | 9          | 0.56 | 8.15  | -8.15  | 32.95 | -32.95 | 32.53 | -32.53 | -40.65 | 40.65 | 9.18  |

Table 3-12. Statistical evaluation metrics of total PM<sub>2.5</sub> for CSN sites in North Carolina during August 2007

A bugle plot of domain-wide annual  $PM_{2.5}$  and its major components shows the performance of individual species of  $PM_{2.5}$  during the entire year (Figure 3-1). All species of  $PM_{2.5}$  show good performance, within the goal fractional bias, except organic matter (OM). However, OM is within the criteria fractional bias.



Figure 3-1. Initial fractional biases of total PM<sub>2.5</sub> and its major components versus the observed average total PM<sub>2.5</sub> concentration at IMPROVE sites in the domain for the year 2007

#### 3.6.3 Acid Deposition

NAPD network has the most useful deposition data. Network-wide, annual precipitation MB is -0.37 mm (NMB = -2%) and ME is 12.4 mm (NME=63%). Sulfate deposition performed well with MB of -0.06 kg/ha (NMB = -18%) and ME is 0.2 kg/ha (NME=60%). Nitrate deposition MB is +0.34 kg/ha (NMB = -150%) and ME is 0.4 kg/ha (NME=170%) while ammonium deposition MB is -0.02 kg/ha (NMB = -30%) and ME is 0.05 kg/ha (NME=64%).

Precipitation MB ranges from -3.5 mm in Mississippi (NMB=-17%) to +5.0 mm in West Virginia (NMB=+22%). Sulfate deposition MB ranges from -0.09 kg/ha in Virginia (MFB=-29%) to 0.05 kg/ha in West Virginia (MFB=+4.8%). Nitrate deposition MB tends to be biased high with ranges from +0.18kg/ha in Virginia (NMB=+82%) to 0.63 kg/ha in Florida (NMB=+350%). On the other hand, ammonium deposition is biased low with MB ranges from -0.02kg/ha in Kentucky (MFB=-16%) to 0.00 kg/ha in West Virginia (MFB=-10%). In Florida, Nitrate Deposition MFB is over +115% in June-and
135% in July and August when precipitation MFB is +55% to +65%. Nitrate Deposition MFB is +175% at FL14 where Precipitation MFB is +115% at FL14

# 3.7 Diagnostics

The initial simulation of the air quality in the year 2007 did not meet all of the model performance goals. In particular, normalized mean error in modeled ozone exceeded the monthly average target of 30-35% (Tesche, 1990) at several monitors. In general, ozone was overestimated at monitors of the Southeast during the summer months, especially in August and in Florida and Georgia. Modeled  $NO_x$  concentrations were also very high compared to the observations. To improve model performance the following configurations were tested:

- 1) Increasing the minimum PBL height and mixing coefficient,
- 2) Changing the PBL heights along the land-water interface,
- 3) Reducing the boundary conditions,
- 4) Removing lightning NO<sub>x</sub> emissions,
- 5) Reducing ground-level  $NO_x$  emissions.

Each diagnostic sensitivity simulation was conducted only for the month of August when ozone performance was worst in the 2007 simulation with the initial model configuration.

### 3.7.1 Sensitivity to PBL height and Mixing Coefficients

A comparison of the modeled PBL heights to PBL heights inferred from soundings at 15 stations throughout the Southeast revealed that the model may be underestimating the early morning PBL heights. The minimum PBL height in CMAQ 5.0 is set to 20 m. In this sensitivity test minimum PBL heights were changed to typical observed values according to land type (Table 3-13). The minimum values for mixing coefficient  $K_{zz}$  were also changed to the values used in version 4.7.1 of CMAQ (Table 3-14).

| Land type     | Minimum PBL height (m) |
|---------------|------------------------|
| Coastal rural | 60                     |
| Coastal urban | 100                    |
| Inland rural  | 200                    |
| Inland urban  | 300                    |

Table 3-13. Minimum PBL heights used in the sensitivity run

Table 3-14. Minimum K<sub>zz</sub> values used in CMAQ 5.0 and in the sensitivity run (also in CMAQ 4.7.1)

|           | Minimum K <sub>zz</sub> (m <sup>2</sup> /s) |            |  |  |  |  |  |  |  |
|-----------|---|------------|--|--|--|--|--|--|--|
| Land type | CMAQ 5.0                                    | CMAQ 4.7.1 |  |  |  |  |  |  |  |
| Rural     | 0.01  | 0.5        |  |  |  |  |  |  |  |
| Urban     | 1.0   | 2.0        |  |  |  |  |  |  |  |

These changes decreased the early morning  $NO_x$  concentrations (Figure 3-2). Because of the decreases in nighttime  $NO_x$ , which titrates ozone, nighttime ozone concentrations went up by about 40 ppb over the Southeast (Figure 3-3). This results in a degradation of nighttime ozone performance.

Afternoon  $NO_x$  concentrations also decreased in this sensitivity run (Figure 3-4). The largest decreases are observed at coastal areas where the PBL heights are relatively low, and are probably due to the increase in minimum  $K_{zz}$  values. There were both increases and decreases in afternoon ozone (Figure 3-5). Note that decreases in  $NO_x$  are not always accompanied by decreases in ozone. In fact, at a number of places such as New Orleans, Tampa and Savannah, ozone increased. Ozone may be  $NO_x$  inhibited at these locations. These changes in afternoon ozone concentrations have little impact on the 8-hr ozone performance.



Figure 3-2. Changes in early morning NOx concentrations after the minimum PBL height and minimum Kzz modifications: 11 UTC August 8, 2007



Figure 3-3. Changes in nighttime/early morning ozone after the minimum PBL height and minimum K<sub>zz</sub> modifications: 11 UTC August 8, 2007



Figure 3-4. Changes in afternoon NO<sub>x</sub> concentrations after the minimum PBL height and minimum K<sub>zz</sub> modifications: 20 UTC August 8, 2007



Figure 3-5. Changes in afternoon ozone after the minimum PBL height and minimum K<sub>zz</sub> modifications: 19 UTC August 8, 2007

#### 3.7.2 Sensitivity to Land-Water Interface

Model performance was compared to performance reported by US EPA for their simulations of the same year. This comparison focused on two coastal sites: one in Delaware and one in Long Island, NY. It was concluded that the differences in ozone between SEMAP and EPA simulations were due to the differences in daytime PBL heights. EPA's WRF runs used a more accurate database to identify the landwater interface. These sites were being assigned land PBL heights in EPA's simulation while they were being assigned, incorrectly, water PBL heights in SEMAP runs; consequently, ozone was being over-predicted at these sites.

In this sensitivity run, the land-water interface was modified by changing the PBL heights along the coast (Figure 3-6). In particular, the PBL heights of blue cells in Figure 3-6 were changed from their original "over-the-water" values to PBL heights of nearby land cells. The minimum PBL height was kept at its original CMAQ 5.0 value of 20 m. However, minimum  $K_{zz}$  values were changed to 2.0 and 0.5 m<sup>2</sup>/s for urban and rural areas, respectively. In CMAQ 5.0 these values are 1.0 and 0.01 m<sup>2</sup>/s, respectively (Table 3-14).

# Layer 1 LWMASKu-LWMASKw



Figure 3-6. Changes made to the land-water interface: land to water (red), no change (gray), and water to land (blue)

Because of the differences in minimum  $K_{zz}$  values between this sensitivity run and the initial CMAQ 5.0 run, the results will be compared to the sensitivity run in Section 1.1 (with modified minimum PBL height and minimum  $K_{zz}$  values). However, although both sensitivity runs used the same minimum  $K_{zz}$  values, the minimum PBL values were different; therefore, the differences between this sensitivity run and the one in Section 1.1 are not solely due to the difference in land-water interface shown in Figure 3-6.

The difference in early morning  $NO_x$  between this sensitivity run and the sensitivity run in Section 3.7.1 is shown in Figure 3-7. This difference proves that most of the  $NO_x$  decreases shown in Figure 3-2 were due to changing the minimum  $K_{zz}$  values.  $NO_x$  concentrations increased relative to the previous sensitivity run (by a fraction of the  $NO_x$  decreases caused by increasing the  $K_{zz}$  values) because of the decrease in minimum PBL heights from 200-300 m inland to 20 m in this sensitivity run. The decrease in  $NO_x$  at New Orleans source region is most likely due to switching from water to land PBL heights.



Figure 3-7. Difference in early morning  $NO_x$  concentrations between the sensitivity run with modified PBL heights along the coast and the sensitivity run with minimum PBL height and minimum  $K_{zz}$  modifications: 11 UTC August 8, 2007

The difference in early morning ozone between this sensitivity run and the sensitivity run in Section 3.7.1 is shown in Figure 3-8. This difference proves that most of the ozone increases in Figure 3-2 were due to changing the minimum  $K_{zz}$  values. The inland differences between the two sensitivity runs are manifested mostly as a decrease in ozone in this sensitivity run due to the slight increase in NO<sub>x</sub>, which was due to the decrease in minimum PBL height from 200-300 m to 20 m. The increases in ozone at New Orleans and other places may be due to decreases in NO<sub>x</sub> or decreases in PBL heights.

The difference in afternoon  $NO_x$  between the two sensitivity runs is shown in Figure 3-9. The decrease in  $NO_x$  at New Orleans is most likely due to switching from water to land PBL heights, which would be higher in the afternoon.

The difference in afternoon ozone between the two sensitivity runs is illustrated in Figure 3-10. The differences inland and over the Great Lakes are due to the difference in the minimum PBL height. Ozone can increase due to the decrease in minimum PBL height from 200-300 m to 20 m but it can also decrease in places where  $NO_x$  emissions are trapped in a shallower PBL and this  $NO_x$  abundance is inhibiting ozone, or in places where  $NO_x$  emissions from elevated point sources are detached from the PBL. On the other hand, the differences along the coastline, especially in the Gulf of Mexico and South- and Mid-Atlantic, are more likely the effect of switching from water to land PBL heights rather than decreasing the minimum PBL height from 60-100 m to 20 m although the two effects cannot be completely discerned. Regardless of the reason, these differences may slightly improve the afternoon ozone performance at some coastal sites.



Figure 3-8. Difference in nighttime/early morning ozone concentrations between the sensitivity run with modified PBL heights along the coast and the sensitivity run with minimum PBL height and minimum  $K_{zz}$  modifications: 11 UTC August 8, 2007



Figure 3-9. Difference in afternoon  $NO_x$  concentrations between the sensitivity run with modified PBL heights along the coast run and the sensitivity run with minimum PBL height and minimum  $K_{zz}$  modifications: 20 UTC August 8, 2007



Figure 3-10. Difference in afternoon ozone concentrations between the sensitivity run with modified PBL heights along the coast and the sensitivity run with minimum PBL height and minimum  $K_{zz}$  modifications: 19 UTC August 8, 2007

#### 3.7.3 Sensitivity to Boundary Conditions

Modeled ozone was also compared to upper air data. For example, comparison to aircraft data collected during a flight between Maryland and Charlotte, NC in August 2007 showed that ozone aloft is overpredicted just like the surface ozone. Comparison with ozonesonde data from Huntsville, AL and Wallops Island, VA supported this conclusion. It was hypothesized that the over-prediction aloft, as well as at the ground level, may be due to high ozone boundary conditions. The flow patterns were analyzed and it was seen that due to the high pressure system over the Southeast, the conditions along the southeastern boundary of the 36-km domain may affect the ozone concentrations over Florida and along the coast of Gulf of Mexico, in early August 2007. Those boundary conditions were obtained from the GEOS-Chem model.

A sensitivity run was conducted by reducing the levels of all species by 50% along the boundaries of the 36-km domain. The results of this simulation were then applied as boundary conditions to the 12-km SEMAP domain.

The decreases in afternoon ozone levels due to 50% reduction of boundary conditions are shown in Figure 3-11 and Figure 3-12. On August 8, 2007, a poor ozone performance day, the decreases in afternoon ozone would be less than 6 ppb over large portions of the Southeast. However, on August 15, a good ozone performance day, the decreases would be larger, as much as 10 ppb, over most of the Southeast. This may degrade ozone performance on August 15 by more than the improvement that can be achieved on August 8.

In this sensitivity run, the reductions in ozone concentrations led to increases in early morning  $NO_x$ , which was already overestimated throughout the region.



Figure 3-11. Changes in afternoon ozone due to 50% reduction of boundary conditions: 20 UTC August 8, 2007



Figure 3-12. Changes in afternoon ozone due to 50% reduction of boundary conditions: 20 UTC August 15, 2007

### 3.7.4 Sensitivity to Lightning NO<sub>x</sub> Emissions

In the initial simulation, CMAQ 5.0 was configured to calculate lightning NO<sub>x</sub> emissions inline. One option is to use modeled flash counts to calculate NO<sub>x</sub> emissions; however, this option is not recommended due to the large uncertainties involved in the modeling of lightning. Alternatively, modeled lightning can be adjusted using data from lightning detection networks. We chose this option and employed the monthly flash count frequency (flash/m<sup>2</sup>) file prepared by US EPA for the CONUS 12-km grid. This method is relatively new and may be subject to uncertainties. As a diagnostic sensitivity, the lightning NO<sub>x</sub> emissions were turned off and the differences in NO<sub>x</sub> and ozone concentrations were observed.

On August 8, 2007, turning off lightning  $NO_x$  emissions decreased afternoon ozone by 5 to 20 ppb (Figure 3-13). Since afternoon ozone was over-predicted on that day, turning off lightning  $NO_x$  emissions would certainly improve ozone performance.

On August 15, 2007, turning off lightning  $NO_x$  emissions did not have any effect over the inland portion of the SEMAP domain (Figure 3-14). It only decreased ozone along the coast and also in Florida. Since afternoon ozone performance was good on that day except in Florida, turning off lightning  $NO_x$  emissions would not degrade ozone performance. In fact, it would improve it in Florida where ozone was over-predicted.



Figure 3-13. Changes in afternoon ozone after turning off lightning NO<sub>x</sub> emissions: 20 UTC August 8, 2007



*Figure 3-14. Changes in afternoon ozone after turning off lightning NO<sub>x</sub> emissions:* 20 UTC August 15, 2007

### 3.7.5 Sensitivity to Ground-level NO<sub>x</sub> Emissions

Excessive lightning  $NO_x$  emissions may explain part of the ozone over-prediction at the ground-level and aloft. But there must be other factors leading to the ozone over-prediction. Also, since lightning  $NO_x$  emissions have little effect on the ground-level  $NO_x$  concentrations, the over-prediction of ground-level  $NO_x$  must be due to other factors.

At part of the investigation, model performance in initial simulation was compared to the model performance in Georgia Tech's past air quality forecasts for the year 2007. Ozone performance during the month of August was acceptable in those forecasts. What could be the reason(s) for this difference in ozone performance?

One interesting discovery made during the investigation was that the ground-level  $NO_x$  emissions in the SEMAP inventory were approximately 30% larger than those used in Georgia Tech's forecasts. The emissions used in the forecasts were grown from the VISTAS typical 2002 inventory.

