Air Quality Model
Draft May 30, 2002

Atmospheric Modeling Objectives

- **Use integrated one-atmosphere model to represent gaseous, aerosol, and deposition processes**
- **Focus greatest precision on the Southern Appalachian Mountains, an area that has generally not been addressed in other modeling exercises**
- **Select episodes to represent seasonal and annual air quality conditions that are most relevant for environmental effects**
- **Demonstrate model performance for selected episodes by comparing modeled air quality to available air quality measurements**
- **Project future air quality in response to SAMI emissions strategies and provide change in air quality for effects and socioeconomic analyses**
- **Evaluate source contributions to change in air quality at specific receptors**

SAMI successfully completed the first demonstration of an integrated, one-atmosphere model to evaluate fine particles, ozone, and acid deposition in the Southern Appalachian Mountains[1,2,3]. The model accounts for the complex chemical and physical processes that control the formation, transport, and removal of gases, fine particles, and deposited pollutants. Previous regional or national modeling efforts have used separate modeling systems to address ozone[4,5], fine particles[5,6,7], or wet deposition[8,9].

SAMI's atmospheric modeling is unique in focusing on air quality in the Southern Appalachian Mountains and the Class I national parks and wilderness areas rather than the urban population centers. SAMI's atmospheric modeling is also unique in assessing the environmental effects of fine particles, ozone, and acid deposition, rather than health effects. Seasonal and annual air quality measures are most relevant to environmental effects. (BJ: EPA has several annual health-based NAAQS. So I'm not sure this is a true statement. You may want to say seasonal and annual air quality measures are most relevant to assess the environmental effects for the SAMI project.) SAMI ~~chose an~~ used an episodic modeling approach to evaluate ~~a range of~~ air quality and meteorological conditions across a five-year period 1991-1995 and to assess the seasonal and annual environmental effects. This approach contrasts with ~~those of~~ the ozone regulatory modeling applications that generally focus on episodes with highest pollutant exposures.

Air Pollution Primer *(separate box from main text)*
Most fine particles~~,~~ and ozone~~, and acid deposition~~ (BJ: acid deposition is a atmospheric removal process, not a produced primary or secondary pollutant). are not emitted directly into the atmosphere, but rather are secondary by-products formed by chemical reactions of primary gaseous and aerosol emissions. For example, ozone is formed from the reaction of nitrogen dioxide and volatile organic compounds in the presence of sunlight

(see formula in insert below). (BJ: You need to add a lead in sentence to state that fine particulates is a mixture consisting of several components or species pollutants (i.e, organic and elemental carbon, sulfates, nitrates, etc.) before you explain what the PM2.5 species are and how they are formed. Primary pollutants are directly emitted from anthropogenic or biogenic sources (e.g., SOx, NOx, PM10 and CO). Secondary pollutants are indirectly produced through chemical reactions between their precursors.) Organic aerosols are formed by condensation of volatile organic gases. Sulfate fine particles are formed from the reaction of sulfur dioxide gas with ozone or hydrogen peroxide. Ammonium and hydrogen ions from water vapor are associated with sulfate particles. Ammonium gas reacts with nitrate acid vapor to form ammonium nitrate particles. These particles can be deposited dry to surfaces or washed out of the atmosphere in precipitation. Dry deposition of particles and gases generally occurs at shorter distances from the emissions sources than does wet deposition of the same chemical components. The atmospheric modeling system accounts for these interacting chemical, transport, and deposition processes.

Insert Definitions and chemical formula for ozone, fine particles, and acid deposition

Meteorology, turbulence, surface roughness, typography and source characteristics are some influences that affect the rate of formation and ~~delivery~~ dispersion of pollutants. For example, ozone formation is ~~greater~~ more likely ~~at higher temperatures and greater~~ on days with full sunlight an high temperatures than on cloudy days. The rate of sulfate particle formation is faster in clouds (where sulfur dioxide reacts with hydrogen peroxide) than in dry air (where sulfur dioxide reacts with ozone). Emissions of volatile organic compounds from highway vehicles and non-road engines will be ~~higher~~ larger on days with higher temperatures. Emissions of volatile organic compounds and nitrogen oxides from natural sources such as vegetation and soils and release of ammonia gas from animal waste are also ~~higher~~ larger at higher temperatures.

Winds can transport emissions and secondary particles (BJ: and not primary particles? Just say pollutants. You appear to try to give a simplistic intro into the factors in the dispersion of pollutants and conditions leading stagnation events but in the process are omitting a few important factors of dispersion in these two paragraphs. You also do not define a stagnation event.) hundreds of miles from the emissions sources. The Southern Appalachian Mountains area experiences frequent air stagnation events (need reference) with low or stagnant winds. During these periods with low wind speeds, emissions build up in the atmosphere. The complex terrain in mountainous areas also influences winds, temperature, clouds, and precipitation. For example, a layer of warm air can be trapped in the valleys below layers of colder air aloft. (BJ: No, the temperature within the troposphere generally decreases with height. An inversion occurs when warm air forms over cooler air. If warm air is under cold air it would tend to rise and not be trapped.) This causes an inversion, or build up of pollutants in the trapped layer.

