Chapter 5. Seasonal Distribution of $PM_{2.5}$ Reconstructed Aerosol Light Extinction Coefficients

Along with the 2005–2008 annual mean $PM_{2.5}$ reconstructed light extinction coefficients (b_{ext}) presented in Chapter 3, we computed monthly mean b_{ext} for major aerosol species including ammonium sulfate (AS), ammonium nitrate (AN), particulate organic matter (POM), light absorbing carbon (LAC), soil, sea salt and coarse mass. These monthly mean b_{ext} values were averaged to regional means based on the IMPROVE and CSN regions discussed in Chapter 4. In this chapter regional monthly and annual mean b_{ext} values are presented as stacked bar charts, similar to the regional mean mass concentrations presented in the previous chapter. For nonhygroscopic species, the seasonality of b_{ext} should be the same as the seasonality in mass concentrations; however, this may not be the case in some instances and is due to the treatment of negative mass concentrations in the calculation of b_{ext} (see Chapter 3). Monthly means are depicted with the first letter of the month, followed by an "A" for annual mean. The seasonal distributions in percent contribution of major $PM_{2.5}$ aerosol species to b_{ext} are also presented. Seasonal periods are defined as winter (December, January, and February), spring (March, April, and May), summer (June, July, and August) and fall (September, October, and November). Seasonal stacked bar charts for monthly mean concentrations are grouped into figures corresponding to four areas of the country: northwestern, southwestern, eastern, and OCONUS (outside the contiguous United States, e.g., Hawaii, Alaska, and Virgin Islands) United States. Regional seasonality is summarized in terms of the ratio of maximum to minimum monthly mean b_{ext} and presented in separate maps for each species. Each region is associated with a set of triangles. The color of the upward pointing triangle refers to the season with the maximum monthly mean concentration. The color of the downward pointing triangle refers to the season with the minimum monthly mean concentration. The size of the triangle corresponds to the ratio of maximum to minimum monthly b_{ext} such that large triangles represent higher levels of seasonality. Recall that most regions comprise many sites; therefore the positions of the triangles on the map are meant to represent the general location of the region. Sections 5.1–5.6 present regional monthly mean b_{ext} for the species listed above. In addition, monthly mean aerosol b_{ext} (b_{ext_aer}), coarse mass b_{ext} (b_{ext_CM}), and deciview are presented in sections 5.7, 5.8, and 5.9, respectively.

5.1 $PM_{2.5}$ AMMONIUM SULFATE LIGHT EXTINCTION COEFFICIENTS

Reconstructed extinction coefficients from ammonium sulfate, b_{ext_AS}, were computed using a dry extinction efficiency of 3 m^2g^{-1} and a humidification factor (f(RH)) to account for hygroscopic effects. The b_{ext_AS} may closely resemble AS mass concentrations, but differences will arise due to its hygroscopic nature. The IMPROVE 2005–2008 regional monthly mean rural b_{ext_AS} ranged from 1.69 Mm^{-1} in the Great Basin region in December to 105.44 Mm^{-1} in the Appalachia region in August. Recall that the eastern United States corresponded to high AS mass concentrations in summer (Chapter 4 and Figure 4.1.1). A similarly high value of 106.33 Mm^{-1} in the IMPROVE urban location of Birmingham demonstrated that the regional influence of AS mass concentrations in conjunction with increased relative humidity in the summer leads to decreased visibility on regional scales. Many of the eastern IMPROVE regions corresponded to high b_{ext_AS} in summer, but values were highest in the Appalachia and Ohio River Valley regions (Figure 5.1.1). Extinction coefficients in the Northeast and Southeast regions were considerably lower, as were values towards the central United States, such as the Central Great Plains and Mid

South regions. Regardless of the magnitude of b_{ext_AS}, it still peaked in the summer at most eastern regions. In the northwestern United States, the b_{ext_AS} was comparable or less than typical values of Rayleigh scattering (~10 Mm^{-1}) (Figure 5.1.2) and only a fraction of the b_{ext_AS} in eastern regions. Values up to 10 Mm^{-1} occurred at the Northern Great Plains, Oregon/Northern California, Columbia River Gorge, and Northwest regions and usually peaked during spring months. Somewhat higher values occurred for some southwestern regions, but values of b_{ext_AS} at many regions were still comparable or less than contributions from Rayleigh scattering (Figure 5.1.3). The West Texas region corresponded to the highest b_{ext_AS}, with values near 20 Mm^{-1} in September. Spring and summer peaks in b_{ext_AS} were common for most of the southwestern regions. Values of b_{ext_AS} were higher at the OCONUS regions compared to the western United States, but not as high as in the eastern United States (Figure 5.1.4).

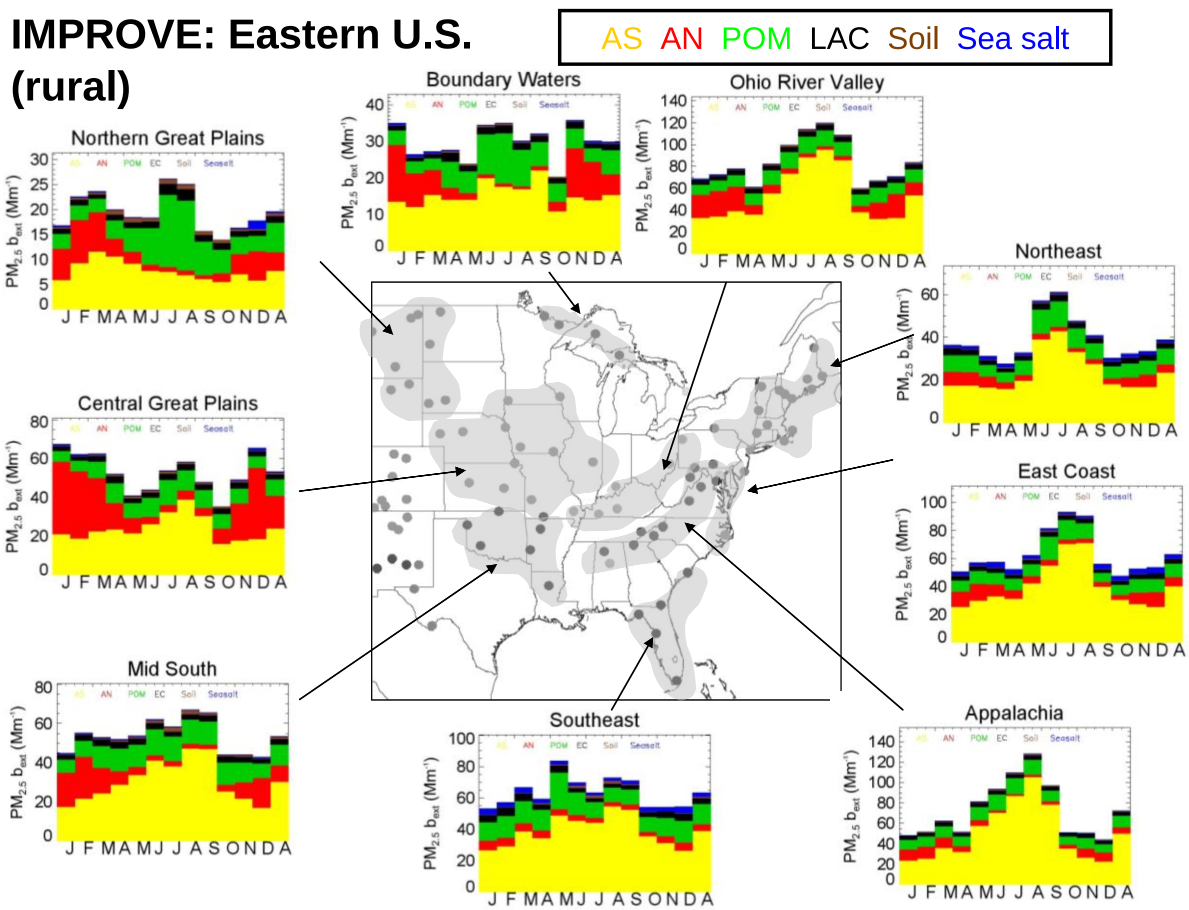

Figure 5.1.1. IMPROVE 2005–2008 regional monthly mean $PM_{2.5}$ reconstructed light extinction coefficients (b_{ext}, Mm^{-1}) for the eastern United States. The letters on the x-axis correspond to the month and "A" corresponds to "annual" mean. Ammonium sulfate (AS) in yellow, ammonium nitrate (AN) in red, particulate organic matter (POM) in green, light absorbing carbon (LAC) in black, soil in brown, and sea salt in blue. The shaded area corresponds to the regions that comprise the sites used in the analysis, shown as dots. The "modified original" IMPROVE algorithm was used (see text). Wavelength corresponds to 550 nm.

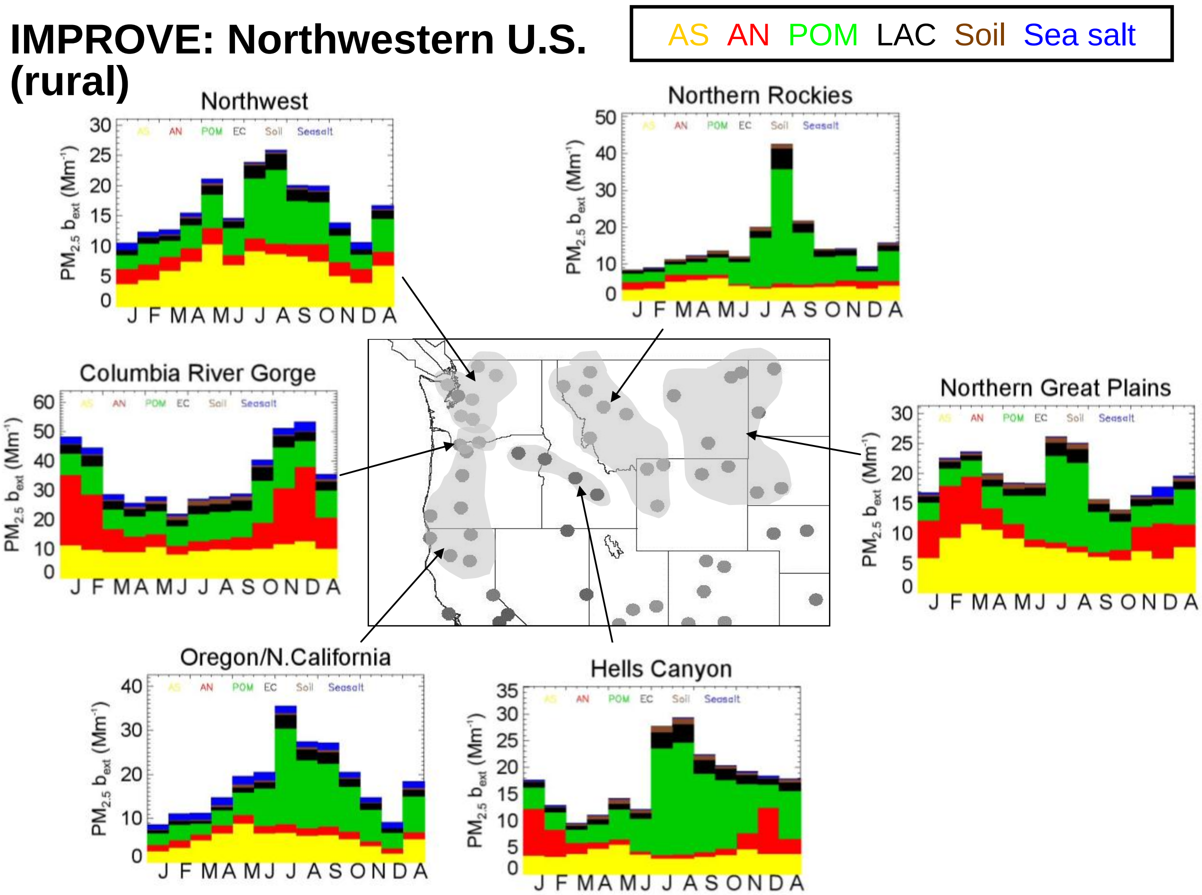

Figure 5.1.2. IMPROVE 2005–2008 regional monthly mean $PM_{2.5}$ reconstructed light extinction coefficients (b_{ext}, Mm^{-1}) for the northwestern United States. The letters on the x-axis correspond to the month and "A" corresponds to "annual" mean. Ammonium sulfate (AS) in yellow, ammonium nitrate (AN) in red, particulate organic matter (POM) in green, light absorbing carbon (LAC) in black, soil in brown, and sea salt in blue. The shaded area corresponds to the regions that comprise the sites used in the analysis, shown as dots. The "modified original" IMPROVE algorithm was used (see text). Wavelength corresponds to 550 nm.

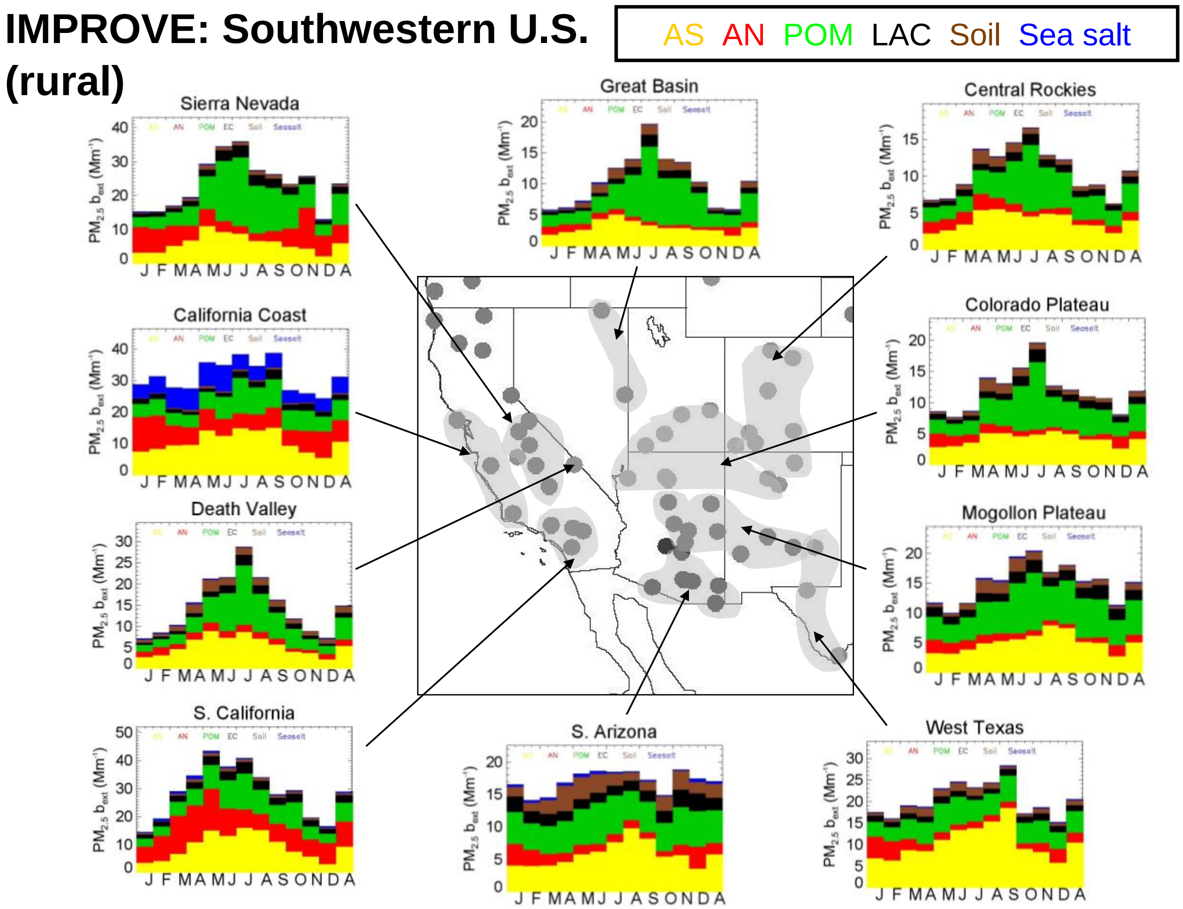

Figure 5.1.3. IMPROVE 2005–2008 regional monthly mean $PM_{2.5}$ reconstructed light extinction coefficients (b_{ext}, Mm^{-1}) for the southwestern United States. The letters on the x-axis correspond to the month and "A" corresponds to "annual" mean. Ammonium sulfate (AS) in yellow, ammonium nitrate (AN) in red, particulate organic matter (POM) in green, light absorbing carbon (LAC) in black, soil in brown, and sea salt in blue. The shaded area corresponds to the regions that comprise the sites used in the analysis, shown as dots. The "modified original" IMPROVE algorithm was used (see text). Wavelength corresponds to 550 nm.

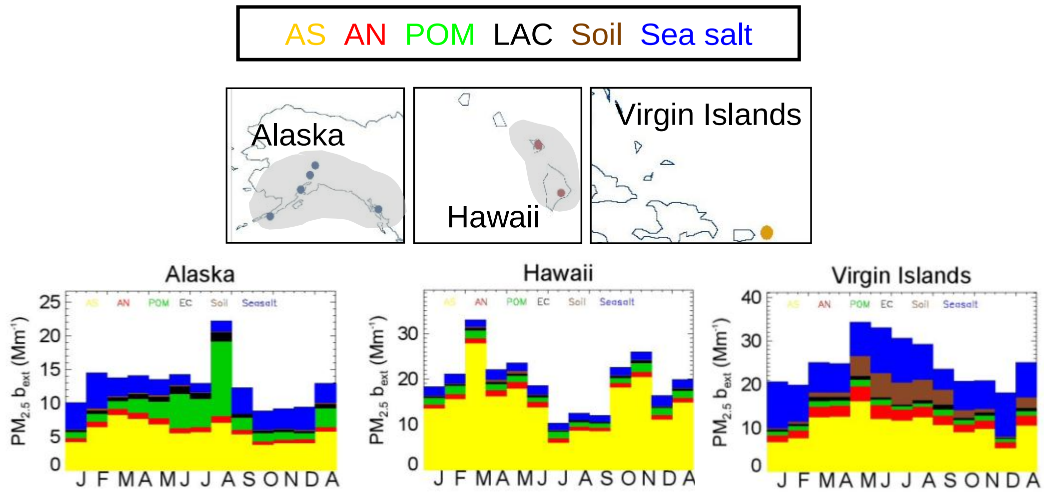

Figure 5.1.4. IMPROVE 2005–2008 regional monthly mean $PM_{2.5}$ reconstructed light extinction coefficients (b_{ext}, Mm^{-1}) for Hawaii, Alaska, and the Virgin Islands. The letters on the x-axis correspond to the month and "A" corresponds to "annual" mean. Ammonium sulfate (AS) in yellow, ammonium nitrate (AN) in red, particulate organic matter (POM) in green, light absorbing carbon (LAC) in black, soil in brown, and sea salt in blue. The shaded area corresponds to the regions that comprise the sites used in the analysis, shown as dots. The "modified original" IMPROVE algorithm was used (see text). Wavelength corresponds to 550 nm.

Only six IMPROVE regions had maximum to minimum b_{ext} ratios less than 2, suggesting a fairly high degree of seasonality in b_{ext_AS}. The largest ratio occurred for the Southern California region (5.2) compared to the lowest in the Colombia River Gorge region (1.6) (Figure 5.1.5). The majority of IMPROVE regions corresponded to summer maxima in b_{ext_AS} (similar to AS mass concentrations), including several regions in the southwestern and eastern United States.

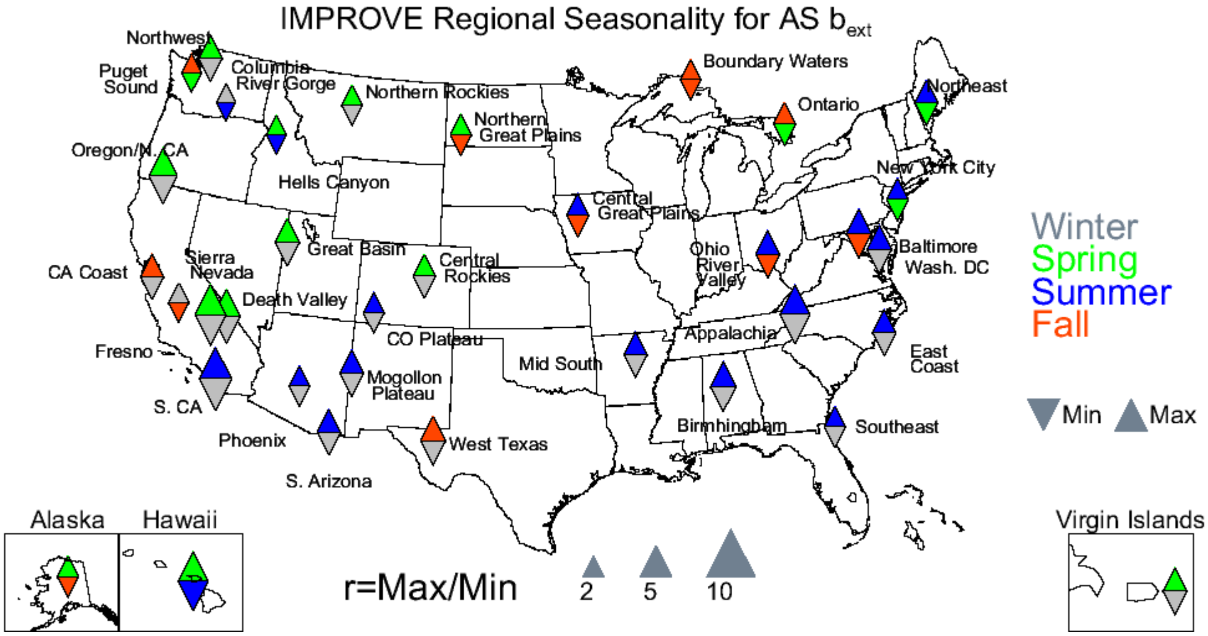

Figure 5.1.5. Seasonal variability for 2005–2008 monthly mean regional IMPROVE ammonium sulfate (AS) light extinction coefficients (b_{ext}). The color of the upward pointing triangle refers to the season with the maximum monthly mean concentration and the downward pointing triangle refers to the season with the minimum monthly mean concentration. The size of the triangles refers to the magnitude of the ratio of maximum to minimum monthly mean mass concentration.

The highest CSN urban b_{ext_AS} occurred at the Ohio River Valley region in September (106.94 Mm^{-1}) and was comparable to the rural regional monthly mean maximum. The lowest urban b_{ext_AS} (3.08 Mm^{-1}) occurred in Las Vegas in December. With the exception of Los Angeles and San Diego, the b_{ext_AS} at the other southwestern regions were similar to the low values at the Las Vegas region (Figure 5.1.6) and also reflected the low AS mass concentrations (Figure 4.1.7). Although AS mass concentrations were similar for the regions in the southwestern and northwestern United States (Figure 4.1.7 and Figure 4.1.8, respectively), the b_{ext_AS} values were higher in the northwestern compared to the southwestern United States for many regions (compare Figure 5.1.7 and Figure 5.1.6, respectively). Much higher b_{ext_AS} values corresponded to eastern regions, especially at the Ohio River Valley, Washington D.C./Philadelphia Corridor, and Southeast regions in summer (and fall for the Ohio River Valley region) (Figure 5.1.8). The b_{ext_AS} values decreased at central U.S. regions but still peaked during summer and fall months. Extinction values were higher in Alaska compared to Hawaii, especially during winter months (Figure 5.1.9).