A sensitivity run was conducted by reducing ground-level  $NO_x$  emissions by 30%. The differences in afternoon ozone between this sensitivity run and the initial simulation are shown in Figure 3-15 and Figure 3-16. On August 8, at 20 UTC, the decrease in ozone is 5-10 ppb over most of the Southeast. This would potentially improve ozone performance. Meanwhile, ozone increased at a number of urban areas including Houston, New Orleans, Tampa, Miami, Norfolk and Baltimore. This may degrade ozone performance at those locations. Also, on August 15, the decrease in ozone may degrade performance.



Figure 3-15. Changes in afternoon ozone after 30% reduction of ground-level NO<sub>x</sub> emissions: 20 UTC August 8, 2007



Figure 3-16. Changes in afternoon ozone after 30% reduction of ground-level NO<sub>x</sub> emissions: 20 UTC August 15, 2007

### 3.7.6 Uncertainties in Meteorological Inputs

Comparisons of clouds and rain in SEMAP modeling to satellite and radar observations showed that the ozone performance issues may be related, in part, to the performance of the meteorological model. For example, at 21 UTC on August 8, 2007 the observed clouds and rain were more scattered while the modeled clouds and rain appeared to be clustered (Figure 3-17). Both of these fields were more scattered in the Georgia Tech forecasts. Clouds and rain may have direct effects on ozone performance.



Figure 3-17. Modeled (left) and observed (right) clouds (top) and rain (bottom): 21 UTC August 8, 2007 (provided by Mr. Nick Witcraft of North Carolina DENR, Division of Air Quality)

Another factor that may affect ozone performance is wind speed. The wind speeds in SEMAP's WRF simulation were underestimated (Figure 3-18). Typically, low wind speeds lead to high ozone concentrations; therefore, the wind speed under-prediction may be one of the reasons for ozone over-prediction. The wind speeds were higher in the Georgia Tech forecasts.



Domain 2 daily Observed and Modeled Wind Speed (m/s) for KATL for 2007

Figure 3-18. Comparison of observed (red) and modeled (blue) wind speeds in Atlanta (from page 61 of AER's WRF Performance Evaluation Report-Part 1)

#### 3.7.7 Recommendations for Final Model Configuration

Based on the results of the diagnostic sensitivity analysis, here are our recommendations for the final modeling configuration.

- Some of the meteorological fields such as clouds, rain and winds could be improved and those improvements might improve ozone modeling performance. Any changes to the meteorological fields should be done through WRF runs to preserve the consistency among the fields. Rerunning the meteorology of the entire year using a different version or configuration of WRF would be costly and time consuming. Therefore, it is not recommended.
- 2) The NO<sub>x</sub> emissions have been reviewed by UNC and no anomalies were found. Since the 2007 SEMAP inventory is one of the best estimates available, any arbitrary changes to the inventory such as 30% reduction of ground-level NO<sub>x</sub> emissions or emissions from a certain sector such as on-road mobile emissions cannot be justified.
- 3) Similarly, there is little evidence to justify the reduction of boundary conditions that were derived from GEOS-Chem, one of the state-of-the-art global chemistry models commonly used for providing boundary conditions to regional-scale models.
- 4) On the other hand, the reduction of lightning NO<sub>x</sub> emissions can be justified. No study to date indicated as large an impact on surface ozone as the lightning NO<sub>x</sub> emissions in the initial simulation has produced. The method used for adjusting the flash counts is relatively new and may be enhancing the impact. Therefore, we recommend turning off the lightning NO<sub>x</sub> emissions in the final modeling.

- 5) Also, we recommend reverting back to the minimum K<sub>zz</sub> values used in CMAQ 4.7.1. This did not have a significant impact on ozone performance but it did improve NO<sub>x</sub> performance. Also, it improved the overall elemental carbon performance.
- 6) We recommend changing the PBL heights along the coast from "over-the-water" values to nearby land cell values if the cells are more than 50% land according to the more accurate coastal information. In our sensitivity tests, this change improved ozone performance at coastal monitors.
- 7) We do not recommend changing the minimum PBL height. It did not have a significant impact on ozone performance inland. Along the coast, changing the minimum PBL height may interfere with the switch from water to land PBL heights recommended above.

# 3.8 Final Model Performance

#### 3.8.1 Ozone

Annual network-wide  $O_3$  MB without using a cut-off is +5.2 ppb (out of 31 ppb, for a NMB of +17%) and ME is 12 ppb (NME = 37%). With a 60 ppb cut-off, the network-wide annual  $O_3$  MB is -5.4 ppb (out of 69 ppb, for a NMB of -8%) and ME is 11 ppb. MFB is -10% and MFE is 17%. Bias and error are smallest for coastal SEMAP states (MFB = -8% and MFE = 15%) and larger for interior SEMAP (KY, TN and WV; MFB = -13% and MFE = 17%) or neighboring states. The network-wide 8-hr max ozone with no cut-off MB is +3 ppb (out of 47 ppb). MFB is +6%. ME is 8 ppb. MFE is 19%. With a cut-off of 60 ppb the MB is -3 ppb (out of 69 ppb). MFB is -5%. ME is 8 ppb. MFE is 12%. The bias and error are smallest for the coastal SEMAP states and larger for the interior SEMAP and neighboring states. In WV, TN and KY MBs are -4 to -6 ppb and MEs are 8 ppb (MFEs are 12%). In VA ans GA biases are positive and small but the errors are large. MBs are 0.09 and 0.63 ppb (MFBs are -0.74 and -0.25%) and MEs are 8.1 and 8.2 ppb (MFEs are both 11.8%).

#### 3.8.2 PM<sub>2.5</sub>

The AQS 24-hr network-wide, MB for PM<sub>2.5</sub> is -0.53  $\mu$ g/m<sup>3</sup> (out of 13  $\mu$ g/m<sup>3</sup>; MFB is -5.2%) and ME is 5  $\mu$ g/m<sup>3</sup> (MFE is 38%). For total PM<sub>2.5</sub> at CSN sites, the network-wide MB is -1.4  $\mu$ g/m<sup>3</sup> (out of 15  $\mu$ g/m<sup>3</sup>; MFB is -11%) and ME is 5.5  $\mu$ g/m<sup>3</sup> (MFE is 37%). MB is negative (about 5  $\mu$ g/m<sup>3</sup>; MFB is about -33%) for SEMAP states and positive for neighboring states (MB is 0.4  $\mu$ g/m<sup>3</sup> out of 15  $\mu$ g/m<sup>3</sup>). Annual bias is largest in Louisiana and WV (MB = 10.5 and -6.1  $\mu$ g/m<sup>3</sup>; MFB = 41% and -42%). In GA MB is -5.3  $\mu$ g/m<sup>3</sup> (out of 17  $\mu$ g/m<sup>3</sup>; MFB = -33%) and ME is 6.3  $\mu$ g/m<sup>3</sup> (MFE = 42%). The largest monthly biases are in May for coastal SEMAP states (recall that FL-GA fires were in May) and in May and August for all interior SEMAP states. In Alabama, MB is -15.5  $\mu$ g/m<sup>3</sup> out of 26.6  $\mu$ g/m<sup>3</sup>. In Florida MB is -15  $\mu$ g/m<sup>3</sup> out of 23  $\mu$ g/m<sup>3</sup> (out of 25.6  $\mu$ g/m<sup>3</sup>; MFB = -66%) (Table 3-15).

A bugle plot of domain-wide annual  $PM_{2.5}$  and its major components shows the performance of individual species of  $PM_{2.5}$  during the entire year (Figure 3-19). All species of  $PM_{2.5}$  show similar good performance, within the goal fractional bias, except organic matter (OM). In the final scenario, OM is still within the criteria fractional bias.

| Site      | Model Mean | CSN mean | # of pairs | Cor  | ME    | MB     | NME   | NMB    | MNE   | MNB    | MFB    | MFE   | RMSE  |
|-----------|------------|----------|------------|------|-------|--------|-------|--------|-------|--------|--------|-------|-------|
| 370210034 | 10.7       | 25.0     | 5          | 0.84 | 14.32 | -14.32 | 57.28 | -57.28 | 54.60 | -54.60 | -76.28 | 76.28 | 15.48 |
| 370350004 | 12.2       | 26.2     | 5          | 0.80 | 13.98 | -13.98 | 53.31 | -53.31 | 52.42 | -52.42 | -71.51 | 71.51 | 14.90 |
| 370570002 | 12.4       | 27.2     | 5          | 0.74 | 14.85 | -14.85 | 54.56 | -54.56 | 53.48 | -53.48 | -74.03 | 74.03 | 16.03 |
| 370670022 | 13.4       | 27.9     | 5          | 0.72 | 14.54 | -14.54 | 52.07 | -52.07 | 49.95 | -49.95 | -67.69 | 67.69 | 16.46 |
| 371070004 | 7.7        | 21.1     | 5          | 0.62 | 13.43 | -13.43 | 63.60 | -63.60 | 62.82 | -62.82 | -93.15 | 93.15 | 14.42 |
| 371190041 | 16.5       | 27.3     | 10         | 0.78 | 10.79 | -10.79 | 39.61 | -39.61 | 39.67 | -39.67 | -50.52 | 50.52 | 11.38 |
| 371590021 | 11.0       | 23.9     | 4          | 0.80 | 12.88 | -12.88 | 53.88 | -53.88 | 52.83 | -52.83 | -72.26 | 72.26 | 13.50 |
| 371830014 | 14.9       | 24.7     | 9          | 0.67 | 9.85  | -9.85  | 39.80 | -39.80 | 39.77 | -39.77 | -50.98 | 50.98 | 10.50 |

Table 3-15. Statistical evaluation metrics of total PM<sub>2.5</sub> for CSN sites in North Carolina during August 2007



SEMAP-12km vs IMPROVE Speciated PM2.5 Annual 2007 Domainwide

Figure 3-19. Final fractional biases of total  $PM_{2.5}$  and its major components versus the observed average total  $PM_{2.5}$  concentration at IMPROVE sites in the domain for the year 2007

### 3.8.3 Acid Deposition

Network-wide, annual precipitation MB is -0.4 mm (NMB = -2%) and ME is 12.5 mm (NME = 62%). Sulfate deposition performed well with MB of -0.06 kg/ha (NMB = -19%) and ME is 0.2 kg/ha (NME = 60%). Nitrate deposition performed better than the initial runs, with MB of -0.03 kg/ha (NMB = -13%) and ME is 0.13 kg/ha (NME = 58%) while ammonium deposition MB is -0.02 kg/ha (NMB = -26%) and ME is 0.05 kg/ha (NME = 65%).

Precipitation MB ranges from -3.5 mm in Mississippi (NMB = -17%) to +5.0 mm in West Virginia (NMB = +22%). Sulfate deposition MB ranges from -0.2 kg/ha in Delaware (NMB = -48%) to 0.07 kg/ha in West Virginia (NMB = 17%). The Nitrate deposition high bias is fixed in this run, with bias ranges from - 0.15 kg/ha in Kansas (NMB = -48%) to 0.05 kg/ha in West Virginia (NMB = 20.7%). Also, ammonium deposition low bias in the initial runs are higher, with MB ranges from -0.09 kg/ha in Iowa (NMB = 58%) to 0.0 kg/ha in West Virginia (NMB = 6.4%).

# 3.9 Typical vs. Actual Year Performance

## 3.9.1 Capping of fire emissions

In addition to using typical fire emissions in the SESARM states, another difference of the 2007 typical case from the 2007 actual case has been the capping of fire emissions in the non-SESARM states. During the comparisons of typical emissions to actual emissions it was noticed that the fire emissions from the non-SESARM states are probably too high. Especially in Mississippi and Louisiana some fire emissions estimated by SMARTFIRE-V2 appeared to be unreasonably high. The maximum of the Alabama and Tennessee fire emissions from the 2007 SEMAP inventory was used to cap the fire emissions in non-SESARM states.

The actual 2007 simulation was not repeated with these capped non-SESARM state fire emissions since the effects were found to be limited to a handful of monitors close to the boundaries with non-SESARM states. The typical 2007 performance may be a more accurate representation of model performance at those monitors.

### 3.9.2 Ozone

Overall, the typical year simulation performed similarly to the actual year simulation. Annual networkwide O<sub>3</sub> MB without using a cut-off is +5.1 ppb (out of 31 ppb, for a NMB of +16%) and ME is 12 ppb (NME = 37%). With a 60 ppb cut-off, the network-wide annual O<sub>3</sub> MB is -5.7 ppb (out of 69 ppb, for a NMB of -8%) and ME is 11 ppb. MFB is -10% and MFE is 17%. MFB is -10% and MFE is 17%. As for the actual year simulations, typical year bias and error are smallest for coastal SEMAP states (MFB = -8% and MFE = 15%) and larger for interior SEMAP (KY, TN and WV; MFB = -13% and MFE = 17%) or neighboring states. The network-wide 8-hr max ozone with no cut-off MB is +3 ppb (out of 47 ppb). MFB is +6%. ME is 8 ppb. MFE is 19%. Using a cut-off of 60 ppb, the actual and typical year simulations performed almost identically, with the MB is -3 ppb (out of 69 ppb). MFB is -5%. ME is 8 ppb. MFE is 12%. The bias and error are smallest for the coastal SEMAP states and larger for the interior SEMAP and neighboring states. In WV, TN and KY MBs are -4 to -6 ppb and MEs are 8 ppb (MFEs are 12%). In Georgia the bias are positive and small but the errors are large. MB is 0.4 ppb (MFB is -0.54 %) and MEs are 8.3ppb (MFE is 11.9%).

### 3.9.3 PM<sub>2.5</sub>

The PM<sub>2.5</sub> performance for the actual and typical year simulations are also similar. The AQS 24-hr network-wide, MB for PM<sub>2.5</sub> is MB is -0.77  $\mu$ g/m<sup>3</sup> (out of 13  $\mu$ g/m<sup>3</sup>; MFB is -6.4%) and ME is 5  $\mu$ g/m<sup>3</sup> (MFE is 38%). For total PM<sub>2.5</sub> at CSN sites, the network-wide MB is --1.6  $\mu$ g/m<sup>3</sup> (out of 15  $\mu$ g/m<sup>3</sup>; MFB is -12%) and ME is 5.5  $\mu$ g/m<sup>3</sup> (MFE is 38%). MB is negative (about 5  $\mu$ g/m<sup>3</sup>; MFB is about -34%) for SEMAP states and positive for neighboring states (MB is 0.2  $\mu$ g/m<sup>3</sup> out of 15  $\mu$ g/m<sup>3</sup>). For the typical year simulation, annual bias is largest in Alabama, as opposed to Louisiana, and WV (MB = -6.1 and -6.2  $\mu$ g/m<sup>3</sup>; MFB = -35% and -44%). In GA MB is -5.4  $\mu$ g/m<sup>3</sup> (out of 17  $\mu$ g/m<sup>3</sup>; MFB = -34%) and ME is 6.5  $\mu$ g/m<sup>3</sup> (MFE = 43%). Again, the largest monthly biases are in May for coastal SEMAP states and in May and August for all interior SEMAP states. In Alabama MB is -16.4  $\mu$ g/m<sup>3</sup> out of 26.6  $\mu$ g/m<sup>3</sup>. In Florida MB is -16.1  $\mu$ g/m<sup>3</sup> out of 23  $\mu$ g/m<sup>3</sup> and in Georgia MB is -15.4  $\mu$ g/m<sup>3</sup> (out of 25.6  $\mu$ g/m<sup>3</sup>; MFB is -70%) (Table 3-16).