~~SAMII's meteorological, emissions, and air quality models account for these influences.~~ These and other influences affecting the formation and dispersion of pollutants of concern are utilized in the SAMI Integrated Assessment modeling system.

(end of separate section)

SAMI Assessment Methods

Episode Selection (BJ: Need a lead-in sentence that lists the two types of episode selection approaches, e.g., episodic/discrete days versus consecutive long-term periods of seasons, year, etc.) The episodic modeling approach allows more detailed representation of atmospheric processes for the modeled days than would be possible ~~for~~ if longer time periods were considered. (BJ: I'm sure many would disagree with this. Need to cite a reference to support this and/or state what you'd lose in modeling longer less discrete periods)

The air quality and meteorological records for 1991 through 1995 at monitoring sites in the Great Smoky Mountain National Park (i.e., Look Rock, Cove Mt, and Elkmont ~~monitoring sites~~) and Shenandoah National Park (i.e., Big Meadows ~~monitoring site~~) are used ~~for~~ in the episode selection assessment/analysis/classification scheme. The data ~~Days with valid monitoring data in 1991 – 1995~~ are classified based on their contribution to each of three air quality measures[11]: (BJ: If you use your sentence, you need to explain why other data generally are not valid, how much of this data were not used, data completeness, and uncertainity in the data. Not terrible things to address)

- W126 - Growing season (April-October), 24-hr cumulative ozone exposures using the W126 ozone metric[12] (where all hourly values are accumulated but values less than 0.10 ppm are weighted less than full value)
- Annual and seasonal fine particulate matter - annual and summer distribution of daily fine particle mass (sulfate, nitrate, organics, soil) as measured as part of the IMPROVE network
- Wet deposition - annual cumulative wet deposition of sulfate, nitrate, calcium, and magnesium as measured as part of the National Atmospheric Deposition Program network

Sixty-nine days in nine episodes (~~each~~ length of episodes ranged from ~~of~~ 6-9 ~~days in length~~) are selected to minimize error in recreating the annual and seasonal air quality measures[13]. The selected 69 modeling days represent, with known frequency of occurrence, all other days in the 1991-1995 record for Great Smoky Mountains (GRSM) and Shenandoah (SHEN) National Parks. Growing season ozone, annual fine particle mass, or annual wet deposition are derived by weighting the air quality contribution of each modeled day by the frequency of occurrence of those meteorological conditions over the 1991 - 1995 period. In general, the episode weights used for the Great Smoky Mountains National Park are also used for Class I areas in AL, GA, and NC and the episode weights used for Shenandoah National Park are also used for Class I areas in VA and WV.

The range of meteorological conditions represented by the nine selected episodes is described in Table Air Quality 1[14]. The winter-time event in February 1994 represents clean air conditions over the Southern Appalachian Mountains with snow in the Ohio River Valley and rain in the southeastern US. In contrast the July 1995 episode represents an air stagnation event that included elevated ozone and fine particle levels over much of the southeastern US.

The selected episode days represent air quality in the Southern Appalachian Mountains but do not represent urban air quality nor episode days appropriate for evaluating compliance with the ozone and fine particulate matter standards. **If this is true, how can it be used for ozone flex?**

Table Air Quality 1. Nine episodes selected for air quality modeling and description of meteorological characteristics[3,14] *(simplify to just list of episodes without description?) (Steve Mueller, Talat Odman to review)*

SAMI Modeling Episode	**Season**	**Meteorological and air quality conditions**
February 8-13, 1994	winter	Clean** air conditions over the Southern Appalachian Mountains with snow in the Ohio River Valley and rain in the southeastern US
March 23-31, 1993	winter	Rain across TN, AL, GA, NC, SC, low particle mass
April 26-May 3, 1995	spring	Clean** episode with several weather systems moving rapidly through eastern US.
May 11-17, 1993	spring	Several rain storms across eastern US with high deposition, low ozone and moderate fine particle mass
May 24-29, 1995	spring	Several rain storms across eastern US, moderate deposition, ozone, and fine particle mass

June 24-29, 1992	summer	Two high pressure systems and two stationary fronts, little precipitation, low ozone, and moderate fine particle mass
July 23-31, 1991	summer	Several rain storms, heavy deposition, also air stagnation period with high fine particle mass but not high ozone
July 11-19, 1995	summer	Stagnation event with light winds, high temperatures, and little precipitation. High ozone and high fine particle mass.
August 3-11, 1993	summer	Several days with stationary front, localized heavy rain along frontal system, low ozone and moderate fine particle mass

BJ: **How can you have clean air with for an episode if that set of days are chosen to represent conditions that are associated with some sort of air pollutant? Isn't that a contradiction?

