6. ANALYSIS OF BRAVO MEASUREMENTS

The measurements made during the BRAVO Study were comprehensive enough that often it was possible to arrive at the value of a particular variable by more than one method. This chapter presents two types of comparisons of BRAVO measurements: (1) measurements of the same variable at the same location, but by more than one identical or similar method; and (2) measurements of two or more different variables that can be related to each other because of known or assumed relationships between them. As in the previous chapters, more detail about the subjects covered here is provided in papers and reports that are cited in the text, many of which are included in the Appendix.

6.1 Collocated Measurements

In addition to the routine 6-hr and 24-hr particulate matter sampling at the K-Bar site, the University of California at Davis (UCD) and Colorado State University (CSU) operated collocated daily samplers for ionic species there. This section will highlight the 24-hour collocated ion data collected by CSU and UCD.

The sulfate ion concentration measured by CSU and UCD agreed well. The difference in slope from unity was only about 5%. Figure 6-1 shows a scatter plot of the two measurements. There are a few disagreements, but overall the correlation is excellent and the slope is close to unity.

The ammonium ion concentrations, also shown in Figure 6-1, did not agree as well as the sulfate measurements. The correlation is high, but the slope of the best fit line for the two sets of measurements deviates from unity. The UCD measurements show, on average,

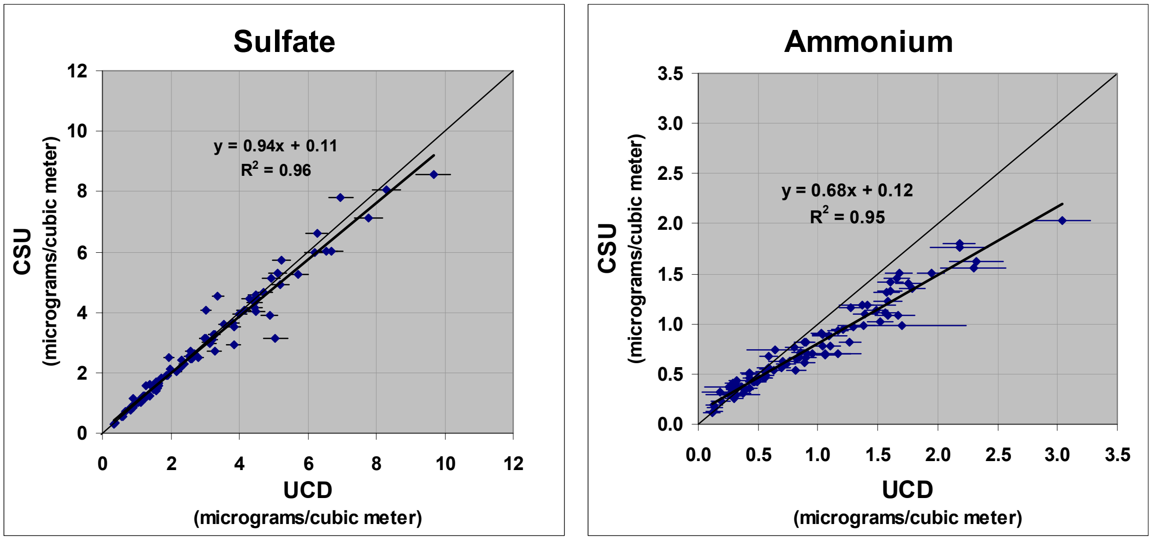

Figure 6-1. *Comparison of sulfate and ammonium measurements by UC Davis and Colorado State University. Uncertainty estimates are also shown for the UCD measurements.*

about 40% more ammonium than the CSU measurements. Although the reason for this discrepancy is not known, the CSU samples were analyzed soon after collection while the UCD samples were held for several months before being logged in and sent to the analysis contractor. The extended holding time for the UC Davis samples may have allowed partial neutralization of the acidic aerosol to occur.

The ammonium to sulfate ratio supports this hypothesis. Figure 6-2 shows that the ratio varied generally between 1 (ammonium bisulfate, not fully neutralized) and 2 (ammonium sulfate, fully neutralized), but that the UCD ratio is generally higher than that for the CSU measurements. Also, the ratio increases during the course of the BRAVO Study, which suggests that the aerosol was more fully neutralized near the end of the study than at the beginning. There was also better agreement between the two measurements toward the end of the period, as the ratio approached the fully-neutralized ceiling of 2.