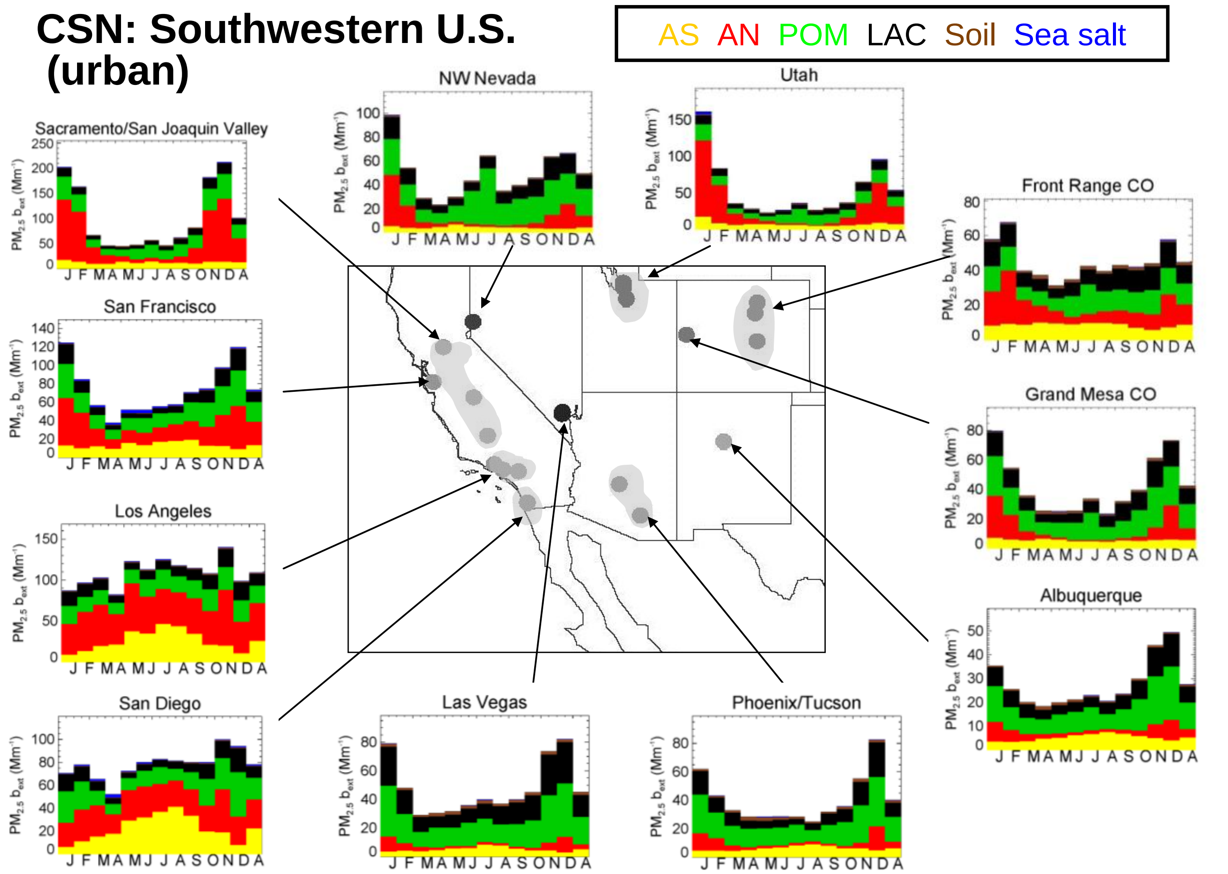

Figure 5.1.6. CSN 2005–2008 regional monthly mean $PM_{2.5}$ reconstructed light extinction coefficients (b_{ext}, Mm^{-1}) for the southwestern United States. The letters on the x-axis correspond to the month and "A" corresponds to "annual" mean. Ammonium sulfate (AS) in yellow, ammonium nitrate (AN) in red, particulate organic matter (POM) in green, light absorbing carbon (LAC) in black, soil in brown, and sea salt in blue. The shaded area corresponds to the regions that comprise the sites used in the analysis, shown as dots. The "modified original" IMPROVE algorithm was used (see text). Wavelength corresponds to 550 nm.

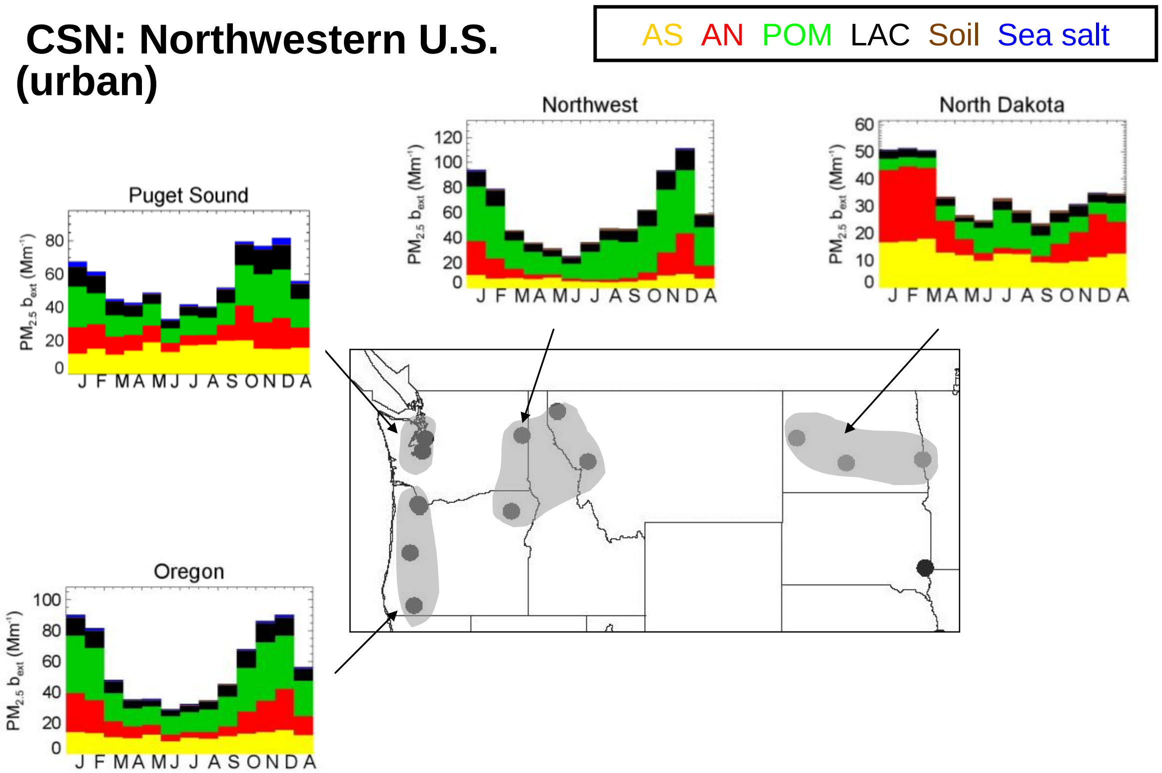

Figure 5.1.7. CSN 2005–2008 regional monthly mean $PM_{2.5}$ reconstructed light extinction coefficients (b_{ext}, Mm^{-1}) for the northwestern United States. The letters on the x-axis correspond to the month and "A" corresponds to "annual" mean. Ammonium sulfate (AS) in yellow, ammonium nitrate (AN) in red, particulate organic matter (POM) in green, light absorbing carbon (LAC) in black, soil in brown, and sea salt in blue. The shaded area corresponds to the regions that comprise the sites used in the analysis, shown as dots. The "modified original" IMPROVE algorithm was used (see text). Wavelength corresponds to 550 nm.

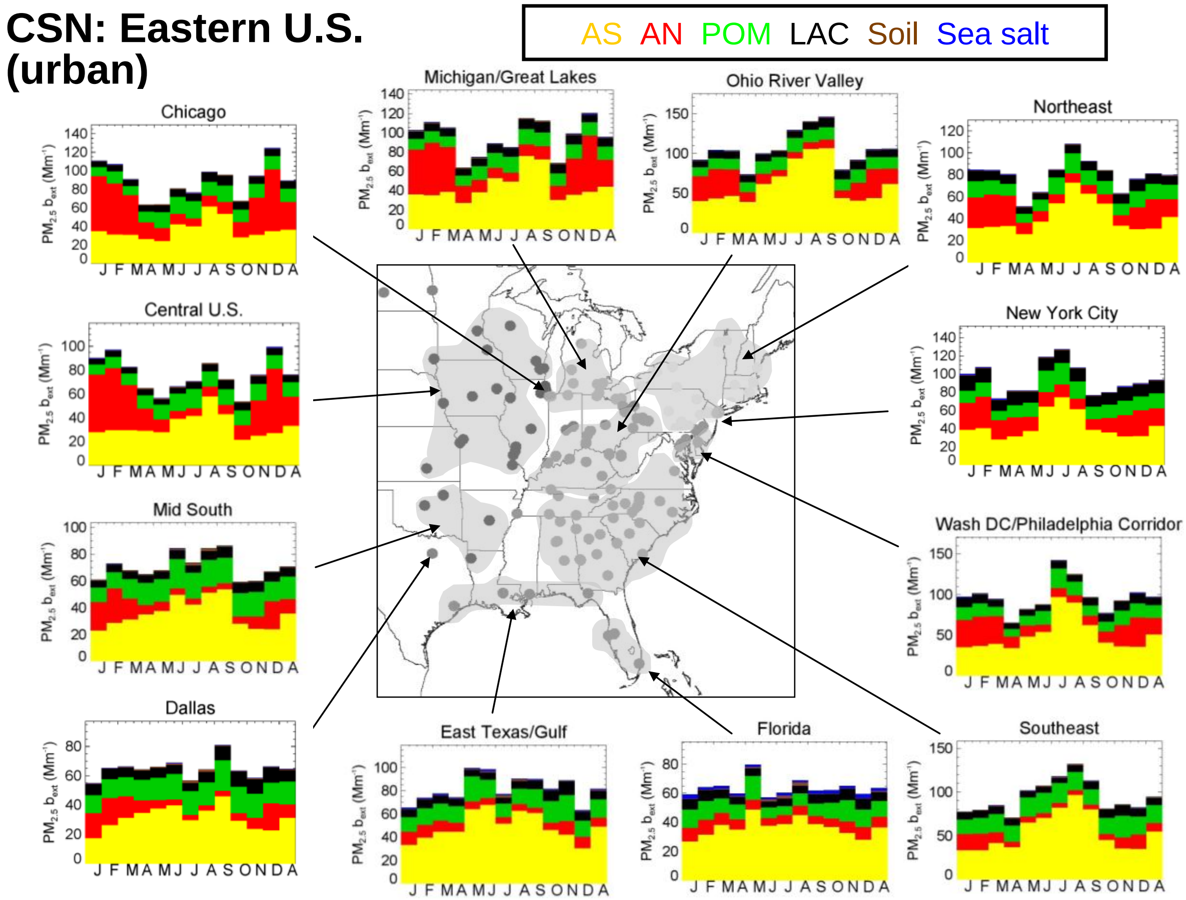

Figure 5.1.8. CSN 2005–2008 regional monthly mean reconstructed light extinction coefficients (b_{ext}, Mm^{-1}) for the eastern United States. The letters on the x-axis correspond to the month and "A" corresponds to "annual" mean. Ammonium sulfate (AS) in yellow, ammonium nitrate (AN) in red, particulate organic matter (POM) in green, light absorbing carbon (LAC) in black, soil in brown, and sea salt in blue. The shaded area corresponds to the regions that comprise the sites used in the analysis, shown as dots. The "modified original" IMPROVE algorithm was used (see text). Wavelength corresponds to 550 nm.

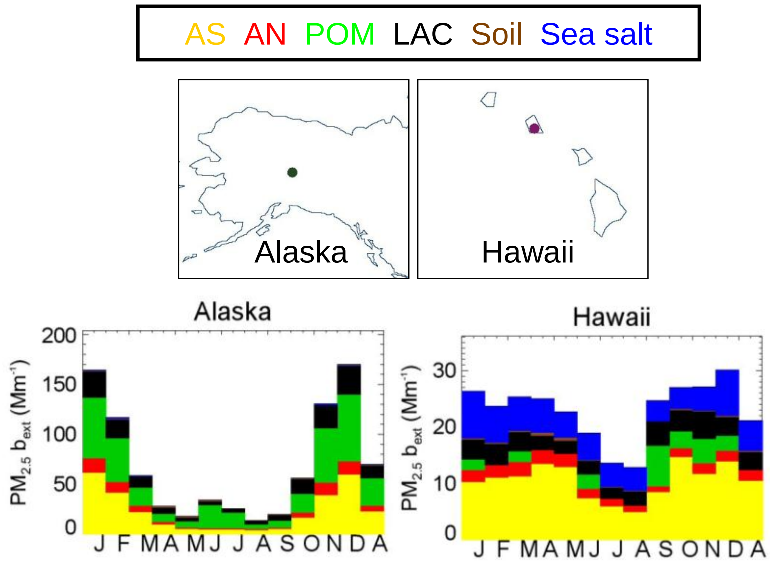

Figure 5.1.9. CSN 2005–2008 regional monthly mean $PM_{2.5}$ reconstructed light extinction coefficients (b_{ext}, Mm^{-1}) for Hawaii and Alaska. The letters on the x-axis correspond to the month and "A" corresponds to "annual" mean. Ammonium sulfate (AS) in yellow, ammonium nitrate (AN) in red, particulate organic matter (POM) in green, light absorbing carbon (LAC) in black, soil in brown, and sea salt in blue. The shaded area corresponds to the regions that comprise the sites used in the analysis, shown as dots. The "modified original" IMPROVE algorithm was used (see text). Wavelength corresponds to 550 nm.

CSN regions corresponded to similar degrees of seasonality for monthly mean b_{ext_AS} and AS mass concentrations (Figures 5.1.10 and 4.1.10, respectively). Regions in southern California and Alaska had the highest degrees of seasonality across the United States. The highest ratio occurred in Alaska (14.0) compared to the lowest in Grand Mesa CO (1.5). Many regions corresponded to summer b_{ext_AS} maxima but may correspond to different regions from those for summer mass concentration maxima (e.g., the Puget Sound, Oregon, Sacramento/San Joaquin Valley, Front Range CO, Mid South, East Texas/Gulf, and Ohio River Valley regions).

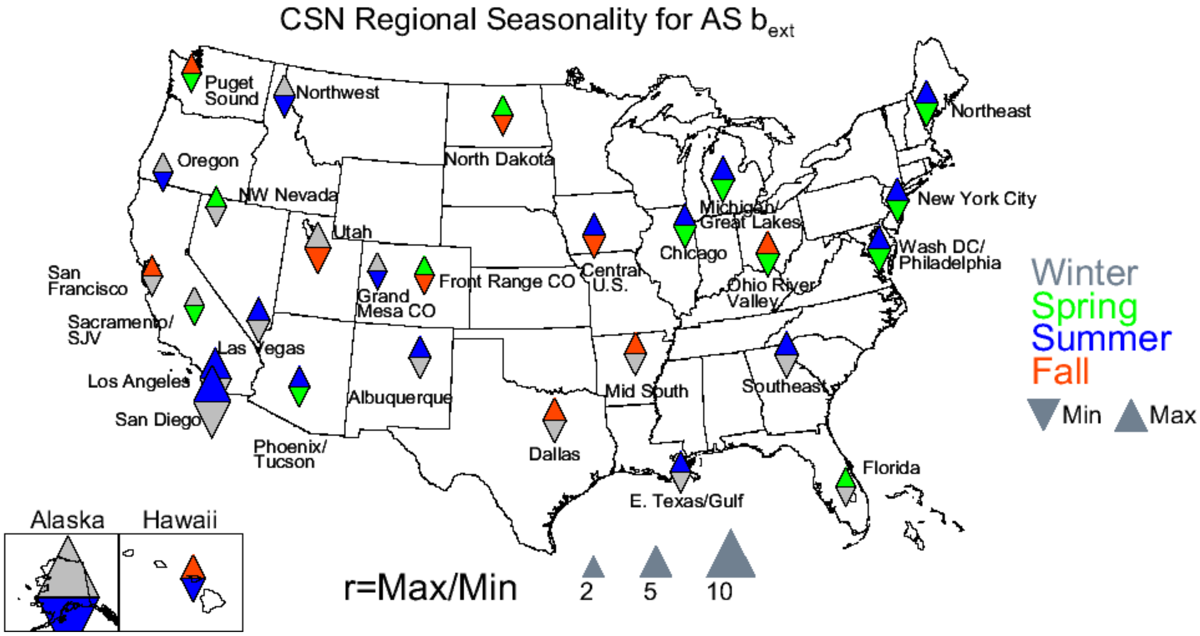

Figure 5.1.10. Seasonal variability for 2005–2008 monthly mean regional CSN ammonium sulfate (AS) light extinction coefficients (b_{ext}). The color of the upward pointing triangle refers to the season with the maximum monthly mean concentration and the downward pointing triangle refers to the season with the minimum monthly mean concentration. The size of the triangles refers to the magnitude of the ratio of maximum to minimum monthly mean mass concentration.

The IMPROVE fractional b_{ext} contribution from AS ranged from 4.6% in Phoenix in December (8.6% in the Northern Rocky Mountains for rural IMPROVE regions) to 84.6% in Hawaii in March, most likely due to volcanic emissions. Other OCONUS regions also had high AS contributions to b_{ext}. Both the Alaska and Virgin Islands regions corresponded to percent contributions of 40% or higher year round, while contributions of AS to b_{ext} at the Hawaii region were 60% or greater year round (Figure 5.1.11). Percent contributions of AS dominated b_{ext} in the eastern United States, ranging from 40% up to ~80% in the Ohio River Valley, East Coast, and Appalachia regions during summer (Figure 5.1.12). The percent contributions of AS to b_{ext} decreased in the southwestern United States to 20–40% at most regions (Figure 5.1.13) but were slightly higher than the AS mass fractions in the same regions (Figure 4.1.13). A similar pattern was observed (higher b_{ext_AS} fractions compared to AS mass fractions) at the northwestern U.S. regions (Figure 5.1.14). Percent contributions of AS to b_{ext} ranged from 15 to 50% and decreased during the summer months at every region except Columbia River Gorge.

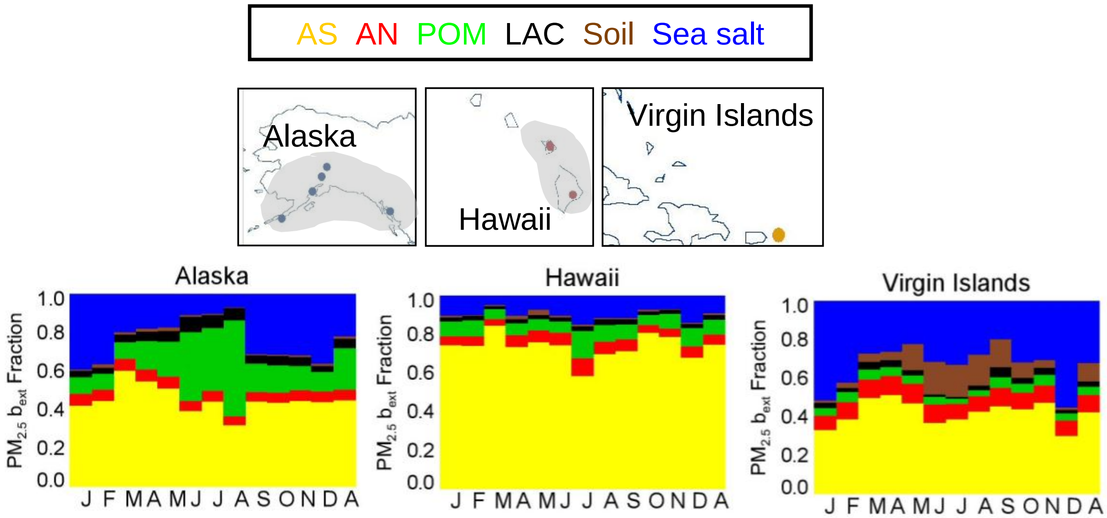

Figure 5.1.11. IMPROVE 2005–2008 regional monthly mean $PM_{2.5}$ light extinction coefficient (b_{ext}) fractions for Hawaii, Alaska, and the Virgin Islands. The letters on the x-axis correspond to the month and "A" corresponds to "annual" mean. Ammonium sulfate (AS) in yellow, ammonium nitrate (AN) in red, particulate organic matter (POM) in green, light absorbing carbon (LAC) in black, soil in brown, and sea salt in blue. The shaded area corresponds to the regions that comprise the sites used in the analysis, shown as dots.

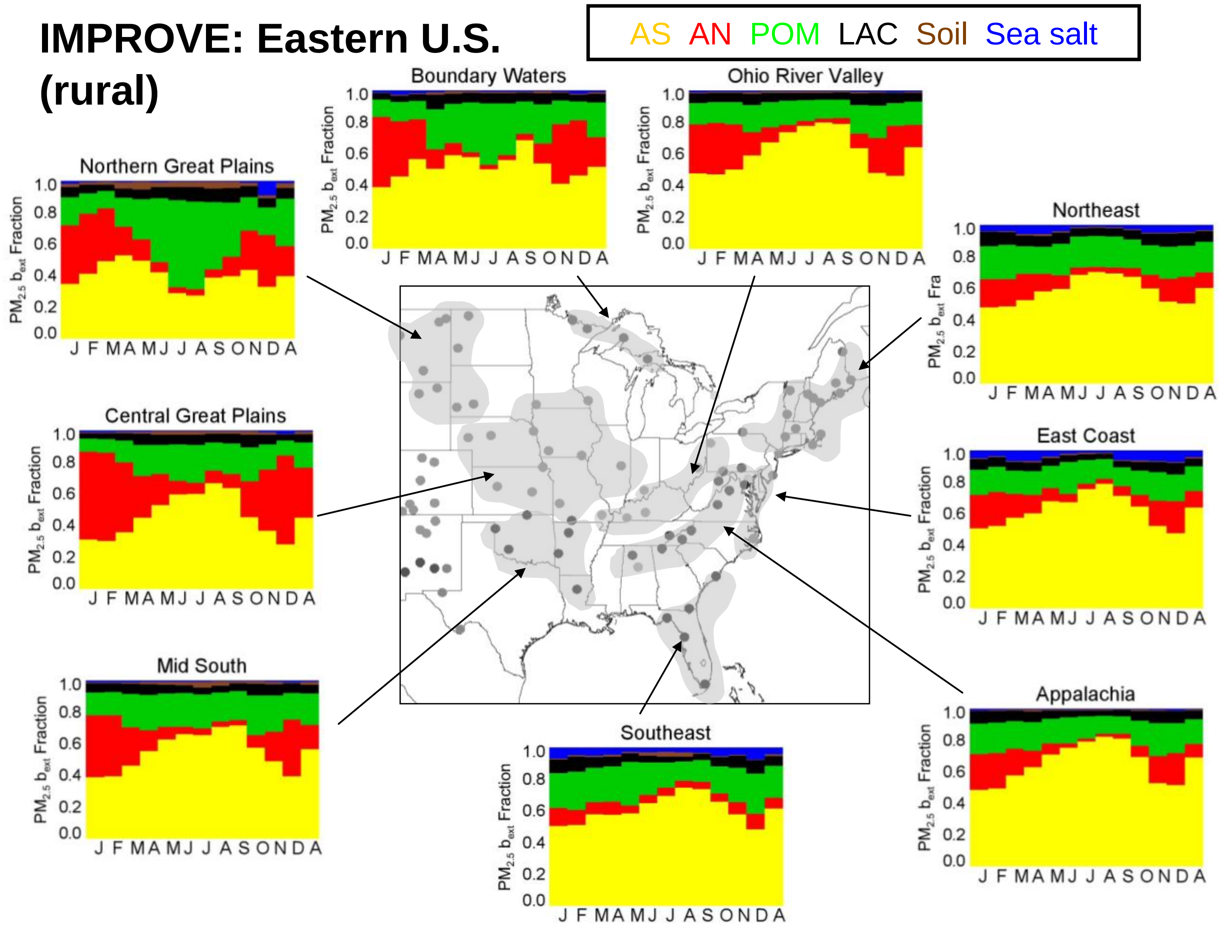

Figure 5.1.12. IMPROVE 2005–2008 regional monthly mean $PM_{2.5}$ light extinction coefficient (b_{ext}) fractions for the eastern United States. The letters on the x-axis correspond to the month and "A" corresponds to "annual" mean. Ammonium sulfate (AS) in yellow, ammonium nitrate (AN) in red, particulate organic matter (POM) in green, light absorbing carbon (LAC) in black, soil in brown, and sea salt in blue. The shaded area corresponds to the regions that comprise the sites used in the analysis, shown as dots.

