A Tale of Two Linkages

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Introduction

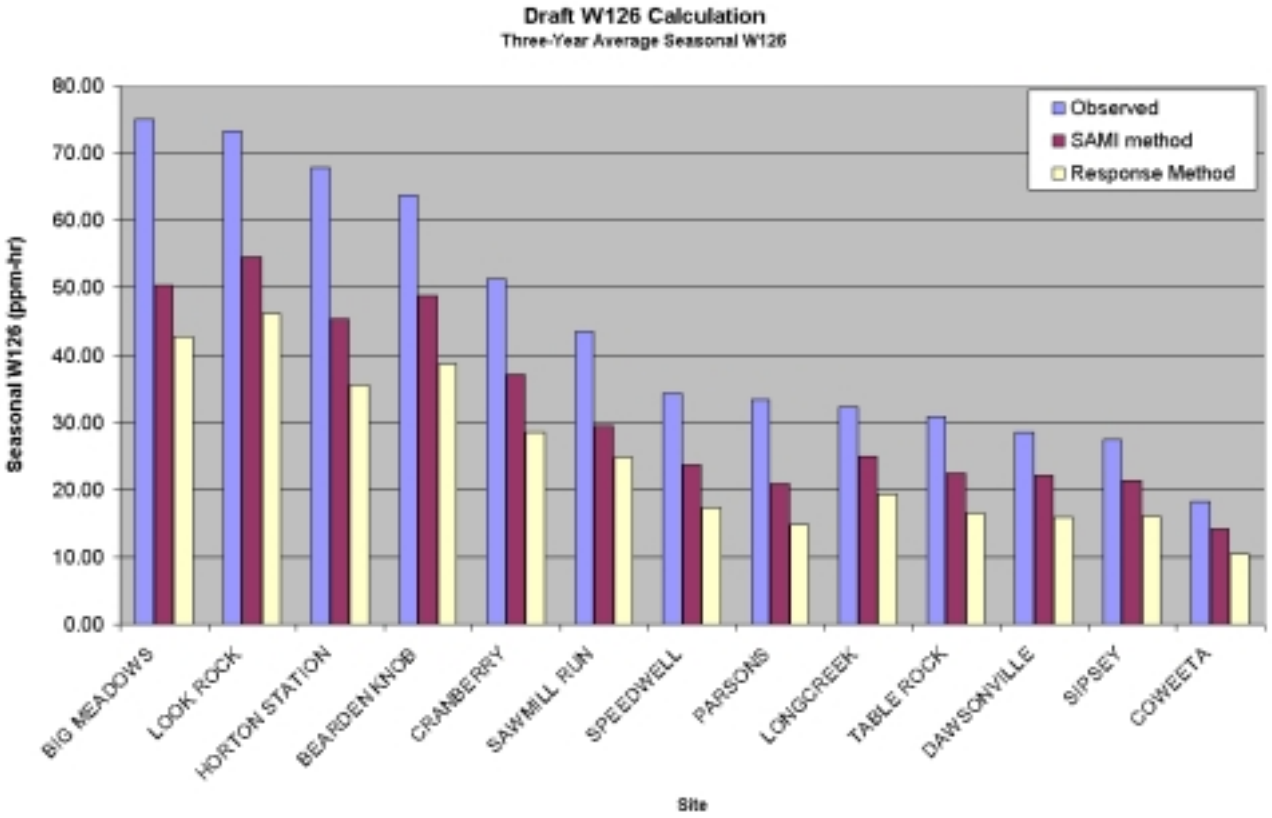
SAMI is attempting to reconstruct a three-year hourly time series of ozone for 13 sites for various emissions scenarios possible in future years. We are doing this by scaling the observed concentrations by the percent change in ozone between the base year simulation and the future year emission simulation. Out of the 642 days during the ozone seasons of 1993-1995, we have simulated a total of about 60 days in the years 1991-1995. The question is how do we link the model results for the 60 modeled days to the 642 observed days. The three-year times series are used as input for a forest effects model, TREGRO.