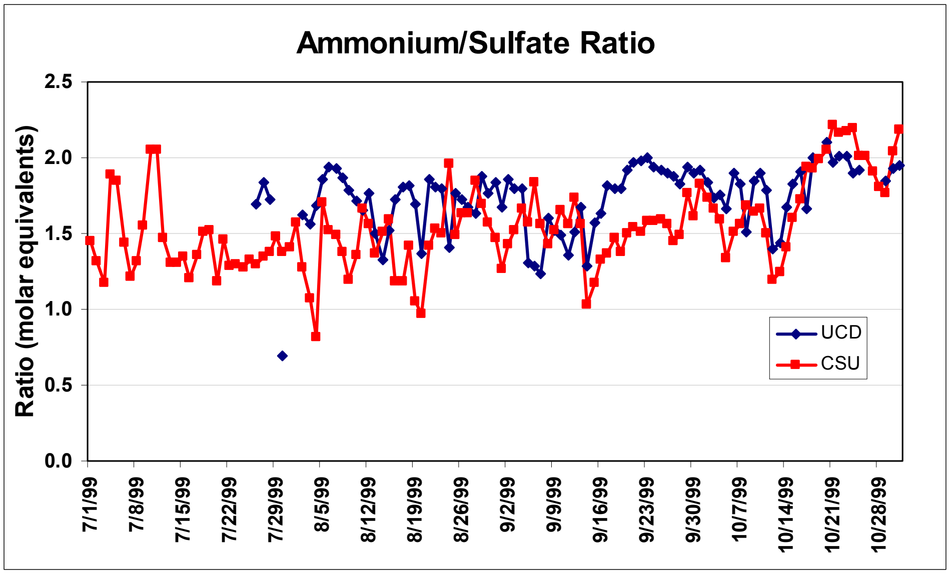

Figure 6-2. *Molar ratio of ammonium to sulfate as measured by UC Davis and Colorado State University during the BRAVO Study period.*

Nitrate measurements showed periods of both disagreement and good agreement between UCD and CSU. Figure 6-3 shows the time series of nitrate concentrations as measured by both UCD and CSU. (Note that the nitrate concentrations are much smaller than the sulfate concentrations.) For the month of August the measurements compared very well. For September the CSU measurements were lower than the UCD measurements, but they agreed well again in October. It's not clear why these measurements did not agree well in September.

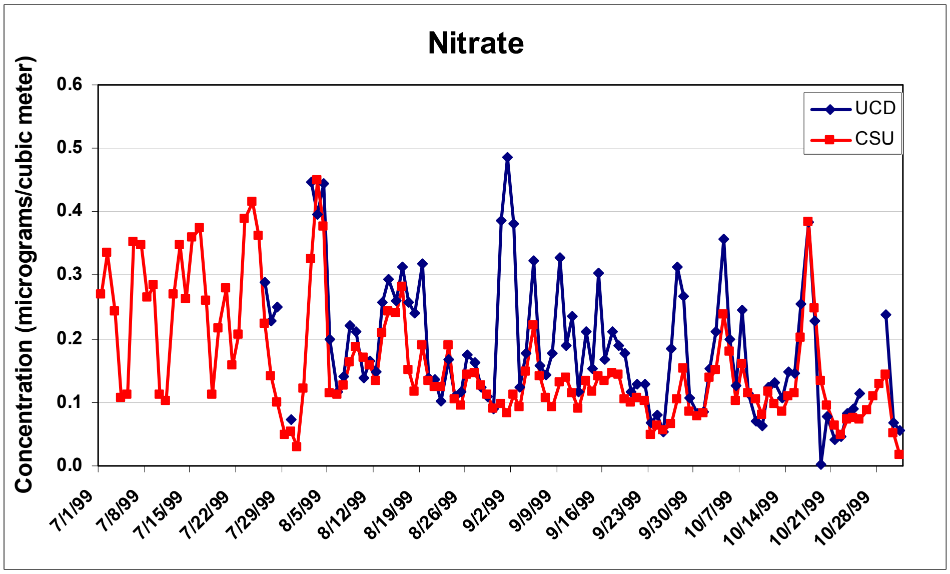

Figure 6-3. *Nitrate concentrations at K-Bar as measured by UC Davis and Colorado State University during the BRAVO Study Period.*

These comparisons provide indications of the relative accuracy and precision of ion measurements. For sulfate, there is a bias of 6% between the two sets of observations and the average relative precision is very good. For ammonium, the relative bias is quite large (the CSU measurements average 32% less than the UCD ones) and the relative precision is larger than for sulfate. For nitrate, because the performance varies from month to month, it is difficult to interpret an overall bias or precision. Figure 6-3 suggests that both have the capability of being quite comparable, despite the generally small concentrations, if consistent measurement performance can be maintained.

6.2 Fine PM Mass Closure

The PM mass concentration was determined gravimetrically throughout the network for both particle aerodynamic diameters less than 10 µm and less than 2.5 µm. Here we compare the gravimetric mass concentrations at the Big Bend site with mass concentrations determined by summing the measured species concentrations. The procedures used to calculate the component mass concentrations were described in Section 5.1.2 and the resulting reconstructed concentrations were presented in Tables 5-1 and 5-2. More detail is provided in the CIRA/NPS report on the BRAVO Study (Schichtel et al., 2004), which is included in the Appendix.

