At all three sites, it can be seen that scattering by fine sulfates dominates when the extinction coefficient is high. When the extinction coefficient is below average, sulfate scattering is still important, but scattering by organics and absorption due to elemental carbon are also often large fractions of the total extinction. This is especially true for Page.

5.5.2 Budgets on Extreme Extinction Days

The maximum 24-hour averaged measured extinction at Page was 0.0769 Km^{-1}. This occurred on Julian day 43 (Feb. 12). The minimum measured extinction at Page occurred 2 days later on Julian day 45 (Feb 14) when it was 0.0129 Km^{-1}. These days were also near the extremes of the reconstructed extinction values at Hopi Point and Canyonlands. Although Julian day 42 (Feb 11) is used as the high extinction day at Hopi Point since the extinction at Hopi Point was higher on that day than on Feb 12. A summary of the extinction budgets for these two days is shown in Table 5.36. On Feb. 12 (Feb 11 at Hopi Point), light extinction was dominated by scattering due to fine sulfates at all three sites. In contrast, Feb 14 was a near-Rayleigh day at all sites, with Rayleigh scattering accounting for 89±14%, 92±16%, and 98±18% of the light extinction at Page, Canyonlands, and Hopi Point, respectively. The pie charts in Figures 5.26, 5.27, 5.28, and 5.29 illustrate these budgets. The relative sizes of the pies are proportional to the measured light extinction.

5.6 Comparison to Previous Studies at Grand Canyon

WHITEX extinction budgets are similar to the results of at least two previous studies which have reported light extinction budgets for Grand Canyon National Park (Hopi Point) (Malm, et al.[5] and Malm and Johnson[7]). Scattering by fine ammonium sulfate was found to be the dominant factor in the non-Rayleigh light extinction budget in all three studies even though WHITEX was during the winter, another study was for summertime data, and the third included data for a full two year time period. During WHITEX, the percent of the non-Rayleigh scattering at Hopi Point due to fine sulfates was 68%. Malm et al. found that 47–48% of the scattering during a two week period in August 1984 was due to fine sulfates and Malm and Johnson attributed 63% of the scattering during two years from December 1979 to November 1981 to fine sulfates.

5.7 Summary

The findings of this chapter are summarized below:

- The nephelometer underestimates the actual scattering coefficient by as much as a factor of three when the relative humidity is very high (> 90%). However there is evidence that it does not dry the particles completely.
- TOR light absorbing carbon measurements appear to be slightly too high and TMO concentrations are too low, but the TOR values are closer to what is expected based on the optical measurements.
- The largest fraction of mean non-Rayleigh extinction at Page, Canyonlands, and Hopi Point is scattering by fine sulfates. The two next largest fractions are absorption by light absorbing carbon and scattering by organics, with organics being more important at Page and particle absorption more important at Canyonlands and Hopi Point. (See Figure 5.3.)