Two linkage methods have been proposed. The one selected by the joint Air Quality and Effects subcommittees (the SAMI method) relies upon a weighted representation of the model days. If the meteorology on one model day A is more common than the meteorology on day B then model day A will be used to represent more days than will model day B. If model day A is selected to represent the response on a given observed day, then the observed ozone is multiplied by the ratio of the future/base modeled ozone for each hour. The strength of this method is that it attempts to preserve the frequency of various types of meteorology and transport.

The second linkage method (response method) relies upon a characteristic noted in air quality modeling of emissions controls. The higher the ozone in the base simulation, the greater the fractional change in response to controls. The basic reason for this is that the response to emissions controls is superimposed on top of a background ozone concentration that does not decrease with controls. The response method also recognizes that the transport in the model is imperfect and will frequently miss time or misplace the occurrence of high ozone concentrations.

The effect of using the two methodologies

The first question to ask is "does it make a difference to TREGRO which method is used?" The answer is very likely yes. We won't really know until the end of May when trial runs of TREGRO are complete that use the results from the two linkage methods for two different sites. We can say that the two methods give significantly different views of the response of ozone to emissions controls, even though they both have the same observations and model results to start with. The first figure shows plots the observed and the 2010 OTW projected ozone W126 metric for the two different ozone linkage methodologies.

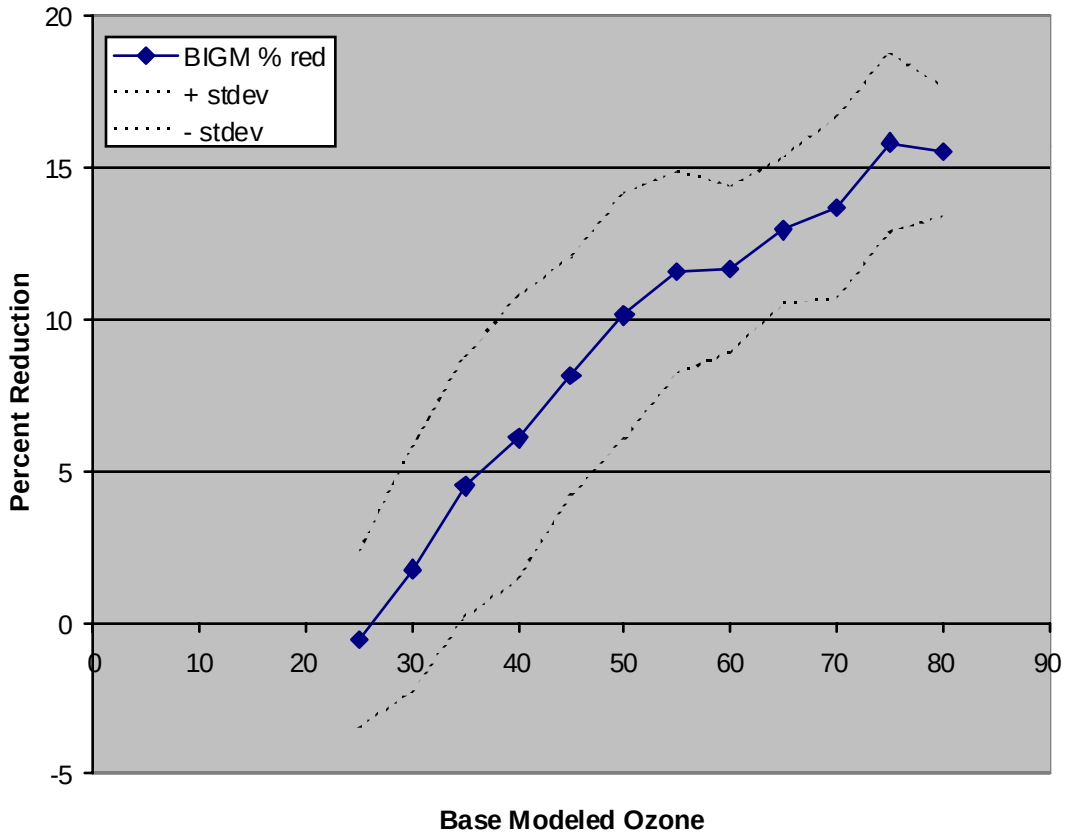


As can be seen from the figure the response method gives significantly lower projected W126 for 2010 OTW at all sites. This is expected to produce a difference in the response in the TREGRO forest effects model.