As shown in those tables, the reconstructed fine mass concentration is about 8% less than the measured concentration. The discrepancy would be greater if the sulfate was not assumed to be fully neutralized. (Note that Figure 6-2 shows that Big Bend sulfate was not always fully neutralized.) The magnitude of shortfall in the reconstructed fine mass concentration represented here is consistent with observations made elsewhere. The difference is often considered to be attributable to water contained in the particles that are weighed, since the mass of the water is not reflected in the chemical component concentrations. Another hypothesis is that the 1.4 factor used to calculate the mass concentration of organic material from the OC measurements should be larger, as presented by Turpin and Lim (2001).

In contrast, the reconstructed coarse mass concentration is about 7% greater than the measured one. The cause of this discrepancy is not known.

6.3 Extinction Budget

A variety of approaches have been used to attribute the light extinction in the Big Bend area to the various components of the particulate matter and to associated water. The discussions below describe analyses to ascertain the contribution to extinction by water associated with inorganic and organic PM constituents and to explain the contributions of various PM components to the extinction.

6.3.1 Light Scattering by Dry Particles

As described in Section 5.2.4, dry particle size distributions were measured with 15 min resolution over the particle diameter size range of $0.05 < Dp < 20$ µm from July to October 1999 at the K-Bar site in Big Bend National Park. Concurrent measurements of light scattering were made using a Radiance Research M903 integrating nephelometer that was configured to measure scattering by dried $PM_{2.5}$, as described in Section 5.3.3. Light absorption was estimated from measurements made by an aethalometer of samples collected on filter paper.

Dry light scattering coefficients (b_{sp}) were computed via Mie theory, using the measured size distributions. The computed values were highly correlated ($r^2 = 0.97$) with nephelometer measurements of dried aerosols, although the two estimates were offset by 33 ± 18%, with the computations generally yielding higher estimates Hand et al., 2002). Based on the computations, on average, accumulation mode particles (which account for most of $PM_{2.5}$) were responsible for 80% of the total measured light scattering by particles (b_{sp}), although during episodes with high dust concentrations, coarse particle scattering contributed a higher percentage (>50%) to the total.

Light absorption contributed only a small amount to accumulation mode aerosol extinction. On average over the entire study, absorption accounted for 8% of the total accumulation mode extinction.

Measurements of fine sulfate concentrations obtained from a real-time instrument during August, September and October (described in Section 5.2.2) were highly correlated ($r^2 = 0.86$) with computed values of b_{sp}. This is consistent with the major role of sulfates in visibility during the BRAVO Study.

6.3.2 Species Contributions to Light Extinction

BRAVO Study measurements at the K-Bar site in Big Bend National Park provide information that allows exploration of the scattering and absorption properties of the fine and coarse particulate matter. As described in Section 5.3.2, light scattered by $PM_{2.5}$ was measured by integrating nephelometers with 2.5 µm cut point cyclone inlets. Measurements were made both with the atmospheric sample at ambient relative humidity and after passing through a dryer. These measurements can be compared to scattering that is estimated from the PM species measurements. Also, open-air nephelometers were used to measure ambient scattering by the aerosol (both fine and coarse), which can be compared with the $PM_{2.5}$ scattering measurements to estimate coarse particle scattering and compared with extinction measurements by transmissometer to estimate light absorption. Finally, light absorption by fine and coarse particles was independently estimated using samples collected on two filter substrates as well as with an aethalometer.

A variety of models have been used to estimate extinction associated with aerosol species concentrations (Trijonis et al., 1990; Malm et al., 1996, 2000). In the West, accounting for scattering and/or absorption by coarse particles, which can account for 30-50% of measured extinction due to particles, becomes an issue (Malm and Day, 2000). Therefore, in this study, special attention was given to fully characterize the coarse mode and estimate its light scattering characteristics.

The following equation was used to estimate the 24-hr average extinction due to particles:

$$\begin{aligned} b_{ext,p} = {} & (e_{sf})\, f_s(RH)[Ammoniated\ SO_4 f] + (e_{nf})\, f_n(RH)[NaNO_3 f] \\ & + (e_{ocmf})[OCMf] + (e_{soilf})[SOILf] \\ & + (e_{sc})\, f_s(RH)[Ammoniated\ SO_4 c] + (e_{nc})\, f_n(RH)[NaNO_3 c] \\ & + (e_{ocmc})\, f_{ocm}(RH)[OCMc] + (e_{soilc})[SOILc] \\ & + 10[LACf + LACc]. \end{aligned}$$