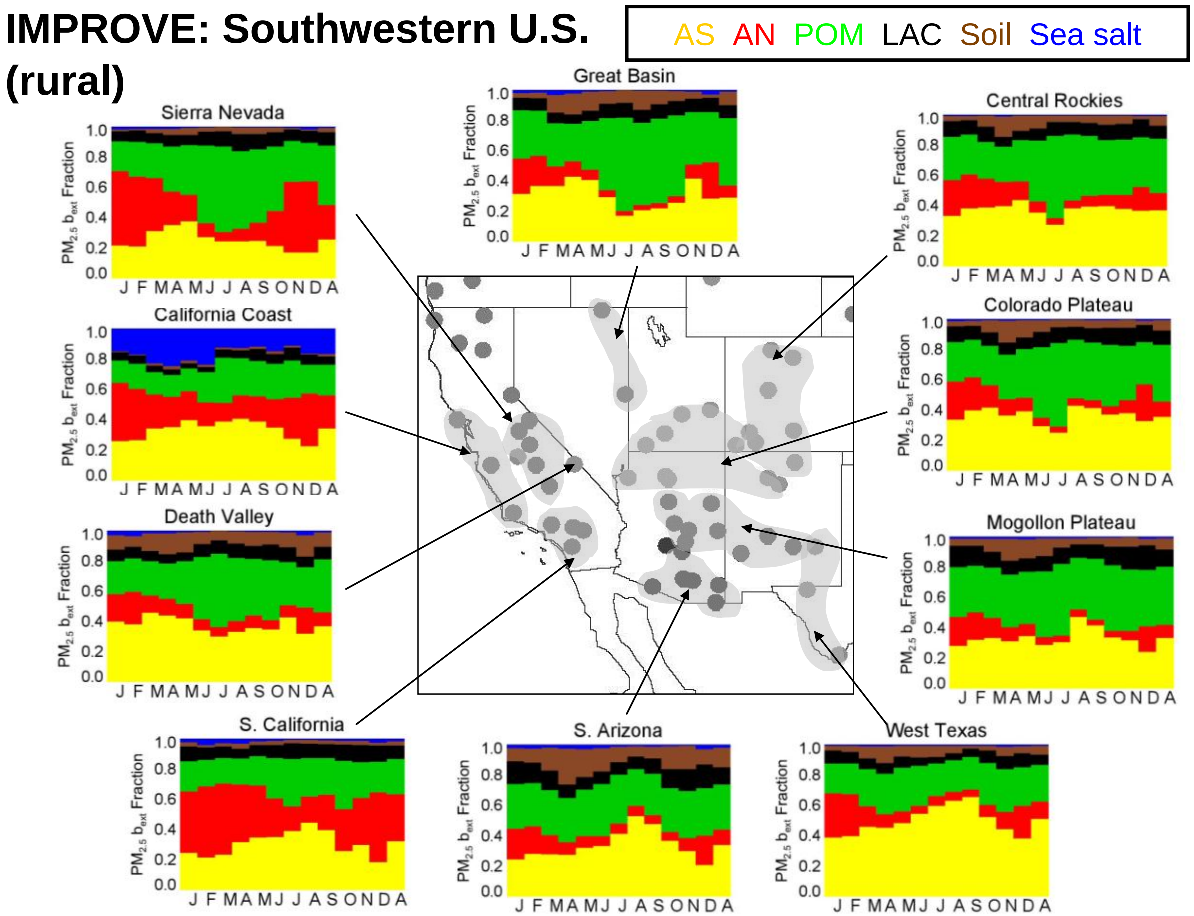

Figure 5.1.13. IMPROVE 2005–2008 regional monthly mean $PM_{2.5}$ light extinction coefficient (b_{ext}) fractions for the southwestern United States. The letters on the x-axis correspond to the month and "A" corresponds to "annual" mean. Ammonium sulfate (AS) in yellow, ammonium nitrate (AN) in red, particulate organic matter (POM) in green, light absorbing carbon (LAC) in black, soil in brown, and sea salt in blue. The shaded area corresponds to the regions that comprise the sites used in the analysis, shown as dots.

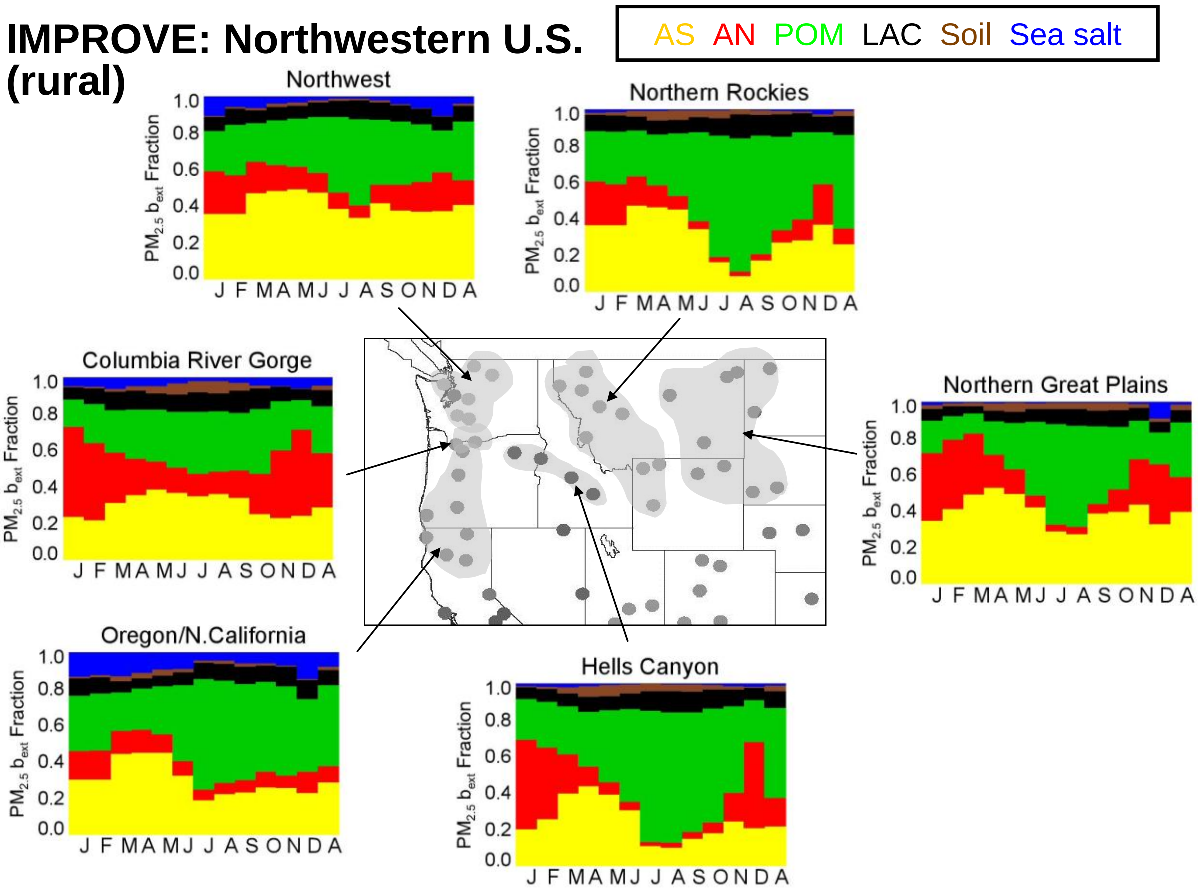

Figure 5.1.14. IMPROVE 2005–2008 regional monthly mean $PM_{2.5}$ light extinction coefficient (b_{ext}) fractions for the northwestern United States. The letters on the x-axis correspond to the month and "A" corresponds to "annual" mean. Ammonium sulfate (AS) in yellow, ammonium nitrate (AN) in red, particulate organic matter (POM) in green, light absorbing carbon (LAC) in black, soil in brown, and sea salt in blue. The shaded area corresponds to the regions that comprise the sites used in the analysis, shown as dots.

Most regions did not experience highly seasonal contributions of AS to b_{ext}; twenty-one regions had maximum to minimum contributions less than 2, suggesting that AS was a consistent contributor to b_{ext} year round. The maximum ratio occurred in Phoenix (7.0, 5.5 for Northern Rocky Mountains) compared to 1.5 in Hawaii. Comparisons of seasonality maps for relative contributions of AS to b_{ext} (Figure 5.1.15) and absolute b_{ext_AS} (Figure 5.1.5) demonstrated interesting differences. The seasonality of the percent contribution of AS to b_{ext} appeared greater than that for absolute b_{ext_AS} for many western U.S. regions (e.g., Northern Rocky Mountains, Hells Canyon, Phoenix, and Fresno). This pattern was reversed in the eastern United States, where b_{ext_AS} had higher seasonality compared to the relative contribution of AS to b_{ext} at many regions. The seasons corresponding to the maximum and minimum absolute b_{ext} and relative b_{ext} also differed for many regions, especially in the western and northeast United States. The seasonality in relative contribution depends on the sources, meteorology, atmospheric processes, and transport that control species concentrations in the atmosphere, but it also depends on the behavior of other species. For example, the minimum absolute b_{ext_AS} values in the western United States occurred during winter for many regions (e.g., Northern Rocky Mountains, Great Basin, and Central Rocky Mountains), but the minimum relative b_{ext_AS} occurred in summer at those same regions, similar to the patterns in AS mass and mass fractions (Figures 4.1.5 and 4.1.15, respectively). While absolute b_{ext_AS} did not decrease considerably in summer in the western United States, the increase in b_{ext_POM} during summer acted to decrease the relative contribution to b_{ext_AS}.

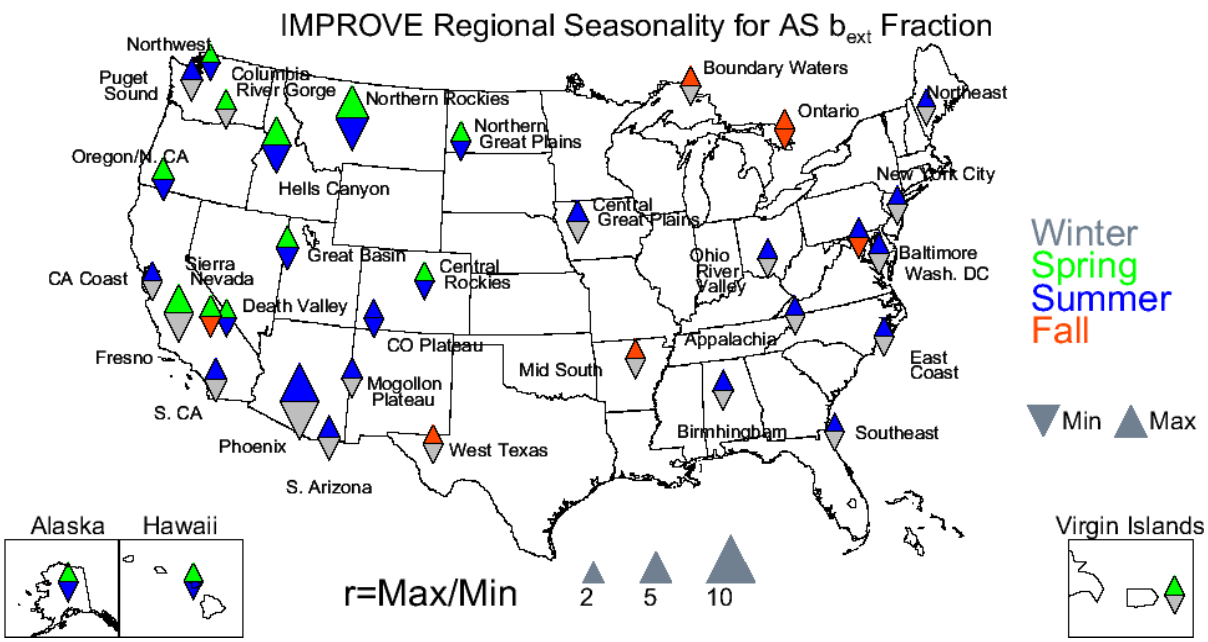

Figure 5.1.15. Seasonal variability for IMPROVE 2005–2008 monthly mean regional ammonium sulfate (AS) light extinction coefficient (b_{ext}) fractions. The color of the upward pointing triangle refers to the season with the maximum monthly mean concentration and the downward pointing triangle refers to the season with the minimum monthly mean concentration. The size of the triangles refers to the magnitude of the ratio of maximum to minimum monthly mean mass concentration.

Urban CSN regional mean b_{ext_AS} fraction ranged from 3.8% in Las Vegas in December to 75.4% in the Ohio River Valley in August. Large contributions of AS to b_{ext} were common for eastern regions (Figure 5.1.16). Contributions ranged from 40 to 75% and increased during summer months for most regions, except the East Texas/Gulf and Florida regions, where the seasonal distribution was flatter. The relative contribution of AS to b_{ext} decreased considerably in the western United States. For example, in the eastern United States the monthly mean fractional b_{ext_AS} rarely dropped below 40%; however, in the northwestern United States 40% was the highest fractional b_{ext_AS} (e.g., the Puget Sound and North Dakota regions, Figure 5.1.17). The summer maxima were not as dominant in the northwestern United States either. In the Puget Sound and Oregon regions, relative b_{ext_AS} increased during summer months, compared to an increase in relative b_{ext_AS} during spring months at the Northwest region and the fairly flat seasonal distribution in the North Dakota region. Higher values of relative b_{ext_AS} during summer months were common for most southwestern regions (Figure 5.1.18), but the magnitudes were consistent with northwestern regions, with fractional b_{ext_AS} less than 40% year round at most regions. The OCONUS regions had similar contributions of AS to b_{ext} (Figure 5.1.19). In the Alaska region the relative b_{ext_AS} was ~40%, except during summer when it decreased to ~20%. In the Hawaii region the contribution of AS to b_{ext} was ~40% but increased to near 60% in May and October.

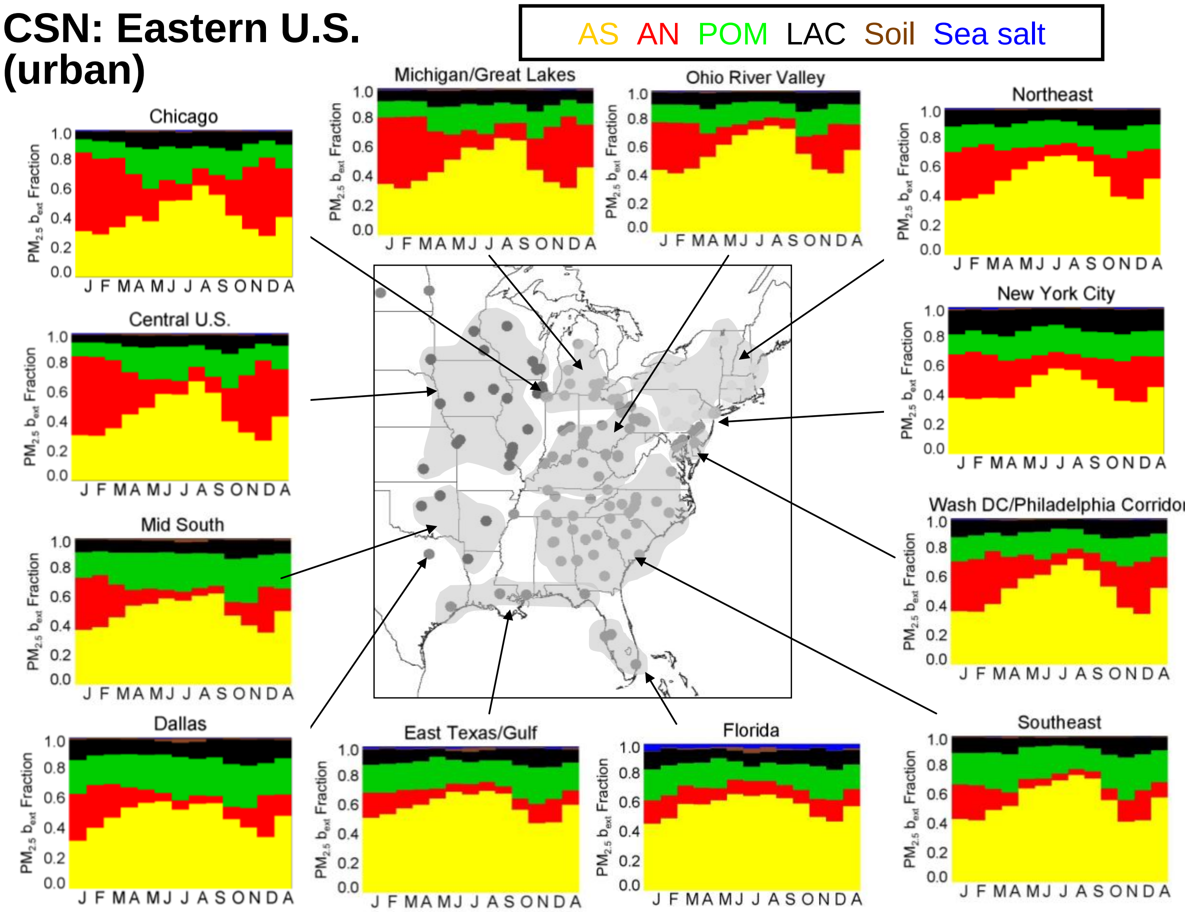

Figure 5.1.16. CSN 2005–2008 regional monthly mean $PM_{2.5}$ light extinction coefficient (b_{ext}) fractions for the eastern United States. The letters on the x-axis correspond to the month and "A" corresponds to "annual" mean. Ammonium sulfate (AS) in yellow, ammonium nitrate (AN) in red, particulate organic matter (POM) in green, light absorbing carbon (LAC) in black, soil in brown, and sea salt in blue. The shaded area corresponds to the regions that comprise the sites used in the analysis, shown as dots.

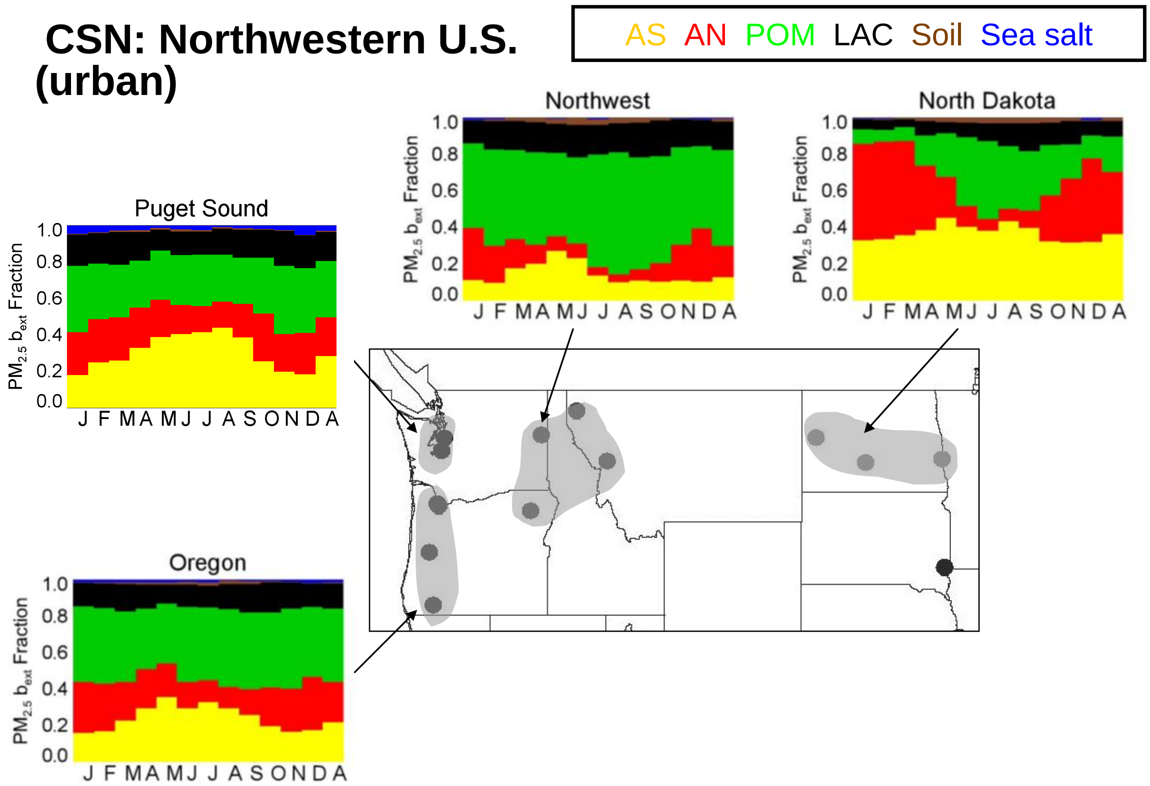

Figure 5.1.17. CSN 2005–2008 regional monthly mean $PM_{2.5}$ light extinction coefficient (b_{ext}) fractions for the northwestern United States. The letters on the x-axis correspond to the month and "A" corresponds to "annual" mean. Ammonium sulfate (AS) in yellow, ammonium nitrate (AN) in red, particulate organic matter (POM) in green, light absorbing carbon (LAC) in black, soil in brown, and sea salt in blue. The shaded area corresponds to the regions that comprise the sites used in the analysis, shown as dots.