PAGE

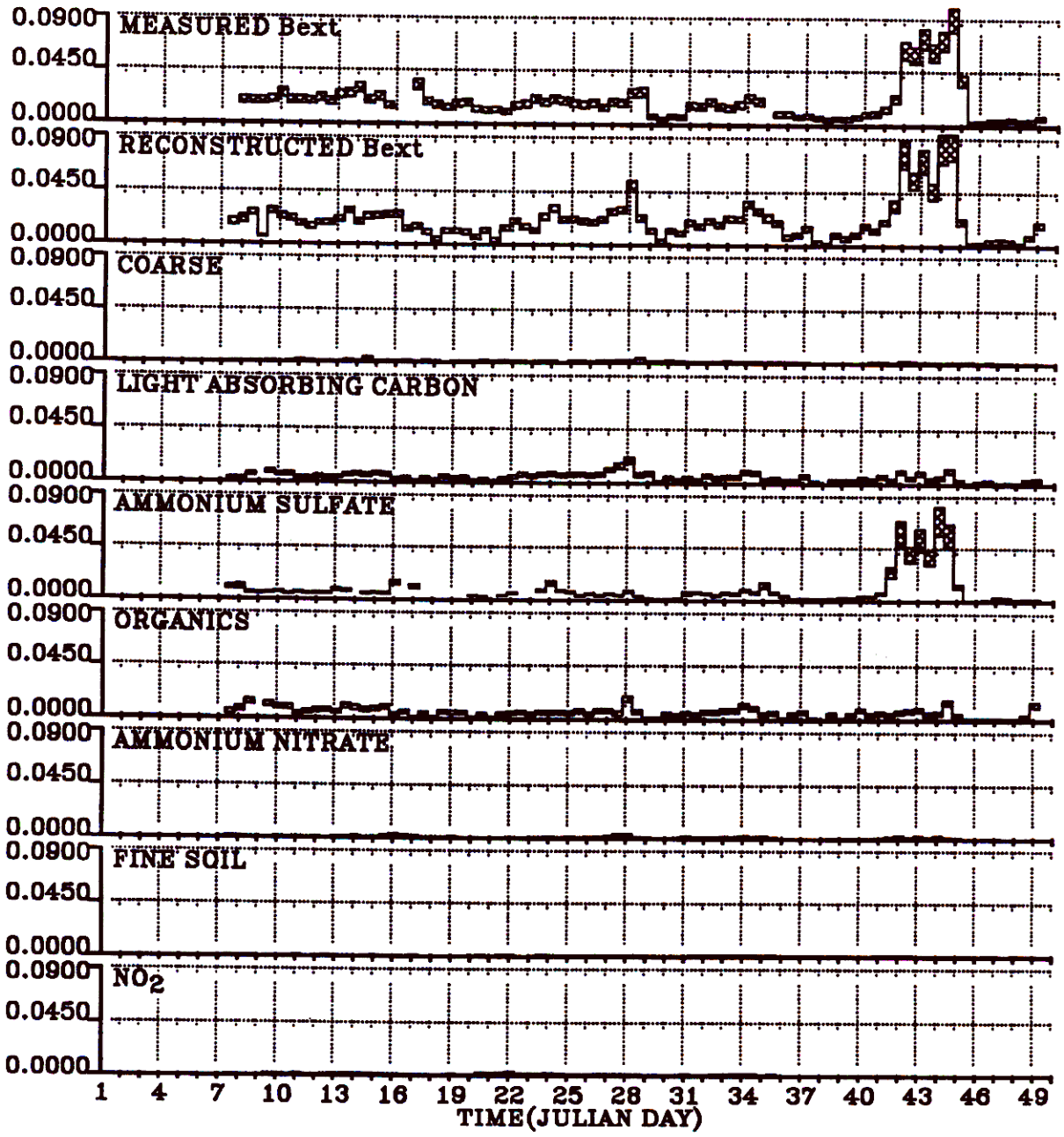


Figure 5.22: Measured and reconstructed 12-hour averaged extinction coefficients (Km^{-1}) at Page. Rayleigh scattering is included.