In this equation, the first two lines account for scattering by fine particles (indicated by the suffix *f*), the next two account for scattering by coarse particles (indicated by the suffix *c*), and the last line accounts for light absorption by both fine and coarse carbon particles. Note that the assumed form of nitrate is sodium nitrate. Brackets indicate the species concentrations, the *e*'s represent dry mass scattering efficiencies (which are discussed further below), and the *f*(RH) represent a moisture enhancement function, i.e., the ratio between dry and wet scattering as a function of RH. The *f*(RH) values were calculated hourly using AIM-derived growth curves and were averaged to arrive at 24-hr values. Nitrates were assumed to have the same *f*(RH) function as sulfates. Organics were assumed not to be hygroscopic. (The rationale for this equation is provided in the CIRA/NPS report (Schichtel et al., 2004), which is included in the Appendix.)

Particulate matter size distributions were determined at Big Bend National Park using an eight-stage MOUDI sampler. For 41 days of the 125 sampling days, the filters were analyzed for the inorganic species discussed above. In addition, a special version of the four-module IMPROVE sampling system was operated with PM_{10} inlets (instead of the $PM_{2.5}$ inlets usually installed on Modules A through C), which enabled estimation of the mass concentrations of the usual IMPROVE chemical species in the coarse mode (PM_{10}-$PM_{2.5}$). Using these data, Mie calculations of light scattering and absorption were carried out for various species in both the fine and coarse modes to determine mass scattering efficiencies.

The average dry mass scattering efficiency estimates obtained from these calculations are listed in Table 6-1. Note that the scattering efficiency for ammoniated sulfate varies with ammoniated sulfate concentration. It is represented by two straight lines that are functions of the ammoniated sulfate concentration and whose slopes differ depending on the concentration of ammoniated sulfate.

Table 6-1. Mass extinction efficiencies derived by Mie theory for PM measured at Big Bend National Park.

Component	Dry scattering to mass ratio (m^2/g)
Ammoniated sulfate	2.4 + 0.42 [ammoniated SO_4] if [ammoniated SO_4] < 2 μg/m^3: 3.2 + 0.07 [ammoniated SO_4] if [ammoniated SO_4] > 2 μg/m^3:
$NaNO_3$	1.6
Organics	4
Soil	1.0
Light absorbing carbon	10
Coarse particles	0.6

The mass scattering efficiencies in Table 6-1 were used in the chemical extinction formula presented above to produce the fine and coarse scattering and absorption coefficients for Big Bend that are presented in Table 6-2. Measured values are also included for comparison.

Using this formula, the average estimated particle extinction is within 3% of the average measured, while estimated coarse and fine particle scattering are within 12% and 2% of measured coarse and fine particle scattering. Coarse and fine particle scattering contribute 4.4 Mm^{-1} and 22.4 Mm^{-1}, or about 15% and 77%, respectively, to particle extinction while coarse plus fine particle absorption adds another 2.5 Mm^{-1} or 9%. Absorption accounts for 8.6% of total extinction, of which 38% is associated with the coarse mode, leaving 62% of absorption linked to the fine mode. These estimated values agree quite well with the average measured values that were shown in Figure 5-12.

Table 6-2. Summary of extinction measurements and calculations.

Component	Mean Extinction		Std. Dev.	Min.	Max.
	Value (Mm^{-1})	% of Calculated Extinction			
Measured					
Fine scattering	22.8		16.3	4.5	61.9
Coarse scattering	5.0		5.1	-4.8	17.7
Total extinction	30.3		20.1	3.6	72.0
Calculated					
Fine scattering	22.4	77	16.6	5.1	75.2
Coarse scattering	4.4	15	2.7	0.0	16.3
Absorption (fine + coarse)	2.5	9	1.4	0.6	6.5
Total extinction	29.3	100	18.6	7.5	84.0
Coarse SO_4	0.7	2.4	1.4	0.0	7.3
Coarse Nitrate	0.4	1.3	0.4	0.0	2.0
Coarse OCM	1.8	6	1.0	0.0	4.2
Coarse Soil	1.5	5	1.1	0.0	5.4
Fine Ammoniated SO_4	16.3	56	14.2	2.4	54.5
Fine $NaNO_3$	0.4	1.3	0.2	0.1	1.3
Fine OCM	5.1	17	3.3	0.5	20.4
Fine Soil	0.6	2.2	0.8	0.1	3.6

Also shown in Table 6-2 is the fraction that each species contributes to the total calculated extinction of 29.3 Mm^{-1}. Calculated coarse and fine particle scattering contribute 4.4 Mm^{-1} and 22.4 Mm^{-1}, respectively, or about 15% and 77%, respectively, to the estimated extinction. Coarse plus fine particle absorption add another 2.5 Mm^{-1} or 9%. Of this amount, coarse mode light absorption accounts for 38% of total absorption, leaving 62% with the fine mode. The fractional contributions of fine plus coarse particle sulfates, nitrates, organics, and crustal material are 58%, 2.6%, 25%, and 7.3%, respectively.

