Table 5.22: Scattering coefficients (Km^{-1}) for fine mass for each site as estimated by 4 different methods

Method	Page	Canyonlands	Minimum Organics Hopi Point	Maximum Organics Hopi Point
1	0.0155±0.0004	0.0091±0.0004	0.0055±0.0004	0.0068±0.0004
2	0.0143±0.0004	0.0096±0.0004	0.0060±0.0004	0.0062±0.0004
3	0.0136±0.0005	0.0118±0.0004	0.0048±0.0003	
4a	0.0206±0.0033	0.0152±0.0026	0.0096±0.0021	
4b	0.0275±0.0039	0.0201±0.0037	0.0134±0.0057	

1. Reconstructed scattering using literature efficiencies for each chemical species.
2. Reconstructed scattering using MLR efficiencies for each chemical species.
3. Measured b_{ext} corrected by subtracting Rayleigh scattering, coarse particle scattering, particle absorption, and gaseous absorption.
4. Measured b_{scat} corrected by subtracting Rayleigh and coarse mass scattering and adding a relative humidity correction. 4a is using the modified Tang curves. 4b is using 1/(1-RH) for the relative humidity correction.

Using results of method 1, mean fine particle scattering coefficients are 0.0155±0.0004 at Page, 0.0091±0.0004 at Canyonlands, 0.0055±0.0004 for minimum organics at Hopi Point, and 0.0068±0.0004 Km^{-1} for maximum organics at Hopi Point. These scattering coefficients are 50±1%, 41±2%, 32±1%, and 37±2% respectively of the total reconstructed extinction.

5.4 Extinction Budget by Species

The only extinction type which can be apportioned by chemical species with the available data is fine particle scattering. Two methods were used to determine the scattering efficiencies for each species: consensus values from previous studies (see Table 5.9) and MLR analyses with b_{ext} and b_{scat} as the dependent variable and the chemical species as the independent variables. These analyses were done for each site for both the low relative humidity subgroup and for all data. The results of the MLR analyses are discussed below in each subsection.

To determine the fraction of fine particle scattering due to each species, the expected scattering due to each was calculated using both the MLR and the literature scattering efficiencies. Then the mean calculated scattering for each species was divided by the mean of the total reconstructed fine particle scattering. These results are summarized in Table 5.23. Although the results of all the regressions are reported in the following sections, the reconstructed fine particle scattering was calculated only using the MLR results obtained when data from all sites were regressed together using b_{ext} as the dependent variable for all relative humidities. This was done for two reasons, 1) increasing the sample size reduced the standard errors for most regressors by reducing the correlation between them; and 2) the results were more physically reasonable.

5.4.1 Sulfates

As can be seen in Table 5.24, the scattering efficiency estimates for sulfates calculated by MLR analyses were all statistically significant and physically reasonable. The literature consensus scattering efficiency for sulfates is 2.55 m^2/g times a relative humidity factor. Note the inflated regression coefficients for low RH and when b_{scat} is the dependent variable. No RH corrections were applied to

Table 5.23: Average fine particle scattering due to each chemical species for Page, Canyonlands, and Hopi Point using both MLR derived and consensus literature values for the scattering efficiencies.

	Page		Canyonlands	
	MLR	Literature	MLR	Literature
Sulfates	61±3%	58±3%	60±4%	65±5%
Organics	19±1%	34±1%	11±1%	23±2%
Nitrates	17±1%	5±0%	26±2%	9±1%
Fine Soil	3±1%	2±0%	4±1%	3±0%
Total (Km^{-1})	0.0143±0.0004	0.0155±0.0004	0.0097±0.0004	0.0091±0.0004

	Hopi Point			
	Minimum Organics		Maximum Organics	
	MLR	Literature	MLR	Literature
Sulfates	76±8%	85±9%	74±7%	69±7%
Organics	1±1%	3±3%	5±1%	23±3%
Nitrates	16±2%	6±1%	16±2%	5±0%
Fine Soil	6±1%	5±1%	5±1%	4±0%
Total (Km^{-1})	0.0060±0.0004	0.0055±0.0004	0.0062±0.0004	0.0068±0.0004

the sulfate and nitrate data for these analyses. This indicates two things 1) the nephelometer must not dry the particles completely since the regression coefficients for sulfates (and nitrates) which result when they are regressed against b_{scat} are too high to be the "dry" scattering efficiencies. 2) Some RH correction is needed for sulfates (and nitrates) for RHs lower than 60%. It seems physically reasonable that the RH correction should probably be extended down to RH of approximately 30%.

