Contents

5 Light Extinction Budget 5–1
5.1 Assumptions and Data Analysis Techniques 5–1
5.1.1 Available Data 5–1
5.1.2 Chemical Composition of Particulate Matter 5–1
5.1.3 Relative Humidity Considerations 5–2
5.1.4 Multiple Linear Regression Analysis 5–2
5.1.5 Consensus Scattering and Absorption Efficiencies 5–7
5.1.6 Reconstructed Scattering and Extinction 5–7
5.2 Preliminary Data Analysis 5–8
5.2.1 Optical Data and Relative Humidity Effects 5–9
5.2.2 Examination of Carbon Data 5–14
5.3 Light Extinction Budget By Extinction Type 5–24
5.3.1 Scattering by gases (Rayleigh Scattering) 5–24
5.3.2 Absorption by gases (NO_2 Absorption) 5–30
5.3.3 Coarse Particle Scattering 5–32
5.3.4 Particle Absorption 5–32
5.3.5 Fine Particle Scattering 5–32
5.4 Extinction Budget by Species 5–36
5.4.1 Sulfates 5–36
5.4.2 Organics 5–37
5.4.3 Nitrates 5–40
5.4.4 Fine Soil Dust 5–40
5.5 Time Variations in the Light Extinction Budget 5–40
5.5.1 Extinction budgets for Individual Time Periods 5–40
5.5.2 Budgets on Extreme Extinction Days 5–58
5.6 Comparison to Previous Studies at Grand Canyon 5–58
5.7 Summary 5–58

List of Tables

5.1 Pearson correlation coefficients for data at Page. 5–4
5.2 Pearson correlation coefficients for Canyonlands. 5–4
5.3 Pearson correlation coefficients for data at Hopi Point. 5–4
5.4 Pearson correlation coefficients for Page, Canyonlands, and Hopi Point combined. . . 5–5
5.5 Rotated factor pattern for Page. 5–5
5.6 Rotated factor pattern for Canyonlands 5–5
5.7 Rotated factor pattern for Hopi Point 5–6
5.8 Rotated factor pattern for Page, Canyonlands, and Hopi Point combined. 5–6
5.9 Consensus literature light extinction efficiencies in m^2/g. 5–7
5.10 Statistics for the 12-hour averaged optical data at Page (Km^{-1}). The low relative humidity subgroup is defined as RH < 60%. 5–15
5.11 Statistics for the 12-hour averaged optical data at Canyonlands (Km^{-1}). The low relative humidity subgroup is defined as RH < 60%. 5–15
5.12 Statistics for the 12-hour averaged optical data at Hopi Point (Km^{-1}). The low relative humidity subgroup is defined as RH < 60%. 5–16
5.13 Correlation matrix for carbonaceous material at Page. 5–16
5.14 Correlation matrix for carbonaceous material at Hopi Point. 5–16
5.15 Summary of multiple linear regression analyses using TOR and TMO Carbon. Results are the predicted light absorption efficiencies for absorbing carbon ± the standard error in m^2/g. The dependent variable for all analyses was b_{ext}. Low RH refers to RH < 60%. 5–23
5.16 Statistics for the 12-hour averaged particulate and NO_2 data at Page, ($\mu g/m^3$). All data except coarse mass and NO_2 are for particles < 2.5 μm diameter. Coarse mass is 2.5–15 μm. Low RH is RH < 60%. 5–28
5.17 Statistics for the 12-hour averaged particulate data at Canyonlands, ($\mu g/m^3$). All data are for particles < 2.5 μm diameter. Low RH is RH < 60%. 5–28
5.18 Statistics for the 12-hour averaged particulate data at Hopi Point, ($\mu g/m^3$). All data are for particles < 2.5 μm diameter. Coarse mass is 2.5–15 μm. Low RH is RH < 60%. 5–30
5.19 Mean extinction budgets by type for Page, Canyonlands, and Hopi Point for the 6-week WHITEX study period. 5–31
5.20 Summary of multiple linear regression analyses for coarse mass. Results are scattering efficiencies in m^2/g. 5–33
5.21 Summary of multiple linear regression analyses for fine mass. Results are scattering efficiencies in m^2/g. Low RH is RH < 60%. (fine-abs. C) is the fine mass remaining after absorbing carbon has been subtracted. 5–35
5.22 Scattering coefficients (Km^{-1}) for fine mass for each site as estimated by 4 different methods 5–36