Daily ambient estimated light extinction at Big Bend, by component, is shown in Figure 6-4. The extinction budget shown there includes the contribution by Rayleigh scattering (the constant-height light blue area at the bottom), which is added to the value of particle extinction estimated using the formula above. To develop this graph, some concentrations had to be estimated to fill in for values that were missing because of sampling malfunctions. The CIRA/NPS report (Schichtel et al., 2004) describes the approach that was used to estimate the missing values.

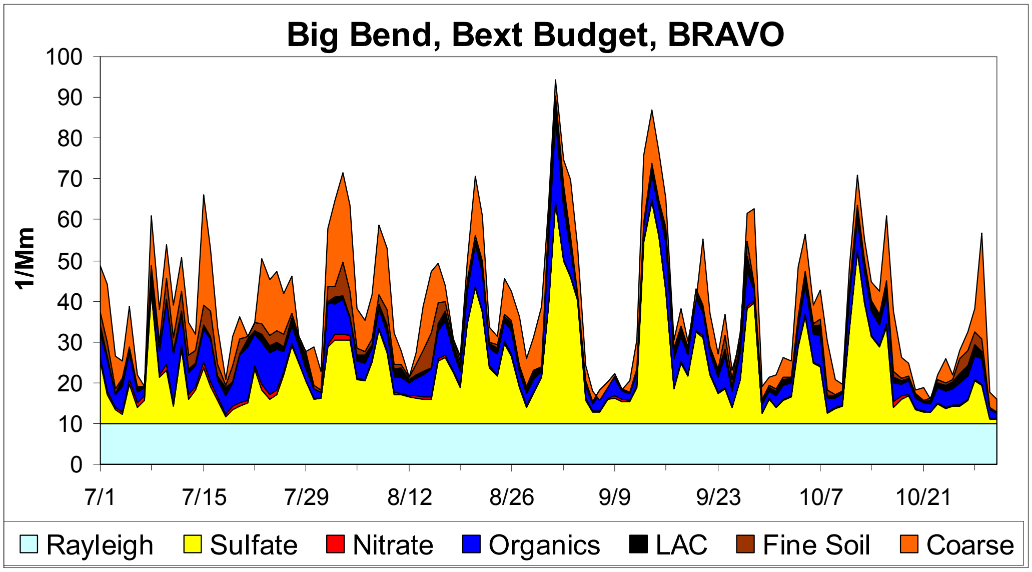

Figure 6-4. *Calculated contributions to haze by components of the aerosol during the BRAVO Study period. "Sulfate" denotes ammoniated sulfate, and "nitrate" denotes sodium nitrate.*

Several interesting points derive from Figure 6-4 and the data that were used to construct it:

- Particulate sulfate compounds (the yellow area) were the single largest contributor to Big Bend light extinction most of the time during the four-month BRAVO Study period. Although the calculation is not shown here, ammoniated sulfate accounts for 35% of the average light extinction. Its relative contribution to light extinction is less during the first two months than during the second two months (30% versus 39%).
- Rayleigh scattering (the light blue area), which is caused by particle-free air, was a major component and it dominated the light extinction on the clearer days. Its contribution to the average extinction is 25%, making it the second largest contributor.
- Coarse particles (18%; orange) and organic compounds (13%; dark blue) were the next two most important contributors, on average. During the first two months of the study, there were times when each of them was the single largest contributor to the light extinction.

6.4 Evaluation of the IMPROVE Equation for Estimating Light Extinction at Big Bend National Park

The measurements of aerosol and atmospheric optical properties during July through October 1999 at Big Bend National Park provided an opportunity to compare daily measured b_{ext} to the b_{ext} calculated using a formula based on particulate matter component concentrations and extinction efficiencies, as was done in Section 6.3.2. The IMPROVE program has also developed simpler version of the formula presented there (presented below), for calculating light extinction from particulate matter species concentration data. That formula has now been stipulated by the U.S. EPA for use under the Regional Haze Rule.

In light of the regulatory application of the IMPROVE formula, the TCEQ used the BRAVO measurements to explore the relationship between BRAVO optical data and light extinction derived from the concentrations of the components of particulate matter using the IMPROVE formula. They also used a formula that has the format of the IMPROVE formula and then derived coefficients ("extinction efficiencies") using multiple linear regression, supplemented by exploratory factor analysis to address collinearity between variables. The discussion of their work below is based on the report by Georgoulias et al. (2003), which is contained in the Appendix.