A bugle plot of domain-wide annual  $PM_{2.5}$  and its major components shows the performance of individual species of  $PM_{2.5}$  during the entire year (Figure 3-20). All species of  $PM_{2.5}$  show similar good performance to the final, within the goal fractional bias, except organic matter (OM). In the final scenario, OM is still within the criteria fractional bias. Ammonia aerosol is also just reaching the goal performance.

| Site      | Month   | Model | CSN  | # pairs | cor  | ME    | MB     | NME   | NMB    | MNE   | MNB    | MFB    | MFE   | RMSE  |
|-----------|---------|-------|------|---------|------|-------|--------|-------|--------|-------|--------|--------|-------|-------|
|           |         | Mean  | mean |         |      |       |        |       |        |       |        |        |       |       |
| 370210034 | 2007-08 | 10.1  | 25.0 | 5       | 0.96 | 14.95 | -14.95 | 59.79 | -59.79 | 57.46 | -57.46 | -81.53 | 81.53 | 16.02 |
| 370350004 | 2007-08 | 11.6  | 26.2 | 5       | 0.73 | 14.58 | -14.58 | 55.62 | -55.62 | 54.77 | -54.77 | -75.99 | 75.99 | 15.55 |
| 370570002 | 2007-08 | 11.9  | 27.2 | 5       | 0.78 | 15.31 | -15.31 | 56.24 | -56.24 | 55.35 | -55.35 | -77.36 | 77.36 | 16.40 |
| 370670022 | 2007-08 | 12.9  | 27.9 | 5       | 0.75 | 15.06 | -15.06 | 53.95 | -53.95 | 52.00 | -52.00 | -71.28 | 71.28 | 16.89 |
| 371070004 | 2007-08 | 7.4   | 21.1 | 5       | 0.59 | 13.69 | -13.69 | 64.83 | -64.83 | 63.77 | -63.77 | -95.14 | 95.14 | 14.71 |
| 371190041 | 2007-08 | 16.2  | 27.3 | 10      | 0.80 | 11.06 | -11.06 | 40.59 | -40.59 | 40.65 | -40.65 | -51.91 | 51.91 | 11.60 |
| 371590021 | 2007-08 | 10.7  | 23.9 | 4       | 0.88 | 13.21 | -13.21 | 55.25 | -55.25 | 54.37 | -54.37 | -74.99 | 74.99 | 13.77 |
| 371830014 | 2007-08 | 14.0  | 24.7 | 9       | 0.67 | 10.72 | -10.72 | 43.34 | -43.34 | 43.11 | -43.11 | -56.03 | 56.03 | 11.30 |

Table 3-16. Statistical evaluation metrics of PM<sub>2.5</sub> for CSN sites in North Carolina during August 2007



SEMAP-12km vs IMPROVE Speciated PM2.5 Annual 2007 Domainwide

Figure 3-20. Fractional biases of total  $PM_{2.5}$  and its major components in the 2007 typical emissions scenario versus the observed average total  $PM_{2.5}$  concentration at IMPROVE sites in the domain for the year 2007

### 3.9.4 Acid Deposition

The actual and typical year simulations also performed similarly for deposition. Network-wide, annual precipitation MB is -0.4 mm (NMB = -2%) and ME is 12.5 mm (NME = 62%). Sulfate deposition performed well with MB of -0.07 kg/ha (NMB = -19%) and ME is 0.2 kg/ha (NME = 60%). Nitrate deposition performed better than the initial runs, with MB of -0.03 kg/ha (NMB = -13%) and ME is 0.13 kg/ha (NME = 58%) while ammonium deposition MB is -0.02 kg/ha (NMB = -26%) and ME is 0.05kg/ha (NME = 65%).

State-by-state, actual and typical year simulations performed almost identically for deposition. Precipitation MB ranges from -3.5 mm in Mississippi (NMB = -17%) to +5.0 mm in West Virginia (NMB = +22%). Sulfate deposition MB ranges from -0.2 kg/ha in Delaware (NMB = -48%) to 0.07 kg/ha in West Virginia (NMB = 17%). The Nitrate deposition high bias is fixed in this run, with bias ranges from -0.15 kg/ha in Kansas (NMB = -48%) to 0.05 kg/ha in West Virginia (NMB = 20.7%). Also, ammonium deposition low bias in the initial runs are higher, with MB ranges from -0.09 kg/ha in Iowa (NMB = -58%) to 0.0 kg/ha in West Virginia (NMB = 6.4%).

# 3.10 Conclusions

### 3.10.1 Ozone and precursors

Monthly mean normalized biases (MNB) in 8-hr maximum O<sub>3</sub> at the AQS sites of the SEMAP 12-km domain generally remained between -15% and +15% in April, May, and October 2007 with a few exceptions (Figure 3-21 through Figure 3-27). In June most Florida sites were biased more than +15%. The high bias spread to some Alabama and Georgia sites in July and persisted through September. On the other hand, monthly mean normalized errors (MNE) in 8-hr maximum O<sub>3</sub> remained less than 35%, except at a very few AQS sites (Figure 3-28 through Figure 3-34). Note that MNB and MNE used in this section were calculated only for values of 8-hr maximum O<sub>3</sub> larger than 60 ppb. In general, it was not possible to find precursor data and perform diagnostic evaluation at the sites that did not meet the ozone performance goals.

#### 3.10.2 PM<sub>2.5</sub>

Monthly mean fractional biases (MFB) in 24-hr average  $PM_{2.5}$  at the AQS sites of the SEMAP 12-km domain generally remained between -30% and +30% in spring and fall with some exceptions in each state (Figure 3-35 through Figure 3-46). Winter overestimations and summer underestimations were outside the limits of the  $PM_{2.5}$  goal at several sites. Summertime underestimations did not meet the  $PM_{2.5}$  criteria of greater than -60% at several sites in the SEMAP states. Monthly mean fractional errors (MFE) in 24-hr average  $PM_{2.5}$  remained less than 50% January through April and September through December, except at a few AQS sites (Figure 3-47 through Figure 3-58). However, from May through August MFE exceeded 75% at several sites.

### 3.10.3 PM<sub>2.5</sub> Components

At the CSN sites of the SEMAP 12-km domain, sulfate was predicted accurately in spring and fall but underestimated both in winter and in summer months (Figure 3-59 through Figure 3-70), nitrate was overestimated in winter and fall months but underestimated in spring and summer months (Figure 3-71 through Figure 3-82), ammonium was underestimated similarly to sulfate in summer and overestimated similarly to nitrate in winter months (Figure 3-83 through Figure 3-94), elemental carbon was overestimated in winter and summer months but underestimated in spring and fall months (Figure 3-95 through Figure 3-106), and organic carbon was underestimated throughout the year.

# 3.11 References

- EPA (2007a) Guidance on the Use of Models and Other Analyses for Demonstrating Attainment of Air Quality Goals for Ozone, PM<sub>2.5</sub>, and Regional Haze. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC, EPA-454/B-07-002, April 2007.
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- Yan, B., M. Zheng, et al. (2008). "Organic composition of carbonaceous aerosols in an aged prescribed fire plume." <u>Atmos. Chem. Phys.</u> 8: 6381-6394. Yan, Zheng et al. (2008)



Figure 3-21. April 2007 mean normalized biases (MNB) in 8-hr maximum  $O_3$  at AQS sites.



Figure 3-22. May 2007 mean normalized biases (MNB) in 8-hr maximum  $O_3$  at AQS sites.



Figure 3-23. June 2007 mean normalized biases (MNB) in 8-hr maximum  $O_3$  at AQS sites.



Figure 3-24. July 2007 mean normalized biases (MNB) in 8-hr maximum  $O_3$  at AQS sites.



Figure 3-25. August 2007 mean normalized biases (MNB) in 8-hr maximum  $O_3$  at AQS sites.



Figure 3-26. September 2007 mean normalized biases (MNB) in 8-hr maximum  $O_3$  at AQS sites.



Figure 3-27. October 2007 mean normalized biases (MNB) in 8-hr maximum  $O_3$  at AQS sites.



Figure 3-28. April 2007 mean normalized errors (MNE) in 8-hr maximum  $O_3$  at AQS sites.



Figure 3-29. May 2007 mean normalized errors (MNE) in 8-hr maximum  $O_3$  at AQS sites.



Figure 3-30. June 2007 mean normalized errors (MNE) in 8-hr maximum  $O_3$  at AQS sites.



Figure 3-31. July 2007 mean normalized errors (MNE) in 8-hr maximum  $O_3$  at AQS sites.



Figure 3-32. August 2007 mean normalized errors (MNE) in 8-hr maximum  $O_3$  at AQS sites.



Figure 3-33. September 2007 mean normalized errors (MNE) in 8-hr maximum  $O_3$  at AQS sites.



Figure 3-34. October 2007 mean normalized errors (MNE) in 8-hr maximum  $O_3$  at AQS sites.



Figure 3-35. January 2007 mean fractional biases (MFB) in 24-hr average PM<sub>2.5</sub> at AQS sites.


Figure 3-36. February 2007 mean fractional biases (MFB) in 24-hr average PM<sub>2.5</sub> at AQS sites.



Figure 3-37. March 2007 mean fractional biases (MFB) in 24-hr average PM<sub>2.5</sub> at AQS sites.



Figure 3-38. April 2007 mean fractional biases (MFB) in 24-hr average PM<sub>2.5</sub> at AQS sites.



Figure 3-39. May 2007 mean fractional biases (MFB) in 24-hr average PM<sub>2.5</sub> at AQS sites.



Figure 3-40. June 2007 mean fractional biases (MFB) in 24-hr average PM<sub>2.5</sub> at AQS sites.



Figure 3-41. July 2007 mean fractional biases (MFB) in 24-hr average PM<sub>2.5</sub> at AQS sites.

3-51



Figure 3-42. August 2007 mean fractional biases (MFB) in 24-hr average PM<sub>2.5</sub> at AQS sites.



Figure 3-43. September 2007 mean fractional biases (MFB) in 24-hr average PM<sub>2.5</sub> at AQS sites.



Figure 3-44. October 2007 mean fractional biases (MFB) in 24-hr average PM<sub>2.5</sub> at AQS sites.



Figure 3-45. November 2007 mean fractional biases (MFB) in 24-hr average PM<sub>2.5</sub> at AQS sites.



Figure 3-46. December 2007 mean fractional biases (MFB) in 24-hr average PM<sub>2.5</sub> at AQS sites.



Figure 3-47. January 2007 mean fractional errors (MFE) in 24-hr average PM<sub>2.5</sub> at AQS sites.



Figure 3-48. February 2007 mean fractional errors (MFE) in 24-hr average PM<sub>2.5</sub> at AQS sites.



Figure 3-49. March 2007 mean fractional errors (MFE) in 24-hr average PM<sub>2.5</sub> at AQS sites.



Figure 3-50. April 2007 mean fractional errors (MFE) in 24-hr average PM<sub>2.5</sub> at AQS sites.

December 31, 2014



Figure 3-51. May 2007 mean fractional errors (MFE) in 24-hr average PM<sub>2.5</sub> at AQS sites.



Figure 3-52. June 2007 mean fractional errors (MFE) in 24-hr average PM<sub>2.5</sub> at AQS sites.



Figure 3-53. July 2007 mean fractional errors (MFE) in 24-hr average PM<sub>2.5</sub> at AQS sites.



Figure 3-54. August 2007 mean fractional errors (MFE) in 24-hr average PM<sub>2.5</sub> at AQS sites.



Figure 3-55. September 2007 mean fractional errors (MFE) in 24-hr average PM<sub>2.5</sub> at AQS sites.



Figure 3-56. October 2007 mean fractional errors (MFE) in 24-hr average PM<sub>2.5</sub> at AQS sites.



Figure 3-57. November 2007 mean fractional errors (MFE) in 24-hr average PM<sub>2.5</sub> at AQS sites.



Figure 3-58. December 2007 mean fractional errors (MFE) in 24-hr average PM<sub>2.5</sub> at AQS sites.



Figure 3-59. January 2007 mean fractional biases (MFB) in 24-hr average PM<sub>2.5</sub> sulfate at CSN sites.



Figure 3-60. February 2007 mean fractional biases (MFB) in 24-hr average PM<sub>2.5</sub> sulfate at CSN sites.



Figure 3-61. March 2007 mean fractional biases (MFB) in 24-hr average PM<sub>2.5</sub> sulfate at CSN sites.



Figure 3-62. April 2007 mean fractional biases (MFB) in 24-hr average PM<sub>2.5</sub> sulfate at CSN sites.



Figure 3-63. May 2007 mean fractional biases (MFB) in 24-hr average PM<sub>2.5</sub> sulfate at CSN sites.



Figure 3-64. June 2007 mean fractional biases (MFB) in 24-hr average PM<sub>2.5</sub> sulfate at CSN sites.



Figure 3-65. July 2007 mean fractional biases (MFB) in 24-hr average PM<sub>2.5</sub> sulfate at CSN sites.



Figure 3-66. August 2007 mean fractional biases (MFB) in 24-hr average PM<sub>2.5</sub> sulfate at CSN sites.



*Figure 3-67. September 2007 mean fractional biases (MFB) in 24-hr average PM*<sub>2.5</sub> *sulfate at CSN sites.* 



Figure 3-68. October 2007 mean fractional biases (MFB) in 24-hr average PM<sub>2.5</sub> sulfate at CSN sites.



*Figure 3-69. November 2007 mean fractional biases (MFB) in 24-hr average PM*<sub>2.5</sub> *sulfate at CSN sites.* 



*Figure 3-70. December 2007 mean fractional biases (MFB) in 24-hr average PM*<sub>2.5</sub> *sulfate at CSN sites.* 



Figure 3-71. January 2007 mean fractional biases (MFB) in 24-hr average PM<sub>2.5</sub> nitrate at CSN sites.


Figure 3-72. February 2007 mean fractional biases (MFB) in 24-hr average PM<sub>2.5</sub> nitrate at CSN sites.



Figure 3-73. March 2007 mean fractional biases (MFB) in 24-hr average PM<sub>2.5</sub> nitrate at CSN sites.



Figure 3-74. April 2007 mean fractional biases (MFB) in 24-hr average PM<sub>2.5</sub> nitrate at CSN sites.



Figure 3-75. May 2007 mean fractional biases (MFB) in 24-hr average PM<sub>2.5</sub> nitrate at CSN sites.



Figure 3-76. June 2007 mean fractional biases (MFB) in 24-hr average PM<sub>2.5</sub> nitrate at CSN sites.



Figure 3-77. July 2007 mean fractional biases (MFB) in 24-hr average PM<sub>2.5</sub> nitrate at CSN sites.



Figure 3-78. August 2007 mean fractional biases (MFB) in 24-hr average PM<sub>2.5</sub> nitrate at CSN sites.