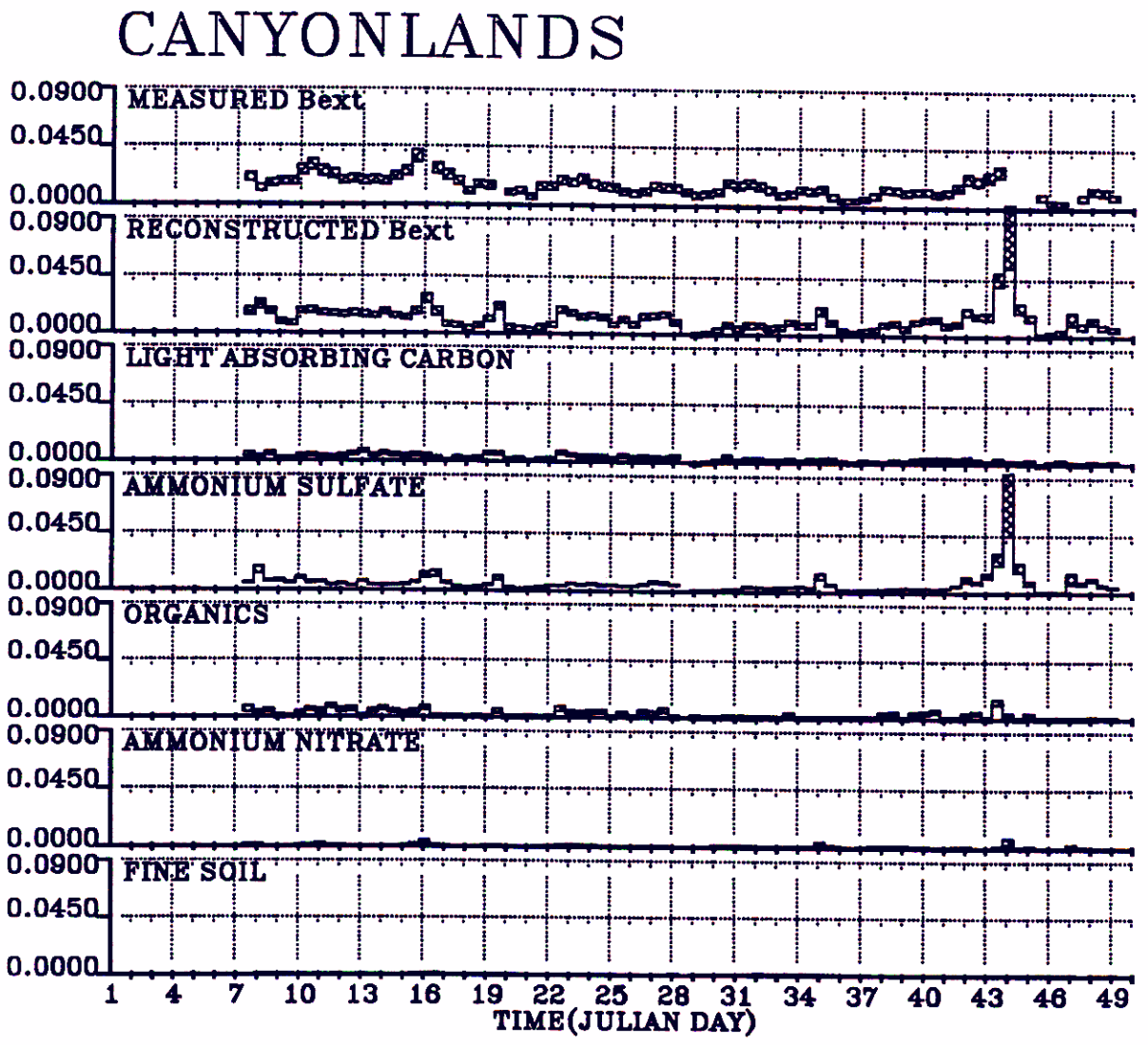


Figure 5.23: Measured and reconstructed 12-hour averaged extinction coefficients (Km^{-1}) at Canyonlands. Rayleigh scattering is included.