The IMPROVE formula for estimating extinction relates concentrations of sulfates, nitrates, organic carbon compounds (OMC), light absorbing carbon (LAC), fine soil, and coarse mass (CM) to light extinction (b_{ext}) (Malm et al., 1996). The equation is a simpler version of the more-comprehensive equation presented in Section 6.3, with constants assigned to the mass scattering efficiencies, as follows:

$$\begin{aligned} b_{ext} = {} & (3)f(RH)[Sulfate] + (3)f(RH)[Nitrate] + (4)[OMC] + (10)[LAC] \\ & + (1)[Fine\ Soil] + (0.6)[CM] + 10. \end{aligned}$$

Here the quantities in square brackets denote the species concentrations in $\mu g/m^3$, and b_{ext} is in units of inverse megameters (Mm^{-1}). The components represented in square brackets in the formula are, in order, ammonium sulfate, ammonium nitrate (versus sodium nitrate in Section 6.3.2), organic carbon compounds, light-absorbing carbon, fine soil, and coarse matter. The relative humidity (RH) adjustment factor (f(RH)) adjusts the light scattering effect of sulfates and nitrates to account for particle growth caused by water vapor in the atmosphere. Note that this formula includes a constant 10 Mm^{-1} for Rayleigh scattering.

This analysis used the BRAVO 24-hour particulate matter measurements that were made at the K-Bar sampling site in Big Bend National Park. Hourly b_{ext} and relative humidity data came from measurements at the BIBE1 transmissometer, located approximately 5 kilometers NNW of the K-Bar PM sampling site. To assure the most appropriate comparison to the particulate matter data, only hours with both acceptable b_{ext} and RH measurements were included in the daily average f(RH) estimate. (See Georgoulias et al., 2003, in the Appendix for details.) Only hourly optical measurements associated with RH below 90% were used to calculate daily average b_{ext}, in order to exclude possible fog or precipitation from the analysis. To correspond with BRAVO particulate matter samples, a day was defined as 8:00 AM to 8:00 AM the following day. Daily averages of optical data were kept if at least 15 hours were valid.

The resulting comparison of daily average transmissometer-measured b_{ext} with the b_{ext} calculated from the particulate matter measurements is shown in Figure 6-5. The two measures of extinction are well correlated, with $R^2 = 0.89$, which indicates that the calculation formula explains 89% of the variance in measured b_{ext}. Measured b_{ext} tends to be higher on average than the calculated b_{ext}, (labeled "reconstructed" extinction on the figure), especially at the higher values, so the linear regression fit line has a slope of 1.2.

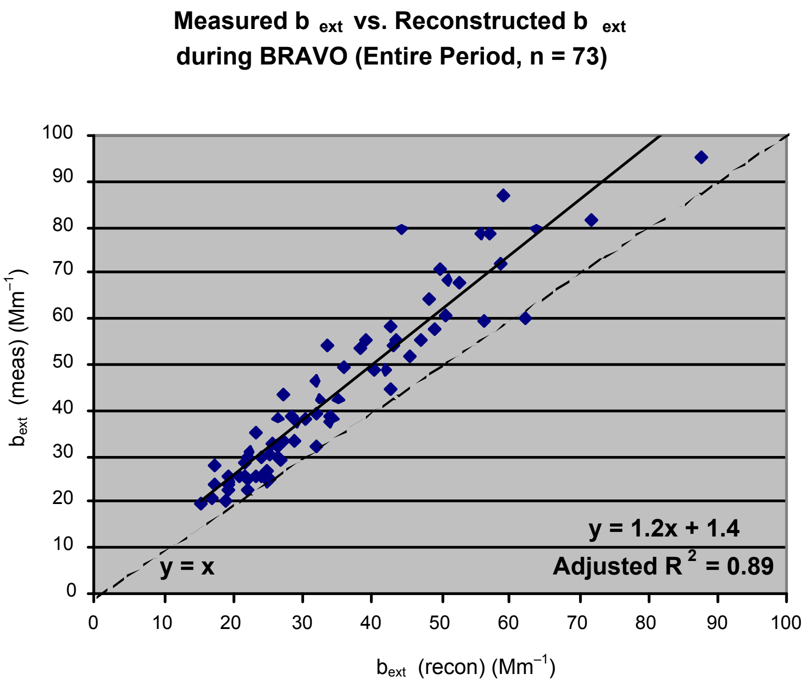

Figure 6-5. *Comparison of extinction measured by the BIBE1 transmissometer and calculated from PM species concentrations.*

The robustness of the numerical coefficients in the IMPROVE equation was evaluated by using multiple regression to estimate those coefficients for the BRAVO Study. The resulting multiple linear regression equivalents of the IMPROVE equation at K-Bar showed a strong correlation with measured b_{ext} in both seasons during BRAVO (R^2 range 0.90-0.94), but the analysis did not produce coefficient estimates that were comparable with those in the IMPROVE equation nor consistent with the literature. (See the report by Georgoulias et al. (2003) in the Appendix for details.) Significant terms were also dependent upon which variables were present in the model and changed as others were eliminated. These inconsistencies may be at least partially attributable to collinearity between some variables, such as coarse mass and fine soil species concentrations.