Atmospheric Modeling System

~~A meteorological model, the~~ The Regional Atmospheric Modeling System prognostic meteorological model (version 3b,RAMS 3b), is used to simulate ~~the~~ meteorological data (e.g., winds, temperature, clouds, and precipitation) across the southeastern US for the selected nine episodes[14]. Two "ramp up" days are also modeled at the beginning of each episode to ~~establish~~ minimize the effects of assumed initial atmospheric conditions on modeled concentrations for the days of interest. Accurately predicting temperature, (BJ: Winds and emissions are equally as important also. Just say accurately developing model inputs) the amount of sunlight, or where clouds will form is important to accurately projecting ozone or sulfate particle formation.

The Emissions Modeling System (EMS)[15] emissions model is used with outputs of the meteorological model and seasonal emissions inventories as appropriate for each episode and year[16]. The emissions model projects emissions from both human ~~and natural~~ (BJ: biogenic emissions are usually held constant. Did SAMI project biogenic emissions? IF so, it there an explanation on why and how?) sources that are specific to the weather conditions on the modeled days. The emissions model also accounts for the height of emissions into the atmosphere. Highway vehicles, non-road engines, and area source emissions enter the atmosphere at ground level, while emissions from utility or industrial smokestacks are released in the third and fourth layers of the modeled atmosphere.

A three-dimensional photochemical model, the Urban-to-Regional Mulitscale – One Atmosphere (URM-1ATM) model integrates meteorology and emissions ~~for the 69 modeled days~~ to ~~project~~ predict ozone, fine particle, and deposition amounts across the modeling domain for the 69 modeled days [1,2,3].

The atmospheric modeling domain covers the eastern half of the US and southeastern Canada (Figure Air Quality 1)[3]. The model uses a variable grid with the greatest resolution of detail, 12-km, centered over the Southern Appalachian Mountains and the surrounding urban areas that are expected to most directly influence air quality in the region. Grid sizes become progressively coarser (12-km, 24-km 48-km, 96-km and 192 km) at greater distances from the Southern Appalachian Mountains. Seven vertical layers up to 13 km in the atmosphere are simulated.

Figure Air Quality 1. Atmospheric modeling domain for the Urban-to-Regional Multiscale – One Atmosphere (URM-1 ATM) model

The modeling system is first run to determine the model's ability to replicate air quality and meteorogolical conditions for each historical episode day in the 1991-1995 period and establish model performance measures. These simulations represent the Baseyear model runs. ~~for the nine episodes in the 1991-1995 Baseyear.~~ The metorological conditions for each episode day from the Baseyear simulations are run with ~~episodes are then run using the same meteorological conditions as the Baseyear and~~ projected emissions inventory data for the ~~emissions in~~ 2010 and 2040 ~~under~~ SAMI~~'s~~ emissions control strategies[17] (see Emissions chapter ___). The percentage in modeled air quality changes between the baseyear and future year simulations in response to SAMI strategies are used to adjust measured air quality values in the environmental effects assessments[18]. (BJ: I don't follow what is being done here, some step(s) is missing. I get the impression that this is not a simple commonly used adjustment for photochemical modeling. Am I right?) The Decoupled Direct Method (DDM) is a sensitivity analysis tool used with the URM-1ATM photochemical model[19]. The tool is used here to evaluate the relative contributions of source areas and source types to air quality in the SAMI region. These results are discussed in the following sections.

Model Performance

The URM-1ATM air quality model calculates hourly ozone, aerosol, and deposition values for each grid cell in the modeling domain for each episode day. Model performance is evaluated, graphically and with statistical measures, by comparing model outcomes to ambient air quality monitoring (i.e., observational) data across the southeastern US, with particular focus on performance within the fine grid of the SAMI modeling domain. Limited monitoring data is available for regional model performance evaluation for the nine episodes (see Table Air Quality 2). Because there are no established criteria for model performance for regional ozone, fine particles, and acid deposition, SAMI ~~established its own criteria for~~ developed model performance evaluation criteria (see Table Air Quality 2). The URM-1ATM model performance is best in the 12-km grid and accepted as comparable to ~~that~~ other modeling efforts [7,8, 20].