Which ozone linkage method is right?

The next question to ask is which method is right? Unfortunately neither method is perfect so it is a matter of degree and not black and white. However, some deficiencies are noted below for the SAMI methodology that, may explain why the SAMI W126 reduction is less than that from the response method and also calls into question the ability of the SAMI method to accurately project the future year ozone concentrations.

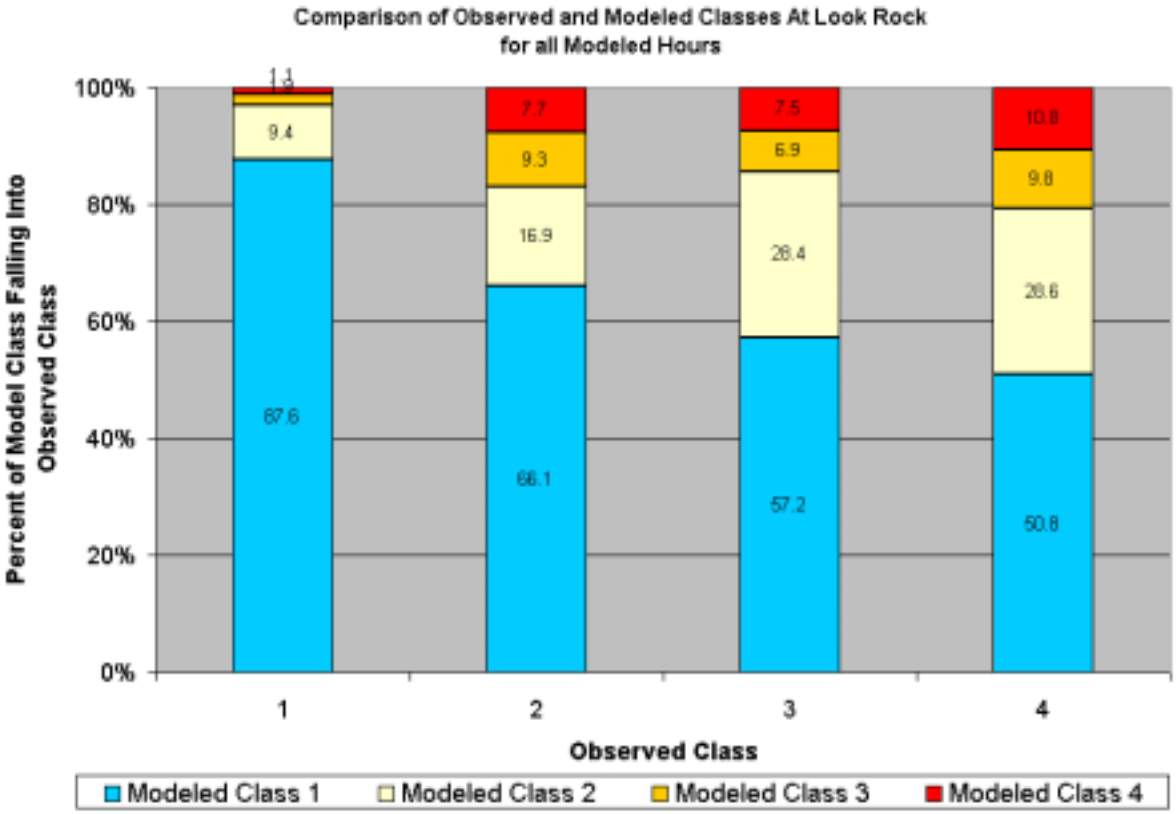
First we will examine the basic tenet of the response method, that the fractional change in ozone concentration to an emissions reduction is greater at higher base ozone concentrations. This has been observed previously in the OTAG ozone modeling and now is observed in the SAMI modeling. The figure below shows the average fractional reduction plotted versus base model ozone concentration for the Big Meadows site. Other sites have different, though similar response plots.