To address collinearity, factor analysis, a method of reducing several variables (species concentrations, in this case) into a smaller set of "underlying factors" responsible for covariation in the data (Hatcher, 1994) was used. The technique assumes the variables are the linear combination of these underlying factors. If these factors are structured orthogonally to one another, via a Varimax rotation, they may be used to predict a response (such as b_{ext}) without the complication of collinearity.

The factor analysis was carried out on the 12-hr and 24-hr $PM_{2.5}$ data from the three sites within Big Bend National Park. This procedure identified five factors, which are summarized in Table 6-3; factor loadings greater than 0.35 were considered significant. In that table, the constituents whose names begin with the letter O or E are the various fractions of organic and elemental carbon that are detected by the analysis method for particulate carbon.

Table 6-3. Summary of factor analysis results (Varimax rotation) for Big Bend $PM_{2.5}$ data.

	Factor 1	**Factor 2**	**Factor 3**	**Factor 4**	**Factor 5**
Species contained in factor	Al, Si, K, Ca, Ti, V, Mn, Fe, Rb, Sr, NO_3^-, Na^+, Mg^{2+}, Ca^{2+}, O1	S, H, SO_4^{2-}, NH_4^+, Se, Br, O2, O4, OP, E1	Zn, Pb, Br, K^+, Ca^{2+}, O3, O4, E1	O2, O3, OP, E1, E2, E3	Na, Na^+, NO_3^-, V (negative loading)
% of variance explained	33 %	23 %	11 %	10 %	7 %

The first factor (F_1) was most likely associated with soil, with the most prominent factor loadings coming from soil-related elements. Factor two (F_2) was sulfate-related. The selenium (Se) loading suggests this second factor was likely associated with coal combustion (Chow et al., 2004). Factor three (F_3) saw the largest factor loadings from zinc (Zn), lead (Pb), and Br; zinc and lead often indicate smelter influence (Gebhart and Malm, 1997). Organic and elemental carbon groups had significant loadings on factor four (F_4), while factor five (F_5) was probably associated with sodium nitrate. Interestingly, a strong negative loading on F_5 suggested significant vanadium (V) concentrations were not present with the other species that loaded on this factor.

The next step was to fit factor scores to b_{ext} values in a regression analysis (i.e., instead of using the components component concentrations, as in the IMPROVE equation, this alternative approach relates extinction to factors that represent types of sources). Because coarse mass (CM) is a major contributor to visibility impairment at Big Bend and was not included in the factor analysis with $PM_{2.5}$, CM was also introduced into the regression formula. (Based on tolerance values, the degree of collinearity between the CM and other factor terms did not unduly influence the resulting equations.) Table 6-4 shows the optimal fits that were derived by this process for summer (July and August) and fall (September and October), along with the R^2 values and standard deviations of error.

Table 6-4. Multiple regression fits of factor scores and CM to BIBE1 transmissometer daily average b_{ext}.

Season	Adj. R^2	Std. Dev. of Error	Resulting Equation
Summer	0.87	5.5	$b_{ext} = 55.3 + 2.7(fRH*F_1) + 17.3(F_2) - 1.5(CM)$
Fall	0.89	6.8	$b_{ext} = 37.2 + 12.2(fRH*F_2) + 3.5(F_3) + 2.2(F_4) + 6.9(F_5) + 0.74(CM)$

Only F_1 (soil-related), F_2 (sulfate-related), and CM were the significant variables in predicting b_{ext} in the summer (although the CM term is negative). In addition to CM, all factors except F_1 were significant in the fall equation. In both seasons, the sulfate-related term (F_2) had the largest coefficient of any other variable. It is unclear why the CM term is negative in the summer equation, but collinearity is not the likely problem. The summer season was hampered by a lack of PM_{10} data, which may have been a contributing factor. (See Georgoulias et al. (2003) in the Appendix for an expanded discussion.)

While this approach bypasses most collinearity problems in relating b_{ext} to PM concentrations, it does not yield a "new" equation for estimating extinction at Big Bend. Rather, it is a different way to examine what contributed to b_{ext} during the BRAVO period. It is also important to remember that, while some factors appeared to coincide with source types, most of the factors were constructed from more than one type of species that affected visibility. Moreover, the factors may represent a combination of sources or even secondary processes. The approach produced results similar to using Equation 6-2, with R^2 values close to 0.9 and standard deviations of errors between 4.0 and 7.0.