Figure 3-79September 2007 mean fractional biases (MFB) in 24-hr average PM<sub>2.5</sub> nitrate at CSN sites.



Figure 3-80. October 2007 mean fractional biases (MFB) in 24-hr average PM<sub>2.5</sub> nitrate at CSN sites.



*Figure 3-81. November 2007 mean fractional biases (MFB) in 24-hr average PM*<sub>2.5</sub> *nitrate at CSN sites.* 



*Figure 3-82. December 2007 mean fractional biases (MFB) in 24-hr average PM*<sub>2.5</sub> *nitrate at CSN sites.* 



*Figure 3-83. January 2007 mean fractional biases (MFB) in 24-hr average PM*<sub>2.5</sub> *ammonium at CSN sites.* 



Figure 3-84. February 2007 mean fractional biases (MFB) in 24-hr average PM<sub>2.5</sub> ammonium at CSN sites.



*Figure 3-85. March 2007 mean fractional biases (MFB) in 24-hr average PM*<sub>2.5</sub> *ammonium at CSN sites.* 



*Figure 3-86. April 2007 mean fractional biases (MFB) in 24-hr average PM*<sub>2.5</sub> *ammonium at CSN sites.* 



Figure 3-87. May 2007 mean fractional biases (MFB) in 24-hr average PM<sub>2.5</sub> ammonium at CSN sites.



*Figure 3-88. June 2007 mean fractional biases (MFB) in 24-hr average PM*<sub>2.5</sub> *ammonium at CSN sites.* 



Figure 3-89. July 2007 mean fractional biases (MFB) in 24-hr average PM<sub>2.5</sub> ammonium at CSN sites.



Figure 3-90. August 2007 mean fractional biases (MFB) in 24-hr average PM<sub>2.5</sub> ammonium at CSN sites.



*Figure 3-91. September 2007 mean fractional biases (MFB) in 24-hr average PM*<sub>2.5</sub> *ammonium at CSN sites.* 



*Figure 3-92. October 2007 mean fractional biases (MFB) in 24-hr average PM*<sub>2.5</sub> *ammonium at CSN sites.* 



*Figure 3-93. November 2007 mean fractional biases (MFB) in 24-hr average PM*<sub>2.5</sub> *ammonium at CSN sites.* 



*Figure 3-94. December 2007 mean fractional biases (MFB) in 24-hr average PM*<sub>2.5</sub> *ammonium at CSN sites.* 



Figure 3-95. January 2007 mean fractional biases (MFB) in 24-hr average PM<sub>2.5</sub> elemental carbon at CSN sites.



Figure 3-96. February 2007 mean fractional biases (MFB) in 24-hr average PM<sub>2.5</sub> elemental carbon at CSN sites.



Figure 3-97. March 2007 mean fractional biases (MFB) in 24-hr average PM<sub>2.5</sub> elemental carbon at CSN sites.



Figure 3-98. April 2007 mean fractional biases (MFB) in 24-hr average PM<sub>2.5</sub> elemental carbon at CSN sites.



*Figure 3-99. May 2007 mean fractional biases (MFB) in 24-hr average PM<sub>2.5</sub> elemental carbon at CSN sites.* 



Figure 3-100. June 2007 mean fractional biases (MFB) in 24-hr average PM<sub>2.5</sub> elemental carbon at CSN sites.



Figure 3-101. July 2007 mean fractional biases (MFB) in 24-hr average PM<sub>2.5</sub> elemental carbon at CSN sites.



Figure 3-102. August 2007 mean fractional biases (MFB) in 24-hr average PM<sub>2.5</sub> elemental carbon at CSN sites.



*Figure 3-103. September 2007 mean fractional biases (MFB) in 24-hr average PM*<sub>2.5</sub> *elemental carbon at CSN sites.* 



Figure 3-104. October 2007 mean fractional biases (MFB) in 24-hr average PM<sub>2.5</sub> elemental carbon at CSN sites.



*Figure 3-105. November 2007 mean fractional biases (MFB) in 24-hr average PM*<sub>2.5</sub> *elemental carbon at CSN sites.* 



Figure 3-106. December 2007 mean fractional biases (MFB) in 24-hr average PM<sub>2.5</sub> elemental carbon at CSN sites.



*Figure 3-107. January 2007 mean fractional biases (MFB) in 24-hr average PM*<sub>2.5</sub> organic carbon at CSN sites.


*Figure 3-108. February 2007 mean fractional biases (MFB) in 24-hr average PM*<sub>2.5</sub> organic carbon at CSN sites.



Figure 3-109. March 2007 mean fractional biases (MFB) in 24-hr average PM<sub>2.5</sub> organic carbon at CSN sites.



*Figure 3-110. April 2007 mean fractional biases (MFB) in 24-hr average PM<sub>2.5</sub> organic carbon at CSN sites.* 



*Figure 3-111. May 2007 mean fractional biases (MFB) in 24-hr average PM<sub>2.5</sub> organic carbon at CSN sites.* 



*Figure 3-112. June 2007 mean fractional biases (MFB) in 24-hr average PM*<sub>2.5</sub> *organic carbon at CSN sites.* 



*Figure 3-113. July 2007 mean fractional biases (MFB) in 24-hr average PM<sub>2.5</sub> organic carbon at CSN sites.* 



*Figure 3-114. August 2007 mean fractional biases (MFB) in 24-hr average PM*<sub>2.5</sub> organic carbon at CSN sites.



*Figure 3-115. September 2007 mean fractional biases (MFB) in 24-hr average PM*<sub>2.5</sub> organic carbon at CSN sites.



*Figure 3-116. October 2007 mean fractional biases (MFB) in 24-hr average PM*<sub>2.5</sub> organic carbon at CSN sites.



*Figure 3-117. November 2007 mean fractional biases (MFB) in 24-hr average PM*<sub>2.5</sub> organic carbon at CSN sites.



*Figure 3-118. December 2007 mean fractional biases (MFB) in 24-hr average PM*<sub>2.5</sub> organic carbon at CSN sites.

# Chapter 4: Future Year (2018) Simulation

## 4.1 Introduction

The year 2018 was simulated with the CMAQ model using the emission projections of Chapter 2. The results were used in conjunction with the results of the 2007 typical simulation of Chapter 3 to calculate relative response factors. Air quality data for the 2005-2009 period were used to calculate future year design values for ozone, annual and daily PM<sub>2.5</sub>, and visibility in the year 2018.

In this chapter, first the methodology used for projecting the current design values to 2018 will be described. Then the results of the 2018 ozone,  $PM_{2.5}$  and visibility projections will be presented. The compositions of  $PM_{2.5}$  and the contributions of  $PM_{2.5}$  constituents to light extinction for the years 2007 and 2018 will be compared. Finally conclusions will be drawn.

## 4.2 Methodology

The 2007 SEMAP meteorology and 2018 SEMAP emissions were used in the 2018 annual simulation of air quality, first over the 36-km then the 12-km-grid SEMAP domains. The boundary conditions for the 12-km domain were derived from the simulation over the 36-km domain. The model used is CMAQv5.01 with the SEMAP modifications described in Chapter 3. Recall that the performance of this model version was evaluated for the final 2007 actual simulation and the same version was used for the 2007 typical simulation in Chapter 3. As in the 2007 simulations, the year was split into four quarters and each quarter was run separately using a 15-day spin-up period in the beginning, for which the results were discarded. The model results were post-processed to obtain daily maximum 8-hr ozone concentrations, and daily 24-hr average PM<sub>2.5</sub> concentrations. Movies showing the evolution of ozone and PM<sub>2.5</sub> concentrations and their differences from the 2007 typical simulation can be found at http://semap.ce.gatech.edu/node/1848.

EPA's Modeled Attainment Test Software  $(MATS)^1$  was used to calculate the relative response factors (RRFs) and future design values (DVFs). The calculations performed by MATS for ozone, PM<sub>2.5</sub> and visibility will be summarized next. The parameters used to run MATS will also be listed.

#### 4.2.1 Calculation of Ozone DVFs

Two sets of modeled concentrations are input to MATS: a "baseline" and a "forecast". Here, the results of the 2007 typical simulation are the "baseline" and the results of the 2018 base case simulation are the "forecast". The RRF calculated by MATS is their ratio:

 $RRF = O_3 (2018_{base}) / O_3 (2007_{typ})$ 

where  $O_3$  denotes the daily maximum 8-hr ozone with the simulation year and case in parenthesis. MATS calculated the ozone DVF as:

#### $DVF = DVC \times RRF$

where DVC is the current design value.

Four different DVFs were calculated using two different sets of DVCs and two different sets of RRFs. The DVCs are:

- 2007 design value, which uses ozone measurements from three years (2005-2007)
- 5-year (2005-2009) weighted average design value, which is the average of 2007, 2008 and 2009 design values

<sup>&</sup>lt;sup>1</sup> <u>http://www.epa.gov/ttn/scram/guidance/guide/MATS-2-5-1 manual.pdf</u>

The two different RRFs are:

- Monitor (1×1) cell RRF
- 3x3 cell block's maximum RRF

Note that the 3x3 cell block's maximum RRF may produce non-intuitive results. The 3x3 cell block'smaximum may be in one cell for the 2007 typical ozone and in another cell for the 2018 base case ozone as illustrated in Figure 4-1. This may result in an RRF that is not specific to any cell in the 3x3 matrix.



Figure 4-1. Illustration of how the design value can shift into a different cell in a 3×3 block of cells around the monitor.

The RRFs were produced using the following thresholds in MATS based on the modeled 2007 typical daily 8-hr maximum ozone concentrations:

- Initial threshold value = 75 ppb
- Minimum number of days in baseline at or above threshold = 10
- Minimum allowable threshold value = 65 ppb
- Minimum number of days at or above minimum allowable threshold = 5

#### 4.2.2 Calculation of PM<sub>2.5</sub> DVFs

Once again, the results of the 2007 typical simulation are input to MATS as the "baseline" and the results of the 2018 base case simulation are input as the "forecast". However, different from the ozone RRF calculations, MATS calculates different RRFs for each of the four quarters and for each of the  $PM_{2.5}$  species as:

$$RRF_{Q,S} = PM_{2.5}(2018_{base})_{Q,S} / PM_{2.5}(2007_{typ})_{Q,S}$$

Here  $PM_{2.5}$  denotes the daily 24-hr average  $PM_{2.5}$  with the simulation year and case in parenthesis, and Q and S are the quarter and species indices, respectively.

The future design values for each quarter and each  $PM_{2.5}$  species are obtained from  $RRF_{Q.S}$  using the current design values  $DVC_{Q.S}$ , also calculated for each quarter and  $PM_{2.5}$  species, as follows:

$$DVF_{Q,S} = DVC_{Q,S} \times RRF_{Q,S}$$

Then, for each  $PM_{2.5}$  species,  $DVF_{Q,S}$  are averaged across the four quarters:

$$DVF_S = \frac{1}{4} \sum_{Q=1}^{4} DVF_{Q,S}$$

GIT/UNC/CIRA-SEMAP 057.v1.0

Finally,  $DVF_s$  are summed for all species to yield the DVF for total  $PM_{2.5}$ 

$$DVF = \sum_{S} DVF_{S}$$

Similar to ozone DVFs, PM<sub>2.5</sub> DVFs were also calculated in four different ways using two different sets of DVCs and two different sets of RRFs. The DVCs are:

- 2007 design value, which uses  $PM_{2.5}$  values from three years (2005-2007)
- 5-year (2005-2009) weighted average design value

The two different sets of RRFs are:

- Monitor (1×1) cell RRF
- 3x3 cell block average RRF

Note that while the 3x3 cell block's maximum RRF was used for ozone, 3x3 cell block's average RRF is used for  $PM_{2.5}$ .

#### 4.2.3 Calculation of 2018 Visibility

We ran MATS with the 2007 typical simulation results as the "baseline" and 2018 base-case simulation results as "forecast" to get the RRFs for each  $PM_{2.5}$  species, *S*, as:

$$RRF_S = PM_{2.5}(2018_{base})_S / PM_{2.5}(2007_{typ})_S$$

Then, using these  $RRF_s$ , the future light extinction for each species was calculated from that species' current light extinction as follows:

Future  $Bext_S = Base Bext_S \times RRF_S$ 

Both Base  $Bext_s$  and  $RRF_s$  were calculated for each species on the 20% worst and 20% best visibility days. Future  $Bext_s$ , which are the contributions of  $PM_{2.5}$  species to light extinction, were summed for all species to give the future light extinction:

Future Bext = 
$$\sum_{S}$$
 Future Bext<sub>s</sub>

Finally, the Haze Index (in deciViews) is the base 10 logarithm of the total light extinction:

Haze Index (dV) = 10 ln ( $B_{\text{ext}}/10$ )

Two different sets of future light extinctions were calculated, both using the 5-year (2005-2009) straight average Base *Bext* but two different sets of RRFs. The RRFs are:

- Monitor (1×1) cell RRF
- 3x3 cell block's average RRF

## 4.3 Future Design Values

Projected 2018 future design values for ozone as well as annual and daily  $PM_{2.5}$  are presented in this section.

#### 4.3.1 Future Ozone Design Values

Before presenting the 2018 future ozone design values, let's first take a look at the current ozone design values. In 2007, in every SESARM state there were multiple non-attainment sites where the ozone design value exceeded 75 ppb (Figure 4-2).

Ozone design values were projected to 2018 in four different ways as described in Section 4.2.1 above. "Bubble" plots were prepared with color-coded circles denoting the level of ozone over each monitor of the 12-km SEMAP modeling domain. The resulting 2018 future design values are shown in Figure 4-3 through Figure 4-6 for the four different ways of calculation. Figure 4-7 shows that using the 2007 design values as DVCs results in higher DVFs than using the 5-year (2005-2009) weighted average design values. This is due to the decreasing trend of ozone from 2007 to 2009 throughout the domain. On the other hand, the DVFs are higher at some sites when the  $3\times3$  cell block's maximum RRF is used while the monitor (1×1 cell) RRF leads to higher DVFs at other sites (Figure 4-8). The 2007 DVC and  $3\times3$  cell block's maximum RRF lead to the most extensive violations of the ozone standard in the SESARM states, with several monitors above 75 ppb and one monitor in Atlanta, GA over 80 ppb (Figure 4-3).

Table 4-1 lists the sites projected to be in non-attainment in 2018 based on the five-year (2005-2009) weighted average DVC both for the  $3\times3$  cell maximum and monitor ( $1\times1$ ) cell RRFs. Non-attainment here is defined as the 2018 ozone DFV exceeding 75 ppb. For the  $3\times3$  cell block's maximum RRF there are four nonattainment sites in Georgia and only one of them is in non-attainment if the monitor ( $1\times1$ ) cell RRF is used.