The plot shows that according to the model the percent change in ozone is a strong function of the base level ozone concentration. The response varies from near zero at 25 ppb base ozone to about 15% at 80 ppb base ozone. As the dashed lines (plus and minus one standard deviation) show there is variability about the average percent reduction. This variability is relatively constant between 3 and 4% across the range of base modeled ozone. This plot clearly shows that the modeled percent reduction of ozone concentrations at Big Meadows is a function of the simulated base ozone. To estimate the future year concentration using the response method the observed ozone is lessened by the percent reduction corresponding to the base ozone. A plus or minus a random term based on the standard deviation is also included to characterize the variability of the response.

Misclassification of hours at Key sites

Since we can now see that the response depends strongly on the base modeled ozone concentration, an essential task that the SAMI linkage method must accomplish to accurately simulate the future year ozone concentration is to establish a correspondence between the hourly simulated ozone and the hourly observed ozone on the modeled days. If such a correspondence does not exist, then low observed ozone concentrations would be reduced by a large fraction and high observed ozone concentrations could be reduced by too low a fraction. The following plot is the result of matching the ozone classes between observations and the model at the Look Rock site. The classes represent low ozone (class 1) to high ozone (class 2). Class 1 includes the lowest 70% of ozone concentrations, Class 2 from 70 to 90%, Class 3 from 90 to 97%, and Class 4 includes the highest 3% of ozone concentrations. The observed and modeled ozone concentrations were classified for all modeled hours at the Look Rock site, then the classes were checked to see how well the corresponded.



For observed Class 1 ozone hours, the model ozone was also Class 1 87% of the time. The accuracy of classification declines for higher ozone: Class 2 16.9%, Class 3, 6.9%, and Class 4 is characterized by the model correctly for only 10.8% of the hours. This does not necessarily mean the ozone performance of the model was bad. In fact the model met the commonly accepted model performance guidelines. It means that we are asking the model to do something that it does not do particularly well – that is to capture the hour to hour variability in concentrations at exactly the right time and place. We are better off asking the model to do those things it does well, such as capture the ozone to NO_y slope, then apply these results in a reasoned way.

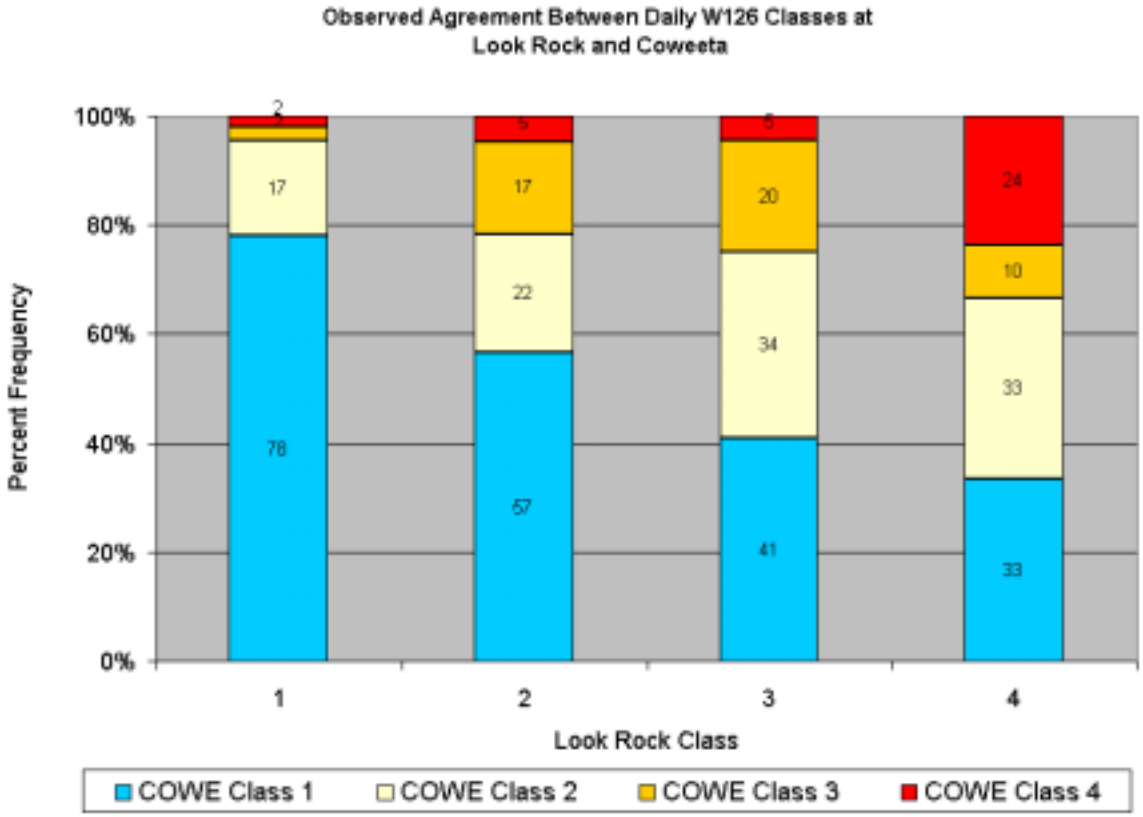
The consequence of misclassifying hours is that low observed ozone concentrations will be reduced too much and high ozone concentrations by too little on the average. This will tend to yield a flatter % reduction to base ozone slope than the one observed in figure 1. It also means that the highest ozone concentrations have a lower percent reduction applied almost 90% of the time. In fact for ½ of the Class 4 ozone hours, a Class 1 reduction will be applied at Big Meadows. It is the highest ozone concentrations that have the most effect on forest species.