Table Air Quality 2. Data used for performance evaluation of the Urban-to-Regional One-Atmosphere (URM-1ATM) model and performance results[3] *(Georgia Tech to review)*

Air Quality Measure	Number of Monitors in SAMI 12-km modeling grid	Frequency of Monitoring record	Performance Evaluation Criteria	Met Criteria > 75% of record?
Ozone	74[a]	hourly	15% normalized bias for daily ozone[e]	Yes, but under estimate peak hourly values
Fine Particle Mass	6[b]	2 days per week	+/- 50% normalized error [f]	Yes, although underpredict sulfate, organic compounds, elemental carbon, and overpredict nitrate, soils, and coarse mass
Wet Deposition	14[c]		+/- 50% normalized error (using best match within 30-km of monitor)	Yes for sulfate, nitrate, and calcium. Overpredict ammonium
Dry Deposition	2[d]	weekly	Insufficient data to establish criteria	Generally overpredict dry deposition of sulfur dioxide, nitric acid, and ammonia for modeled episodes

[a]Aerometric Information Retrieval System (AIRS) monitoring network[21]
[b]Interagency Monitoring of Protected Visual Environments (IMPROVE) network[22]
[c]National Atmospheric Deposition Program (NADP) network[23]
[d]Atmospheric Integrated Research Monitoring Network (AIRMoN) [24]
[e]SAMI adopted the Environmental Protection Agency's criteria for model performance for regulatory modeling of maximum hourly ozone in urban areas [20]
[f] *add comparison* to Environmental Protection Agency's guidance for model performance for regional haze[25]

The URM-1ATM model meets ozone performance criteria for 6 of 7 ozone episodes[1,3]. The daily variation in ozone and the timing of the modeled ozone peaks are generally in good agreement with observations in both urban and rural locations. The model underestimates peak hourly ozone on many days and likely also underestimates the change in peak ozone values in response to SAMI strategies. Because we have greater confidence in relative change in ozone than in absolute modeled ozone values, for SAMI's forest effects modeling, ozone values were not used directly from the URM-

1ATM model. Instead, measured hourly ozone values at forested sites were adjusted by modeled percentage change in hourly ozone to represent responses to SAMI strategies[26].(BJ: What is your confidence and how are percentages determined in the use of unique this adjustment technique? I hope this is addressed in the atmospheric modeling report.)

The URM-1ATM model performance[3]for fine particle mass is best for sulfate and organic compounds which are the two largest contributors to fine particle mass. Nitrate and soils particle levels are frequently over predicted but have smaller contributions to fine particle mass. Precipitation events are difficult to accurately model. Because precipitation volumes can vary greatly over short distances, model performance is evaluated using the best match between observed and modeled deposition within a 30-km radius of the monitoring site. Sulfate, nitrate, and calcium wet deposition meet performance criteria while ammonium wet deposition is overestimated. Dry depositions of sulfur dioxide and nitric acid vapor are generally overestimated for the modeled episodes[3]. Episodes are selected to represent annual wet deposition~~, and the 9 modeled episodes do not represent high dry deposition events~~. The appropriate weights to estimate total/annual dry uncertain/less than accurate because the episodes were not analyzed for dry deposition events. Therefore total annual dry deposition is underestimated by the modeled episodes. Modeled percentage changes rather than absolute values are used to represent changes in dry deposition in response to SAMI the strategy results in the acid deposition effects models.

Separate text box

Influence of meteorology on air quality

The influence of meteorology on air quality was evaluated as part of episode selection[11]. At Look Rock, a ridge top site in the Great Smoky Mountains in eastern TN, days with the highest ozone levels tended to have winds speeds greater than _____ mph. In contrast, days with the highest fine particle mass tended to have low wind speeds. These results suggest that for the Great Smoky Mountains both local and regional sources contribute to elevated ozone levels, and that local sources have a greater contribution to fine particle mass than regional sources. For acid deposition……. At Shenandoah, *…(fill in from SAI episode selection report).*

Meteorological influences on air quality can also be interpreted from URM-1ATM model results. The four maps in Figure Air Quality 2 illustrate modeled maximum hourly ozone values for four consecutive days during the week of July 11-18, 1995. An air stagnation episode was centered over the southeastern US during this week. The light winds circled slowly counter clock-wise across the southeastern US. On July 12, a high pressure center with elevated temperatures and low wind speeds was centered over eastern Tennessee and north Georgia. This high pressure center circled northwest over Nashville, TN, on July 13, over _____ on July 14, and over _____ on July 15, 1995. The geographic areas with elevated ozone levels followed the high pressure center and wind patterns for this episode[27].

Figure Air Quality 2.

End of separate text

SAMI Strategy Results

Generally, the largest air quality changes in response to SAMI emissions strategies occurred on the days with the poorest air quality.

Ozone responses to SAMI strategies

Ozone levels are projected to decrease in 2010 and 2040 under all three SAMI strategies[1,18]. The largest reductions occur for the hours and days with the highest ozone values. As an example, modeled changes in hourly ozone values for July 11-19, 1995, at Look Rock in Great Smoky Mountains National Park in response to SAMI strategies are illustrated in Figure Air Quality 3. The black line represents the modeled ozone values for each hour of the 9 days. The red, turquoise, and blue lines represent hourly ozone levels in 2010 under the SAMI A2, B1, and B3 strategies, respectively. Ozone reductions from peak hourly values for the A2 strategy ranged from 10 to 18% compared to 1995. Ozone reductions are similar for the B1 strategy. The B3 strategy shows reductions of 20 to 25% compared to 1995. These reductions in ozone values are smaller than the reductions in summer-day nitrogen dioxide emissions (44% reduction for the A2 strategy in 2010, see Emissions Chapter ____). The differences between strategies are consistent with emissions trends. Modeled changes in hourly ozone are used to adjust measured hourly ozone values for ozone effects modeling (see Ozone Chapter ___).