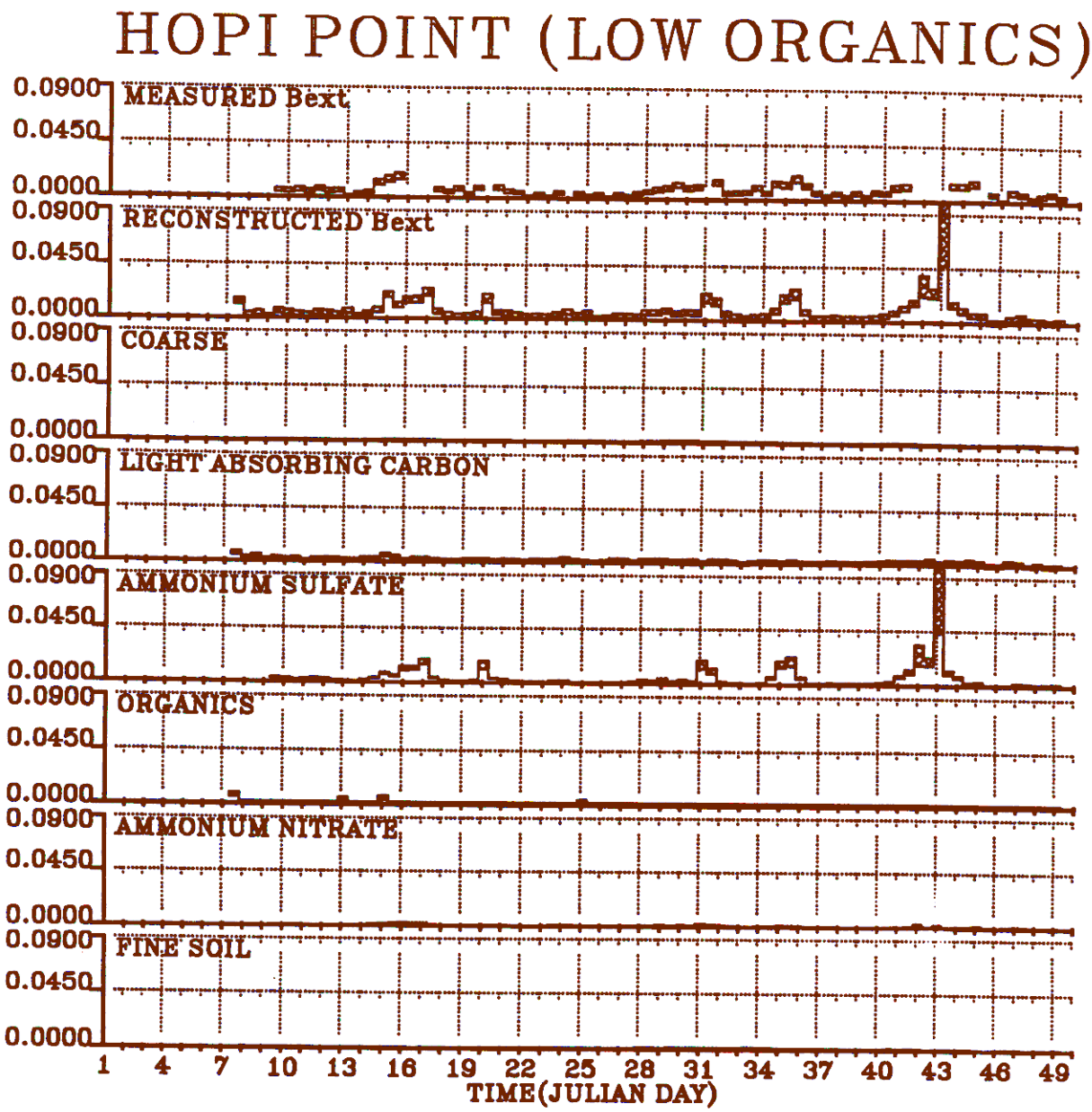


Figure 5.24: Measured and reconstructed 12-hour averaged extinction coefficients (Km^{-1}) at Hopi Point when minimum organics are used. Rayleigh scattering is included.