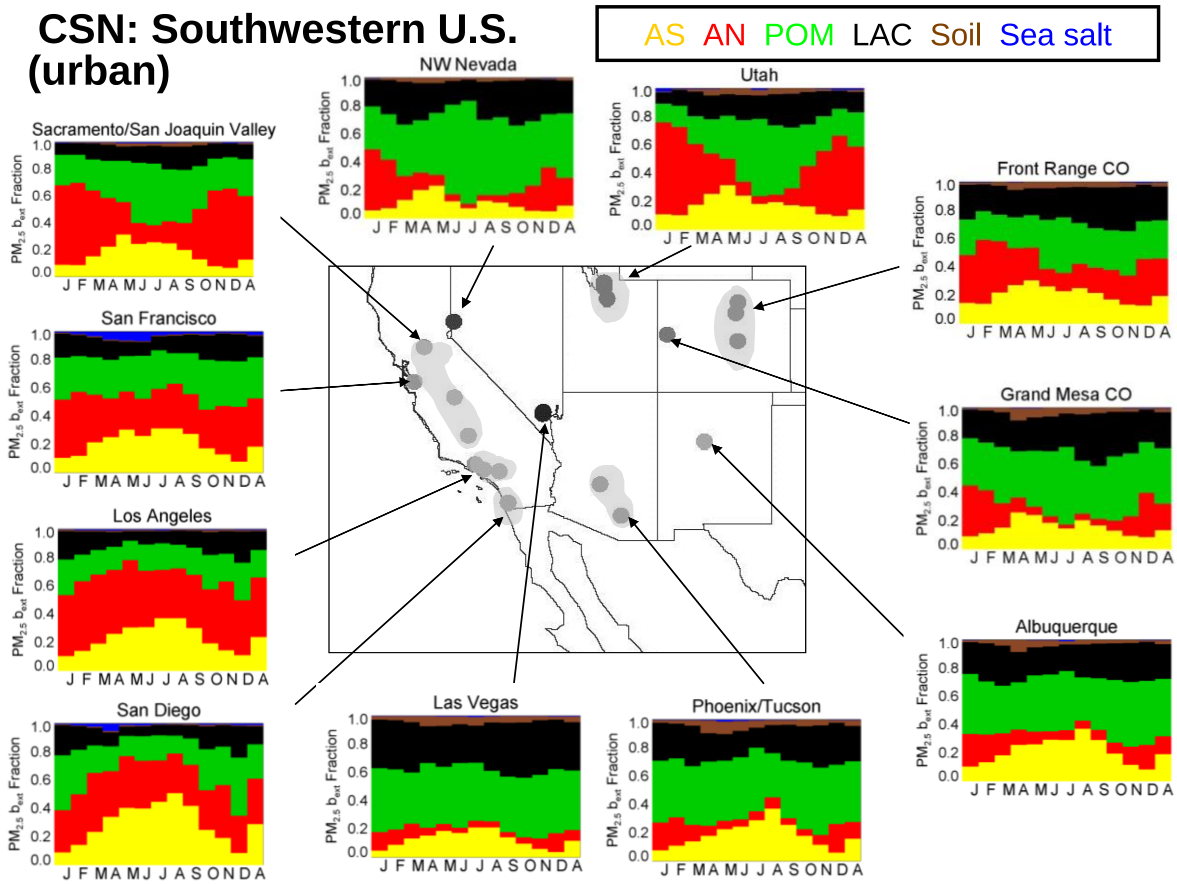

Figure 5.1.18. CSN 2005–2008 regional monthly mean $PM_{2.5}$ light extinction coefficient (b_{ext}) fractions for the southwestern United States. The letters on the x-axis correspond to the month and “A” corresponds to “annual” mean. Ammonium sulfate (AS) in yellow, ammonium nitrate (AN) in red, particulate organic matter (POM) in green, light absorbing carbon (LAC) in black, soil in brown, and sea salt in blue. The shaded area corresponds to the regions that comprise the sites used in the analysis, shown as dots.

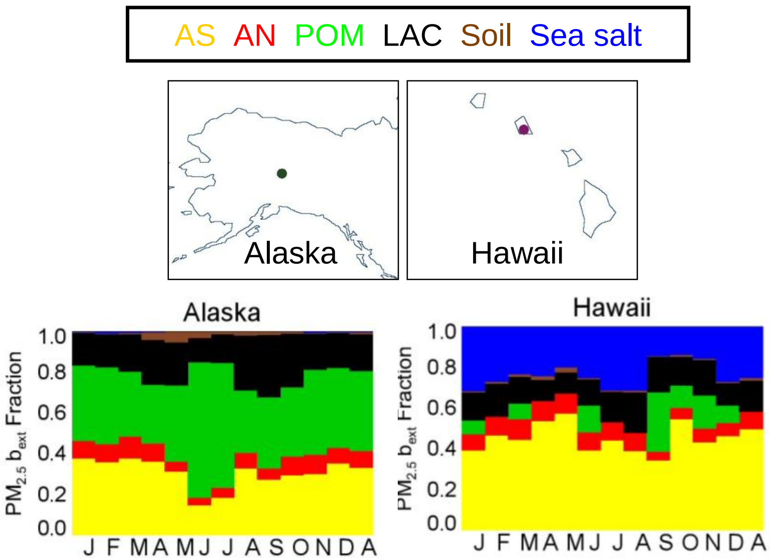

Figure 5.1.19. CSN 2005–2008 regional monthly mean $PM_{2.5}$ light extinction coefficient (b_{ext}) fractions for Hawaii and Alaska. The letters on the x-axis correspond to the month and "A" corresponds to "annual" mean. Ammonium sulfate (AS) in yellow, ammonium nitrate (AN) in red, particulate organic matter (POM) in green, light absorbing carbon (LAC) in black, soil in brown, and sea salt in blue. The shaded area corresponds to the regions that comprise the sites used in the analysis, shown as dots.

Ten of the CSN regions had ratios of maximum to minimum percent contributions less than 2 (Figure 5.1.20). The largest ratio occurred in the Phoenix/Tucson region (6.3) compared to the lowest in the North Dakota region (1.4). Western regions had the highest level of seasonality, with the highest in the southwestern United States (e.g., the Albuquerque, Phoenix/Tucson, Las Vegas, and San Diego regions). These regions were also associated with summer maxima and winter minima. The seasons of maxima and minima shifted in the northwestern United States to spring maxima and winter minima. The winter maxima at urban regions contrasted with the summer maxima that occurred for rural regions. Lower degrees of seasonality corresponding to eastern U.S. regions suggested that AS was a consistent contributor to b_{ext} year round at those regions.

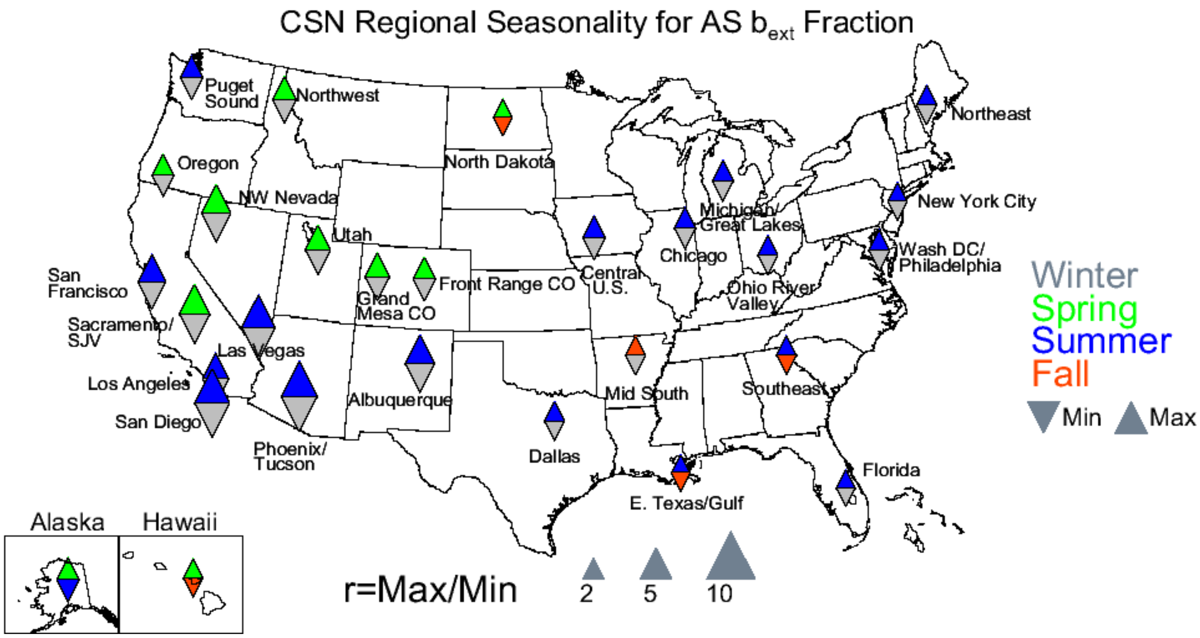

Figure 5.1.20. Seasonal variability for CSN 2005–2008 monthly mean regional ammonium sulfate (AS) light extinction coefficient (b_{ext}) fractions. The color of the upward pointing triangle refers to the season with the maximum monthly mean concentration and the downward pointing triangle refers to the season with the minimum monthly mean concentration. The size of the triangles refers to the magnitude of the ratio of maximum to minimum monthly mean mass concentration.

5.2 $PM_{2.5}$ AMMONIUM NITRATE LIGHT EXTINCTION COEFFICIENTS

The extinction efficiency and f(RH) values used to compute reconstructed light extinction coefficients from ammonium nitrate, b_{ext_AN}, were the same as those used to compute b_{ext_AS}. In a similar manner, while general patterns of b_{ext_AN} mostly follow AN mass concentrations, differences may occur due to hygroscopic effects. Winter maxima in 2005–2008 regional monthly mean b_{ext_AN} were common at many IMPROVE regions, consistent with favorable AN formation in winter conditions. In fact, the maximum b_{ext_AN} at urban and rural IMPROVE regions occurred in winter. In addition, the urban IMPROVE regional monthly mean maximum b_{ext_AN} (149.46 Mm^{-1} at Fresno in December) was almost four times higher than the rural IMPROVE regional monthly mean maximum (37.56 Mm^{-1} in the Central Great Plains region in January). The minimum IMPROVE regional monthly mean b_{ext_AN} was in 0.44 Mm^{-1} in the Great Basin region in October. The b_{ext_AN} values at the Central Great Plains region were larger than most regions in the eastern half of the United States (Figure 5.1.1), especially with respect to other species. Higher values of b_{ext_AN} also occurred during winter at the Northern Great Plains, Boundary Waters, and Mid South regions, due to their proximity to source regions. In contrast, regions farther east corresponded to relatively low values of b_{ext_AN}, especially in comparison to other species (e.g., the Southeast, Appalachia, East Coast, and Northeast regions). The values of b_{ext_AN} varied considerably between regions in the northwestern United States (Figure 5.1.2). The Northern Great Plains, Hells Canyon, and Columbia River Gorge regions corresponded to relatively higher values with strong winter maxima. In contrast, values in the Oregon/Northern California and Northern Rocky Mountain regions were fairly low and did not have strong winter maxima. Extinction coefficients due to AN in the southwestern United States were typically less than contributions from Rayleigh scattering (~10 Mm^{-1}) at most regions

(Figure 5.1.3). The exceptions included the Sierra Nevada and California Coast regions; these regions corresponded to higher winter b_{ext_AN}. In addition, the Southern California region experienced relatively high b_{ext_AN} year round, similar to monthly mean AN mass concentrations (Figure 4.1.3). Monthly mean AN mass concentrations and b_{ext_AN} at OCONUS regions also had very similar patterns (Figures 4.1.4 and 5.1.4, respectively), except at the Virgin Islands site where b_{ext_AN} increased relative to other species, probably due to its hygroscopic nature and higher extinction efficiency compared to other species (e.g., soil).

Most IMPROVE regions demonstrated a high degree of seasonality, with only two regions having a maximum to minimum b_{ext_AN} ratio less than 2. The largest ratios occurred in the Fresno (21.2, urban) and Boundary Waters regions (17.9, rural), and the lowest ratio occurred in the Northwest region (1.8). Most of the IMPROVE regions corresponded to winter maxima (Figure 5.2.1), although fall maxima occurred at the Ontario, Northwest, and Sierra Nevada regions. Spring maxima occurred at the Virgin Islands, Hawaii, Southern California, Death Valley, and Central Rocky Mountain regions. Summer and fall minima were common for most regions. In general, b_{ext_AN} exhibited a higher degree of seasonality compared to monthly mean AN mass concentrations (see Figure 4.2.1), and for many regions the seasons corresponding to maximum and minimum shifted (especially at southwestern U.S. regions).

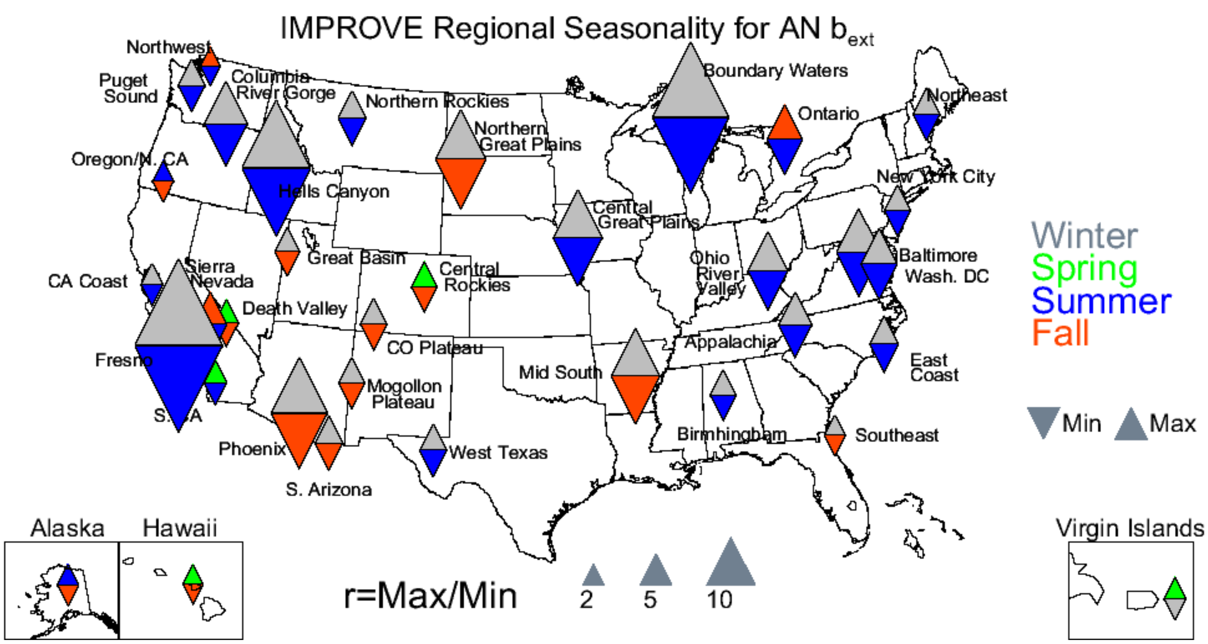

Figure 5.2.1. Seasonal variability for IMPROVE 2005–2008 monthly mean regional ammonium nitrate (AN) light extinction coefficients (b_{ext}). The color of the upward pointing triangle refers to the season with the maximum monthly mean concentration and the downward pointing triangle refers to the season with the minimum monthly mean concentration. The size of the triangles refers to the magnitude of the ratio of maximum to minimum monthly mean mass concentration.

The CSN urban regional monthly mean b_{ext_AN} ranged from 0.92 Mm^{-1} in the Alaska region in May to 125.28 Mm^{-1} in the Sacramento/San Joaquin Valley region in December. Values of b_{ext_AN} at urban regions were considerably higher than at rural regions in the southwestern United States (compare Figures 5.1.6 and 5.1.3). Regions in California, Nevada, Utah, and Colorado corresponded to b_{ext_AN} values that were several times higher than Rayleigh scattering (~10 Mm^{-1}). Values of b_{ext_AN} increased considerably during winter months at most regions except Los Angeles and San Diego, where they were high year round. Compared to AN mass concentrations, b_{ext_AN} was higher relative to other species, especially at the San Francisco, Sacramento/San Joaquin Valley, Northwest Nevada, and Utah regions. Values of b_{ext_AN} decreased in the northwestern United States compared to regional values in the southwestern United States but were still much larger than those at rural northwestern U.S. regions. Values near 20 Mm^{-1} during winter months were common at most regions (Figure 5.1.7) and similar in seasonal pattern to AN mass concentrations (Figure 4.1.8), although higher relative to other species. Extinction coefficients near 40 Mm^{-1} were common at eastern U.S. regions, especially during winter months (Figure 5.1.8). Regions closer to the central United States corresponded to higher b_{ext_AN} values compared to estimates at regions near the eastern or in the southeastern United States. Values of b_{ext_AN} at the Florida and Southeast regions were actually similar to estimates at rural regions in the same vicinity (Figure 5.1.6). Values of b_{ext_AN} were much higher at the Alaska region compared to the Hawaii region (Figure 5.1.9), similar to patterns in monthly mean AN mass concentrations. Urban b_{ext_AN} values at the Hawaii region were much higher than rural regional Alaska b_{ext_AN} values.

Urban b_{ext_AN} was highly seasonal, with only two sites having ratios less than 2. The majority of regions corresponded to winter maxima (Figure 5.2.2). The highest ratio occurred in the Utah region (75.12) and the lowest occurred in the Los Angeles region (1.8). The degree of seasonality for b_{ext_AN} was noticeably higher than that for AN mass concentrations (compare Figure 5.2.2 to Figure 4.2.2). Western U.S. regions corresponded to the greatest degree of seasonality. Most seasons corresponded to maximum and minimum b_{ext_AN} in winter and summer, respectively. The differences in seasonality between rural and urban b_{ext_AN} were also quite noticeable, with more winter maxima and summer minima associated with urban regions, especially in the southwestern United States.

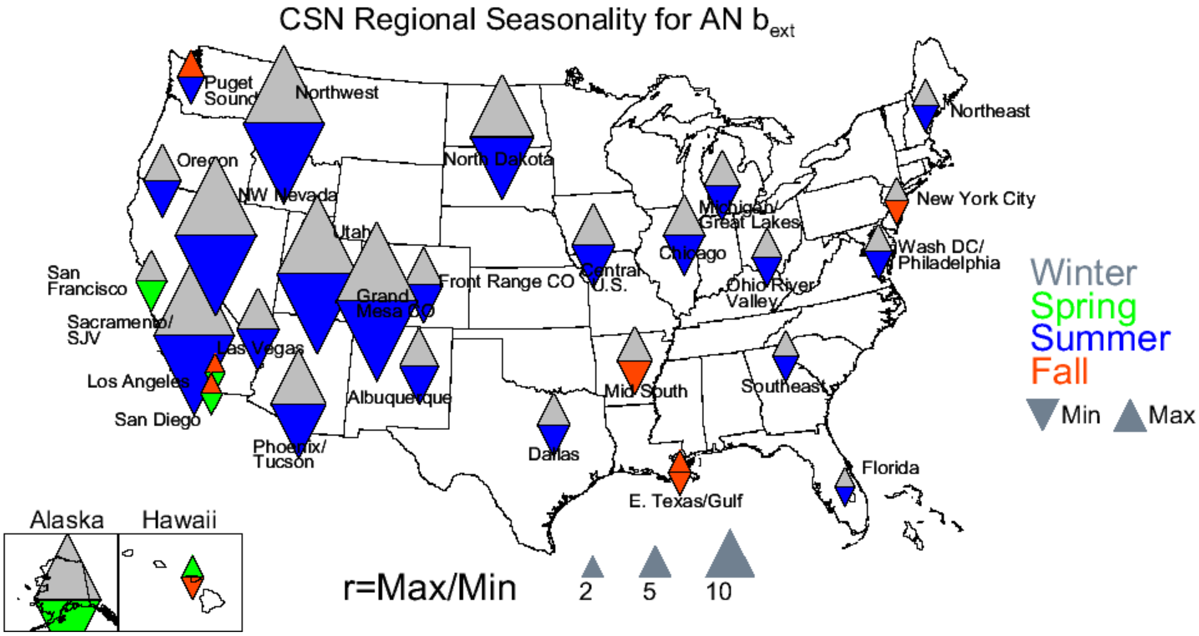

Figure 5.2.2. Seasonal variability for CSN 2005–2008 monthly mean regional ammonium nitrate (AN) light extinction coefficients (b_{ext}). The color of the upward pointing triangle refers to the season with the maximum monthly mean concentration and the downward pointing triangle refers to the season with the minimum monthly mean concentration. The size of the triangles refers to the magnitude of the ratio of maximum to minimum monthly mean mass concentration.

AN dominated the IMPROVE b_{ext} in Fresno (61.3%) in February and in the Central Great Plains region (56.2%) in December. The lowest monthly mean AN contributions to b_{ext} occurred in the Appalachia region in August (1.8%), similar to the other eastern U.S. regions (Figure 5.1.12) with values reaching up to 20% during winter months at the Ohio River Valley, Northeast, and East Coast regions. The contributions of AN to b_{ext} increased toward the central United States, with values near 40% or more in winter at regions such as Central Great Plains, Boundary Waters, Northern Great Plains, and the Mid South. Contributions of AN to b_{ext} were even higher than its contributions to reconstructed fine mass (RCFM) (Figure 4.1.11) at these regions, in part due to its hygroscopic properties and higher extinction efficiencies relative to other species (e.g., soil). Percent contributions of AN to b_{ext} of 40% were common at northwestern U.S. rural IMPROVE regions (Figure 5.1.14). The Colombia River Gorge, Hells Canyon, and Northern Great Plains regions all corresponded to large AN b_{ext} fractions, especially during winter months. While the Northwest, Northern Rocky Mountains, and Oregon/Northern California regions did not experience as high a b_{ext_AN} fraction, these regions did experience high values during winter months. AN contributed more to b_{ext} than it did to RCFM (see Figure 5.1.14 compared to Figure 4.1.12), especially at the Northern Great Plains and Columbia River Gorge regions. The relative contribution of AN to b_{ext} was somewhat lower in the southwestern United States (Figure 5.1.13). Values near 20% were more common for regions in this area, although higher contributions in the winter still occurred. Somewhat elevated contributions (~40%) occurred at the Sierra Nevada and Southern California regions. These regions also experienced higher contributions of AN to b_{ext} compared to RCFM (compare Figures 4.1.13 and 5.1.13) but not to the same degree as other U.S. regions. Compared to other regions, the AN contributions to b_{ext} in the OCONUS regions were relatively low (<10%) (Figure 5.1.11).

Most IMPROVE regions showed a high degree of seasonality for the contribution of AN to b_{ext}, with only two regions having ratios less than 2 (Virgin Islands was the lowest with 1.4). The highest ratio occurred at the Hells Canyon region (21.4). Most regions corresponded to winter maxima and summer minima (Figure 5.2.3). Only two regions in the continental United States had spring maxima (Baltimore and Southern California), and only five regions had fall minima. The OCONUS regions had very different seasonal patterns and had a lower degree of seasonality. In general, the degree of seasonality was higher for relative b_{ext_AN} compared to absolute b_{ext_AN} (compare Figure 5.2.1). In addition, more regions had winter maxima and summer minima. The degree of seasonality of relative b_{ext_AN} was actually quite similar to that of AN mass fraction (Figure 4.2.3), although the seasons corresponding to maximum and minimum varied for some regions.