Measurements made by the BBEP transmissometer, which was located about 0.5 km from the BIBE1 transmissometer, were compared with those of BIBE1. For this comparison, additional lamp brightening adjustments (beyond the standard IMPROVE adjustments) were made. (See Georgoulias et al. (2003) in the Appendix for more information.) Correlations with the extinction calculated using the IMPROVE equation were similarly as strong as at BIBE1. An overall positive bias, similar to that in Figure 6-5, was removed with the additional adjustments of the measurements for lamp brightening, so that the tendency of the adjusted equation shown in Figure 6-6 was to overestimate the measured b_{ext} in the lower ranges, and underestimate values above about 30 Mm^{-1}, as shown in the same figure.

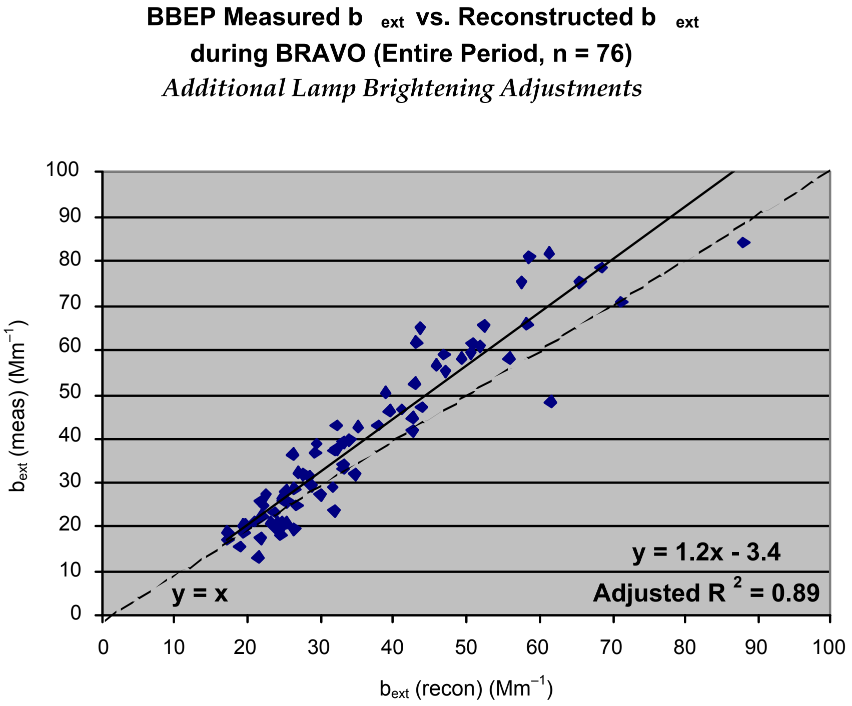

Figure 6-6. *Comparison of extinction measured by the BBEP transmissometer (with additional lamp brightening adjustments) with that calculated from PM species concentrations.*

Table 6-5 summarizes results from the BIBE1 and BBEP comparisons (uncertainties noted are the 95% confidence intervals). Table 6-6 shows results for regression fits of factor scores to BBEP data (with lamp brightening adjustments); results are similar to BIBE1, but not the same. In this case, the organic/elemental carbon factor (F_4) was not significant in the fall, and the CM term was not significant in either season. Coarse mass was undoubtedly important, but its relationship with some of the other factors and lack of data made its role ambiguous in this analysis.

Table 6-5. Summary of results from regressing measured extinction (Mm^{-1}) against extinction calculated using the IMPROVE equation.

	No Lamp Adjustments	**No Lamp Adjustments**	**Additional Lamp Adjustments**
Site	BIBE (Mm^{-1})	BBEP (Mm^{-1})	BBEP (Mm^{-1})
Slope	1.2 ± 0.1	1.2 ± 0.1	1.2 ± 0.1
Intercept	1.4 ± 3.7	2.3 ± 4.1	-3.4 ± 3.8
Adj. R^2	0.89	0.87	0.89

Table 6-6. Multiple regression fits of factor scores and CM to BBEP daily average b_{ext}.

Season	No. of Days	Adj. R^2	Std. Dev. of Error	Resulting Equation
Summer	46	0.74	7.6	$b_{ext} = 42.6 + 2.6(fRH*F1) + 13.9(F2)$
Fall	55	0.88	7.0	$b_{ext} = 34.5 + 12.5(fRH*F2) + 4.5(F3) + 2.6(F5)$

Despite differences between BIBE1 and BBEP, the factor analysis approach did demonstrate that PM-fine sources explained most of the variance in optical b_{ext} during BRAVO, and that these sources were associated with many of the components in the reconstruction equation. In both periods of the study, sulfate-related F_2 (possibly partially attributed to coal combustion) explained most of the variance in b_{ext} in the regression formulas in Tables 6-4 and 6-6.