Table 4-2 lists the "maintenance" sites for which the DVFs based on the five-year (2005-2009) weighted average DVC are less than 75 ppb but the DVFs based on the 2007 DVC exceed 75 ppb. If the  $3\times3$  cell block's maximum RRF is used there a one maintenance site in Alabama, one in Georgia, two in Virginia and one in West Virginia. If the monitor ( $1\times1$ ) cell RRF is used then there are three maintenance sites in Alabama and one in Virginia.4.2.1



Figure 4-2. Five year (2005-2009) weighted average O<sub>3</sub> DVCs



Figure 4-3. 2018 O<sub>3</sub> DVFs: 3×3 RRF & 2007 DVC





Figure 4-5. 2018 O3 DVFs: 3×3 RRF & 2005-2009 DVC



Figure 4-6. 2018 O3 DVFs: 1×1 RRF & 2005-2009 DVC



Figure 4-7. 2018 O<sub>3</sub> DVFs calculated using 2007 DVCs vs. 5-year weighted DVCs



Figure 4-8. 2018 O<sub>3</sub> DVFs calculated using 3×3 Max vs. 1×1 Cell RRFs

| STATE | AIRS ID   | DVC  | 3x3 MAX | 1x1 CELL |
|-------|-----------|------|---------|----------|
| СТ    | 90010017  | 86.3 | 78.8    | 79.1     |
| СТ    | 90011123  | 88.7 | 76.9    | 75.8     |
| СТ    | 90013007  | 87   | 77.9    | 79.1     |
| СТ    | 90019003  | 85.3 | 77.1    | 76.3     |
| СТ    | 90070007  | 87   | 75.4    | 74.2     |
| СТ    | 90093002  | 87.3 | 77.3    | 76.8     |
| СТ    | 90110008  | 88   | 77.6    | 76.9     |
| GA    | 130890002 | 90.7 | 77.2    | 74.4     |
| GA    | 131210055 | 90.3 | 77.3    | 76.3     |
| GA    | 131510002 | 92   | 76.2    | 74.7     |
| GA    | 132470001 | 91.7 | 75.2    | 73.4     |
| LA    | 220050004 | 81.7 | 75.4    | 76.4     |
| LA    | 220330003 | 83   | 76.2    | 76.3     |
| LA    | 220470012 | 81.3 | 75.4    | 72.9     |
| LA    | 220511001 | 79.3 | 73      | 80       |
| LA    | 220770001 | 82   | 77.6    | 75       |
| LA    | 220930002 | 74   | 68.9    | 76.6     |
| MD    | 240251001 | 90.7 | 77.1    | 76.2     |
| MI    | 260050003 | 86.7 | 75.4    | 75.6     |
| MI    | 260991003 | 81.3 | 76.9    | 75.9     |
| MI    | 261630019 | 81.7 | 75.6    | 80       |
| MO    | 290990012 | 86   | 77.3    | 78.6     |
| MO    | 291890004 | 82   | 76.1    | 75.7     |
| MO    | 291890014 | 82.3 | 75.6    | 76       |
| MO    | 295100086 | 83.5 | 76.9    | 77.6     |

Table 4-1. 2018 Ozone "Nonattainment" ( $DVF \ge 75 \text{ ppb}$  based on 2005-2009 DVC)

| STATE | AIRS ID   | DVC  | 3x3 MAX | 1x1 CELL |
|-------|-----------|------|---------|----------|
| NJ    | 340070003 | 87.5 | 77.6    | 79.2     |
| NJ    | 340150002 | 85.7 | 76.1    | 75.2     |
| NJ    | 340170006 | 85   | 77.5    | 77.7     |
| NJ    | 340210005 | 86.3 | 76.1    | 74.6     |
| NY    | 360050133 | 74.7 | 70      | 75.1     |
| NY    | 360610135 | 76   | 70.8    | 75       |
| NY    | 361030002 | 85.3 | 80.2    | 79       |
| NY    | 361030004 | 86   | 76.7    | 74.9     |
| NY    | 361030009 | 88   | 79.9    | 80.5     |
| NY    | 361192004 | 86.3 | 79      | 78.3     |
| PA    | 420170012 | 90.7 | 80.1    | 80.4     |
| PA    | 421010024 | 88   | 79.5    | 78.1     |
| ТХ    | 480391004 | 86.7 | 81.3    | 78.8     |
| тх    | 482010024 | 83.3 | 78.9    | 74.2     |
| ТХ    | 482010026 | 80.3 | 80.1    | 79.2     |
| тх    | 482010029 | 86.7 | 75.6    | 76.1     |
| ТХ    | 482010051 | 81   | 75.7    | 75.9     |
| тх    | 482010055 | 90.3 | 84.3    | 84.6     |
| ТХ    | 482010062 | 81   | 78.2    | 82.1     |
| тх    | 482010066 | 86.7 | 81.5    | 82.6     |
| ТХ    | 482010070 | 75.7 | 73      | 77.5     |
| тх    | 482010075 | 76.3 | 73.6    | 78.2     |
| ТХ    | 482010416 | 83.5 | 80.2    | 85.6     |
| тх    | 482011015 | 82   | 81.8    | 80.9     |
| ТХ    | 482011034 | 78   | 75.1    |          |
| тх    | 482011039 | 87   | 84.7    | 83.2     |
| ТХ    | 482011050 | 81.3 | 79.2    | 77.8     |
| тх    | 482450009 | 78.3 | 73.3    | 75.9     |
| ТХ    | 482450101 | 79   | 76.1    | 72.2     |
| WI    | 551170006 | 83.3 | 72.2    | 76.5     |

Table 4-1 (Continued). 2018 Ozone "Nonattainment" ( $DVF \ge 75 \text{ ppb}$  based on 2005-2009 DVC)

| STATE | AIRS ID   | DVC | 3x3 MAX | 1x1 CELL |
|-------|-----------|-----|---------|----------|
| AL    | 10730023  | 86  | 72.9    | 76.2     |
| AL    | 10732006  | 89  | 74.4    | 75.7     |
| AL    | 10736002  | 89  | 75.8    | 76.2     |
| AR    | 50350005  | 89  | 76.7    | 76.8     |
| СТ    | 90031003  | 90  | 75.9    | 76.7     |
| DC    | 110010043 | 87  | 75.4    | 76.4     |
| GA    | 131130001 | 89  | 75.9    | 71.9     |
| IL    | 170310001 | 82  | 73.3    | 75.2     |
| LA    | 220190002 | 81  | 76.4    | 69.3     |
| LA    | 220330013 | 81  | 75.5    | 75.4     |
| LA    | 220331001 | 84  | 78.6    | 77.5     |
| LA    | 220470007 | 86  | 79.7    | 79       |
| LA    | 220470009 | 81  | 75      | 74.4     |
| LA    | 220890003 | 77  | 70.1    | 75.2     |
| LA    | 221210001 | 83  | 76.7    | 77.1     |
| MD    | 240030014 | 90  | 75.8    | 75.2     |
| MD    | 240053001 | 87  | 75.7    | 76.5     |
| MD    | 240150003 | 93  | 77.9    | 77       |
| MD    | 240259001 | 91  | 76.8    | 77       |
| MD    | 240338003 | 91  | 76.5    | 75.2     |
| MA    | 250130008 | 92  | 76.8    | 77.2     |
| MI    | 260990009 | 86  | 77.1    | 76.6     |
| MI    | 261210039 | 88  | 75.6    | 75       |
| MI    | 261470005 | 85  | 75      | 76.5     |

Table 4-2. 2018 Ozone "Maintenance" (DVF < 75 ppb based on 2005-2009 DVC but  $DVF \ge 75$ ppb based on 2007 DVC)

| STATE | AIRS ID   | DVC | 3x3 MAX | 1x1 CELL     |
|-------|-----------|-----|---------|--------------|
| МО    | 290470005 | 87  | 76.5    | 74.6         |
| MO    | 290470006 | 87  | 75.2    | 74.2         |
| MO    | 291130003 | 87  | 74.6    | 75.2         |
| MO    | 291831002 | 89  | 79      | 79.4         |
| MO    | 291831004 | 89  | 78.8    | 77.7         |
| MO    | 295100085 | 84  | 77.4    | 78.1         |
| NJ    | 340071001 | 89  | 76.6    | 74.5         |
| NJ    | 340190001 | 89  | 75      | 73.6         |
| NJ    | 340230011 | 91  | 78.3    | 77.4         |
| NJ    | 340250005 | 88  | 77.3    | 74.7         |
| NJ    | 340290006 | 92  | 78.3    | 75.9         |
| NY    | 360130006 | 86  | 76.5    | 75.8         |
| NY    | 360290002 | 86  | 75.6    | 76.9         |
| NY    | 360810124 | 79  | 72.4    | 76.3         |
| NY    | 360850067 | 89  | 78.6    | 81. <b>2</b> |
| ОН    | 390071001 | 90  | 76.9    | 71.2         |
| ОН    | 390490029 | 87  | 76      | 74.9         |
| ОН    | 390610006 | 86  | 75.2    | 76.4         |
| ОН    | 390610010 | 84  | 74.9    | 75           |
| ОН    | 391650007 | 88  | 75.6    | 75.5         |
| PA    | 420030010 | 83  | 74.3    | 77.2         |
| PA    | 420031005 | 87  | 76.1    | 73.9         |
| PA    | 420450002 | 85  | 74.6    | 76.7         |
| PA    | 420910013 | 86  | 76.4    | 75.1         |
| ТХ    | 481830001 | 84  | 76.4    | 75.3         |
| ТХ    | 482011035 | 79  | 76.1    |              |
| ТХ    | 482450018 | 83  | 76.4    | 76.4         |
| VA    | 510130020 | 87  | 75.4    | 73.9         |
| VA    | 510590018 | 89  | 76.2    | 75           |
| WV    | 540110006 | 84  | 75.1    | 74.8         |
| WI    | 550710007 | 86  | 75.8    | 75.2         |

Table 4-2. (Continued) 2018 Ozone "Maintenance" (DVF < 75 ppb based on 2005-2009 DVC but DVF</th> $\geq$  75 ppb based on 2007 DVC)

#### 4.3.2 Future Annual PM<sub>2.5</sub> Design Values

The 2007 annual PM<sub>2.5</sub> design values are shown in Figure 4-9 (2007 DVC) and Figure 4-10 (5-year weighted average DVC). In 2007 wide-spread exceedance of the annual PM<sub>2.5</sub> standard, which is currently at 12  $\mu$ g m<sup>-3</sup>, is observed across the SESARM states as well as the neighboring RPOs. The coastal sites appear to be the only compliant SESARM sites according to the 2007 DVC and some mountain sites along the Southern Appalachians are added to the non-exceedance list according to the five-year (2005-2009) weighted average DVC.

Annual  $PM_{2.5}$  design values were projected to 2018 in four different ways as described in Section Calculation of Ozone DVFs above. The resulting 2018 future design values are shown in Figure 4-11 through Figure 4-14. The 2007 DVCs lead to higher DVFs than the 5-year (2005-2009) weighted average

DVCs (Figure 4-15). This is due to the decreasing trend of  $PM_{2.5}$  from 2007 to 2009 throughout the domain. On the other hand, while the 3×3 cell average RRFs lead to higher DVFs at some sites the monitor (1×1) cell RRFs lead to higher DVFs at other sites (Figure 4-16). The 2007 DVC and monitor (1×1) cell RRF show more exceedances of the  $PM_{2.5}$  standard than the other DVC–RRF combinations. The DVFs exceed 12 µg m<sup>-3</sup> at Macon, GA, Knoxville, TN and at two sites around Birmingham, AL they are larger than 13 µg m<sup>-3</sup> (Figure 4-12).



Figure 4-9. 2007 Annual PM<sub>2.5</sub> DVC



Figure 4-10. 5-Year (2005-09) Annual PM<sub>2.5</sub> DVC



Figure 4-11. 2018 Annual PM<sub>2.5</sub> DVFs: 3×3 RRF & 2007 DVC



Figure 4-12. 2018 Annual PM<sub>2.5</sub> DVFs: 1x1 RRF & 2007 DVC



*Figure 4-13. 2018 Annual PM*<sub>2.5</sub> *DVFs: 3×3 RRF & 2005-2009 DVC* 



*Figure 4-14. 2018 Annual PM*<sub>2.5</sub> *DVFs: 1×1 RRF & 2005-2009 DVC* 



Figure 4-15. Annual PM<sub>2.5</sub> DVFs calculated using 2007 DVCs vs. 5-year weighted DVCs



Figure 4-16. Annual PM<sub>2.5</sub> DVFs calculated using 3×3 Cell Average vs. 1×1 Cell RRFs

### 4.3.3 Future Daily PM<sub>2.5</sub> Design Values

The current daily  $PM_{2.5}$  design values are shown in Figure 4-17 (2007 DVC) and Figure 4-18 (5-year weighted average DVC). In 2007 only a few exceedances of the daily  $PM_{2.5}$  standard, which is currently at 35 µg m<sup>-3</sup> in the US (30 µg m<sup>-3</sup> in Canada) were observed in the SESARM states, primarily in Alabama, Tennessee, Kentucky, and West Virginia. However, if the standard were changed to 30 µg m<sup>-3</sup> there would be wide-spread exceedances in the SESARM states with the exception of the coastal sites. Also, there are more exceedances according to the 2007 DVC compared to the 5-year weighted average DVC.

Daily  $PM_{2.5}$  design values were projected to 2018 in four different ways as described in Section 4.2.1 above. The resulting 2018 future design values are shown in Figure 4-19 through Figure 4-22. The 2007

DVCs lead to higher DVFs than the 5-year (2005-2009) weighted average DVCs (Figure 4-23). This is due to the decreasing trend of  $PM_{2.5}$  from 2007 to 2009 throughout the domain. On the other hand, while the 3×3 cell average RRFs lead to higher DVFs at some sites, the monitor (1×1) cell RRFs lead to higher DVFs at other sites (Figure 4-24). The 2007 DVC and monitor cell RRF lead to higher daily  $PM_{2.5}$  DVFs than the other DVC–RRF combinations but no exceedances of the  $PM_{2.5}$  standard are projected. In the SESARM states, only in Birmingham, AL the DVF is expected to exceed 30 µg m<sup>-3</sup> (Figure 4-20).



Figure 4-17. 2007 Daily PM<sub>2.5</sub> DVC



GIT/UNC/CIRA-SEMAP 057.v1.0


*Figure 4-19. 2018 Daily PM*<sub>2.5</sub> *DVFs: 3×3 RRF & 2007 DVC* 





*Figure 4-21. 2018 Daily PM*<sub>2.5</sub> *DVFs: 3×3 RRF & 2005-2009 DVC* 



Figure 4-22. 2018 Daily PM<sub>2.5</sub> DVFs: 1×1 RRF & 2005-2009 DVC



Figure 4-23. 2018 Daily PM<sub>2.5</sub> DVFs calculated using 2007 DVCs vs. 5-year weighted DVCs



Figure 4-24. 2018 Daily PM<sub>2.5</sub> DVFs calculated using 3×3 cell average vs. 1×1 cell RRFs

# 4.4 Projected changes in PM<sub>2.5</sub> composition

Comparisons were made between the 2007 and 2018 compositions of  $PM_{2.5}$  at each site of the 31 states in the 12-km SEMAP domain. Figure 4-25 through Figure 4-34 show the comparisons for annual and daily  $PM_{2.5}$  components for the 10 SESARM states. In general, the sulfate component of  $PM_{2.5}$  is expected to decrease considerably in 2018 relative to 2007. As a result of the sulfate decrease the particle bound water will also decrease. The nitrate component is expected to increase significantly at a number of sites while the other components will generally stay the same.