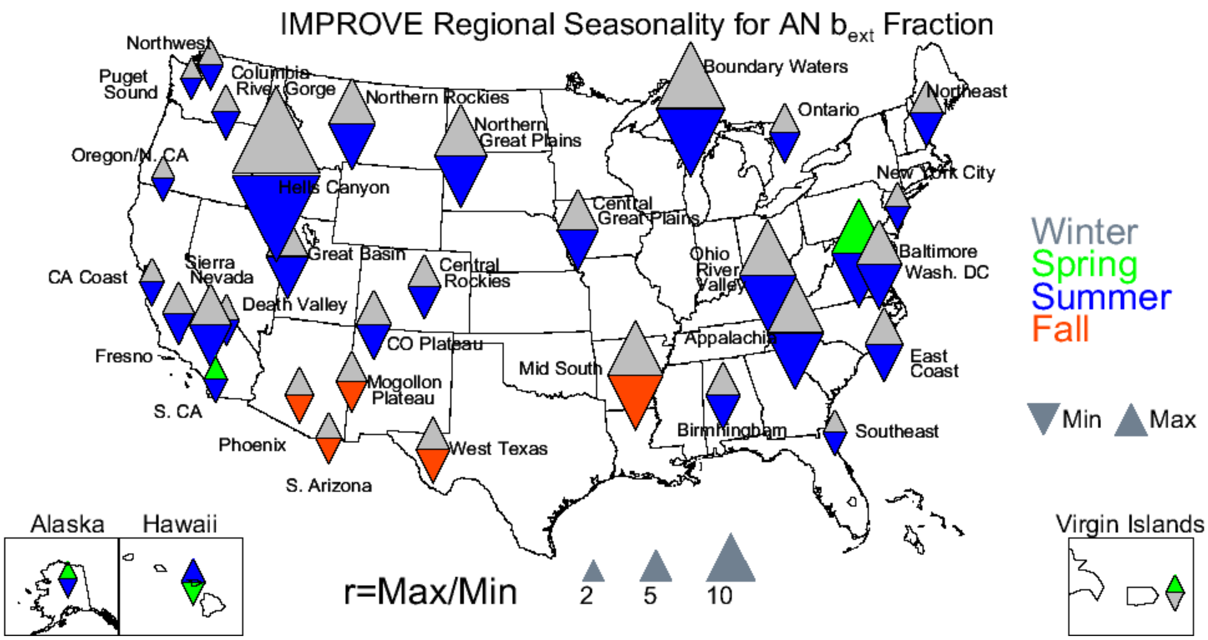

Figure 5.2.3. Seasonal variability for IMPROVE 2005–2008 monthly mean regional ammonium nitrate (AN) light extinction coefficient (b_{ext}) fractions. The color of the upward pointing triangle refers to the season with the maximum monthly mean concentration and the downward pointing triangle refers to the season with the minimum monthly mean concentration. The size of the triangles refers to the magnitude of the ratio of maximum to minimum monthly mean mass concentration.

CSN urban monthly mean b_{ext_AN} fractions ranged from 2.7% at the Grand Mesa CO region in July to 64.8% at the Utah region in January. The southwestern United States was home to many regions where AN contributed significantly to b_{ext} (Figure 5.1.18). Contributions of 40% or higher were common at many regions (e.g., Utah, Northwest Nevada, Sacramento/San Joaquin Valley, San Francisco, Los Angeles, and San Diego). Contributions were much lower at regions farther south, such as the Las Vegas, Phoenix/Tucson, and Albuquerque regions. Although most regions did exhibit higher AN contributions to b_{ext} during winter months, some regions, such as San Diego and Los Angeles, had fairly flat seasonal patterns. In general, urban regions experienced a much higher contribution of AN to b_{ext} than did rural regions in the southwestern United States. Contributions of AN to b_{ext} reached ~20% at northwestern U.S. regions, except at the North Dakota region where relative b_{ext_AN} during winter months reached up to ~40% (Figure 5.1.17). The relative b_{ext} at central U.S. regions was similar to the North

Dakota region in that they reached up to 40% of b_{ext} during winter months (e.g., the Chicago, Central U.S., and Michigan/Great Lakes regions, Figure 5.1.16). AN contributions to b_{ext} at regions farther east were somewhat lower. Twenty percent contributions were common during winter months, though they were somewhat lower during winter months at southern regions (e.g., East Texas/Gulf, Florida, and Southeast). Urban regions experienced much higher contributions of AN to b_{ext} compared to rural regions in the eastern United States (see Figure 5.1.12). The lowest urban relative contributions occurred at the OCONUS regions (Figure 5.1.19) and were more comparable to rural regions.

Most CSN regions had the highest contributions of AN to b_{ext} in winter, as was observed in the bar charts of monthly mean b_{ext_AN} fraction. Only five regions had ratios of maximum to minimum contributions less than 2; the highest occurred in the Northwest Nevada region (14.8) and the lowest in the Los Angeles region (1.5) (Figure 5.2.4). The highest maximum to minimum ratios occurred in the western United States, including the Utah, Grand Mesa CO, Northwest Nevada, North Dakota, and Northwest regions. Most regions corresponded to winter maxima and summer minima, with the exception of several southern U.S. regions (e.g., East Texas/Gulf, Dallas TX, Mid South, Phoenix/Tucson, and Las Vegas). The degree of seasonality of the relative contributions of AN to b_{ext} was lower than the degree of seasonality of absolute b_{ext_AN}, especially in the western United States (see Figure 5.2.2). The seasonality of relative b_{ext_AN} suggested that the contributions of AN to b_{ext} were consistent year round for many western U.S. regions. The seasonality pattern of fractional b_{ext_AN} followed that of the AN mass fraction (see Figure 4.2.4).

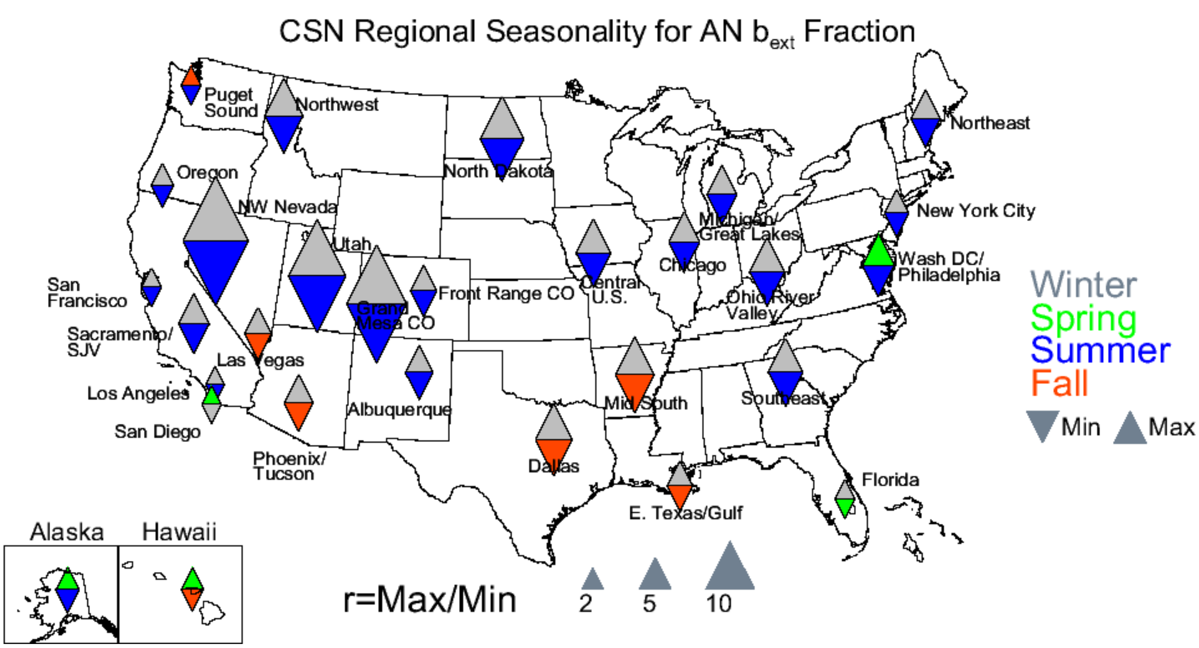

Figure 5.2.4. Seasonal variability for CSN 2005–2008 monthly mean regional ammonium nitrate (AN) light extinction coefficient (b_{ext}) fractions. The color of the upward pointing triangle refers to the season with the maximum monthly mean concentration and the downward pointing triangle refers to the season with the minimum monthly mean concentration. The size of the triangles refers to the magnitude of the ratio of maximum to minimum monthly mean mass concentration.

5.3 $PM_{2.5}$ PARTICULATE ORGANIC MATTER LIGHT EXTINCTION COEFFICIENTS

POM light extinction coefficients (b_{ext_POM}) were scaled to POM mass because, unlike AS and AN, POM was considered nonhygroscopic in reconstructed b_{ext} calculations (section 3.1). On a similar dry mass basis, b_{ext_POM} would be higher than b_{ext_AS} or b_{ext_AN} because its extinction efficiency is higher (4 m^2 g^{-1} compared to 3 m^2 g^{-1}; see section 3.1).

The minimum IMPROVE 2005–2008 regional monthly mean b_{ext_POM} occurred at the Virgin Islands in December (0.68 Mm^{-1}). The urban IMPROVE maximum b_{ext_POM} was considerably higher than the rural maximum; b_{ext_POM} in Fresno was 52.06 Mm^{-1} in December compared to 31.03 Mm^{-1} in the Northern Rocky Mountains region in August. Relatively high values of b_{ext_POM} during summer months were common at several northwestern U.S. regions (Figure 5.1.2), probably related to wildfire or biogenic emissions. The Columbia River Gorge region was the exception to this pattern, with fairly constant b_{ext_POM} year round. Similar regional and seasonal patterns of b_{ext_POM} and POM mass were observed as expected (Figure 4.1.2). The northerly regions in the southwestern United States had somewhat higher b_{ext_POM} values compared to regions farther south (Figure 5.1.3). For example, the Sierra Nevada, Great Basin, Central Rocky Mountains, Colorado Plateau, Mogollon Plateau, and Hells Canyon regions all corresponded to values near or greater than 10 Mm^{-1}, especially during summer. However, the Southern California, Southern Arizona, and West Texas regions corresponded to values on the order of Rayleigh scattering (10 Mm^{-1}). Values of b_{ext_POM} in the eastern United States ranged from 10 to 20 Mm^{-1} at many regions (Figure 5.1.1). Higher b_{ext_POM} during summer months occurred at the Northern Great Plains and Boundary Water regions, probably also related to biomass burning or biogenic emissions. Distinct seasonal patterns were not as obvious at regions along the eastern coast. Of the OCONUS regions, the Alaska region was the only one with considerable b_{ext_POM}, especially during summer (Figure 5.1.4).

The seasonal patterns in IMPROVE b_{ext_POM} (Figure 5.3.1) were similar to the seasonal patterns in POM mass (Figure 4.3.1). Most rural regions corresponded to summer maxima and winter or spring minima. Summer maxima were most likely associated with biomass burning emissions (especially in the western United States) or biogenic emissions. Only six regions had maximum to minimum contributions less than 2. The ratios ranged from 1.6 in the Southern Arizona region to 13.3 in the Northern Rocky Mountains region.

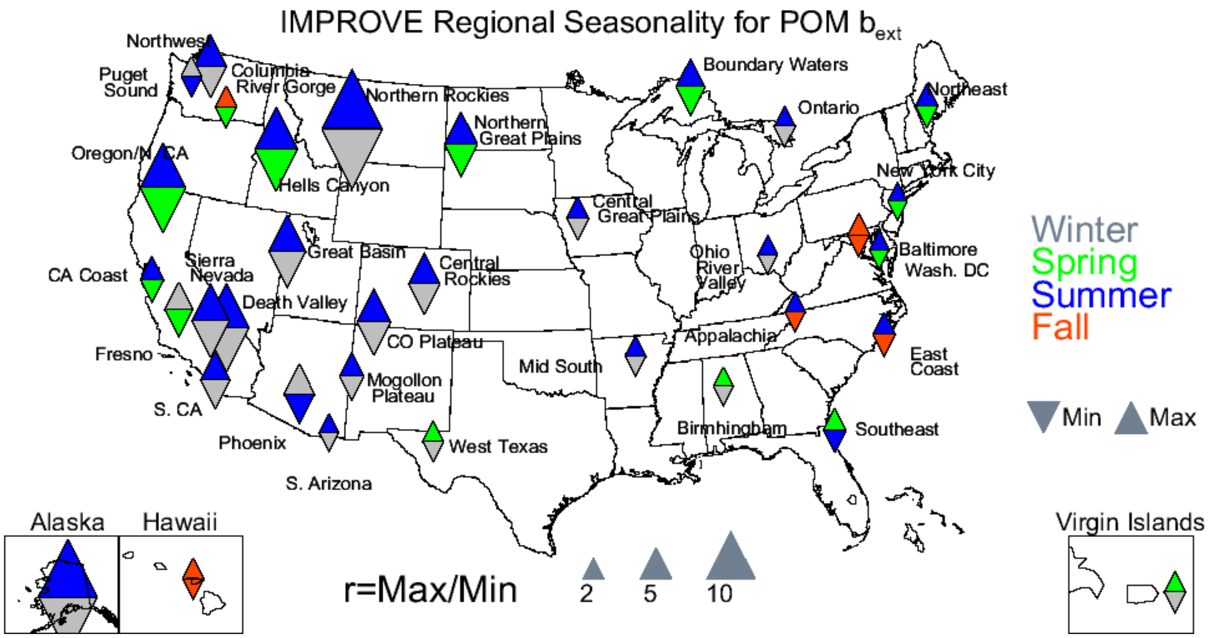

Figure 5.3.1. Seasonal variability for IMPROVE 2005–2008 monthly mean regional particulate organic matter (POM) light extinction coefficients (b_{ext}). The color of the upward pointing triangle refers to the season with the maximum monthly mean concentration and the downward pointing triangle refers to the season with the minimum monthly mean concentration. The size of the triangles refers to the magnitude of the ratio of maximum to minimum monthly mean mass concentration.

CSN urban regions were associated with higher b_{ext_POM} compared to rural regions. In the eastern United States the b_{ext_POM} values approached 20 Mm^{-1} or higher and were fairly steady year round (Figure 5.1.8). However, in the southwestern United States b_{ext_POM} increased during winter months at several regions (e.g., Albuquerque, Phoenix/Tucson, Las Vegas, San Diego, San Francisco, Sacramento/San Joaquin Valley, Figure 5.1.6). Estimates of urban b_{ext_POM} in the southwestern United States were also higher than in rural regions in the same area. The magnitudes of urban b_{ext_POM} were often greater than rural b_{ext_POM} in the northwestern United States also (Figure 5.1.7), but seasonal patterns were very different. Values of urban b_{ext_POM} increased during winter months for most regions, with the exception of the North Dakota region. Different seasonal patterns also occurred at urban versus rural OCONUS regions (Figure 5.1.9), as did higher magnitudes of b_{ext_POM}. Higher b_{ext_POM} corresponded to winter months in the Alaska region and during fall in the Hawaii region. The range in b_{ext_POM} at CSN regions was similar to the urban IMPROVE regions, with a minimum of 1.83 Mm^{-1} in the Hawaii region in January and a maximum of 66.94 Mm^{-1} in the Alaska region in December.

The seasonality for CSN regions did not correspond to high summer maxima as did IMPROVE rural regions. In fact, many regions actually corresponded to winter maxima, just as did the CSN POM monthly mean mass concentrations (Figure 5.3.2). The urban regions corresponded to a lower degree of seasonality in b_{ext_POM} compared to the rural regions (compare Figure 5.3.2 and Figure 5.3.1). Seven regions did not experience significant seasonality (ratio < 2). The maximum to minimum ratios ranged from 1.5 in the Ohio River Valley region to 16.13 in the Alaska region. The urban and rural differences in the seasons corresponding to the maximum b_{ext_POM} suggested different sources contributing to POM, with rural summer maxima most likely associated with wildfire and biogenic emissions and urban winter maxima likely associated with local urban sources.

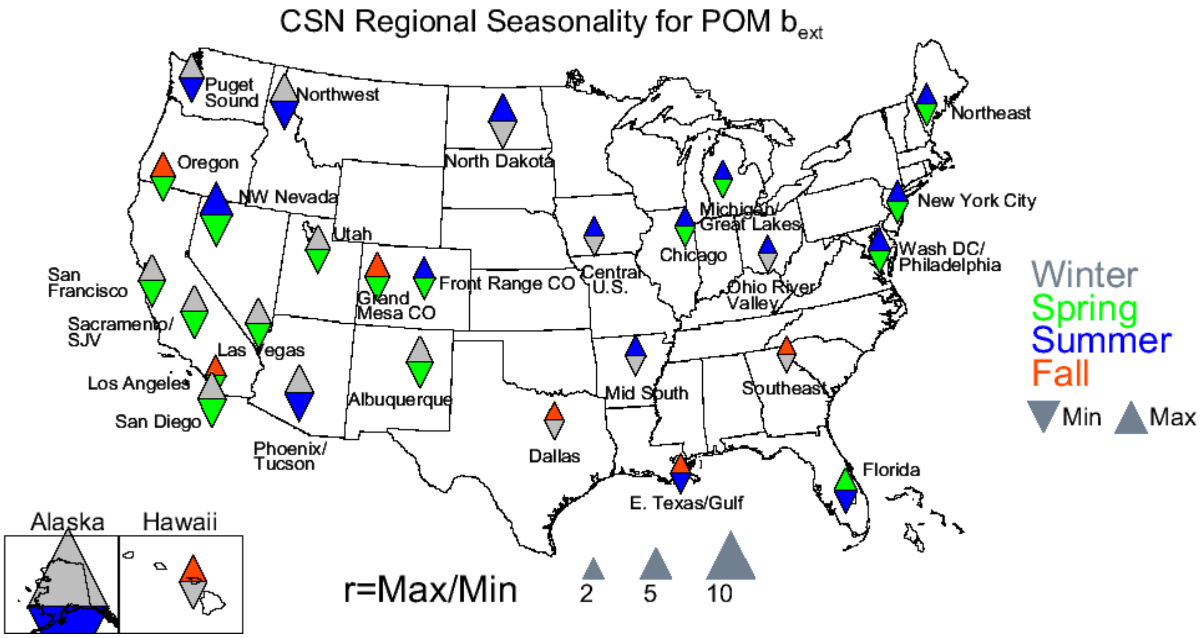

Figure 5.3.2. Seasonal variability for CSN 2005–2008 monthly mean regional particulate organic matter (POM) light extinction coefficients (b_{ext}). The color of the upward pointing triangle refers to the season with the maximum monthly mean concentration and the downward pointing triangle refers to the season with the minimum monthly mean concentration. The size of the triangles refers to the magnitude of the ratio of maximum to minimum monthly mean mass concentration.

Although the patterns of b_{ext_POM} were similar to those of POM mass concentrations, its relative contributions to reconstructed b_{ext} were not because of the hygroscopic and optical properties of other species contributing to b_{ext}. For example, in the eastern United States the b_{ext_POM} fraction was generally lower than the POM mass fraction at several IMPROVE regions (compare Figures 5.1.12 and 4.1.11), probably due to the increased importance of hygroscopic AS on b_{ext}. The percent contribution of POM to b_{ext} was fairly constant year round at most eastern regions, except for the Boundary Waters, Northern Great Plains, and Central Great Plains regions, which had higher contributions during summer. Contributions of POM to b_{ext} were significant for many northwestern U.S. regions. The relative b_{ext_POM} values were generally lower than POM mass fraction for these regions (compare Figure 5.1.14 to Figure 4.1.12). In the summer, POM was the dominant contributor to b_{ext} at the Hells Canyon, Northern Rocky Mountains, Northern Great Plains, and Oregon/Northern California regions. POM contributions to b_{ext} were typically 20–30% at most southwestern U.S. regions (Figure 5.1.13). Higher fractions during summer months occurred at the Sierra Nevada, Great Basin, Central Rocky Mountains, Colorado Plateau, Mogollon Plateau, and Death Valley regions. Other regions, such as the West Texas, Southern Arizona, Southern California, and California Coast regions corresponded to relatively flat seasonal patterns. The Alaska region was the only OCONUS region that had considerable contributions of POM to b_{ext}. These contributions peaked in summer and dropped off fairly rapidly in fall (Figure 5.1.11). Relative contributions of POM to b_{ext} were fairly low (~10% or less) in the Hawaii and Virgin Islands regions. The IMPROVE mean fractional contribution of POM to b_{ext} ranged from 2.6% in the Virgin Islands in July to 72.9% in the Northern Rocky Mountains region in August.

The rural IMPROVE POM b_{ext} fraction did not exhibit a high degree of seasonality (Figure 5.3.3). Nearly half of the regions had maximum to minimum ratios less than 2. The maximum ratio occurred in the IMPROVE Alaska region (6.0) and the minimum in the Puget Sound (1.2) and Northeast regions (1.2). The relative b_{ext_POM} had a much lower degree of seasonality compared to absolute b_{ext_POM} (see Figure 5.3.1), especially in the western United States. Summer maxima were still the most common, but in some rural regions, such the Hawaii, Southern California, Mid South, Appalachia, Ohio River Valley, and Virgin Islands and many northwestern U.S. regions, the seasons corresponding to the maximum relative b_{ext_POM} changed from the maximum seasons corresponding to absolute b_{ext_POM}.

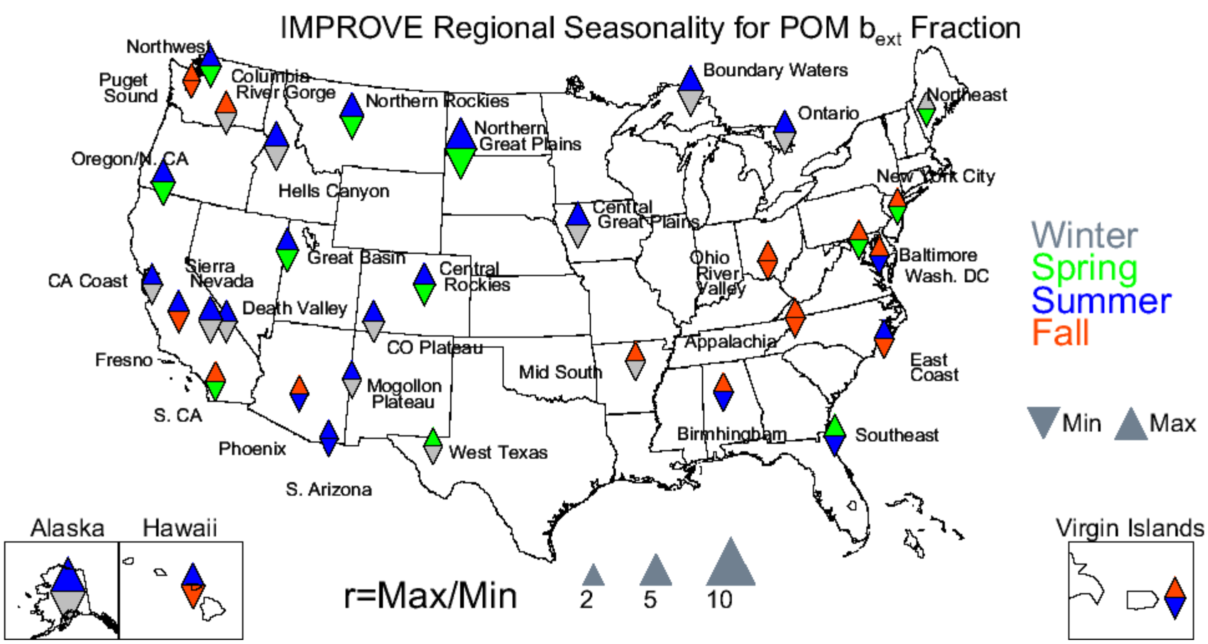

Figure 5.3.3. Seasonal variability for IMPROVE 2005–2008 monthly mean regional particulate organic matter (POM) light extinction coefficient (b_{ext}) fractions. The color of the upward pointing triangle refers to the season with the maximum monthly mean concentration and the downward pointing triangle refers to the season with the minimum monthly mean concentration. The size of the triangles refers to the magnitude of the ratio of maximum to minimum monthly mean mass concentration.