Misclassification of Days at Sub sites.

The SAMI ozone linkage method relies upon the classification of days by ranking the observed W126 into Classes 1-4 as above. The W126 classification for the two key sites is then applied to the sub sites (see Table 1). A critical question is how well on a day by day basis do the classes at a sub site agree with the observed class at its key site?

Monitor Site	Key Site
Ashland	Look Rock
Sand Mountain	Look Rock
Dawsonville	Look Rock
Long Creek	Look Rock
Jacks River	Look Rock
Cowetta	Look Rock
Look Rock	Look Rock
Table Rock	Look Rock
Cranberry	Look Rock
Speedwell	Look Rock
Horton Station	Big Meadows
Sawmill Run	Big Meadows
Big Meadows	Big Meadows
Parsons	Big Meadows
Bearden Knob	Big Meadows

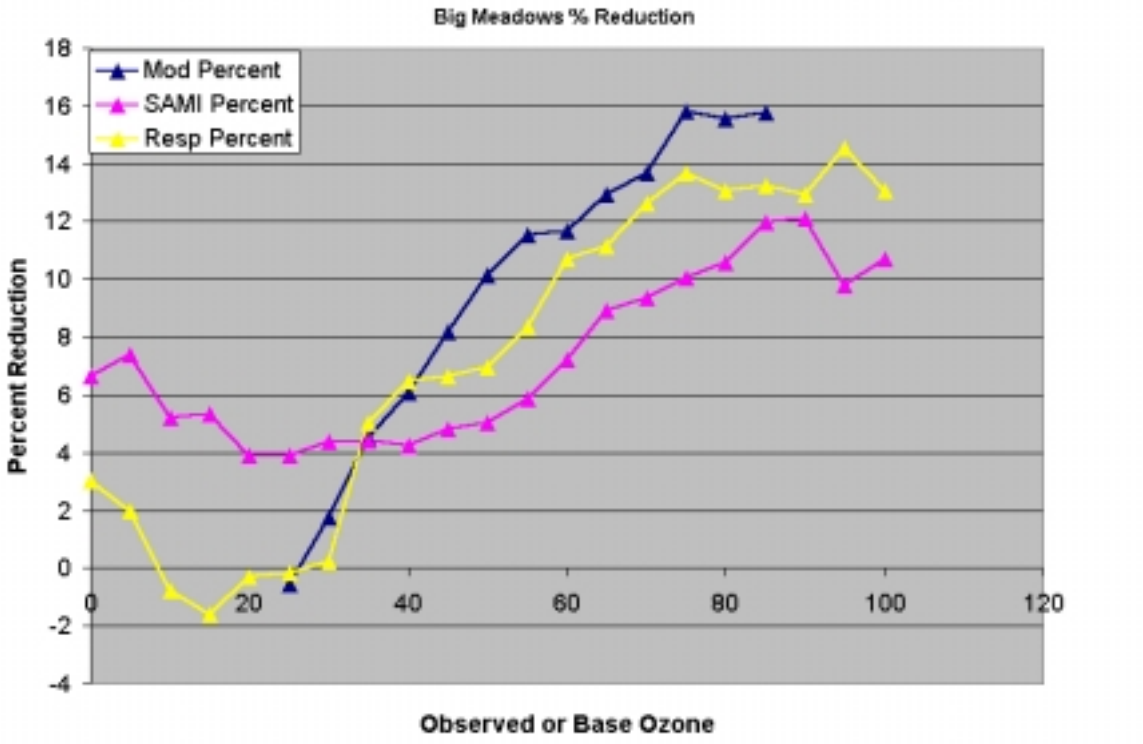
A comparison was carried out between the W126 daily classification between Coweeta and its key site Look Rock. The results of the comparison are given in figure 4.