Figure Air Quality 3. Hourly ozone values at Look Rock in Great Smoky Mountains National Park for July 11-19, 1995 and modeled changes in hourly ozone values in response to SAMI strategies

Fine particle responses to SAMI strategies

Changes in fine particle mass are consistent with emissions changes (see Emissions Chapter ____). The largest changes in PM2.5 mass occurred on the days with highest mass. In Figure Air Quality 4, the map on the upper left illustrates modeled PM2.5 mass for July 15, 1995. The highest PM2.5 concentrations on July 15, 1995, occur over West Virginia and over urban areas in GA, TN, KY, and NC. The map on the upper right illustrates modeled PM2.5 mass using the same meteorological conditions as occurred on July 15, 1995, and using emissions for the 2010 A2 reference strategy. PM2.5 mass is reduced 10 to 40% (*check*) across the Southern Appalachian Mountains under the 2010 A2 strategy compared to July 15, 1995. The maps on the lower left and lower right illustrate PM2.5 mass on July 15 assuming emissions under the 2010 B1 and B3 strategies, respectively. The spatial areas with PM2.5 mass above 32 μg/m3

Figure Air Quality 4. Change in Fine Particle Mass on July 15, 1995, in response to SAMI strategies.

Most of the reductions in daily average fine particle mass are due to reductions in sulfate particles[1,18]. This is illustrated with the ??date of??? episode in Figure Air Quality 5 ~~for example modeled days at~~ the Great Smoky Mountains National Park *(and Figure Air Quality 5b for Shenandaoh??).* Across the mdoeled days, daily-average sulfate particle mass is projected to decrease from 6% (for the 2010 A2 strategy) to 60% (for the 2040 B3 strategy) at Great Smoky Mountains and from 16% (2010 A2 strategy) to 58% (2040 B3 strategy) at Shenandoah. Daily-average sulfate particle mass is projected to increase slightly in 2010 under the A2 strategy for a few modeled days. This is in response to projected increases in sulfur dioxide emissions between the modeled days and the 2010 A2 strategy.

Modeled responses to the control strategies for ~~changes in~~ organic particle mass in the SAMI Class I areas ~~in response to SAMI strategies~~ are generally small. (BJ: This is so qualitative. Can you provide numerical ranges, concentrations or some quantitative values to better facilitate comparisons between the different pollutant species.) This is consistent with emisions inventory data which indicate that organic compounds are composed of X% of biogenic sources versus X% of anthropogenic (i.e., man-made) sources in the SAMI Class I areas. ~~This is consistent with the emissions model results that natural sources are much larger contributors to organic compounds in the SAMI Class I areas than are human sources~~[1, 18]. Changes to soils, elemental carbon, and coarse mass are also small in response to SAMI strategies. Nitrate particle mass increases on some days; these results are discussed in greater detail in the Visibility Chapter ____. SAMI focused on results for Class I areas, fine particle responses to SAMI strategies are somewhat different in urban areas.

Figure Air Quality 5a Changes in Fine Particle Mass on Example Modeled Days at Great Smoky Mountains National Park in Response to SAMI Strategies in 2010

The changes in fine particle mass for the 22 modeled days are weighted to define the change in summer average, class average, or annual average fine particle mass for 2010 and 2040[28] (see Visibility Chapter ____).

Deposition responses to SAMI strategies

Sulfate deposition is reduced in response to all SAMI strategies in 2010 and 2040. Model results for sulfate deposition for the week of July 23-31, 1991 are illustrated in Figure Air Quality 6. The map on the upper left illustrates modeled wet sulfate deposition for the week of July 23-31, 1991. Precipitation volume and deposition were heaviest along and east of the Southern Appalachian Mountains. The map on the upper right illustrates modeled wet sulfate deposition for this episode using the same meteorological conditions as occurred during July 23-31, 1991, and using emissions for the 2010 A2 reference strategy. The maps on the lower left and lower right illustrate sulfate wet deposition for the 2010 B1 and B3 strategies, respectively.

Figure Air Quality 6. Changes in Sulfate Wet Deposition during the week of July 23-31, 1991, in Response to SAMI Strategies in 2010 *(or several weeks at GRSM and Shen similar to format of Figure 5?)*

Nitrogen deposition is little changed in 2010 and 2040 in response to SAMI strategies[1,18] (see Acid Deposition Chapter ___). Dry deposition of ammonia gas and wet deposition of ammonium are projected to increase in the A2 and B1 strategies and to decrease in the B3 strategy. These deposition trends are consistent with projected emissions trends. Wet and dry deposition of oxidized nitrogen (nitrate, nitrogen oxides, nitric acid vapor) are projected to decrease in 2010 and 2040 under all strategies. The model projected that dry deposition of oxidized nitrogen components (nitric acid vapor) will be reduced more than wet deposition of nitrate. This result may be dependent on the assumed initial and boundary conditions for nitrogen dioxide and precursor components and is treated as an added uncertainty in the nitrogen deposition results.