Of the CSN urban regions, the contribution of POM to b_{ext} was 6.6% in the North Dakota region in February compared to the highest at the Northwest Nevada region in July (73.2%). POM contributed significantly to b_{ext} at many southwestern urban regions (Figure 5.1.18). Percent contributions of 40% year round were typical at the Las Vegas, Phoenix/Tucson, Albuquerque, and Grand Mesa CO regions. Contributions of POM to b_{ext} were less (~20%) farther west, such as at regions in California. Contributions increased during summer months in the Sacramento/San Joaquin Valley, Northwest Nevada, and Utah regions; elsewhere the contributions were fairly constant year round. POM contributions to b_{ext} at urban regions were higher than at rural regions (compare to Figure 5.1.13). Urban POM contributions to b_{ext} in the northwestern United States were similar to the regions in the southwest United States, with values of ~40% or less (Figure 5.1.17). The Northwest region was the exception where contributions reached up to 60% during summer months. The North Dakota region had the most pronounced seasonal variability; contributions were fairly flat in the other northwestern U.S. regions. POM contributions to b_{ext} generally were lower than its contributions to RCFM in the northwestern United States (compare to Figure 4.1.12). Relative b_{ext_POM} values were lower at eastern U.S. regions compared to northwestern and southwestern U.S. regions (Figure 5.1.16). Values of 20% or less were typical and, with the exception of regions toward the central United States (e.g., Chicago and Central U.S.), the contributions were fairly flat seasonally. AS was the main contributor to b_{ext} in the eastern United States, followed by POM or AN, depending on the month. Finally, contributions of POM to b_{ext} were much higher at the Alaska region compared to the Hawaii region (Figure 5.1.19). Values near 40% were typical during most months at the Alaska region, except during summer when they increased to ~60%. This pattern was in contrast to the seasonal pattern in absolute b_{ext_POM}, with higher values during winter months.

More than half of the CSN regions did not experience significant seasonality with the contribution of POM to b_{ext}. The largest ratio occurred in the North Dakota region (6.5) compared to smallest in the Las Vegas region (1.3). The seasons corresponding to the maximum and minimum were different for many regions when comparing the seasonal patterns in relative b_{ext_POM} (Figure 5.3.4) to absolute b_{ext_POM} (Figure 5.3.2). While many urban regions corresponded to winter maxima in absolute b_{ext_POM}, the maximum in relative b_{ext_POM} switched to summer at many regions (such as in the previous example of the Alaska region).

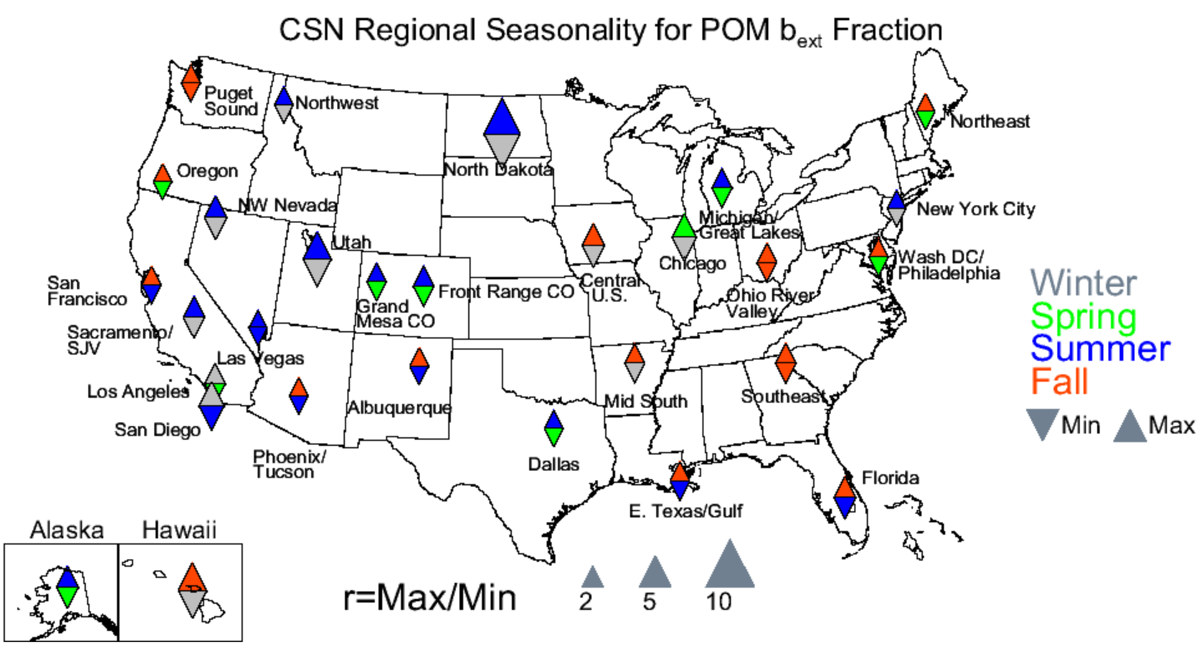

Figure 5.3.4. Seasonal variability for CSN 2005–2008 monthly mean regional particulate organic matter (POM) light extinction coefficient (b_{ext}) fractions. The color of the upward pointing triangle refers to the season with the maximum monthly mean concentration and the downward pointing triangle refers to the season with the minimum monthly mean concentration. The size of the triangles refers to the magnitude of the ratio of maximum to minimum monthly mean mass concentration.

5.4 $PM_{2.5}$ LIGHT ABSORBING CARBON LIGHT EXTINCTION COEFFICIENT

As we saw in the Chapter 4, the monthly mean LAC mass concentrations were relatively low compared to other species, and urban concentrations were generally higher than rural concentrations. Recall that LAC light extinction coefficients (b_{ext_LAC}) were computed by scaling the LAC mass by its extinction efficiency (10 m^2 g^{-1}), which is higher than the other species, due to its ability to both scatter and absorb visible light. This higher extinction efficiency increased LAC's relative contribution to b_{ext} compared to RCFM.

The rural IMPROVE 2005–2008 regional monthly mean LAC light extinction coefficient (b_{ext_LAC}) ranged from 0.24 Mm^{-1} in the Hawaii region in July to 5.67 Mm^{-1} in the Northern Rocky Mountain region in August (roughly half of the contribution by Rayleigh scattering). The maximum urban IMPROVE regional mean b_{ext_LAC} was considerably higher (26.88 Mm^{-1} in Phoenix in December). Values of b_{ext_LAC} at rural southwestern U.S. regions were much lower (<5 Mm^{-1}) than at the urban site of Phoenix (Figure 5.1.3). However, the magnitudes of b_{ext_LAC} were greater relative to other species compared to that for LAC mass concentrations (Figure 4.1.3). Higher b_{ext_LAC} values during summer months were common (e.g., the Sierra Nevada, Great Basin, Central Rocky Mountains, Colorado Plateau, and Death Valley regions), but a few regions lacked strong seasonality (e.g., Southern California, Southern Arizona, and West Texas). Values of b_{ext_LAC} for regions in the northwestern United States were similar in magnitude to regions in the southwestern United States (Figure 5.1.2). Higher b_{ext_LAC} occurred during summer months for all of the regions with the exception of the Columbia River Gorge region. Relatively high b_{ext_LAC} values during summer months, such as those at the Northern Rocky Mountains and Hells Canyon regions, were most likely associated with wildfire emissions. LAC extinction coefficients were also relatively low in the eastern U.S. regions (~5 Mm^{-1} or less, Figure 5.1.1). The higher values of b_{ext_LAC} in summer months that occurred for many western U.S. regions did not occur for regions in the eastern United States; in fact, b_{ext_LAC} increased during fall and winter months. In addition, b_{ext_LAC} values were fairly constant year round. With the exception of the Alaska region during summer, the b_{ext_LAC} values were negligible at the OCONUS regions (Figure 5.1.4).

The seasons corresponding to maximum and minimum monthly mean b_{ext_LAC} at IMPROVE regions were the same as for LAC mass concentrations (compare Figure 5.4.1 to Figure 4.4.1), with the exception of the Virgin Islands region due to treatment of missing data in the calculation of b_{ext} (see Chapter 3). LAC mass concentrations and b_{ext_LAC} also demonstrated the same level of seasonality. Just over a third of the regions did not exhibit significant seasonality. The largest maximum to minimum ratio occurred in the Northern Rocky Mountains region (7.4), compared to the smallest in the Ohio River Valley region (1.3).

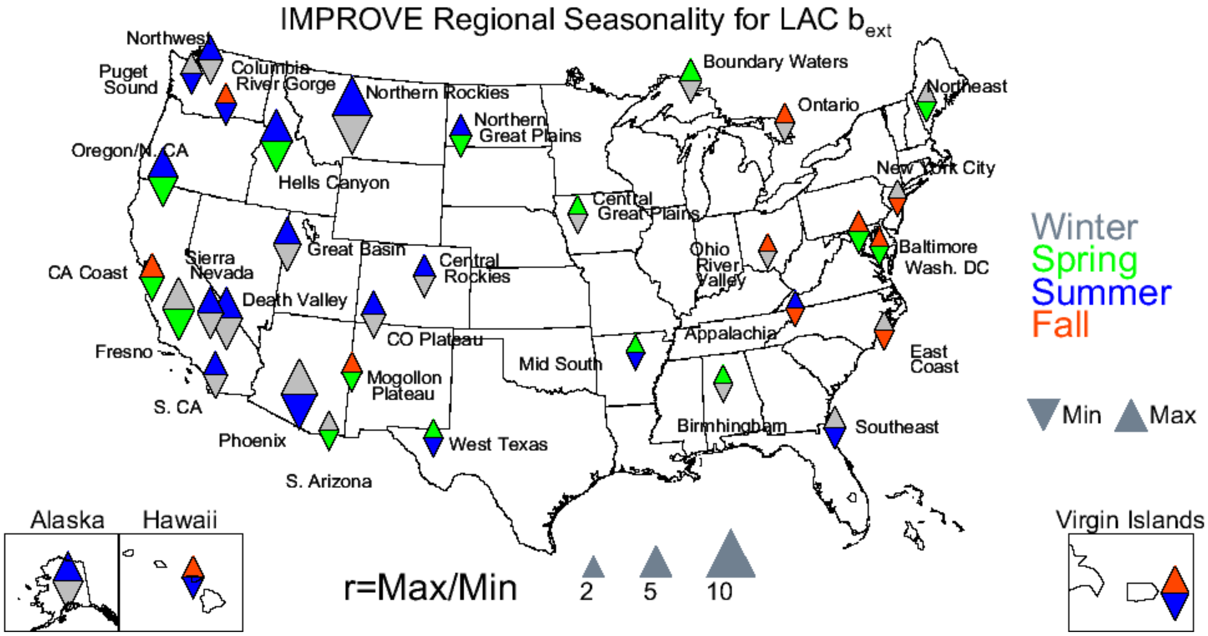

Figure 5.4.1. Seasonal variability for IMPROVE 2005–2008 monthly mean regional light absorbing carbon (LAC) light extinction coefficients (b_{ext}). The color of the upward pointing triangle refers to the season with the maximum monthly mean concentration and the downward pointing triangle refers to the season with the minimum monthly mean concentration. The size of the triangles refers to the magnitude of the ratio of maximum to minimum monthly mean mass concentration.

Urban CSN regional mean b_{ext_LAC} values were similar to the urban IMPROVE regions, ranging from 1.59 Mm^{-1} in the North Dakota region in May to 29.15 Mm^{-1} in the Alaska region in December. The CSN b_{ext_LAC} values in the Alaska region were much higher than those in the IMPROVE regions and peaked in winter months rather than in summer months (Figure 5.1.9). Values of b_{ext_LAC} at the urban Hawaii region were also considerably higher than at the rural regions. The highest b_{ext_LAC} values in the eastern United States occurred at the New York City region (~20 Mm^{-1}, Figure 5.1.8). However, in general the b_{ext_LAC} values were near 10 Mm^{-1} at most eastern regions and fairly constant year round. Urban b_{ext_LAC} values were higher than rural b_{ext_LAC} at most regions in the same vicinity. LAC extinction coefficients were around 10 Mm^{-1} and generally peaked in winter months at regions in the northwestern United States (Figure 5.1.7). This seasonal pattern was opposite to that for rural regions, where b_{ext_LAC} peaked during summer months, and suggested urban sources of LAC that were mostly likely localized and related to combustion emissions. Values of b_{ext_LAC} in the southwestern United States were comparable to b_{ext} from other species at several regions (e.g., Front Range CO, Grand Mesa CO, Albuquerque, Phoenix/Tucson, and Las Vegas, Figure 5.1.6). In contrast, LAC mass concentrations were typically much lower than mass concentrations of other species (see Figure 4.1.7). Winter months were often associated with higher b_{ext_LAC}, and urban b_{ext_LAC} values were higher than rural b_{ext_LAC} values in the southwestern United States (compare to rural b_{ext_LAC} in Figure 5.1.3).

The seasons corresponding to maximum and minimum monthly mean urban b_{ext_LAC} were exactly the same as for urban LAC mass concentrations (compare Figure 5.4.2 to Figure 4.4.2). However, the urban versus rural seasonal patterns were very different. Most urban maxima occurred in fall or winter, most likely associated with residential heating or other urban emissions. These regions did not exhibit a high degree of seasonality; the highest levels of seasonality occurred in western U.S. regions and in the Alaska region, where the maximum b_{ext_LAC} was 8.0 times higher than the minimum. The lowest ratio occurred in New York City, where the maximum was only 1.4 times higher than the minimum b_{ext_LAC}.

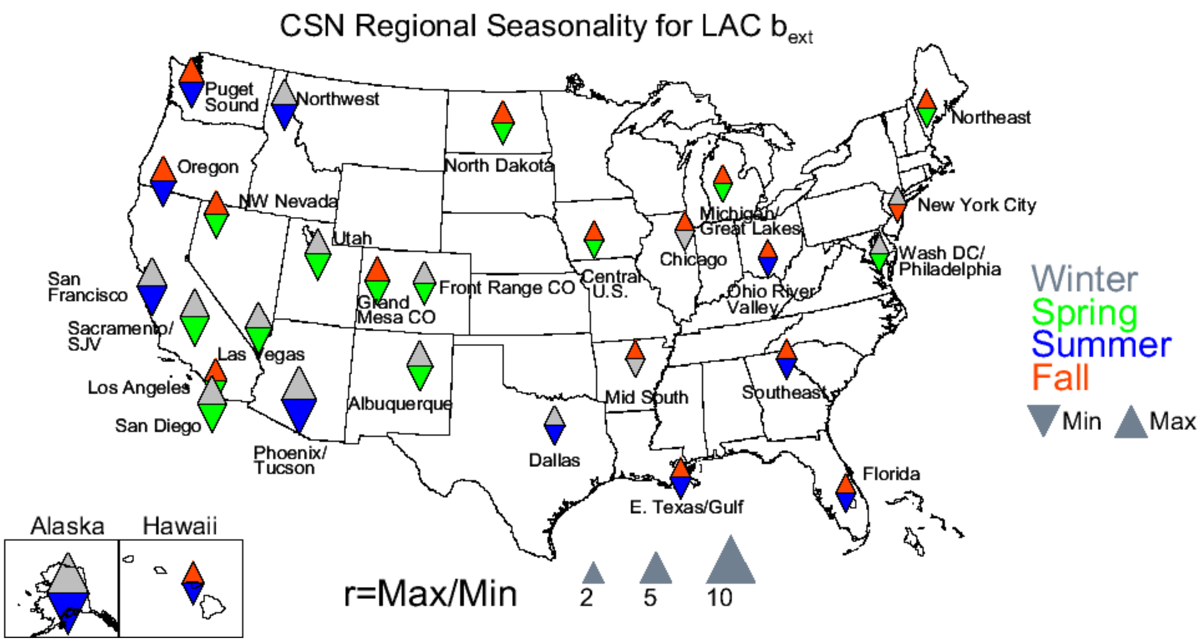

Figure 5.4.2. Seasonal variability for CSN 2005–2008 monthly mean regional light absorbing carbon (LAC) light extinction coefficients (b_{ext}). The color of the upward pointing triangle refers to the season with the maximum monthly mean concentration and the downward pointing triangle refers to the season with the minimum monthly mean concentration. The size of the triangles refers to the magnitude of the ratio of maximum to minimum monthly mean mass concentration.

The contribution of LAC to b_{ext} was higher than its contribution to RCFM at most IMPROVE eastern U.S. regions (compare Figure 5.1.12 to Figure 4.1.11). The higher contribution to b_{ext} was due to the high extinction efficiency of LAC compared to the extinction efficiencies of other relatively low mass concentration species (e.g., soil). Contributions were less than 10% at most eastern IMPROVE regions (e.g., Appalachia, Southeast, and East Coast, among others) and higher in fall and winter. Somewhat higher LAC contributions to b_{ext} occurred for southwestern U.S. regions (Figure 5.1.13), including the highest in the United States at the rural Mogollon Plateau region (16.2% in December) and the urban Phoenix site in November (29.1%). Lower contributions also occurred at southwestern U.S. regions, such as California Coast and West Texas. LAC contributions to b_{ext} were considerably higher than its contributions to RCFM at regions in the southwestern United States (Figure 4.1.13). LAC contributed more significantly to b_{ext} than RCFM in the northwestern United States as well (e.g., the Northern Rocky Mountains, Hells Canyon, and Oregon/Northern California regions, Figure 5.1.14). Relative b_{ext_LAC} contributions of 10% or more were common at most regions and fairly steady year round. Contributions of LAC to b_{ext} were greater than its contributions to RCFM in the eastern United States also (Figure 5.1.12). Estimates of 10% or less were typical at most regions. Of the OCONUS regions, the Alaska region had the highest b_{ext_LAC} contributions (Figure 5.1.11). The Hawaii and Virgin Islands regions had the lowest b_{ext_LAC} contributions of any in the

United States; in fact, the smallest contribution occurred at the Virgin Islands region in July (0.97%).

The relative b_{ext_LAC} had a much lower degree of seasonality compared to absolute b_{ext_LAC}, especially in the western United States (e.g., the Northern Rocky Mountains region, compare Figure 5.4.3 to Figure 5.4.1). The maximum ratio occurred in the Virgin Islands (5.2) and the minimum ratio occurred at the Puget Sound (1.4) and Northwest regions (1.5). Summer minima were common in the eastern and some southwestern U.S. regions. Although the degree of seasonality of relative b_{ext_LAC} was similar to its relative contribution to RCFM (Figure 4.4.3), the seasons corresponding to maxima and minima were different for many regions, especially in the western United States. While LAC mass fractions were typically higher in winter months for many regions, the b_{ext_LAC} fraction was highest in summer, as was absolute b_{ext_LAC} (e.g., the Great Basin, Fresno, Sierra Nevada, Northwest, and Hells Canyon regions). These differences were mostly likely a reflection of the changes in seasonal behavior of other species as well. For example, species that may be more important on a mass basis, like soil, may be less important optically.

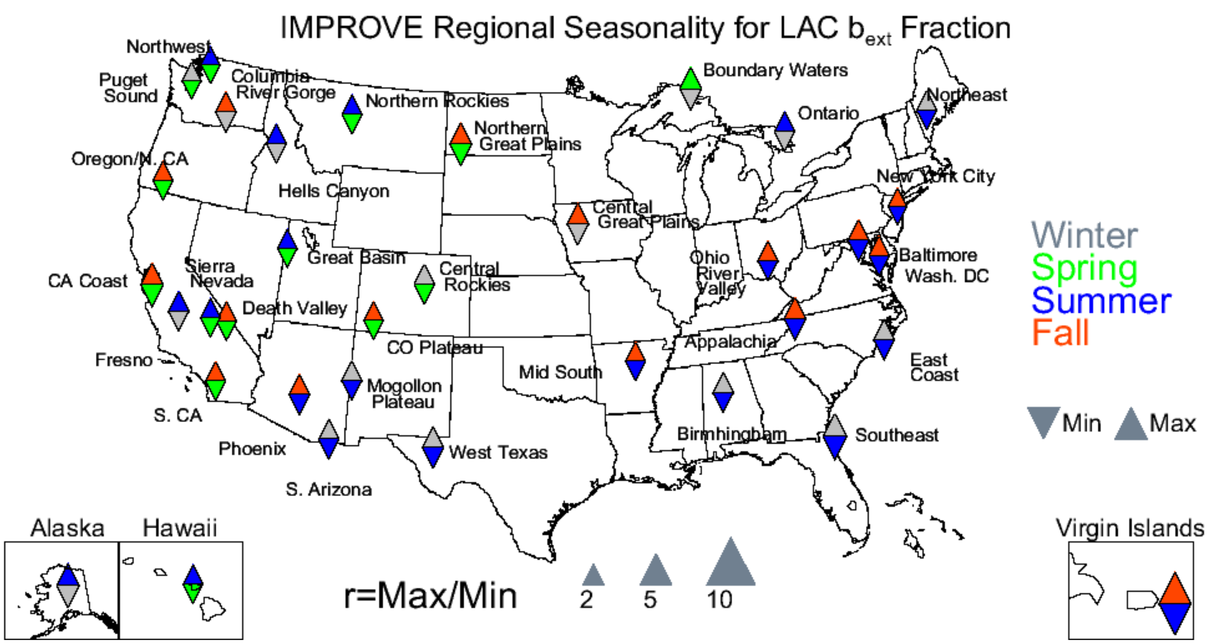

Figure 5.4.3. Seasonal variability for IMPROVE 2005–2008 monthly mean regional light absorbing carbon (LAC) light extinction coefficient (b_{ext}) fractions. The color of the upward pointing triangle refers to the season with the maximum monthly mean concentration and the downward pointing triangle refers to the season with the minimum monthly mean concentration. The size of the triangles refers to the magnitude of the ratio of maximum to minimum monthly mean mass concentration.

CSN urban contributions of LAC to b_{ext} were considerably higher than rural contributions to b_{ext}. For example, in the southwestern United States, contributions of 20% or greater were common at most regions (Figure 5.1.18). The highest contribution in the United States occurred at the Las Vegas region in October (39.2%). In comparison, rural contributions were ~10% or less in the southwestern United States. Regions in California (e.g., Sacramento, San Francisco, Los Angeles, and San Diego) had lower contributions compared to those regions farther east, such as the Northwest Nevada, Front Range CO, Grand Mesa CO, Albuquerque, Las Vegas, and

Phoenix/Tucson regions. Contributions of LAC to b_{ext} were somewhat lower in the northwestern United States, with values less than 20% year round (Figure 5.1.17). However, relative b_{ext_LAC} values were still higher than its contributions to RCFM in the northwestern United States (Figure 4.1.17). The lowest contributions in the United States occurred at the North Dakota region in March (4.5). Urban b_{ext_LAC} contributions at eastern U.S. regions were lower than other sections in the United States. Estimates of relative b_{ext_LAC} were typically 10% or less (Figure 5.1.16). LAC contributions to b_{ext} were higher than its contributions to RCFM in the eastern United States but not to the same degree as in other regions, probably because of the dominance of other species such as AS, AN, and POM. Urban OCONUS regions corresponded to significantly higher relative b_{ext_LAC} values compared to rural regions (Figure 5.1.19 compared to Figure 5.1.11). In the Alaska region the contributions were greater than 20% in spring and fall. In the Hawaii region the contributions ranged from 10 to 20%.

The urban contributions to b_{ext} from LAC did not exhibit a strong seasonality (Figure 5.4.4). The lowest maximum to minimum ratio occurred at the Las Vegas region (1.5) compared to the largest at the North Dakota region (3.5). The relative contribution of b_{ext_LAC} was less seasonal than absolute b_{ext_LAC} for several regions in the western United States, suggesting LAC had fairly steady contributions to b_{ext} for many regions. The contributions of LAC to b_{ext} generally were highest in the fall and lowest during winter, spring and summer.