Figure 4-25. 2007 and 2018 PM<sub>2.5</sub> compositions at Alabama sites for annual (top) and daily (bottom) PM<sub>2.5</sub> design values



Figure 4-26. 2007 and 2018 PM<sub>2.5</sub> compositions at Florida sites for annual (top) and daily (bottom) PM<sub>2.5</sub> design values



Figure 4-27. 2007 and 2018 PM<sub>2.5</sub> compositions at Georgia sites for annual (top) and daily (bottom) PM<sub>2.5</sub> design values



Figure 4-28. 2007 and 2018 PM<sub>2.5</sub> compositions at Kentucky sites for annual (top) and daily (bottom) PM<sub>2.5</sub> design values



Figure 4-29. 2007 and 2018 PM<sub>2.5</sub> compositions at Mississippi sites for annual (top) and daily (bottom) PM<sub>2.5</sub> design values



Figure 4-30. 2007 and 2018 PM<sub>2.5</sub> compositions at North Carolina sites for annual (top) and daily (bottom) PM<sub>2.5</sub> design values



Figure 4-31. 2007 and 2018 PM<sub>2.5</sub> compositions at South Carolina sites for annual (top) and daily (bottom) PM<sub>2.5</sub> design values



Figure 4-32. 2007 and 2018 PM<sub>2.5</sub> compositions at Tennessee sites for annual (top) and daily (bottom) PM<sub>2.5</sub> design values



Figure 4-33. 2007 and 2018 PM<sub>2.5</sub> compositions at Virginia sites for annual (top) and daily (bottom) PM<sub>2.5</sub> design values



Figure 4-34. 2007 and 2018 PM<sub>2.5</sub> compositions at West Virginia sites for annual (top) and daily (bottom) PM<sub>2.5</sub> design values

# 4.5 Future Visibility Projections

The light extinctions obtained from the  $3\times3$  cell average and monitor (1×1) cell RRF were compared on the best 20% and worst 20% visibility days. On the best 20% visibility days the  $3\times3$  cell average RRF leads to lower light extinction hence better visibility (Figure 4-35). On the worst 20% visibility days the  $3\times3$  cell average RRF leads to higher light extinction hence worst visibility (Figure 4-36).

In Table 4-3 the 2007 and 2018 haze indices (dV) obtained from 5-year (2005-2009) average DVCs and 3x3 cell average RRFs are compared for best and worst 20% visibility days. The haze indices decrease in 2018 both for best and worst visibility.



Figure 4-35. Best Visibility DVF: 3×3 vs. 1×1



Figure 4-36. Worst Visibility DVF: 3×3 vs. 1×1

| IMPROVE | Best Visibility |       | Worst Visibility |       |
|---------|-----------------|-------|------------------|-------|
| Site    | 2007            | 2018  | 2007             | 2018  |
| BRIG    | 13.87           | 11.65 | 27.32            | 22.04 |
| CHAS    | 15.43           | 12.63 | 23.68            | 19.53 |
| СОНИ    | 12.5            | 9.77  | 28.01            | 20.26 |
| DOSO    | 10.21           | 7.64  | 27.55            | 18.75 |
| EVER    | 11.92           | 10.59 | 20.41            | 18.29 |
| GRSM    | 12.38           | 9.92  | 28.5             | 21.11 |
| HEGL    | 12.52           | 11.17 | 26.05            | 22.71 |
| JARI    | 13.61           | 10.92 | 27.29            | 19.9  |
| JOAC    | 12.38           | 9.92  | 28.5             | 21.11 |
| LIGO    | 11.29           | 9.14  | 27.39            | 19.74 |
| MACA    | 15.76           | 12.89 | 30.68            | 23.65 |
| MING    | 13.9            | 12.06 | 27.08            | 23    |
| OKEF    | 14.46           | 11.9  | 26               | 21.47 |
| OTCR    | 10.21           | 7.64  | 27.55            | 18.75 |
| ROMA    | 14.97           | 12.47 | 26.45            | 20.44 |
| SAMA    | 14.77           | 12.43 | 25.58            | 21.77 |
| SHEN    | 9.72            | 7.39  | 27.26            | 19.03 |
| SHRO    | 7.3             | 5.68  | 26.6             | 19.45 |
| SIPS    | 14.06           | 11.54 | 28.32            | 22.04 |
| SWAN    | 13.04           | 10.57 | 24.56            | 18.18 |
| UPBU    | 11.73           | 10.35 | 25.86            | 22.79 |
| WOLF    | 14.46           | 11.9  | 26               | 21.47 |

Table 4-3. 5-year average (2005-2009) current visibility design values and future visibility projections(in deciViews) using 3x3 cell average RRFs.

# 4.6 Contributions to Light Extinctions

Comparisons were made between the 2007 and 2018 contributions of  $PM_{2.5}$  components to light extinction at each of the 22 IMPROVE sites in the 12-km SEMAP domain. Figure 4-37 shows the comparison on the best 20% visibility days. The light extinctions are expected to decrease due to the large decreases in the contributions of ammonium sulfate. Ammonium nitrate contributions are also expected to decrease. The contributions of other  $PM_{2.5}$  components are expected to remain the same. Figure 4-38 shows the comparison of the contributions of  $PM_{2.5}$  components to light extinction on the worst 20% visibility days. The light extinctions are expected to decrease due to the large decreases in the contributions of ammonium nitrate contributions are also expected to decrease at several sites. The contributions of other  $PM_{2.5}$  components are expected to remain the same.



Figure 4-37. Comparison of contributions of PM<sub>2.5</sub> components to light extinction on best 20% visibility days in 2007 and 2018



Figure 4-38. Comparison of contributions of PM<sub>2.5</sub> components to light extinction on worst 20% visibility days in 2007 and 2018

## 4.7 Progress towards Regional Haze Goals

The goal of the Regional Haze Rule is to reach natural visibility conditions at Class I areas by the year 2064. This goal must be achieved by improving visibility on 20% worst visibility days and protecting visibility on 20% best visibility days. To measure the progress towards the 2064 target, uniform rates of reasonable progress were evaluated for each of the Class I areas in the SEMAP domain. Figure 4-39 through Figure 4-60 show these rates, a.k.a. "glide paths", on 20% worst and 20% best visibility days at 22 Class I areas. These Class I areas are: 1) Breton, 2) Brigantine, 3) Caney Creek, 4) Cape Romain, 5) Chassahowitzka, 6) Cohutta, 7) Dolly Sods, 8) Everglades, 9) Great Smoky Mountain, 10) Hercules Glade, 11) James River Face, 12) Linville Gorge, 13) Mammoth Cave, 14) Cadiz, 15) Mingo, 16) Okefenokee, 17) Saint Marks, 18) Shenandoah, 19) Shining Rock, 20) Sipsey, 21) Swanquarter, and 22) Upper Buffalo.





Reasonable Progress Assessment Base G2 inventory, new IMPROVE Algorithm Breton - Best 20% Days



Figure 4-39. Visibility progress at Breton on 20% worst (top) and 20% best (bottom) days





Reasonable Progress Assessment Base G2 inventory, new IMPROVE Algorithm Brigantine - Best 20% Days



Figure 4-40. Visibility progress at Brigantine on 20% worst (top) and 20% best (bottom) days



Uniform Rate of Reasonable Progress Glide Path Caney Creek - W20% Data Days

Reasonable Progress Assessment Base G2 inventory, new IMPROVE Algorithm Caney Creek - Best 20% Days



Figure 4-41. Visibility progress at Caney Creek on 20% worst (top) and 20% best (bottom) days



### Uniform Rate of Reasonable Progress Glide Path Cape Romain - W20% Data Days

Reasonable Progress Assessment Base G2 inventory, new IMPROVE Algorithm Cape Romain - Best 20% Days



Figure 4-42. Visibility progress at Cape Romain on 20% worst (top) and 20% best (bottom) days





Reasonable Progress Assessment Base G2 inventory, new IMPROVE Algorithm Chassahowitzka - Best 20% Days



Figure 4-43. Visibility progress at Chassahowitzka on 20% worst (top) and 20% best (bottom) days





Reasonable Progress Assessment Base G2 inventory, new IMPROVE Algorithm Cohutta - Best 20% Days



Figure 4-44. Visibility progress at Cohutta on 20% worst (top) and 20% best (bottom) days



Uniform Rate of Reasonable Progress Glide Path Dolly Sods - W20% Data Days

Reasonable Progress Assessment Base G2 inventory, new IMPROVE Algorithm Dolly Sods - Best 20% Days



Figure 4-45. Visibility progress at Dolly Sods on 20% worst (top) and 20% best (bottom) days



Uniform Rate of Reasonable Progress Glide Path Everglades - W20% Data Days

Reasonable Progress Assessment Base G2 inventory, new IMPROVE Algorithm Everglades - Best 20% Days



Figure 4-46. Visibility progress at Everglades on 20% worst (top) and 20% best (bottom) days



### Uniform Rate of Reasonable Progress Glide Path Great Smoky Mountains - W20% Data Days

Reasonable Progress Assessment Base G2 inventory, new IMPROVE Algorithm Great Smoky Mountains - Best 20% Days



Figure 4-47. Visibility progress at Great Smoky Mountains on 20% worst (top) and 20% best (bottom) days



Uniform Rate of Reasonable Progress Glide Path Hercules - Glade - W20% Data Days

### Reasonable Progress Assessment Base G2 inventory, new IMPROVE Algorithm Hercules - Glade - Best 20% Days



Figure 4-48. Visibility progress at Hercules Glade on 20% worst (top) and 20% best (bottom) days



Uniform Rate of Reasonable Progress Glide Path James River Face - W20% Data Days

Reasonable Progress Assessment Base G2 inventory, new IMPROVE Algorithm James River Face - Best 20% Days



Figure 4-49. Visibility progress at James River Face on 20% worst (top) and 20% best (bottom) days



### Uniform Rate of Reasonable Progress Glide Path Linville Gorge - W20% Data Days

Reasonable Progress Assessment Base G2 inventory, new IMPROVE Algorithm Linville Gorge - Best 20% Days



Figure 4-50. Visibility progress at Linville Gorge on 20% worst (top) and 20% best (bottom) days





Reasonable Progress Assessment Base G2 inventory, new IMPROVE Algorithm Mammoth Cave - Best 20% Days



Figure 4-51. Visibility progress at Mammoth Cave on 20% worst (top) and 20% best (bottom) days





Reasonable Progress Assessment Base G2 inventory, new IMPROVE Algorithm Cadiz - Best 20% Days



Figure 4-52. Visibility progress at Cadiz on 20% worst (top) and 20% best (bottom) days





Reasonable Progress Assessment Base G2 inventory, new IMPROVE Algorithm Mingo - Best 20% Days



Figure 4-53. Visibility progress at Mingo on 20% worst (top) and 20% best (bottom) days


### Reasonable Progress Assessment Base G2 inventory, new IMPROVE Algorithm Okefenokee - Best 20% Days

Uniform Rate of Reasonable Progress Glide Path Okefenokee - W20% Data Days



Figure 4-54. Visibility progress at Okefenokee on 20% worst (top) and 20% best (bottom) days



Uniform Rate of Reasonable Progress Glide Path Saint Marks - W20% Data Days

Reasonable Progress Assessment Base G2 inventory, new IMPROVE Algorithm Saint Marks - Best 20% Days



Figure 4-55. Visibility progress at Saint Marks on 20% worst (top) and 20% best (bottom) days



Uniform Rate of Reasonable Progress Glide Path Shenandoah - W20% Data Days

Reasonable Progress Assessment Base G2 inventory, new IMPROVE Algorithm Shenandoah - Best 20% Days



Figure 4-56. Visibility progress at Shenandoah on 20% worst (top) and 20% best (bottom) days



Uniform Rate of Reasonable Progress Glide Path Shining Rock - W20% Data Days

Reasonable Progress Assessment Base G2 inventory, new IMPROVE Algorithm Shining Rock - Best 20% Days



Figure 4-57. Visibility progress at Shining Rock on 20% worst (top) and 20% best (bottom) days





Reasonable Progress Assessment Base G2 inventory, new IMPROVE Algorithm Sipsey - Best 20% Days



Figure 4-58. Visibility progress at Sipsey on 20% worst (top) and 20% best (bottom) days



Uniform Rate of Reasonable Progress Glide Path Swanquarter - W20% Data Days

Reasonable Progress Assessment Base G2 inventory, new IMPROVE Algorithm Swanquarter - Best 20% Days



Figure 4-59. Visibility progress at Swanquarter on 20% worst (top) and 20% best (bottom) days



Uniform Rate of Reasonable Progress Glide Path Upper Buffalo - W20% Data Days

# Reasonable Progress Assessment Base G2 inventory, new IMPROVE Algorithm Upper Buffalo - Best 20% Days



Figure 4-60. Visibility progress at Upper Buffalo on 20% worst (top) and 20% best (bottom) days

# 4.8 Conclusions

In 2018, future ozone design values (DVFs) will remain below the current 75 ppb standard in the SESARM states, except at a handful of sites around Atlanta, GA. However, DVFs are expected to exceed 70 ppb at several sites in almost every SESARM state. The use of 2007 DVCs and 3×3 cell block's maximum RRFs generally led to higher ozone DVFs.

Both for annual and daily  $PM_{2.5}$ , the use of 2007 DVCs and monitor (1×1) cell RRFs generally led to higher DVFs. In 2018, annual  $PM_{2.5}$  DVFs are not expected to exceed the current 12 µg m<sup>-3</sup> standard in the SESARM states, except at a few sites. Birmingham, AL is expected to be the most problematic area. In 2018, daily  $PM_{2.5}$  DVFs are not expected to exceed the current 35 µg m<sup>-3</sup> anywhere in the SESARM states. However, they are expected to be higher than 30 µg m<sup>-3</sup> around Birmingham, AL.

The expected decreases in  $PM_{2.5}$  from 2007 to 2018 will be primarily due to the large decreases of sulfate and associated ammonium in the SESARM states. Ammonium nitrate is expected to increase at a number of sites. No significant changes are expected for other components of  $PM_{2.5}$ .

Visibility will improve in Class I areas of the SEMAP region, primarily due to the decrease in ammonium sulfate. Based on the 2007/2018 SEMAP modeling, the 2018 visibility is projected to have less impairment on the 20% worst days compared to the previous 2002/2018 VISTAS modeling (Odman et al., 2007).

# 4.9 References

Odman, M. T., Y. Hu, A. Unal, A. G. Russell and J. W. Boylan (2007). "Determining the sources of regional haze in the southeastern United States using the CMAQ model." Journal of Applied <u>Meteorology and Climatology</u> **46**(11): 1731-1743.