The model results for 9 episodes are separately weighted to define the changes in annual average wet and changes in annual average dry deposition for 2010 and 2040 in response to SAMI strategies[29].

Geographic Sensitivities

The DDM sensitivity analysis ~~tool~~ module is used in lieu of the full chemistry in the URM-1ATM photochemical model to evaluate the relative contributions of different geographic source areas and different source types to air quality in the SAMI region for incremental changes in pollutants[19]. The 2010 A2 reference strategy is used as the basis for these geographic sensitivity analyses. In 2010 the A2 strategy represents those federally required emissions controls for which we have the greatest ~~confidence in the methods of implementation~~ confidence on being implemented. Included in the 2010 A2 reference strategy are assumptions for implementation of the one-hour ozone standard (BJ: I do not know what these assumptions mean or include. Would anyone else in the public know?), the acid rain rules, EPA's regional reductions of nitrogen oxide emissions from utilities and large industries under the NOx SIP Call ~~the Environmental Protection Agency's call for revised State Implementation Plans~~, highway vehicle Tier I and Tier II standards, low-sulfur fuel rules, and industrial controls of volatile organic compounds[17] (see Emissions Chapter ____).

The SAMI geographic sensitivity analyses can be used to interpret the benefits of emissions reductions in specific geographic areas beyond those in the 2010 A2 strategy. Emissions reductions beyond those included in the 2010 A2 strategy will? be required to comply with 8 hour ozone standard (BJ: I don't think I would make this conclusion since we haven't finished developing our 8-hr implementation guidance yet. Are you saying the SAMI reductions or some other combination of reductions which go beyond the A2 strategy will be required all areas for 8-hr compliance or are you saying that additional emission reductions will/may/could need to be assessed for compliance with the 8-hr NAAQS ? Who can conclusively state now how much if any additional controls may be needed for certain areas.), the PM2.5 standard, and the regional haze rules, but the

specific implementation strategies have not yet been determined. By adjusting emissions from the 2010 A2 reference strategy, we can evaluate the benefits expected from the next incremental set of SAMI controls. All results reported here are for 10% changes in single pollutant emissions from the 2010 A2 strategy. These results can be linearly? extrapolated to emissions changes up to 30% from the 2010 A2 strategy.

For these analyses, the SAMI modeling domain was subdivided into 12 geographic areas of interest (Figure Air Quality 7). These geographic areas correspond to the regional planning organizations established as part of the regional haze rule[30]. In addition to each of the eight SAMI states, the collective contributions of states in the Midwest, Northeast, and Central regions and the combined effect of Florida and Mississippi (states in regional planning organization for the southeastern US that are not also SAMI states) are considered. Any areas of the modeling domain not covered in these 12 geographic areas are assigned to an "all other"category.

Figure Air Quality 7. Geographic areas considered in SAMI geographic sensitivity analyses.

(delete line, unintended)

Confidence

Confidence in geographic sensitivity results is greatest for those cases where both source areas and receptors are within the SAMI region (12-km and 24-km grids). Confidence is somewhat lower for those cases where emissions sources are in the SAMI region and receptors are in coarser grids (influence of SAMI states on other regions). Confidence is lowest for those cases where emissions sources are in the coarse (48-km and larger) grids (influence of other regions on SAMI region). The impacts of emissions in these coarse grids, particularly utility and large industrial point sources, to receptors in the SAMI region are likely underestimated[19]. All sensitivities consider changes in a single pollutant at a time. We do not know if results would be different if multiple pollutants were changed at the same time. In general we have greatest confidence in the relative contributions of the SAMI states to air quality at specific receptors. We have less confidence in the absolute magnitude of the air quality responses to emissions reductions. (BJ: Since you state earlier in the *Model Performance* section and here that the modeling results should not be used in an absolute sense and that some percentage adjustment is made to the modeled concentrations, why can you now use the model results in an absolute manner for the sensitivity analyses and how should these results be interpreted?)

Source Contributions to Sulfate Fine Particles

On most modeled days, the greatest benefits of reducing sulfur dioxide emissions from the 2010 A2 strategy in the SAMI states are projected to occur in the SAMI states[31]. On some days, sulfur dioxide emissions reductions in other regions also benefit the SAMI states. Changes in sulfate fine particles in response to 10% changes in sulfur dioxide emissions from the 2010 A2 strategy are illustrated for July 15, 1995 in Figure Air Quality 8. Modeled sulfate fine particle levels for the 2010 A2 strategy are illustrated in

the upper left map. On this day, the benefits of reducing sulfur dioxide emissions in the SAMI states occur primarily in the SAMI states (lower center map). Benefits of reducing sulfur dioxide emissions in the five Midwestern states occur primarily in those states, but also provide some benefits in the SAMI states (upper center map). On this day, reducing sulfur dioxide emissions from Northeastern or Central states and from Mississippi and Florida have small or no benefits in the SAMI states.