Coweeta's class agrees with the class at Look Rock 78%, 22%, 20%, and 24% of the time for Look Rock Classes 1-4 respectively. This means that Class 4 days at Coweeta are misclassified ¾ of the time when using the observed class at Look Rock as the SAMI method does. This source of error will induce additional error into the application of the modeled percent reduction to the observed data. This should lead to an additional flattening of the response to controls beyond that noted at the key sites.

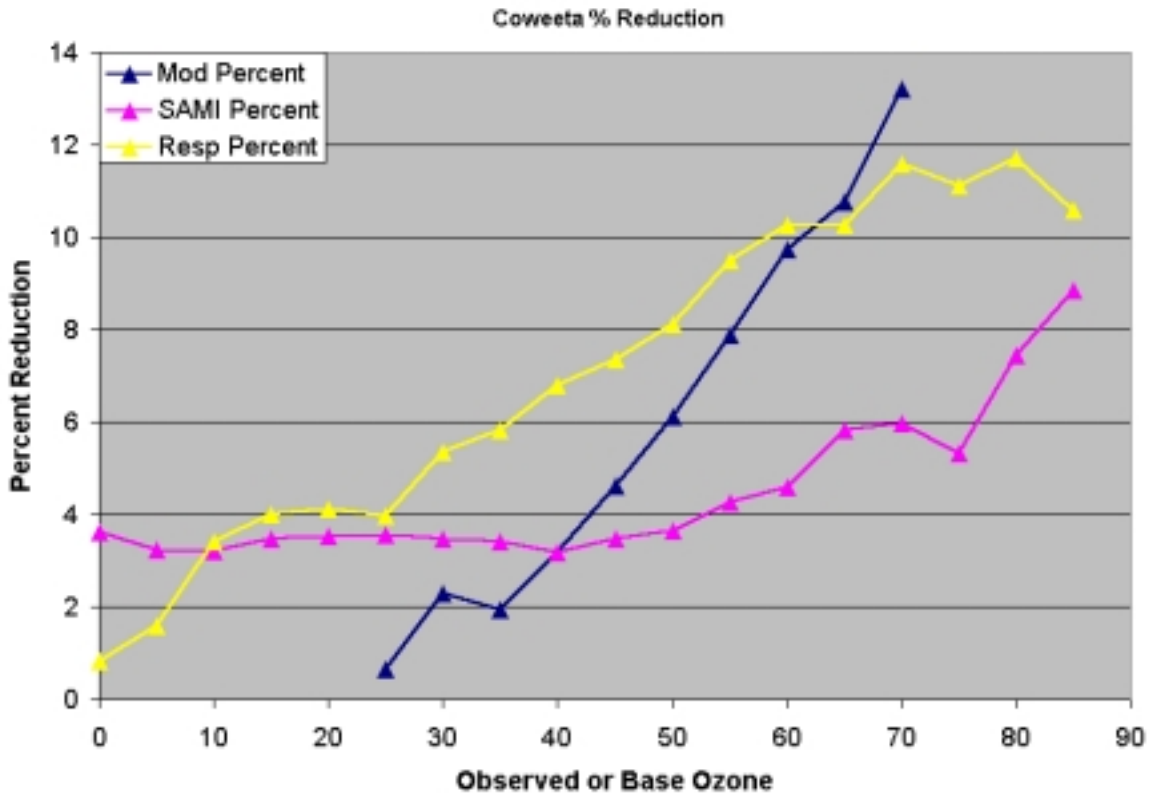
Comparison Of The Reduction From The Ozone Linkage Methods To The Modeled Ozone Reduction

Examples of the difference in response for a key site, Big Meadows, and a sub-site Coweeta are given below.