The mean percentages of reconstructed fine particle scattering due to sulfates are 62±3% at Page, 60±4% at Canyonlands, 76±8% for minimum organics at Hopi Point, and 69±% for maximum organics at Hopi Point if the MLR scattering efficiencies are used, and are 58±3% at Page, 65±5% at Canyonlands, 85±9% for minimum organics at Hopi Point, and 69±7 for maximum organics at Hopi Point if the literature consensus efficiencies are used.

5.4.2 Organics

Table 5.25 summarizes the scattering efficiencies obtained for organics by MLR analyses. Many of the MLR scattering efficiencies for organic matter were statistically insignificant and all were also lower than the consensus value of 4.0 m^2/g.

The percent of reconstructed fine particle scattering due to organics is 18±1% at Page, 10±1% at Canyonlands, 1±1% for minimum organics at Hopi Point, and 16±2 for maximum organics at Hopi Point if the MLR scattering efficiencies are used. The percent of fine particle scattering by organics is 34±1% at Page, 23±2% at Canyonlands, 3±3% for minimum organics at Hopi Point, and 23±3% for maximum organics if literature scattering efficiencies are used.

Table 5.24: Summary of multiple linear regression analyses used to determine sulfate scattering efficiency for 0% RH. Results are in m^2/g.

Site	RH Subgroup	Dependent Variable	†Result for Minimum Organics	†Result for Maximum Organics
Page	All	b_{ext}	2.8±0.2	
Page	All	b_{scat}	5.2±0.4	
Page	Low	b_{ext}	6.0±2.3	
Page	Low	b_{scat}	4.4±2.1	
Cany	All	b_{ext}	1.3±0.4	
Cany	All	b_{scat}	6.2±0.6	
Cany	Low	b_{ext}	6.6±1.4	
Cany	Low	b_{scat}	6.1±1.3	
Hopi	All	b_{ext}	1.3±0.2	1.3±0.2
Hopi	All	b_{scat}	4.6±0.4	4.6±0.4
Hopi	Low	b_{ext}	2.6±1.0	2.7±1.0
Hopi	Low	b_{scat}	4.2±0.5	4.1±0.5
All	All	b_{ext}	2.5±0.1	2.5±0.1
All	All	b_{scat}	5.2±0.2	5.2±0.2
All	Low	b_{ext}	5.6±1.0	5.8±1.0
All	Low	b_{scat}	4.3±0.6	4.5±0.6

The independent variables used for each MLR were sulfates, organics, nitrates, absorbing carbon, and coarse mass when the dependent variable was b_{ext}. When the dependent variable was b_{scat}, total carbon was used rather than organics and absorbing carbon.

†When b_{ext} was the dependent variable and all relative humidities were included, sulfates and nitrates were multiplied by the modified Tang relative humidity functions. No RH correction was applied to the other three cases for each site.

When "All" is the site, no coarse mass data are included in the regression since this would eliminate all Canyonlands data.

Table 5.25: Summary of multiple linear regression analyses used to determine the scattering efficiency for organics. Results are in m^2/g.

Site	RH Subgroup	Dependent Variable	Result for Minimum Organics	Result for Maximum Organics
Page	All	b_{ext}	3.7±1.3	
Page	All	b_{scat}	1.4±0.7	
Page	Low	b_{ext}	3.5±1.6	
Page	Low	b_{scat}	*1.9±1.4	
Cany	All	b_{ext}	*1.2±1.1	
Cany	All	b_{scat}	*0.4±0.6	
Cany	Low	b_{ext}	*-0.8±1.1	
Cany	Low	b_{scat}	*1.2±1.1	
Hopi	All	b_{ext}	-2.9±1.4	-5.0±2.0
Hopi	All	b_{scat}	*0.6±0.7	*0.8±0.9
Hopi	Low	b_{ext}	*-2.4±1.5	-4.2±2.3
Hopi	Low	b_{scat}	*1.1±0.8	*1.8±1.3
All	All	b_{ext}	2.0±0.7	*0.8±0.8
All	All	b_{scat}	1.1±0.3	1.0±0.3
All	Low	b_{ext}	*0.5±0.8	*-0.8±0.8
All	Low	b_{scat}	1.5±0.5	1.4±0.5

* These values are statistically insignificant ($t > 0.05$).