Figure Air Quality 8. Sulfate fine particle mass modeled for July 15, 1995, using emissions for the 2010 A2 strategy and changes in sulfate fine particle mass in response to 10% reductions in sulfur dioxide emissions from the 2010 A2 strategy for the SAMI, Midwest, Northeast, and Central regions and from Mississippi and Florida.

The greatest benefits from reducing sulfur dioxide emissions generally occur within the state where the reductions are made. Figure Air Quality 9 illustrates changes in sulfate fine particles in response to 10% reductions in sulfur dioxide emissions in the 2010 A2 strategy from each of the SAMI states on July 15, 1995. A high pressure was centered over the southeastern US on this day and light winds were circulating counterclockwise. On this day, sulfur dioxide reductions in each state reduce sulfate fine particles in that state. Each state also has some contribution to changes in sulfate fine particles in neighboring states.

Figure Air Quality 9. Sulfate fine particle mass modeled for July 15, 1995, using emissions for the 2010 A2 strategy and changes in sulfate fine particle mass in response to 10% reductions in sulfur dioxide emissions from the 2010 A2 strategy for each of the eight SAMI states.

Changes in annual average fine particle mass are useful to evaluate relative source contributions over a range of meteorological conditions. Source contributions from SAMI states and non-SAMI states to changes in annual average sulfate fine particle mass at SAMI Class I areas are illustrated in Figure Air Quality 10. A 10% reduction in the 2010 A2 strategy sulfur dioxide emissions from the entire SAMI modeling domain is projected to result in 4 to 7% reductions in sulfate fine particle mass at these sites. SAMI states collectively account for 40-80% of the total change in sulfate fine particles at each SAMI Class I area to sulfur dioxide emissions reductions.

Figure Air Quality 10 Annual Sulfate Fine Particle Responses at SAMI Class I areas to 10% Sulfur Dioxide reductions from 2010 A2 strategy in SAMI states and non-SAMI states

The SAMI Class I areas can be grouped by common source contributions to air quality changes. The greatest benefits from sulfur dioxide reductions are projected to occur at receptors in the same state or adjacent states. Figure Air Quality 11 illustrates the same changes in sulfur dioxide emissions as Figure Air Quality 10, but separates contributions from each SAMI states and surrounding regions. Annual average sulfate particle mass at Cohutta Wilderness Area in northern Georgia and Sipsey Wilderness Area in

northwestern Alabama are most influenced by sulfur dioxide emissions reductions in Georgia and Alabama, respectively. Tennessee, the Central Region, the Midwest Region, and Mississippi also influence these sites.

Figure Air Quality 11 Annual Sulfate Fine Particle Responses at SAMI Class I areas to 10% Sulfur Dioxide reductions from 2010 A2 strategy in each SAMI state and surrounding regions

Annual average sulfate particle mass at Great Smoky Mountains National Park on the Tennessee-North Carolina border and at Joyce Kilmer Slickrock, Shining Rock, and Linville Gorge Wilderness Areas in western North Carolina are most influenced by sulfur dioxide reductions in Tennessee. Sulfur dioxide emissions in Georgia, Alabama, North Carolina, and the Central and Midwest regions also influence these sites. Annual average fine particle mass at Shenandoah National Park and James River Face Wilderness Area in Virginia and at Dolly Sods and Otter Creek Wilderness Areas in West Virginia are most influenced by sulfur dioxide reductions in Virginia, West Virginia, and the Midwest region. Annual average sulfate particle mass at Shenandoah and Dolly Sods is also influenced by the Northeast region.

Annual average sulfate wet deposition is reduced 4-9% at the SAMI Class I areas in response to a 10% reduction in sulfur dioxide emissions throughout the modeling domain (Figure Air Quality 12). Source contributions to changes in annual average sulfate wet deposition are somewhat different than those for changes in annual average sulfate particle mass. Class I areas in Georgia, Tennessee, and western North Carolina receive greater contributions to annual average sulfate wet deposition from sulfur dioxide emissions in Georgia and Alabama than is the case for annual average sulfate fine particle mass. Precipitation events generally proceed from the Gulf of Mexico, across Alabama and Georgia, to eastern Tennessee and western North Carolina. Thus Alabama and Georgia have greater contributions to sulfate wet deposition at these sites. Class I areas in Virginia and West Virginia receive greater contributions to annual average sulfate wet deposition from those two states than is the case for annual average sulfate fine particle mass.