At Big Meadows, the range of modeled percent reduction if from 0 to 16 percent, increasing from the minimum modeled concentration of 25 ppb to the maximum modeled concentration of 85 ppb. The response method gives nearly the same range of percent reduction but spreads it over a wider range of observed concentrations at the site. In contrast, the SAMI method gives a reduction of 4 to 8 percent from an observed concentration of 0 to 60 ppb, then increases the reduction to 12 percent at about 90 ppb. The low concentrations have too great a reduction and the high concentrations too small a reduction as anticipated from the analysis of the misclassification. It is the difference in the projected reduction in the higher ozone concentrations that results in the difference in W126 estimated by the two linkage methods. This is because ozone below 40 ppb has a weight near 0 in the W126 classification; the weight increases to near 1.0 at an ozone concentration of 100 ppb.

At Coweeta, the model gives a reduction of near zero at the lowest modeled concentration (25 ppb) and increases to a reduction of above 12% at the highest modeled concentration. The response method gives a similar range of reductions, but spreads it out over the wider range of observed concentrations. In contrast, the response of the SAMI ozone linkage method is constant at about 4% up to an observed concentration of about 60 ppb, then it increases to 9% at the highest concentrations. The additional flattening of the response of the SAMI method is consistent with the added misclassification incurred by applying the Look Rock class to Coweeta.



The Effect of Transport Errors on Model to Observation Comparisons

At rural sites it has been noted (Trainer for ROSE site, Olszyna for Giles county site) that the ozone concentration measured is a strong function of the total odd nitrogen (NOy) or processed nitrogen (NOz) concentrations measured at the same time. In fact, one way of estimating the number of ozone molecules produced by a given emitted NOx molecule is to calculate the slope of the line of ozone plotted against NOz concentration. It has also been noted that models do a fairly good job of reproducing the measured slope. The figure below is a comparison of the measured and OTAG modeled O3 to NOz at a rural site in Tennessee during the 1995 SOS study. The model does a good job in estimating the observed O3 to NOz slope. However, it was also noted that on an hour-by-hour comparison that the modeled ozone did not match the measured ozone well at all. The conclusion was that the model was doing the chemistry better than the transport at this rural site. If an urban plume actually hit the site, while missing it in the model then the modeled ozone would be much lower than the measured ozone, and visa versa.

In the method selected by the SAMI joint working group for the ozone linkage, we are relying exactly on that aspect of the model performance that is least reliable; that is the hour-by-hour matching of the model results to observations. This matching is used to scale the observed ozone to estimate the ozone for future years. By relying upon this hour-hour matching we suffer the consequences noted above. The strength of the SAMI method is the linkage to frequency of meteorology. But if the differences in hourly classification of ozone between observation and the model are caused by errors in transport, then how much value is gained by this link?

Since the response method does not weight the model results for one day more than another, all days have equal weight. Thus one model day that has a more common meteorology rightfully should receive a higher weight than a day with less common meteorology. If the emissions reductions were domain-wide and uniform, this would be of little consequence. However, some to the emissions control scenarios that SAMI is examining are geographically based, some confined to just the SAMI states. How will the lack of weighting affect stations that are near the boundary of the controlled area? This will be a source of error in the response method, since the transport embedded in the percent reduction could over or underestimate

transport from the uncontrolled region. The method can be modified by weighting the reduction from common days more than reductions from less common days. While fairly easily done, it would probably make only a limited difference in the results, based on the relatively small standard deviation of the percent reductions shown in figure 2. That is, if there were a lot of variation from day to day in the percent reduction for a given base concentration, the standard deviation would be large. But if this is the deciding factor in choosing between the methods, TVA is willing to perform the modification.