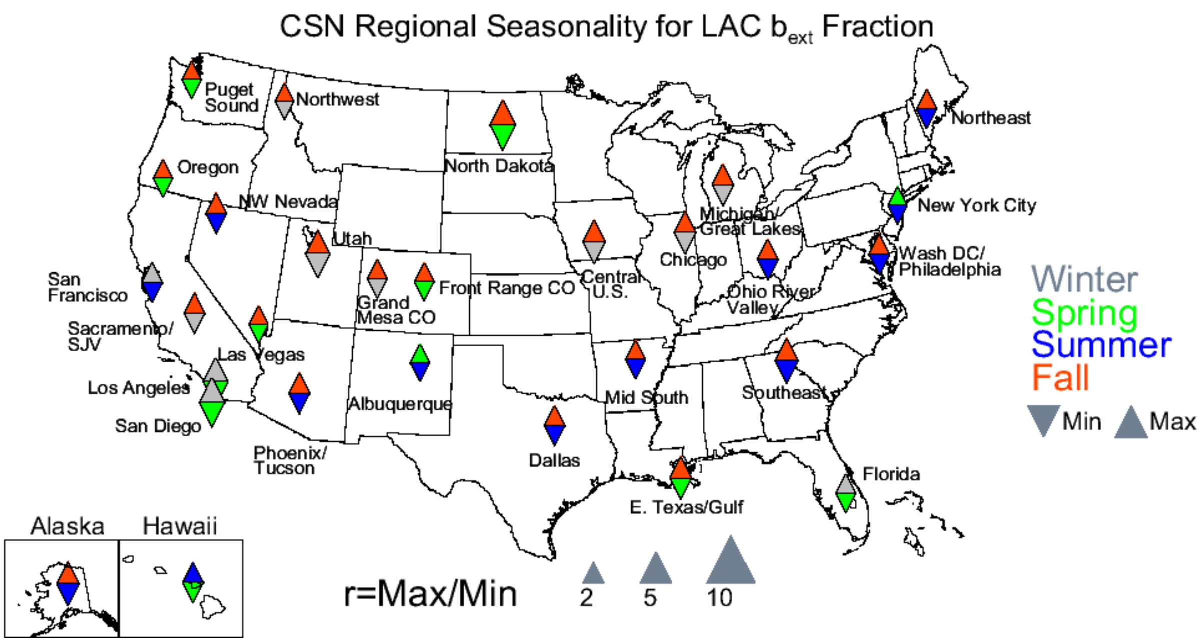

Figure 5.4.4. Seasonal variability for CSN 2005–2008 monthly mean regional light absorbing carbon (LAC) light extinction coefficient (b_{ext}) fractions. The color of the upward pointing triangle refers to the season with the maximum monthly mean concentration and the downward pointing triangle refers to the season with the minimum monthly mean concentration. The size of the triangles refers to the magnitude of the ratio of maximum to minimum monthly mean mass concentration.

5.5 $PM_{2.5}$ SOIL LIGHT EXTINCTION COEFFICIENTS

Recall from section 3.1 that the soil extinction efficiency used to compute b_{ext_soil} in the IMPROVE algorithm was 1 $m^2\ g^{-1}$. The soil extinction efficiency is lower than for most other species and soil is nonhygroscopic; therefore light extinction coefficients from soil, b_{ext_soil}, were the same as the soil mass concentrations, as were its seasonal and regional patterns. However, the magnitude of b_{ext} might change relative to other species, as well as its relative contribution to b_{ext}. The IMPROVE 2005–2008 regional monthly mean b_{ext_soil} ranged from 0.049 Mm^{-1} in the Alaska region in September to 5.54 Mm^{-1} in the Virgin Islands in June. Long-distance transport of dust from North Africa in summer is well documented and the likely reason for high soil concentrations and consequent light extinction in summer in the Virgin Islands. Light extinction coefficients due to soil were negligible at other OCONUS regions (Figure 5.1.4). However, several regions in the southwestern United States were associated with non-negligible b_{ext_soil}, especially relative to b_{ext} from other species (Figure 5.1.3). The highest values of b_{ext_soil} in the southwestern United States were at the Southern Arizona region, due to high soil mass concentrations at that region. The Death Valley, Central Rocky Mountains, Great Basin, and Colorado Plateau and Mogollon Plateau regions all had higher b_{ext_soil}, especially during spring months. Regions farther west, such as the Sierra Nevada, California Coast, and Southern California regions, had relatively low b_{ext_soil}, less than 5 Mm^{-1}. Light extinction coefficients due to soil at northwestern U.S. regions were lower still, only 1–2 Mm^{-1} at most regions (Figure 5.1.2). The Northwest and Oregon/Northern California regions had the lowest values year round. Similar to the northwestern United States, values of b_{ext_soil} in the eastern United States were negligible compared to other species. With the exception of the Northern Great Plains, Mid South, and Southeast regions, the values were not visible on the bar charts (Figure 5.1.1).

The highest monthly mean b_{ext_soil} occurred most frequently in summer for IMPROVE regions (Figure 5.5.1). These regions were located in the central and eastern United States, as well as a few regions in the western United States (e.g., Puget Sound, Columbia River Gorge, Hells Canyon, Northern Rocky Mountains, Great Basin, Northern Great Plains, and Phoenix). Spring maxima occurred at regions along the western coast and in the southwestern United States. Winter maxima occurred at the Alaska region, but generally most regions were associated with winter minima. As expected, the seasons corresponding to the maximum and minimum b_{ext_soil} were exactly the same as for the soil mass concentrations (Figure 4.5.1). Light extinction coefficients from soil were strongly seasonal, with only four regions having maximum to minimum ratios less than 2. The largest ratio occurred in the Virgin Islands (28.9) compared to the lowest in the New York City region (1.6) (2.3 in the rural Northeast region). In general IMPROVE regions in the eastern United States had lower degrees of seasonality (with the exception of the Southeast region) compared to most western U.S. regions.

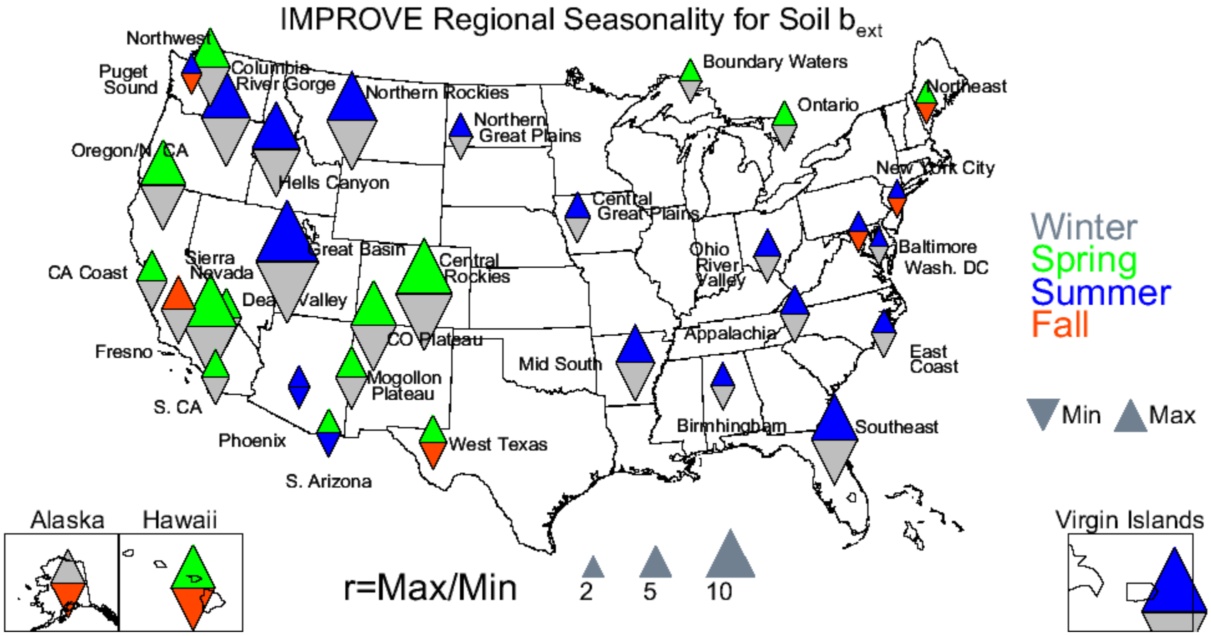

Figure 5.5.1. Seasonal variability for IMPROVE 2005–2008 monthly mean regional soil light extinction coefficients (b_{ext}). The color of the upward pointing triangle refers to the season with the maximum monthly mean concentration and the downward pointing triangle refers to the season with the minimum monthly mean concentration. The size of the triangles refers to the magnitude of the ratio of maximum to minimum monthly mean mass concentration.

The CSN maximum regional monthly mean b_{ext_soil} was lower than the maximum value for the IMPROVE network (recall the relative bias in soil mass concentrations between the two networks, with IMPROVE having higher soil concentrations; see section 1.4). The CSN maximum value of 2.55 Mm^{-1} occurred in the Phoenix region in April compared to the lowest value of 0.089 Mm^{-1} in the Hawaii region in September. Similar to the rural regions, b_{ext_soil} was negligible at eastern U.S. regions (Figure 5.1.8). Only at the Florida, East Texas/Gulf, Dallas, and Mid South regions were the values of b_{ext_soil} even visible on the bar charts. Light extinction coefficients due to soil at these regions were most likely due to long-range transport of dust during summer. The relative values of b_{ext} for all species in the southwestern United States demonstrated that, while a species may contribute significantly to RCFM, it may not contribute as significantly to b_{ext} because it is not as optically efficient as other species. For example, recall that soil mass concentrations were fairly significant and comparable to or larger than LAC mass concentrations at some urban regions in the southwestern United States (Figure 4.1.7). The effects of the larger extinction efficiency for LAC compared to that for soil were obvious in magnitudes of b_{ext} in Figure 5.1.6. For most regions, the b_{ext_soil} values were much lower than b_{ext_LAC}. A similar pattern was observed at the regions in the northwestern United States (Figure 5.1.7). Soil mass concentrations that were easily viewed on the bar charts for the North Dakota and Northwest regions were no longer visible on the associated b_{ext_soil} bar charts. Of the OCONUS regions, very low b_{ext_soil} values occurred at the Hawaii region during spring months, but values of b_{ext_soil} were not even visible on the Alaska region bar chart (Figure 5.1.9).

Many CSN regions had maximum b_{ext_soil} in summer in the eastern United States, as well as at a few western U.S. regions (e.g., North Dakota, Utah, Las Vegas, Oregon, and Northwest, Figure 5.5.2). A few spring maxima occurred for eastern U.S. regions (e.g., Northeast, New York

City, Michigan/Great Lakes, and Chicago) and in the western United States (Grand Mesa CO, Front Range CO, Albuquerque, Phoenix/Tucson, Northwest Nevada, Puget Sound, and Hawaii). Only a few regions in California corresponded to fall maxima. Most regions corresponded to winter minima. Urban regions were also strongly seasonal, with only seven regions having maximum to minimum monthly mean b_{ext_soil} ratios less than 2. The maximum ratio occurred in the Florida region (8.2) compared to 1.5 in the New York City region. In general urban regions corresponded to a lower degree of seasonality compared to the rural regions, especially in the West (see Figure 5.5.1).

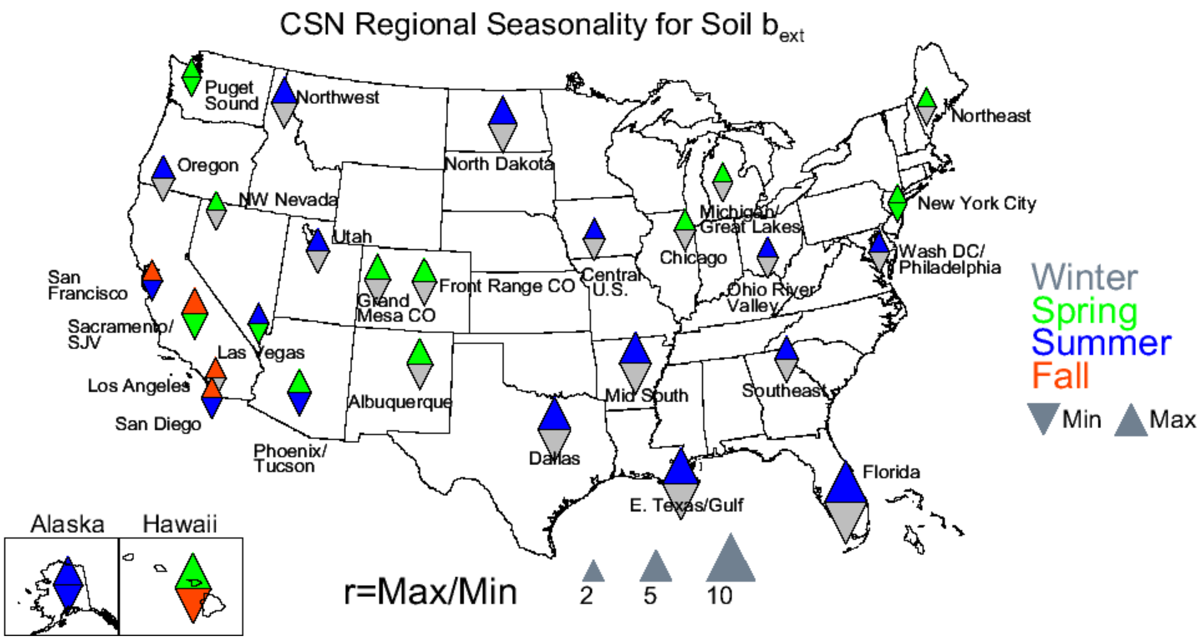

Figure 5.5.2. Seasonal variability for CSN 2005–2008 monthly mean regional soil light extinction coefficients (b_{ext}). The color of the upward pointing triangle refers to the season with the maximum monthly mean concentration and the downward pointing triangle refers to the season with the minimum monthly mean concentration. The size of the triangles refers to the magnitude of the ratio of maximum to minimum monthly mean mass concentration.

As was expected from the discussion of Figure 5.1.1, relative contributions of soil to b_{ext} in the eastern United States were negligible at most rural regions. Relative b_{ext_soil} reached a few percent at the Southeast, Mid South, Central Great Plains, and Northern Great Plains IMPROVE regions (Figure 5.1.12). In contrast, soil mass contributions to RCFM reached 10–20% at these same regions, depending on time of year (Figure 4.1.11). Compared to the eastern United States, soil contributions to b_{ext} were higher in the southwestern United States and reached up to 15–20%, especially during spring months at the Death Valley, Southern Arizona, West Texas, Mogollon Plateau, Colorado Plateau, Central Rocky Mountains, and Great Basin regions (Figure 5.1.13). However, at these same regions soil mass contributed up to 50% to RCFM. At the Sierra Nevada, California Coast, and Southern California regions the relative b_{ext_soil} values were comparable to regional mean values in the eastern United States. Contributions of only a few percent were common at northwestern U.S. regions. The highest relative b_{ext_soil} occurred at the Hells Canyon, Northern Great Plains, Northern Rocky Mountains, and Columbia River Gorge regions, where contributions of 5–10% were more likely during spring and summer months (Figure 5.1.14). Soil contributions to b_{ext} increased to ~20% at the Virgin Islands region during summer (Figure 5.1.11); however, its contribution to RCFM was near 60% during the same months (Figure 4.1.14). Relative b_{ext_soil} values were low at other OCONUS regions. The maximum contribution of soil to b_{ext} in rural regions occurred in the Southern Arizona region in April (23.7%). The lowest contribution occurred at the Ontario (Egbert) region (0.26% in December).

Contributions to b_{ext} from soil were typically highest in the spring for IMPROVE regions. The seasons corresponding to the maximum and minimum in monthly mean relative b_{ext_soil} were different than for its maximum and minimum contributions to RCFM at some regions (compare Figure 5.5.3 to 4.5.3). Although the seasons at the OCONUS regions remained the same, many other regions shifted when comparing the seasonality of relative b_{ext_soil} to soil mass fractions (e.g., the Fresno, Phoenix, Birmingham, Ohio River Valley, and East Coast regions). However, the shift in seasons occurred at a larger number of regions for relative b_{ext_soil} compared to absolute b_{ext_soil} (e.g., the Hells Canyon, Northern Rocky Mountains, and Great Basin regions, among others; compare Figures 5.5.3 and 5.5.1). Many regions shifted from summer maxima in absolute b_{ext_soil} to spring maxima for relative b_{ext_soil}. Most regional minima still occurred during winter for relative b_{ext_soil}. Strong seasonality in relative b_{ext_soil} was associated with IMPROVE regions, with only three regions having maximum to minimum ratios less than 2. The highest occurred in the IMPROVE urban site of Fresno (22.4) and the rural Columbia River Gorge region (17.5). The lowest occurred in the rural East Coast region (1.9) and New York City region (1.6). The regions with the highest degrees of seasonality changed for absolute b_{ext_soil} compared to relative b_{ext_soil}, especially for southwestern U.S. regions (e.g., Fresno, Colombia River Gorge, and Great Basin, among others).

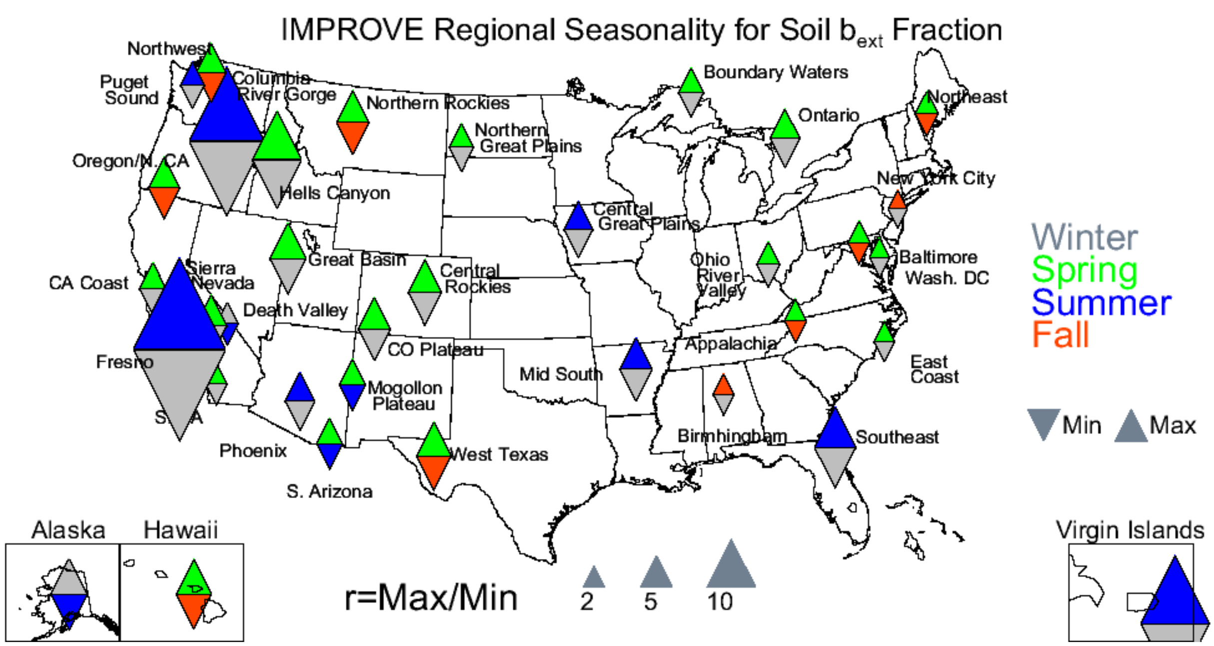

Figure 5.5.3. Seasonal variability for IMPROVE 2005–2008 monthly mean regional soil light extinction coefficient (b_{ext}) fractions. The color of the upward pointing triangle refers to the season with the maximum monthly mean concentration and the downward pointing triangle refers to the season with the minimum monthly mean concentration. The size of the triangles refers to the magnitude of the ratio of maximum to minimum monthly mean mass concentration.

The highest urban CSN contribution of soil to b_{ext} also occurred in the Phoenix/Tucson region in April (8.9%), a factor of 2.5 less than the maximum contribution at rural regions. The lowest contribution occurred in the Alaska region in December (0.23%). During spring months in the Alaska region, the soil contribution to b_{ext} was a few percent, larger than at any time of the year in the Hawaii region (Figure 5.1.19). Low relative contributions were also common at eastern U.S. regions. With the exception of the Florida, East Texas/Gulf, Dallas, and Mid South regions, the contributions were not visible on the bar charts (Figure 5.1.16). In contrast, soil contributions to RCFM of up to 20% in summer occurred at the Florida region and were ~10% at other eastern U.S. regions (Figure 4.1.16). Soil contributed only a few percent to b_{ext} in the northwestern United States (Figure 5.1.17). The bar charts associated with the Northwest and North Dakota regions had the most visible fractional b_{ext_soil}, but only 1–2%. In contrast, the soil mass fractions approached 20% at the same locations (Figure 4.1.17). Of all the urban regions, those in the southwestern United States corresponded to the highest contributions of soil to b_{ext} (Figure 5.1.18), but the contributions were still less than 10% for most regions. The Las Vegas, Phoenix/Tucson, Albuquerque, Grand Mesa CO, Front Range CO, and Utah regions corresponded to the highest contributions, compared to regions along the western coast, where relative b_{ext_soil} was not visible on the associated bar charts.

Similar to IMPROVE regions, many CSN regions had maximum relative b_{ext_soil} in spring. Many regions shifted to spring maxima for relative b_{ext_soil} compared to the summer maxima common for absolute b_{ext_soil}. For example, the Southeast, Ohio River Valley, Washington DC/Philadelphia Corridor, Las Vegas, San Francisco, San Diego, Puget Sound, Utah, and Alaska regions all corresponded to spring maxima (Figure 5.5.4). Minima in relative b_{ext_soil} occurred mainly in winter except for fall minima at the Hawaii, Puget Sound, and Southeast regions and a few regions with summer minima (New York City, Los Angeles, and San Diego). All but one region demonstrated strong seasonality in the contribution of soil to b_{ext}. The lowest ratio occurred in the New York City region (1.6) compared to the highest ratio in the Alaska region (21.7). The relative contributions of soil to b_{ext} generally displayed a higher degree of seasonality than did absolute b_{ext_soil} (Figure 5.5.2) or soil mass fraction (Figure 4.5.4). In addition, the western U.S. regions generally corresponded to higher seasonality in relative b_{ext_soil} compared to the eastern U.S. regions.