Figure Air Quality 12 Annual Sulfate Wet Deposition Responses at SAMI Class I areas to 10% Sulfur Dioxide reductions from 2010 A2 strategy in each SAMI state and surrounding regions

Relative source contributions to nitrate fine particle mass and nitrate wet deposition at the SAMI Class I areas are similar to those illustrated here for sulfate fine particle mass and sulfate wet deposition [1,19,31]. The absolute magnitudes of nitrate wet deposition responses to nitrogen oxide emissions reductions are much smaller (1.5 – 3.5 % in response to 10% emissions reduction) and are less certain than for sulfate wet deposition responses to sulfur dioxide emissions reductions.

Contributions of nitrogen oxide sources emitted at ground-level (highway vehicles, non-road engines, and area sources) are considered separately from contributions of elevated sources (utility and industrial) of nitrogen oxide. Nitrogen oxide emissions from utilities and large industries under the NOx SIP call are included in the 2010 A2 strategy. In all SAMI states except West Virginia, nitrogen oxide emissions in the 2010 A2 strategy are higher from ground level sources than from elevated sources (Figure Air Quality 13).

Figure Air Quality 13 Nitrogen oxide emissions in the 2010 A2 strategy modeled for July 12, 1995 for elevated (utility and industrial point sources) and ground-level (highway vehicle, non-road engines, and area) sources

In general, responses to nitrogen oxide emissions reductions from ground level sources are larger than responses to nitrogen oxide emissions reductions from elevated sources. This point is illustrated in Figure Air Quality 14 for responses of growing season (April to October) ozone to nitrogen oxide reductions from elevated and ground-level sources. For all SAMI Class I areas, reductions in ground level nitrogen oxide emissions are projected to be more effective in decreasing growing season ozone than nitrogen oxide reductions from elevated point sources. Ground level sources of nitrogen oxide emissions in the SAMI states have larger percentage contributions to reductions in growing season ozone at SAMI Class I areas than ground level sources in non-SAMI states.

Delete this line, unintended
Figure Air Quality 14 Growing season ozone responses at SAMI Class I areas to 10% reductions in nitrogen oxide emissions in the 2010 A2 strategy for each SAMI state and surrounding regions

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separate text box

Local vs Regional Transport (Are you going to mention the uncertainities in the initial and boundary conditions inputs, the work that is being done to address them, and possible implications on this work?)
Incomplete
The following general conclusions can be drawn from SAMI's episode selection and geographic sensitivity analyses:

- In general transport distances from emissions source areas are shorter for gases, fine particles, and dry deposition, than for wet deposition. This means that local sources have greater contributions to ozone and fine particles than to acid deposition.
- In general, ground level sources of nitrogen oxides have more localized contributions to ozone than elevated sources of nitrogen oxides

- Once the NOx SIP call is implemented, reducing ground-level nitrogen oxide emissions will have the greater benefits in reducing growing season ozone than reducing elevated source of nitrogen oxides.

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SAMI Accomplishments/Experience

- Demonstrated integrated one-atmosphere photochemical modeling to simulate changes in fine particles, ozone, and acid deposition in response to ~~SAMI~~ emissions control strategies
- Demonstrated use of discrete episode form a variety of seasons and meteorological conditions to represent ~~episode selection techniques to minimize error in representing~~ seasonal and annual air quality measures
- Developed and demonstrated model performance evaluation methodology for photochemical and meteorological models for one-atmospheric modeling of ozone, fine particulates and visibility
- ~~Demonstrated photochemical model performance for 2 winter-time episodes~~
- Demonstrate sensitivity analysis tool to evaluate source contribution to air quality changes at selected receptors

Model Uncertainty (Lessons Learned?)

Errors associated with the atmospheric modeling system effect our confidence in model results. The major sources of uncertainty include:

- emissions inventory and emissions model (BJ: I believe that this is the first mention of the emissions model in this chapter. Is there something on this elsewhere in the final report? What model drawback is this referencing, the ammonia model, NONROAD, unavialibility of MOBILE6, etc?), especially emissions of ammonia gas, organic carbon particles, elemental carbon, and soils
- meteorological model, especially difficulty representing precipitation and clouds
- episode selection techniques, especially reliance on episode weightings for two parks to define weighting for other locations in SAMI region, need to model more days from more distinct seasons, maybe even a year?, do a comparative analysis on merits of modeling longer periods
- air quality model, especially representing initial and boundary conditions and influence of grid size on model outcome (BJ: I don't recal these being mentioned earlier in this document? IF I'm correct why not.)
- monitoring data, data collection resolution and especially methods of collection?analysis? for ammonium, total organic, and nitrate particle mass and scarcity of dry deposition monitoring data
- source contribution assessment, especially the contributions from areas covered by coarse modeling grids (BJ: Seems like this, "influence of grid size on model outcome," belongs here also for clarity.)

Key Findings *(to be provided)*

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4) OTAG

5) NAPAP ozone modeling

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