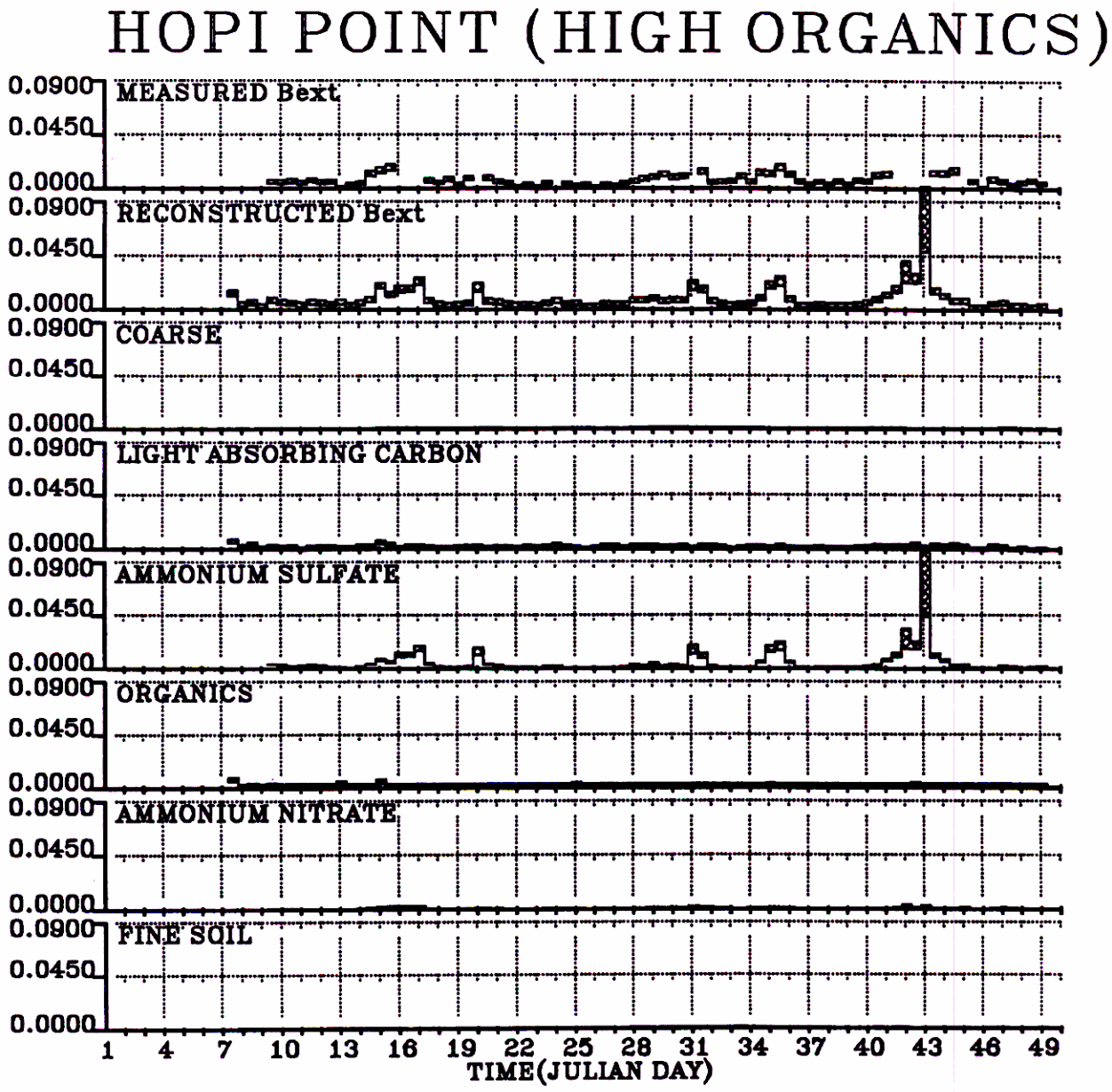


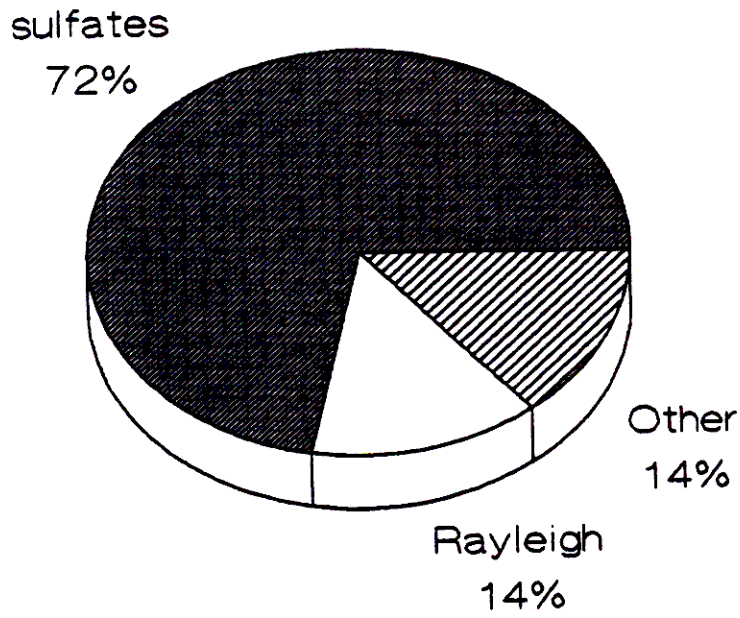
Figure 5.25: Measured and reconstructed 12-hour averaged extinction coefficients (Km^{-1}) at Hopi Point when maximum organics are used. Rayleigh scattering is included.

Table 5.36: 24-hour average extinction budgets for extreme extinction days. Feb 12 is Julian day 43. Feb 14 is Julian day 45.

	Feb. 12			
	Page	Cany	Min Organics †Hopi	Max Organics †Hopi
Scatter by Gases (%)	14±2	14±3	16±4	16±4
Coarse Particle Scattering (%)	0±0	ND	0±0	0±0
Scatter by Fine Sulfates (%)	72±11	67±21	77±30	75±28
Scatter by Fine Organics (%)	7±1	11±3	0±2	3±2
Scatter by Fine Nitrates (%)	2±0	5±2	2±1	2±1
Scatter by Fine Soil (%)	0±0	0±0	0±0	0±0
Particle Absorption (%)	6±1	3±1	4±2	4±2
Reconstructed (Km^{-1})	0.0743±0.0070	0.0716±0.0126	0.0584±0.0138	0.0604±0.0138
Measured (Km^{-1})	0.0769±0.0054	*0.0378±0.0041	ND	ND

	Feb 14			
	Page	Cany	Min Organics Hopi	Max Organics Hopi