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. 5–37
5.24 Summary of multiple linear regression analyses used to determine sulfate scattering efficiency for 0% RH. Results are in m^2/g. 5–38
5.25 Summary of multiple linear regression analyses used to determine the scattering efficiency for organics. Results are in m^2/g. 5–39
5.26 Summary of multiple linear regression analyses used to determine nitrate scattering efficiency for 0% RH. Results are in m^2/g. 5–41
5.27 Summary of multiple linear regression analyses used to determine fine soil scattering efficiency. Results are in m^2/g. 5–42
5.28 Extinction coefficients (Km^{-1}) due to each chemical species at Page. The total and measured extinction do not include Rayleigh scattering. 5–43
5.28 Extinction coefficients (Km^{-1}) due to each chemical species at Page. The total and measured extinction do not include Rayleigh scattering (continued from previous page). 5–44
5.29 Fraction of non-Rayleigh extinction due to each chemical species at Page. 5–45
5.29 Fraction of non-Rayleigh extinction due to each chemical species at Page (continued from previous page). 5–46
5.30 Extinction coefficients (Km^{-1}) due to each chemical species at Canyonlands. The total and measured extinction do not include Rayleigh scattering. 5–47
5.30 Extinction coefficients (Km^{-1}) due to each chemical species at Canyonlands. The total and measured extinction do not include Rayleigh scattering (continued from previous page). 5–48
5.31 Fraction of non-Rayleigh extinction due to each chemical species at Canyonlands. . . 5–49
5.31 Fraction of non-Rayleigh extinction due to each chemical species at Canyonlands (continued from previous page). 5–50
5.32 Extinction coefficients (Km^{-1}) due to each chemical species at Hopi Point when maximum organics are used. The total and measured extinction do not include Rayleigh scattering. 5–51
5.32 Extinction coefficients (Km^{-1}) due to each chemical species at Hopi Point when maximum organics are used. The total and measured extinction do not include Rayleigh scattering (continued from previous page). 5–52
5.33 Fraction of non-Rayleigh light extinction due to each chemical species at Hopi Point when maximum organics are used. 5–53
5.33 Fraction of non-Rayleigh light extinction due to each chemical species at Hopi Point when maximum organics are used (continued from previous page). 5–54
5.34 Extinction coefficients (Km^{-1}) due to each chemical species at Hopi Point when minimum organics are used. The total and measured extinction do not include Rayleigh scattering. 5–55
5.34 Extinction coefficients (Km^{-1}) due to each chemical species at Hopi Point when minimum organics are used. The total and measured extinction do not include Rayleigh scattering (continued from previous page). 5–56
5.35 Fraction of non-Rayleigh extinction due to each chemical species at Hopi Point when minimum organics are used. 5–57
5.35 Fraction of non-Rayleigh extinction due to each chemical species at Hopi Point when minimum organics are used (continued from previous page). 5–58

5.36 24-hour average extinction budgets for extreme extinction days. Feb 12 is Julian day 43. Feb 14 is Julian day 45. 5–64

List of Figures

5.1 Relative light scattering coefficients for ammonium sulfate and ammonium nitrate aerosols. 5–3
5.2 Time traces of optical data and relative humidity at Page 5–10
5.3 Time traces of optical data and relative humidity at Canyonlands. 5–11
5.4 Time traces of optical data and relative humidity at Hopi Point. 5–12
5.5 Ratio of b_{ext}/b_{scat} as a function of relative humidity for Page. 5–13
5.6 Ratio of b_{ext}/b_{scat} as a function of relative humidity for Canyonlands. 5–13
5.7 Ratio of b_{ext}/b_{scat} as a function of relative humidity for Hopi Point. 5–14
5.8 Scatter plot of measured extinction vs reconstructed extinction for Page using TMO carbon. Sulfate and nitrate scattering efficiencies are both 2.55/(1-RH). 5–18
5.9 Scatter plot of measured extinction vs reconstructed extinction for Page using TMO carbon. Sulfate scattering efficiency is 2.55× fs(RH). Nitrate scattering efficiency is 1.1×fn(RH). 5–18
5.10 Scatter plot of measured extinction vs reconstructed extinction for Page using TOR carbon. Sulfate and nitrate scattering efficiencies are both 2.55/(1-RH). 5–19
5.11 Scatter plot of measured extinction vs reconstructed extinction for Page using TOR carbon. Sulfate scattering efficiency is 2.55× fs(RH). Nitrate scattering efficiency is 1.1×fn(RH). 5–19
5.12 Scatter plot of measured extinction vs reconstructed extinction for Hopi Point using TMO carbon. Sulfate and nitrate scattering efficiencies are both 2.55/(1-RH). 5–20
5.13 Scatter plot of measured extinction vs reconstructed extinction for Hopi Point using TMO carbon. Sulfate scattering efficiency is 2.55× fs(RH). Nitrate scattering efficiency is 1.1×fn(RH). 5–20
5.14 Scatter plot of measured extinction vs reconstructed extinction for Hopi Point using minimum TOR carbon. Sulfate and nitrate scattering efficiencies are both 2.55/(1-RH). 5–21
5.15 Scatter plot of measured extinction vs reconstructed extinction for Hopi Point using minimum TOR carbon. Sulfate scattering efficiency is 2.55× fs(RH). Nitrate scattering efficiency is 1.1×fn(RH). 5–21
5.16 Scatter plot of measured extinction vs reconstructed extinction for Hopi Point using maximum TOR carbon. Sulfate and nitrate scattering efficiencies are both 2.55/(1-RH). 5–22
5.17 Scatter plot of measured extinction vs reconstructed extinction for Hopi Point using maximum TOR carbon. Sulfate scattering efficiency is 2.55× fs(RH). Nitrate scattering efficiency is 1.1×fn(RH). 5–22
5.18 Time traces of particulate and NO_2 data ($\mu g/m^3$) at Page. 5–25
5.19 Time traces of particulate data ($\mu g/m^3$) at Canyonlands. 5–26
5.20 Time traces of particulate data ($\mu g/m^3$) at Hopi Point. 5–27

5.21 Mean light extinction budgets. 5–29
5.22 Measured and reconstructed 12-hour averaged extinction coefficients (Km^{-1}) at Page. Rayleigh scattering is included. 5–60
5.23 Measured and reconstructed 12-hour averaged extinction coefficients (Km^{-1}) at Canyonlands. Rayleigh scattering is included. 5–61
5.24 Measured and reconstructed 12-hour averaged extinction coefficients (Km^{-1}) at Hopi Point when minimum organics are used. Rayleigh scattering is included. 5–62
5.25 Measured and reconstructed 12-hour averaged extinction coefficients (Km^{-1}) at Hopi Point when maximum organics are used. Rayleigh scattering is included. 5–63
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). 5–65
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). 5–66
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). 5–67
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). 5–68