# Chapter 5: Sensitivity of Ozone to NO<sub>x</sub> and VOC Emissions

# 5.1 Introduction

A sensitivity analysis was conducted to study how ozone responds to  $NO_x$  and VOC emission reductions. The objective was to determine the direction of the response (i.e., increase or decrease) and quantify its magnitude. Simulations of various 2018 scenarios were conducted reducing  $NO_x$  and VOC emissions individually from different states and Regional Planning Organizations (RPOs) in the SEMAP domain. The amount of reductions used in this analysis is 30%. Since ozone response is nonlinear the results are most accurate for the amount of reduction used here, i.e., 30% of either  $NO_x$  or VOC emissions. Caution should be exercised if the results are used for other purposes, for example in attempts to calculate the responses to other levels of emission reductions, especially those larger than 30%, or responses to combined  $NO_x$  and VOC reductions. An extreme attempt might be to extrapolate the results to 100% and calculate interstate contributions. The nonlinear nature of the relation between ozone and  $NO_x$  or VOC emissions should be kept in mind in such interpretations of the results. Any such attempt can only be a first estimate and should be followed by simulations of the actual emission reduction case.

In this chapter, first the methodology used in the sensitivity analysis will be described. Then, the results of the simulations will be presented as absolute sensitivities or responses of ozone to emission reductions. This will be followed by relative sensitivities calculated from the relative response factors and future ozone design values. The relative sensitivities will be normalized by the amount of emissions reduced and presented as responses per ton of NO<sub>x</sub> and VOC emission reductions. Finally conclusions will be drawn.

# 5.2 Methodology

The sensitivity analysis method used here is known as the "Brute Force" method. Air quality simulations are conducted for the base case and reduced emission scenarios. The difference in ozone between the reduced emission case and the base case yields the response of ozone to emission reductions. The base case is the simulation with the 2018 baseline emission projections. Recall that the annual 2018 simulation in Chapter 4 was completed in four quarterly runs, each with a 15-day period in the beginning for model spin-up. June 1, the first day of the third quarter, was Day 16 of the third quarter run in that annual simulation. The 15-day spin-up period is generally long enough for the effects of initial conditions to damp out and the differences from a continuous run are small. However, since we are going to look at the differences from the reduced emission scenarios, which are also relatively small, it is desirable to get rid of any other source of difference. Therefore the 2018 ozone season (May 1 through September 30) was (re-) simulated with a continuous model run over the 12-km grid, using boundary conditions derived from the annual simulation over the 36-km grid. All of the emission reduction scenarios were also simulated for the ozone season over the 12-km grid using the same boundary conditions. Hence the only source of difference between the base case and the reduced emissions cases are the emissions.

In each emission reduction scenario anthropogenic emissions, either NO<sub>x</sub> or VOC, from a geographic region were reduced by 30%. The geographic region where the emissions were reduced was either one of the ten SESARM states (Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, Tennessee, Virginia and West Virginia), the state of Maryland, or one of the three portions of RPOs in the 12-km grid domain (CENRAP or Central, LADCO or Midwest, and MANE-VU or Northeast RPOs). When NO<sub>x</sub> emissions were reduced VOC emissions were held constant and vice versa. A total of 28 (2 precursors x 14 regions) emission reduction scenarios were simulated.

The CMAQ code was modified to apply the desired amount of reduction in a specified geographic region during the simulation (i.e., inline). This approach was preferred over inputting reduced emissions because

of the ease in processing and time savings. The off-line process of preparing reduced emissions inputs is not only tedious but also prone to human errors. The modified CMAO code, on the other hand, once verified leaves little room for error. The user has to input only a few parameters such as the amount of reduction, the type of emissions to be reduced ( $NO_x$  or VOC) and a description of the region where the reduction is to be applied. Since CMAQ was configured to process point-source emissions (i.e., calculate the plume rise and distribute the emissions to the model's vertical layers) inline, the point-source emissions inputs are already in a form that can be tracked by their stationary source IDs (SSIDs). These IDs contain the Federal Information Processing Standards (FIPS) numeric codes for states. Hence the point sources belonging to the state or states forming the geographic region where emission reductions are to be applied is easily identifiable. The area source on the other had are already gridded (i.e. blended into the 12km×12km grid cells) therefore they cannot be split back to the states they belong. The modified CMAQ code expects a description of the boundary of the geographic region. Gridded emissions are distributed according to the fractional area of the grid cell that lies inside this boundary. If the entire cell lies in the geographic region, all the emissions of the specified type in that grid cell are reduced by the specified amount. If only a certain fraction of the grid cell lays in the geographic domain only that fraction of the grid cell emissions of the specified type are reduced by the specified amount.

Only anthropogenic emissions were reduced including point, area, residential wood combustion, mobile, nonroad, airport, aircraft/locomotive/marine emissions. The individual source categories of emissions that were reduced are listed in Table 5-1. Biogenic, livestock, fertilizer, fugitive dust, and fire emissions as well as non-US anthropogenic and off-shore shipping emissions were not reduced (Table 5-2).

The differences between this study and a prior sensitivity analysis conducted for the same region (Odman et al., 2009) are summarized in Table 5-3. In the previous study, VISTAS 2009 "on-the-way" emission projections were used as the base case to simulate one summer month. NO<sub>x</sub> emission reductions were applied only in the non-attainment areas of the Southeast while VOC reductions were applied simultaneously in all SESARM states. In this study, a number of improvements have been implemented. First, the contemporary version of the CMAQ model (CMAQv5.01), which incorporates numerous improvements over the older version (CMAOv4.4), is used. Second, an entire ozone season is simulated instead of a single summer month as in the previous study; hence, the results should be more representative of the changing weather conditions during summer. In this study, mobile emissions are modeled using the MOVES model, which incorporates several improvements over MOBILE6 used in the previous study. The sensitivities to VOC reductions are analyzed on a state-by-state basis in this study. which is a big improvement over the previous study where the differences in VOC sensitivities of different states were not studied. Also, the previous study did not calculate relative sensitivities. Their addition is another improvement by this study: relative sensitivities combine model results with observations; therefore, they are more reliable than absolute sensitivities, which are based solely on modeling results. Finally, since this study simulates the sensitivities in the year 2018, a comparison to the previous study, which simulated 2009, may give a first sense of how the responses to emission reductions are changing over time.

|      | Source Sector |  |  |  |
|------|---------------|--|--|--|
| Area | •             | Nonpoint ( <b>nonpt</b> ) – area sources with ammonia, residential wood combustion, and dust sources removed |  |  |
|      | •             | Aircraft/locomotive/marine (alm)   |  |  |
|      | •             | Residential wood combustion ( <b>rwc</b> )   |  |  |
|      | •             | Nonroad mobile ( <b>nonroad</b> )  |  |  |
|      | •             | U.S. onroad ( <b>usmb</b> ) – WRAP, CENRAP, and LADCO using monthly EPA MOVES proxy 2007 inventories         |  |  |
|      | •             | U.S. running PM ( <b>runpm</b> ) – WRAP, CENRAP, and LADCO using monthly EPA MOVES proxy 2007 inventories    |  |  |
|      | •             | U.S. start PM ( <b>startpm</b> ) – WRAP, CENRAP, and LADCO using monthly EPA MOVES proxy 2007 inventories    |  |  |
|      | •             | SESARM MOVES rate-per-profile ( <b>sesarm_rpp</b> )  |  |  |
|      | •             | SESARM MOVES rate-per-vehicle (sesarm_rpv)   |  |  |
|      | •             | SESARM MOVES rate-per-distance (sesarm_rpd)  |  |  |
|      | •             | MARAMA rate-per-profile (manevu_rpp)   |  |  |
|      | •             | MARAMA rate-per-vehicle ( <b>manevu-rpv</b> )  |  |  |
|      | •             | MARAMA rate-per-distance (manevu-rpd)  |  |  |
|      | •             | VA MOVES rate-per-profile ( <b>va_rpp</b> )  |  |  |
|      | •             | VA MOVES rate-per-vehicle ( <b>va_rpv</b> )  |  |  |
|      | •             | VA MOVES rate-per-distance (va_rpd)  |  |  |
|      | •             | Airport point ( <b>airpt</b> ) – SESARM only   |  |  |
|      | •             | SESARM non-CEM point EGU (sesarm_ptncem_EGU)   |  |  |
|      | •             | SESARM non-CEM point non-EGU (sesarm_ptncem_nonEGU)  |  |  |
| int  | •             | SESARM CEM point EGU ( <b>sesarm_ptcem_EGU</b> )   |  |  |
| Po   | •             | SESARM CEM point non-EGU (sesarm_ptcem-nonEGU)   |  |  |
|      | •             | MARAMA non-CEM point ( <b>mv_ptncem</b> )  |  |  |
|      | •             | MARAMA CEM point ( <b>mv_ptcem</b> )   |  |  |
|      | •             | U.S point sources (uspt) – LADCO, CENRAP, and WRAP point sources from the NEI08v2                            |  |  |

#### Table 5-1. Emission sectors that were reduced

|       | Source Sector |   |  |
|-------|---------------|---|--|
| Area  | •             | MEGAN biogenic (bg)   |  |
|       | •             | Livestock ammonia (lv)  |  |
|       | •             | Fertilizer ammonia (ft)   |  |
|       | •             | Fugitive dust ( <b>fdust</b> ) – WRAP, CENRAP, and LADCO using NEI2008 and SESARM using SEMAP 2007 inventory            |  |
|       | •             | MARAMA fugitive dust ( <b>mv_fdust</b> ) – MARAMA 2007v3.3 inventory with transport factors applied at the county level |  |
|       | •             | Non-US nonpoint (nusar) – Canada and Mexico non-point and nonroad mobile  |  |
|       | •             | Non-US onroad (nusmb) – Canada and Mexico onroad mobile   |  |
| Point | •             | Point fires ( <b>ptfire</b> ) WRAP, CENRAP, LADCO, MARAMA, and MS 2007 Smartfire inventories                            |  |
|       | •             | SESARM point fires (sesarm_ptf) – SESARM 2007 fire inventories (no MS)  |  |
|       | •             | Non-US point (nuspt) – Canada and Mexico point  |  |
|       | •             | Offshore shipping ( <b>ptseca</b> ) - > 0.5km offshore  |  |

Table 5-2. Emission sectors that remained unchanged

| <b>Previous Sensitivity Modeling</b><br>(Odman et al., 2009) | New Sensitivity Modeling                    |  |  |  |
|--|---|--|--|--|
| CMAQv4.4   | CMAQv5.01                                   |  |  |  |
| 1-Month summer episode                                       | 5-Month ozone season                        |  |  |  |
| VISTAS 2009 OTW BaseD  | SEMAP 2018                                  |  |  |  |
| SEMAP-wide VOC reductions                                    | State-wide VOC reductions                   |  |  |  |
| County/state NO <sub>x</sub> reductions                      | State-wide NO <sub>x</sub> reductions       |  |  |  |
| MOBILE6  | MOVES                                       |  |  |  |
| Absolute difference  | Absolute difference and RRF approach (MATS) |  |  |  |

Table 5-3. Updates to the previous sensitivity analysis

(based on modeled base year values)

>70 ppb cutoff

>70 ppb cutoff

(based on modeled future year values)

### 5.2.1 Calculation of Absolute Sensitivities

Absolute sensitivities, or  $\Delta O_3$ , are calculated by taking the difference of daily maximum 8-hr ozone between the 2018 emission reduction or sensitivity case and the 2018 base case.

$$\Delta O_3 = O_3 (2018_{\text{sens}}) - O_3 (2018_{\text{base}})$$

A negative value of  $\Delta O_3$  indicates a decrease in ozone in response to the emission reduction while a positive value indicated an increase. A decrease should be viewed as a benefit and an increase as a disbenefit.

After  $\Delta O_3$  were calculated for all days of the ozone season they were averaged in three different ways:

- 1. Over all days
- 2. Over days with  $2007_{typ}$  daily maximum 8-hr O<sub>3</sub> above 75 ppb
- 3. Over days with 2018<sub>base</sub> daily maximum 8-hr O<sub>3</sub> above 70 ppb

The first average gives an overall picture of the sensitivities during the simulated ozone season. The second one focuses on days when simulated 2007 typical ozone exceeds the current national standard. The third one can be viewed as the projected 2018 sensitivity on potential exceedance days with the assumption that the national ozone standard, currently at 75 ppb, may be lowered to 70 ppb.

## 5.2.2 Calculation of Relative Sensitivities

Relative sensitivities, or changes in future design values (DDVF), are obtained from current design values (DVCs) and relative response factors (RRFs). Since DVCs are derived from measured ozone concentrations, relative sensitivities ought to be more realistic than absolute sensitivities that are solely based on simulated ozone concentrations. RRF is the ratio of simulated 2018 ozone to simulated typical 2007 ozone. Hence, two sets of simulated ozone concentrations are used relative to one another in relative sensitivities. The method used here to calculate DDVFs is slightly different than taking the difference of two future design values as will be described below but the essence is the same in that there is a reality basis.

EPA's Modeled Attainment Test Software (MATS)<sup>22</sup> was used to calculate the RRFs. MATS expects two sets of modeled concentrations as inputs: a "baseline" and a "forecast". Here, the 2018 base case was provided as the "baseline" and the sensitivity or reduced emission case was provided as the "forecast". Hence the RRF that MATS calculates is:

 $RRF = O_3 (2018_{sens}) / O_3 (2018_{base})$ 

MATS was executed for each of the 28 sensitivity cases to calculate 28 different sets of RRFs, one for each emission reduction scenario. An RRF was produced by MATS for all sites with at least one day in 2018 with ozone projection above 70 ppb. This was assured by using the following thresholds in MATS based on the 2018 baseline daily 8-hr maximum ozone concentrations:

- Initial threshold value = 75 ppb
- Minimum number of days in baseline at or above threshold = 10
- Minimum allowable threshold value = 70 ppb
- Minimum number of days at or above minimum allowable threshold = 1

<sup>&</sup>lt;sup>22</sup> http://www.epa.gov/ttn/scram/guidance/guide/MATS-2-5-1\_manual.pdf

Finally, DDVF was calculated from the RRF and the DVF as follows:

$$DDVF = (DVF \times RRF) - DVF = DVF \times (RRF-1)$$

Recall that future design values (DVFs) were already calculated in Chapter 4. Out of the four different sets of DVFs calculated, the DVFs obtained from the 5-year (2005-2009) weighted average DVCs and the monitor cell RRF (i.e.,  $1 \times 1$  cell maximum) were employed here.

### 5.2.3 Normalized Sensitivities

Normalized sensitivities are calculated by dividing the relative sensitivities by the amount of emissions reduced. Here normalized sensitivities were calculated only for the ten SESARM states. They were not calculated for the RPO portions in the domain since the emissions in those RPOs vary too much from one state to another; therefore, an average sensitivity divided by the total emission reduction from all states in the RPO portion would not yield a very reliable normalized sensitivity. The annual average emissions were used for normalization. A more accurate calculation would require the averaging of emissions during the ozone season since emissions vary from day to day and month to month. The reductions are 30% of either  $NO_x$  or VOC emissions statewide. The amounts of daily emission reductions, in tons per day (TPD) for each state are listed in Table 5-4.

| State          | NOx (TPD) | VOC (TPD) |
|----------------|-----------|-----------|
| Alabama        | 190       | 146       |
| Florida        | 378       | 403       |
| Georgia        | 251       | 223       |
| Kentucky       | 185       | 133       |
| Mississippi    | 156       | 113       |
| North Carolina | 190       | 242       |
| South Carolina | 119       | 112       |
| Tennessee      | 223       | 174       |
| Virginia       | 201       | 197       |
| West Virginia  | 111       | 53        |

Table 5-4. Emission Reductions (30% of annual average emissions)

The normalized sensitivities that will be reported below are equal to the relative  $NO_x$  or VOC sensitivity for the home state, calculated using MATS as described in the previous section, divided by the  $NO_x$  or VOC emission reduction amount for that state. Unit conversion to parts per trillion (ppt) per TPD, or ppt/TPD, was performed as follows:

(DDVF<sub>NOx</sub> x 1000)/TPD<sub>NOx</sub>

and

(DDVF<sub>VOC</sub> x 1000)/TPD<sub>VOC</sub>

# 5.3 Absolute Sensitivities

Absolute sensitivities were calculated for each of the 674 ozone monitoring sites in the SEMAP 12-km modeling domain. They are available in day-by-day form for each site and also in averaged forms for all the sites in each of the 31 states in the domain.