Scatter by Gases (%)	89±12	92±14	98±17	86±13
Coarse Particle Scattering (%)	7±1	ND	1±1	1±1
Scatter by Fine Sulfates (%)	2±0	8±1	2±0	1±0
Scatter by Fine Organics (%)	0±8	0±9	0±10	13±9
Scatter by Fine Nitrates (%)	0±0	1±0	0±0	0±0
Scatter by Fine Soil (%)	1±0	3±0	1±0	1±0
Particle Absorption (%)	1±7	-3±8	-2±9	-2±8
Reconstructed (Km^{-1})	0.0116±0.0014	0.0106±0.0015	0.0097±0.0015	0.0111±0.0015
Measured (Km^{-1})	0.0129±0.0009	0.0161±0.0014	0.0126±0.0009	0.0126±0.0009

ND = No Data.
†Data is for Feb 11 (Julian day 42) at Hopi Point.
*One of the 12-hour time periods had missing b_{ext}.



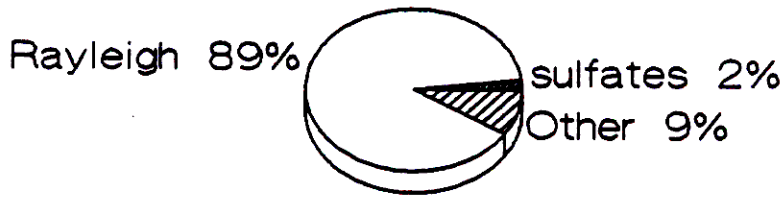


Figure 5.26: Extinction budgets on extreme days at Page. Areas of the wedges are proportional to the light extinction for each component. Total reconstructed extinction is 0.0742±0.0070 Km^{-1} on Feb 12 (Julian day 43) and 0.0116±0.0014 Km^{-1} on Feb 14 (Julian day 45).