The independent variables used for each MLR were sulfates, organics, nitrates, absorbing carbon, and coarse mass when the dependent variable was b_{ext}. When the dependent variable was b_{scat}, total carbon was used rather than organics and absorbing carbon.

When b_{ext} was the dependent variable and all relative humidities were included, sulfates and nitrates were multiplied by the modified Tang relative humidity functions. No RH correction was applied to the other three cases for each site.

When the site is "All" no coarse mass data are included in the regression since this would eliminate all Canyonlands data.

5.4.3 Nitrates

The scattering efficiency of nitrates is not well known, but according to Tang et al.[12] it should be between approximately 1.1 and 7.0 m^2/g at low relative humidities depending on the particle size distribution. The lowest efficiency corresponds to a highly polydisperse size distribution ($\sigma_g = 2.0$) and the highest efficiency corresponds to a monodisperse size distribution ($\sigma_g = 1.01$) assuming a mass median diameter of 0.98 μm which is based on measurements of Los Angeles aerosols. If the WHITEX nitrate particles actually had a smaller mean diameter, for example if they were similar in size to the sulfate particles, then the scattering efficiency would be higher. Results of the regression analyses indicate that this may be true. The RH corrected scattering efficiencies when b_{ext} is the dependent variable are 5.5±1.5 at Hopi Point, 2.4±1.2 at Canyonlands, and 3.2±1.0 m^2/g for all sites combined. The result for Page was negative, and also not statistically significant.

Most of the nitrate scattering efficiencies estimated by the MLR analyses (see Table 5.26) were statistically significant, and physically reasonable. However, when the regressions were done using b_{scat} as the dependent variable, the results were higher than expected. No RH correction was used when b_{scat} was the dependent variable, but these results indicate that perhaps the nephelometer does not completely dry the particles and that some RH correction is needed. 60% RH may also be too high to use as "low" RH. Similar results were seen for sulfates.

When literature scattering efficiencies are used, the percents of fine particle scattering due to nitrates are 5±0% at Page, 9±1% at Canyonlands, 6±1% at Hopi Point with minimum organics, and 5±0% at Hopi Point with maximum organics. When the MLR efficiency is used, the scattering due to nitrates are 17±1% at Page, 26±2% at Canyonlands, and 16±2% at Hopi Point with both maximum and minimum organics.

5.4.4 Fine Soil Dust

All fine soil regression coefficients except two were statistically insignificant (see Table 5.27). The significant estimates for the scattering efficiency of fine soil dust were 4.4±2.1 and 5.5±2.5 m^2/g. These are more than 3 times greater than the consensus efficiency of 1.3 m^2/g.

Using the literature scattering efficiency, the percentages of fine particle scattering due to fine soil are 2±0% at Page, 3±0% at Canyonlands, 5±1% at Hopi Point with minimum organics, and 4±1% at Hopi Point with maximum organics.. Using the MLR efficiency, the percentages of fine scattering due to fine soil are 3±1 at Page, 4±1 at Canyonlands, 6±1 at Hopi Point with minimum organics, and 5±1% at Hopi Point with maximum organics.

5.5 Time Variations in the Light Extinction Budget

5.5.1 Extinction budgets for Individual Time Periods

Time plots of 12-hour averaged measured and reconstructed scattering and absorption coefficients are shown in Figures 5.22, 5.23, 5.24, and 5.25 and in Tables 5.28-5.35. The scattering and absorption efficiencies used are the consensus literature values. Extinction due to missing particulate or NO_2 data was set to zero unless the missing value was sulfate. If sulfate was missing, then the time period was deleted. Missing data should not cause serious underestimation of the reconstructed extinction since with the exception of NO_2 at all sites and coarse mass at Canyonlands, there were very few missing data.