### 5.3.1 Site-by-Site Absolute Sensitivities

Absolute sensitivities were calculated for each day at each site as described in Section 5.2.1 above. The responses to  $NO_x$  or VOC reductions from each state and RPO are shown as stacked bars so that they can be compared to each other for any given day (e.g., Figure 5-1). The left axis is for  $\Delta O_3$  while the right axis is for  $O_3$  and the x-axis labels the date for the day the stacked bar represents. There are charts that show all the days, days above 75 ppb in 2007 (used for 2007 to 2018 projections) and days above 70 ppb in 2018 (used for 2018 sensitivities). Hence there are 6 charts for each site (2 precursors × 3 groups of days) showing absolute sensitivities to emission reductions.

The set of 6 charts are illustrated here for Atlanta, GA (Figure 5-1 through Figure 5-6) and Baltimore, MD (Figure 5-7 through Figure 5-12). On the days when ozone in 2018 is above 70 ppb (Figure 5-3) the greatest sensitivity of Atlanta's ozone is to Georgia's NO<sub>x</sub> emissions. On August 15 the response to 30% Georgia NO<sub>x</sub> emissions is almost 9 ppb for a predicted 8-hour maximum ozone in 2018 of 95 ppb. Depending on wind direction the second largest sensitivity can be to NO<sub>x</sub> emissions from Alabama, Tennessee, Florida, North Carolina, South Carolina or even Kentucky but those sensitivities are generally smaller than 2 ppb. The largest sensitivity of Atlanta's ozone to 30% VOC reductions is less than 2.5 ppb on August 3 (Figure 5-6). VOC reductions from states other than Georgia have no significant impact on Atlanta's ozone.

30% of NO<sub>x</sub> emissions from SESARM states have a combined impact less than 3 ppb on Baltimore's ozone on days above 70 ppb in 2018 (Figure 5-9). The largest impacts are from Virginia followed by West Virginia. The largest impact of 30% VOC emissions from Virginia is less than 0.2 ppb on any day above 70 ppb in 2018 (Figure 5-12).

The absolute sensitivity charts for other sites can be found at <u>http://semap.ce.gatech.edu/node/1861</u>.



Figure 5-1. Absolute NO<sub>x</sub> sensitivities at Atlanta, GA (all days)



*Figure 5-2. Absolute NO<sub>x</sub> sensitivities at Atlanta, GA (days with O\_3 \ge 75 ppb in 2007)* 



*Figure 5-3.* Absolute  $NO_x$  sensitivities at Atlanta, GA (days with  $O_3 \ge 70$  ppb in 2018)



Figure 5-4. Absolute VOC sensitivities at Atlanta, GA (all days)



Figure 5-5. Absolute VOC sensitivities at Atlanta, GA (days with  $O_3 \ge 75$  ppb in 2007)



Figure 5-6. Absolute VOC sensitivities at Atlanta, GA (days with  $O_3 \ge 70$  ppb in 2018)



Figure 5-7. Absolute NO<sub>x</sub> sensitivities at Baltimore, MD (all days)



Figure 5-8. Absolute  $NO_x$  sensitivities at Baltimore, MD (days with  $O_3 \ge 75$  ppb in 2007)



Figure 5-9. Absolute  $NO_x$  sensitivities at Baltimore, MD (days with  $O_3 \ge 70$  ppb in 2018)



Figure 5-10. Absolute VOC sensitivities at Baltimore, MD (all days)



Figure 5-11. Absolute VOC sensitivities at Baltimore, MD (days with  $O_3 \ge 75$  ppb in 2007)



*Figure 5-12. Absolute VOC sensitivities at Baltimore, MD (days with O\_3 \ge 70 ppb in 2018)* 

### 5.3.2 State Summaries

The absolute sensitivities were averaged on days when modeled 8-hr maximum ozone in 2018 was above 70 ppb and the results for each state's sites were summarized on a single chart. These state summaries were created for 31 states in the SEMAP 12-km modeling domain. Figure 5-13 through Figure 5-23 show the absolute NO<sub>x</sub> sensitivity state summaries for the 10 SESARM states (Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, Tennessee, Virginia and West Virginia) and Maryland. Figure 5-24 through Figure 5-34 show the absolute VOC sensitivity state summaries for the 10 SESARM states and Maryland. The summary charts for the other 20 states in the SEMAP domain can be found at <a href="http://semap.ce.gatech.edu/node/1861">http://semap.ce.gatech.edu/node/1861</a>.



Figure 5-13. Absolute  $NO_x$  sensitivities at Alabama sites (days with  $O_3 \ge 70$  ppb in 2018)



Figure 5-14. Absolute  $NO_x$  sensitivities at Florida sites (days with  $O_3 \ge 70$  ppb in 2018)



*Figure 5-15.* Absolute  $NO_x$  sensitivities at Georgia sites (days with  $O_3 \ge 70$  ppb in 2018)



Figure 5-16. Absolute  $NO_x$  sensitivities at Kentucky sites (days with  $O_3 \ge 70$  ppb in 2018)



Figure 5-17. Absolute  $NO_x$  sensitivities at Maryland sites (days with  $O_3 \ge 70$  ppb in 2018)



Figure 5-18. Absolute  $NO_x$  sensitivities at Mississippi sites (days with  $O_3 \ge 70$  ppb in 2018)



Figure 5-19. Absolute  $NO_x$  sensitivities at North Carolina sites (days with  $O_3 \ge 70$  ppb in 2018)



Figure 5-20. Absolute  $NO_x$  sensitivities at South Carolina sites (days with  $O_3 \ge 70$  ppb in 2018)


*Figure 5-21. Absolute NO<sub>x</sub> sensitivities at Tennessee sites (days with O\_3 \ge 70 ppb in 2018)* 



Figure 5-22. Absolute  $NO_x$  sensitivities at Virginia sites (days with  $O_3 \ge 70$  ppb in 2018)



Figure 5-23. Absolute  $NO_x$  sensitivities at West Virginia sites (days with  $O_3 \ge 70$  ppb in 2018)



Figure 5-24. Absolute VOC sensitivities at Alabama sites (days with  $O_3 \ge 70$  ppb in 2018)



Figure 5-25. Absolute VOC sensitivities at Florida sites (days with  $O_3 \ge 70$  ppb in 2018)



Figure 5-26. Absolute VOC sensitivities at Georgia sites (days with  $O_3 \ge 70$  ppb in 2018)



Figure 5-27. Absolute VOC sensitivities at Kentucky sites (days with  $O_3 \ge 70$  ppb in 2018)



*Figure 5-28. Absolute VOC sensitivities at Maryland sites (days with*  $O_3 \ge 70$  *ppb in 2018)* 



Figure 5-29. Absolute VOC sensitivities at Mississippi sites (days with  $O_3 \ge 70$  ppb in 2018)



Figure 5-30. Absolute VOC sensitivities at North Carolina sites (days with  $O_3 \ge 70$  ppb in 2018)



Figure 5-31. Absolute VOC sensitivities at South Carolina sites (days with  $O_3 \ge 70$  ppb in 2018)



Figure 5-32. Absolute VOC sensitivities at Tennessee sites (days with  $O_3 \ge 70$  ppb in 2018)



Figure 5-33. Absolute VOC sensitivities at Virginia sites (days with  $O_3 \ge 70$  ppb in 2018)



Figure 5-34. Absolute VOC sensitivities at West Virginia sites (days with  $O_3 \ge 70$  ppb in 2018)

## 5.4 Relative Sensitivities

Relative sensitivities were calculated using RRFs derived from MATS and 2018 DVFs of Chapter 4, as described in Section 5.2.2 for sites that have at least one day in 2018 with predicted 8-hr maximum ozone concentration above 70 ppb. Charts were prepared showing the relative sensitivities as stacked bars for every monitor of each state in the domain.

## 5.4.1 Relative Sensitivities to NO<sub>x</sub> emissions

Figure 5-35 through Figure 5-45 show the relative  $NO_x$  sensitivities for the 10 SESARM states (Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, Tennessee, Virginia, and West Virginia) and Maryland. The charts for the other 20 states in the 12-km SEMAP modeling domain can be found at <u>http://semap.ce.gatech.edu/node/1861</u>.

## 5.4.2 Relative Sensitivities to VOC emissions

Figure 5-46 through Figure 5-56 show the relative VOC sensitivities for the 10 SESARM states (Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, Tennessee, Virginia, and West Virginia) and Maryland. The charts for the other 20 states in the 12-km SEMAP modeling domain can be found at <a href="http://semap.ce.gatech.edu/node/1861">http://semap.ce.gatech.edu/node/1861</a>.



Figure 5-35. Relative NO<sub>x</sub> sensitivities at Alabama sites



Figure 5-36. Relative NO<sub>x</sub> sensitivities at Florida sites



Figure 5-37. Relative NO<sub>x</sub> sensitivities at Georgia sites



Figure 5-38. Relative NO<sub>x</sub> sensitivities at Kentucky sites



Figure 5-39. Relative NO<sub>x</sub> sensitivities at Maryland sites



Figure 5-40. Relative NO<sub>x</sub> sensitivities at Mississippi sites



Figure 5-41. Relative NO<sub>x</sub> sensitivities at North Carolina sites



Figure 5-42. Relative NO<sub>x</sub> sensitivities at South Carolina sites



Figure 5-43. Relative NO<sub>x</sub> sensitivities at Tennessee sites



Figure 5-44. Relative NO<sub>x</sub> sensitivities at Virginia sites



Figure 5-45. Relative NO<sub>x</sub> sensitivities at West Virginia sites



Figure 5-46. Relative VOC sensitivities at Alabama sites



Figure 5-47. Relative VOC sensitivities at Florida sites



Figure 5-48. Relative VOC sensitivities at Georgia sites



Figure 5-49. Relative VOC sensitivities at Kentucky sites



Figure 5-50. Relative VOC sensitivities at Maryland sites



Figure 5-51. Relative VOC sensitivities at Mississippi sites



Figure 5-52. Relative VOC sensitivities at North Carolina sites



Figure 5-53. Relative VOC sensitivities at South Carolina sites



Figure 5-54. Relative VOC sensitivities at Tennessee sites



Figure 5-55. Relative VOC sensitivities at Virginia sites


Figure 5-56. Relative VOC sensitivities at West Virginia sites

## 5.5 Normalized Sensitivities

Normalized NO<sub>x</sub> and VOC sensitivities were calculated for each monitor by dividing the relative sensitivities to the home state's NO<sub>x</sub> or VOC emissions by the amount of emission reductions in the home state listed in Table 5-4. Normalized NO<sub>x</sub> and VOC sensitivities were stacked in a bar for each monitor and all the monitors in a state were grouped in a chart. Figure 5-57 through Figure 5-66 show the normalized NO<sub>x</sub> and VOC sensitivities at the monitors of the 10 SESARM states (Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, Tennessee, Virginia and West Virginia). The averages for each state are summarized in Figure 5-67.

In general, the normalized  $NO_x$  sensitivities are an order of magnitude larger than the normalized VOC sensitivities. This means that one ton of  $NO_x$  reduction is at least ten times more beneficial than one ton of VOC reduction. But there are several exceptions to this rule. First and foremost, in Florida the normalized VOC sensitivities are of the same order of magnitude as normalized  $NO_x$  sensitivities at several sites and even larger at some sites. Then at some Kentucky sites and one Virginia site normalized  $NO_x$  or VOC sensitivities are of the same order of magnitude.  $NO_x$  or VOC reductions are sometimes disbeneficial; in those cases the normalized sensitivity is positive. The ratio of normalized  $NO_x$  sensitivity to normalized VOC sensitivity was calculated for each monitor. This ratio is typically larger than 10 except at several coastal sites and some sites along the borders of the SESARM states with CENRAP, LADCO and MANE-VU (Figure 5-68).



Figure 5-57. Normalized NO<sub>x</sub> and VOC sensitivities at Alabama sites



Figure 5-58. Normalized NO<sub>x</sub> and VOC sensitivities at Florida sites



Figure 5-59. Normalized NO<sub>x</sub> and VOC sensitivities at Georgia sites



Figure 5-60. Normalized NO<sub>x</sub> and VOC sensitivities at Kentucky sites



Figure 5-61. Normalized NO<sub>x</sub> and VOC sensitivities at Mississippi sites



Figure 5-62. Normalized NO<sub>x</sub> and VOC sensitivities at North Carolina sites



Figure 5-63. Normalized NO<sub>x</sub> and VOC sensitivities at South Carolina sites



Figure 5-64. Normalized NO<sub>x</sub> and VOC sensitivities at Tennessee sites



Figure 5-65. Normalized NO<sub>x</sub> and VOC sensitivities at Virginia sites



Figure 5-66. Normalized NO<sub>x</sub> and VOC sensitivities at West Virginia sites



Figure 5-67. Average normalized NO<sub>x</sub> and VOC sensitivities at SEMAP states



Figure 5-68. Ratios of normalized sensitivities (NO<sub>x</sub>/VOC) at SEMAP sites

## 5.6 Conclusions

In general, absolute sensitivities ( $\Delta O_3$ ) and relative sensitivities (DDVF) of ozone to NO<sub>x</sub> and VOC emissions are very similar. Relative sensitivities may be more reliable because they are based on 2007 measured ozone concentrations through DVCs used to derive DVFs, and the modeling results are used in a relative sense through RRFs.

Anthropogenic  $NO_x$  emission reductions are much more effective at reducing 8-hour maximum ozone concentrations in the SESARM states compared to anthropogenic VOC emission reductions. Some sites in Florida and along the coast in AL, GA, and VA show comparable benefits from VOC and  $NO_x$  reductions.

 $NO_x$  and VOC emissions from the home states typically have the largest impact on the ozone levels of its own monitors. Neighboring states have the next largest impact. The impacts of VOC emissions from neighboring states are much smaller than the impacts of  $NO_x$  emissions from neighboring states relative to home state impacts.

## 5.7 References

Odman, M. T., Y. T. Hu, A. G. Russell, A. Hanedar, J. W. Boylan and P. F. Brewer (2009). "Quantifying the sources of ozone, fine particulate matter, and regional haze in the Southeastern United States." Journal of Environmental Management **90**(10): 3155-3168.