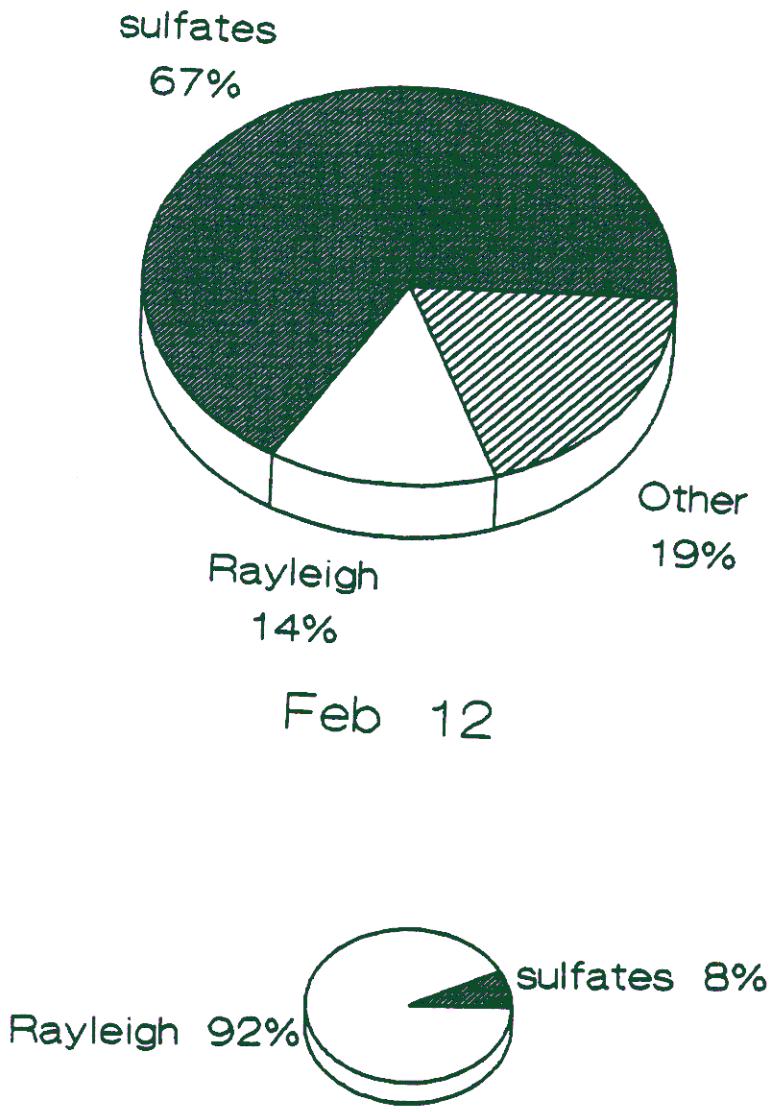
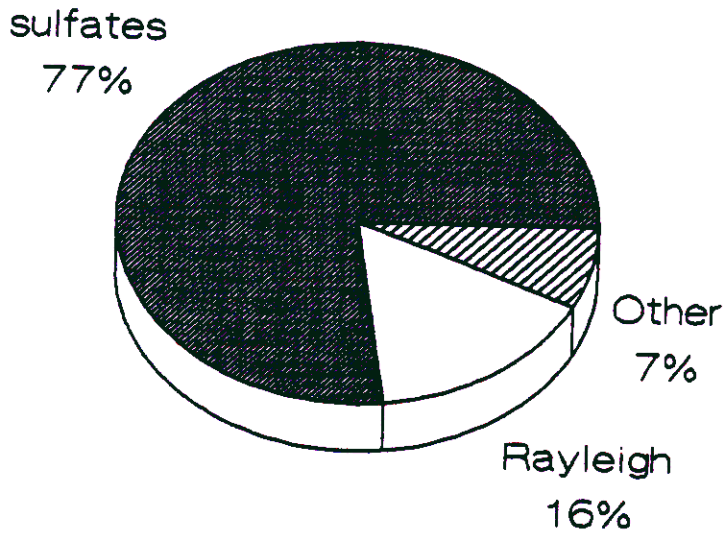
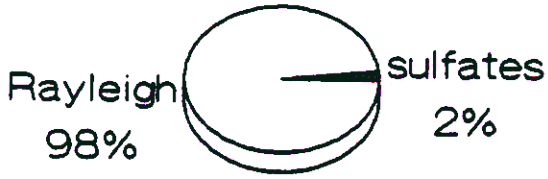


Figure 5.27: Extinction budgets on Feb 12 and 14 at Canyonlands. Areas of the wedges are proportional to the light extinction for each component. Total reconstructed extinction is 0.0716±0.0126 Km^{-1} on Feb 12 (Julian day 43) and 0.0106±0.0015 Km^{-1} on Feb 14 (Julian day 45).

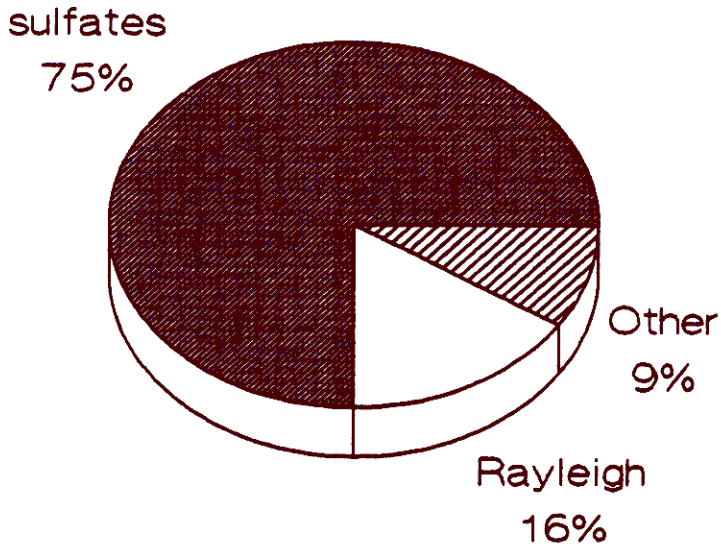


Feb 11



Feb 14

Figure 5.28: Extinction budgets on Feb 11 and 14 at Hopi Point using minimum organics. Areas of the wedges are proportional to the light extinction for each component. Total reconstructed extinction is 0.0584±0.0138 Km^{-1} on Feb 11 (Julian day 42) and 0.0097±0.0015 Km^{-1} on Feb 14 (Julian day 45).



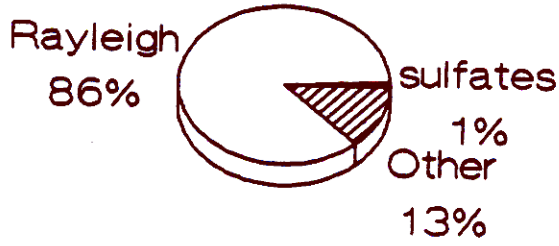


Figure 5.29: Extinction budgets on Feb 11 and 14 at Hopi Point using maximum organics. Areas of the wedges are proportional to the light extinction for each component. Total reconstructed extinction is 0.0604±0.0138 Km^{-1} on Feb 11 (Julian day 42) and 0.0111±0.0015 Km^{-1} on Feb 14 (Julian day 45).

- The extinction budgets vary considerably from time period to time period. Scattering by sulfates dominates on high extinction days. (See Figures 5.22, 5.23, 5.24, and 5.25).
- Extinction budget results for the WHITEX time period are similar to those obtained in previous studies for the same area.