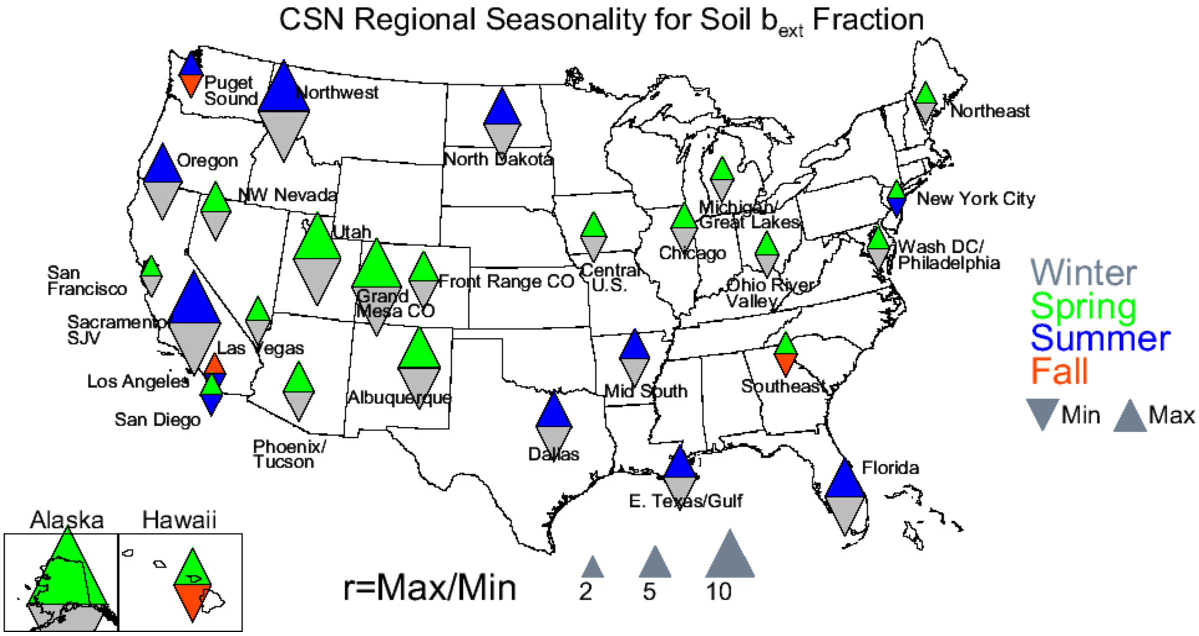

Figure 5.5.4. Seasonal variability for CSN 2005–2008 monthly mean regional soil light extinction coefficient (b_{ext}) fractions. The color of the upward pointing triangle refers to the season with the maximum monthly mean concentration and the downward pointing triangle refers to the season with the minimum monthly mean concentration. The size of the triangles refers to the magnitude of the ratio of maximum to minimum monthly mean mass concentration.

5.6 $PM_{2.5}$ SEA SALT LIGHT EXTINCTION COEFFICIENTS

Recall from section 3.1 that sea salt is a hygroscopic species and was treated as such in the algorithm for computing reconstructed light extinction coefficient for sea salt (b_{ext_SS}). While sea salt mass concentrations were relatively low, except at coastal regions, values of b_{ext_SS} were significant at some regions due to hygroscopic effects. We point to some of these cases in the discussion below.

IMPROVE 2005–2008 regional monthly mean light extinction from sea salt ranged from 0.033 Mm^{-1} in the Central Rocky Mountains region in December to 10.65 Mm^{-1} in January in the Virgin Islands region. Sea salt b_{ext} was fairly significant year round at the Virgin Islands region, with estimates near 10 Mm^{-1} (Figure 5.1.4). While soil mass concentrations were higher than sea salt mass concentrations at the Virgin Island region (see Figure 4.1.4), b_{ext_SS} was higher than b_{ext_soil} by a factor of 2 or more due to hygroscopic effects of sea salt, as well as a higher sea salt dry extinction efficiency. Light extinction coefficients from sea salt were lower at the Hawaii region (<5 Mm^{-1}) and the Alaska region (5-10 Mm^{-1}) compared to the Virgin Islands region. In the eastern United States, b_{ext_SS} was significantly lower than b_{ext} from other species at most regions (~5 Mm^{-1}) and was barely visible on the bar charts associated with the East Coast, Southeast, Northeast, and the Northern Great Plains (December) regions. Light extinction from sea salt was non-negligible at the California Coast region in the southwestern United States (Figure 5.1.3), as was sea salt mass (Figure 4.1.3); values of b_{ext_SS} at the California Coast region were still relatively low (5–10 Mm^{-1}). Some of the northwestern U.S. coastal regions corresponded to b_{ext_SS} values of a few inverse megameters. With the exception of the higher b_{ext_SS} at the Northern Great Plains region in December, most non-coastal regions had negligible

b_{ext_SS} (Figure 5.1.2). The winter high in b_{ext_SS} at the Northern Great Plains region was associated with one sample day in December (14 December 2008), when all of the sites within the region corresponded to historically high chloride ion concentrations. The event may have been associated with transport of Arctic air (White et al., 2010), but is such a rare event that its contribution could be treated as an outlier.

The seasons corresponding to maxima and minima in IMPROVE b_{ext_SS} (Figure 5.6.1) were very similar to those corresponding to rural sea salt mass concentrations (Figure 4.6.1), except at the Death Valley, Phoenix, West Texas, Ohio River Valley, Appalachia, New York City, and East Coast regions. Most regions experienced winter maxima that were possibly associated with road salt. A strong seasonality was observed in rural regions, with only three regions having maximum to minimum ratios less than 2. The highest occurred in the Northern Great Plains region (28.9) and the lowest in the Hawaii region (1.7). The degree of seasonality increased for some regions, with high ratios for b_{ext_SS} compared to sea salt mass (e.g., the Northern Great Plains and Fresno regions). The degree of seasonality was lower for a few regions on the eastern coast (e.g., Baltimore and Washington, D.C., regions) for b_{ext_SS} compared to sea salt mass.

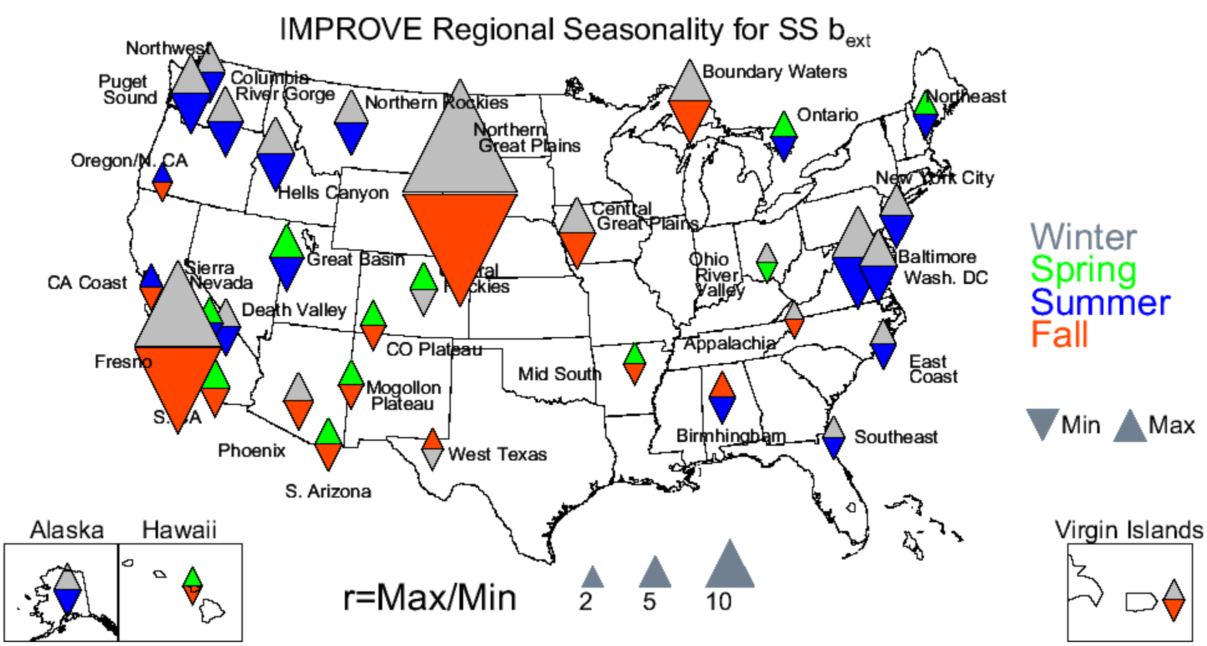

Figure 5.6.1. Seasonal variability for IMPROVE 2005–2008 monthly mean regional sea salt (SS) light extinction coefficients (b_{ext}). The color of the upward pointing triangle refers to the season with the maximum monthly mean concentration and the downward pointing triangle refers to the season with the minimum monthly mean concentration. The size of the triangles refers to the magnitude of the ratio of maximum to minimum monthly mean mass concentration.

The range in b_{ext_SS} in CSN regions was similar to the range for IMPROVE regions, with the lowest in Albuquerque in October (0.0079 Mm^{-1}) and the highest regional mean in the Hawaii region in January (8.31 Mm^{-1}). Values of b_{ext_SS} were higher at the urban Hawaii region compared to the rural Hawaii region (Figure 5.1.9) (recall the large bias in sea salt mass concentrations between IMPROVE and CSN, with higher IMPROVE concentrations, Table 1.9 in Chapter 1). Estimates of b_{ext_SS} were negligible compared to b_{ext} from other species at the

Alaska region. Extinction coefficients for sea salt were relatively insignificant at eastern U.S. urban regions, except at the Florida region, where it was barely visible on the corresponding bar chart (Figure 5.1.8). Similar magnitudes of b_{ext_SS} occurred in the southwestern (Figure 5.1.6) and northwestern United States (Figure 5.1.7). Values of b_{ext_SS} of 5 Mm^{-1} occurred at the Puget Sound region, mostly during winter months.

The majority of urban regions had maximum b_{ext_SS} in winter (Figure 5.6.2). Recall that rural regions also corresponded mainly to winter maxima. The seasons corresponding to maximum and minimum sea salt mass concentrations were different for some regions for b_{ext_SS} (e.g., San Francisco, Sacramento/San Joaquin Valley, Las Vegas, Phoenix/Tucson, Chicago, and Southeast). The urban regions also experienced a strong seasonality in b_{ext_SS}, with only one region having maximum to minimum ratios less than 2 (Southeast, 1.7). The highest ratio was observed in the Utah region (93.8). Most of the western U.S. regions experienced a higher degree of seasonality compared to the eastern U.S. regions. Regions in the southeastern United States corresponded to the lowest degree of seasonality (e.g., Dallas, Mid South, East Texas/Gulf, and Florida).

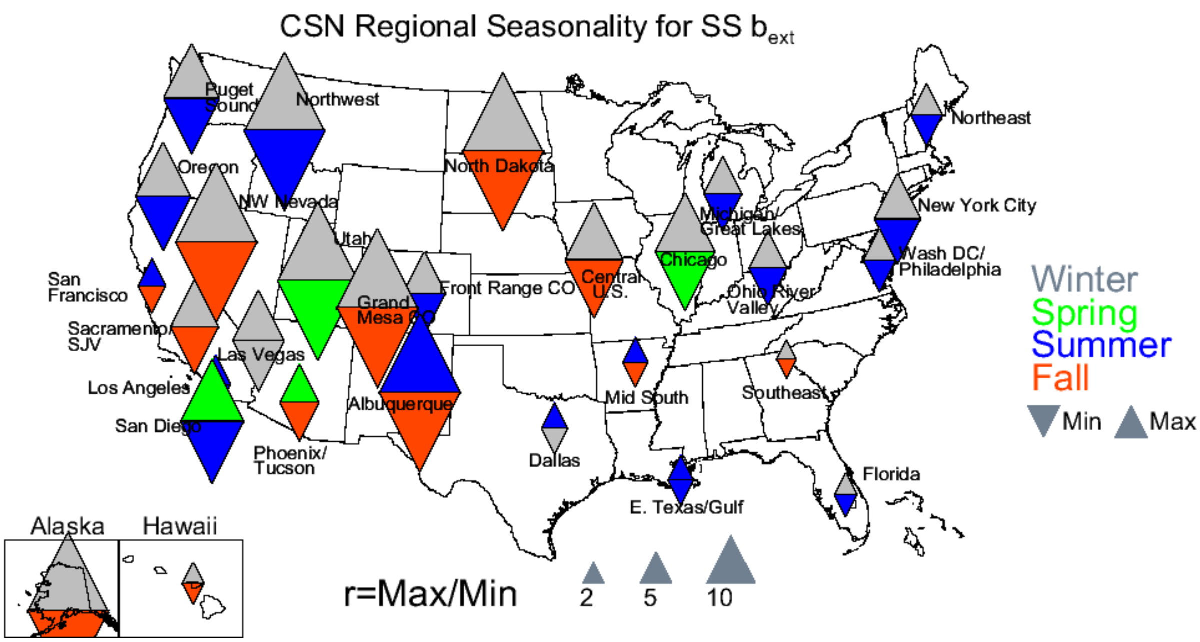

Figure 5.6.2. Seasonal variability for CSN 2005–2008 monthly mean regional sea salt (SS) light extinction coefficients (b_{ext}). The color of the upward pointing triangle refers to the season with the maximum monthly mean concentration and the downward pointing triangle refers to the season with the minimum monthly mean concentration. The size of the triangles refers to the magnitude of the ratio of maximum to minimum monthly mean mass concentration.

The fractional contribution of sea salt to b_{ext} in rural regions ranged from 0.0015% in the IMPROVE Northern Rocky Mountains region in August to 55.2% in the Virgin Islands in December. The major contributions to b_{ext} at the Virgin Islands region were sea salt and AS (Figure 5.1.11), in contrast to the major contributors to RCFM (AS, soil, and sea salt). In the Alaska region the contributions of sea salt to b_{ext} were near 40% during winter months. Contributions at the Hawaii region were lower (~10%). Contributions of sea salt to b_{ext} in the eastern United States were 10% or lower at the coastal locations of the Southeast, East Coast, and Northeast regions and negligible at other regions (Figure 5.1.12). The only southwestern U.S. region with non-negligible contributions of sea salt to b_{ext} (~20%) was the California Coast region (Figure 5.1.13). The northwestern U.S. coastal regions, such as Oregon/Northern California, Columbia River Gorge, and Northwest, corresponded to contributions of 10% or less.

The seasons corresponding to maximum and minimum b_{ext_SS} fraction and sea salt mass fractions were fairly similar for most regions (Figure 5.6.3 and Figure 4.6.3, respectively). However, the California Coast, West Texas, Hells Canyon, Colorado Plateau, Central Rocky Mountains, Boundary Waters, Mid South, and Southeast regions all shifted seasons. The maps of seasonality for relative and absolute b_{ext_SS} were quite different (compare Figure 5.6.3 to Figure 5.6.1). Both the maximum and minimum seasons and the degree of seasonality changed for many regions. Most regions experienced the greatest contribution from sea salt to b_{ext} in winter. Only one region did not experience strong seasonality: West Texas had a maximum to minimum ratio of 1.99. The greatest ratio occurred in the Northern Great Plains region (31.0).

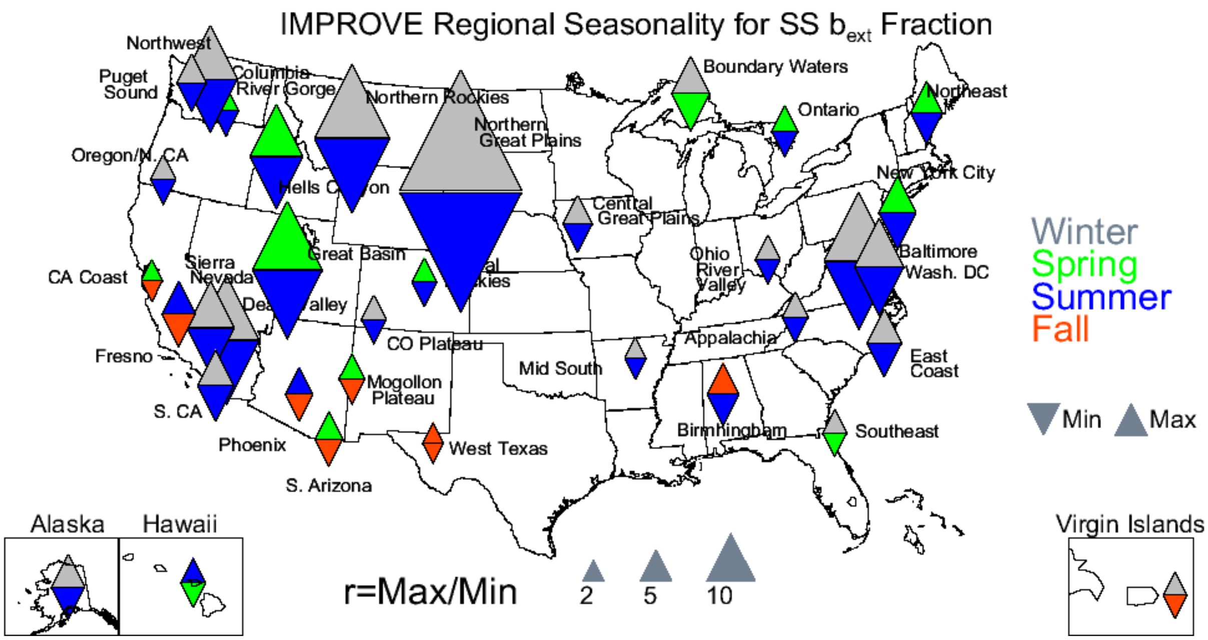

Figure 5.6.3. Seasonal variability for IMPROVE 2005–2008 monthly mean regional sea salt (SS) light extinction coefficients (b_{ext}) fraction. The color of the upward pointing triangle refers to the season with the maximum monthly mean concentration and the downward pointing triangle refers to the season with the minimum monthly mean concentration. The size of the triangles refers to the magnitude of the ratio of maximum to minimum monthly mean mass concentration.

Contributions of sea salt to b_{ext} in CSN urban regions ranged from 0.026% in the Albuquerque region in October to 31.6% in January in the Hawaii region. The contributions of sea salt to b_{ext} at the Hawaii region were 20% or greater year round but negligible at the Alaska region (Figure 5.1.19). Of all the urban regional bar charts associated with the eastern United States, only the Florida region corresponded to visible relative b_{ext_SS}, and those contributions were less than 5% (Figure 5.1.16). In the southwestern United States, relative b_{ext_SS} values were visible in the Southern California and San Francisco regional bar charts (Figure 5.1.18). Of the northwestern U.S. regions, Puget Sound was the only region with visible b_{ext_SS} values on the bar chart (Figure 5.1.17).

Similar to IMPROVE regions, most CSN regions also experienced maxima b_{ext_SS} in winter (Figure 5.6.4). The seasons corresponding to maximum and minimum were fairly similar for sea salt mass fractions and relative sea salt b_{ext} (compare Figures 4.6.4 and 5.6.4). Differences in seasons between relative and absolute b_{ext_SS} occurred at the Hawaii, Oregon, Utah, Grand Mesa CO, Mid South, and Northwest regions. Unlike the rural regions, the seasons corresponding to relative b_{ext_SS} and absolute b_{ext_SS} were fairly similar for most urban regions (Figure 5.6.4 and Figure 5.6.2, respectively). Shifts in seasons occurred at the Alaska, San Francisco, Sacramento/San Joaquin Valley, Las Vegas, Utah, East Texas/Gulf, Southeast, Chicago, and New York City regions. Generally, urban regions had a similar degree of seasonality for relative b_{ext_SS} compared to absolute b_{ext_SS}, although it varied for individual regions (e.g., Grand Mesa CO). Several regions exhibited strong seasonality. The highest ratio of maximum to minimum percent contribution occurred in the Albuquerque region (30.8) and the lowest occurred in the Hawaii region (2.3). The high degree of seasonality in b_{ext_SS} and relative b_{ext_SS} compared to other species may have been partly due to the very low sea salt mass concentrations that occurred at most regions year round.

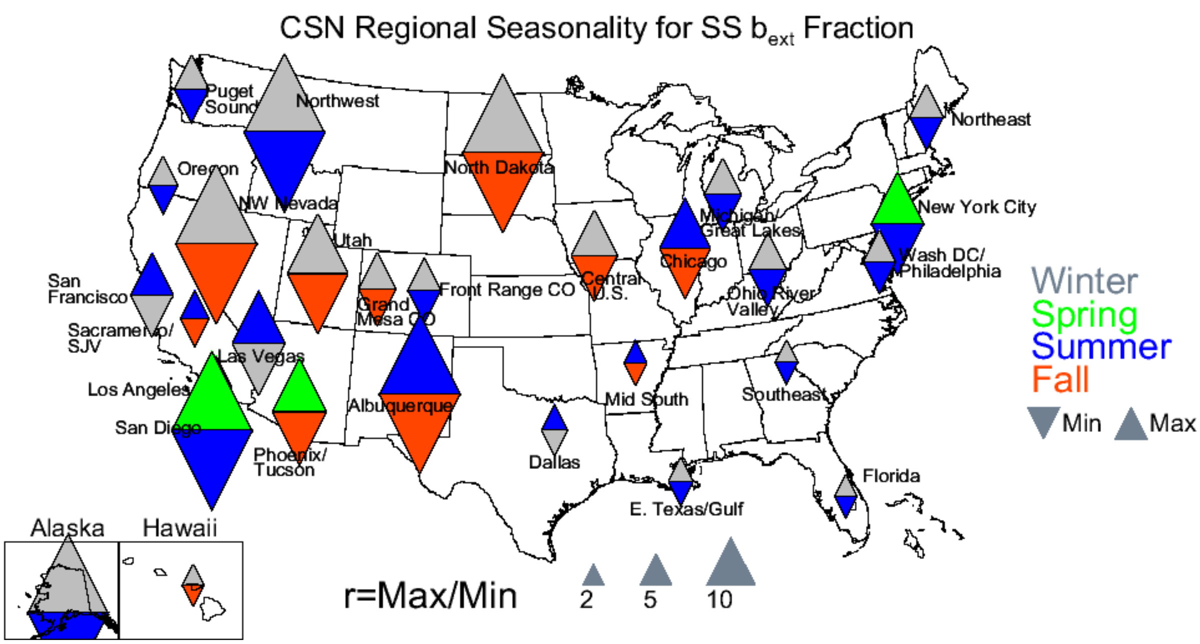

Figure 5.6.4. Seasonal variability for CSN 2005–2008 monthly mean regional sea salt (SS) light extinction coefficient (b_{ext}) fractions. The color of the upward pointing triangle refers to the season with the maximum monthly mean concentration and the downward pointing triangle refers to the season with the minimum monthly mean concentration. The size of the triangles refers to the magnitude of the ratio of maximum to minimum monthly mean mass concentration.

5.7 $PM_{2.5}$ RECONSTRUCTED AEROSOL LIGHT EXTINCTION COEFFICIENTS

The $PM_{2.5}$ reconstructed aerosol light extinction coefficient (b_{ext_aer}) is the sum of light extinction coefficients from the previous $PM_{2.5}$ components discussed above, namely, AS, AN, POM, LAC, soil, and sea salt. The range in 2005–2008 regional monthly mean IMPROVE b_{ext_aer} was from 5.73 Mm^{-1} in the Great Basin region in January to 127.26 Mm^{-1} in the Appalachia region in August (rural) and 246.09 Mm^{-1} in the urban region of Fresno in December. Given the discussion regarding b_{ext} from individual species in the previous sections, it is reasonable to assume that the high b_{ext_aer} in the Appalachian region in August was due to AS and the high b_{ext_aer} in Fresno CA in December was due to AN. Most of the maximum b_{ext_aer} occurred in summer (Figure 5.7.1), probably also associated with AS in the eastern and POM in the western United States. Regions with fall maxima corresponded to the Puget Sound, California Coast, Phoenix, West Texas, Boundary Waters, and Ontario regions. Spring maxima corresponded to the Hawaii, Virgin Islands, Southern California, and the Southeast regions. Minima at most regions were associated with fall and winter, although summer minima did occur (Hawaii, Puget Sound, Columbia River Gorge, Phoenix, and Ontario regions). Most (21 regions) of all IMPROVE regions experienced some degree of seasonality. The highest occurred in Fresno (5.7) and the Northern Rocky Mountains regions (5.0) compared to the Southern Arizona region (1.3). Higher degrees of seasonality tended to occur for western U.S. regions. In general, however, the degree of seasonality in b_{ext_aer} was lower than for individual species.

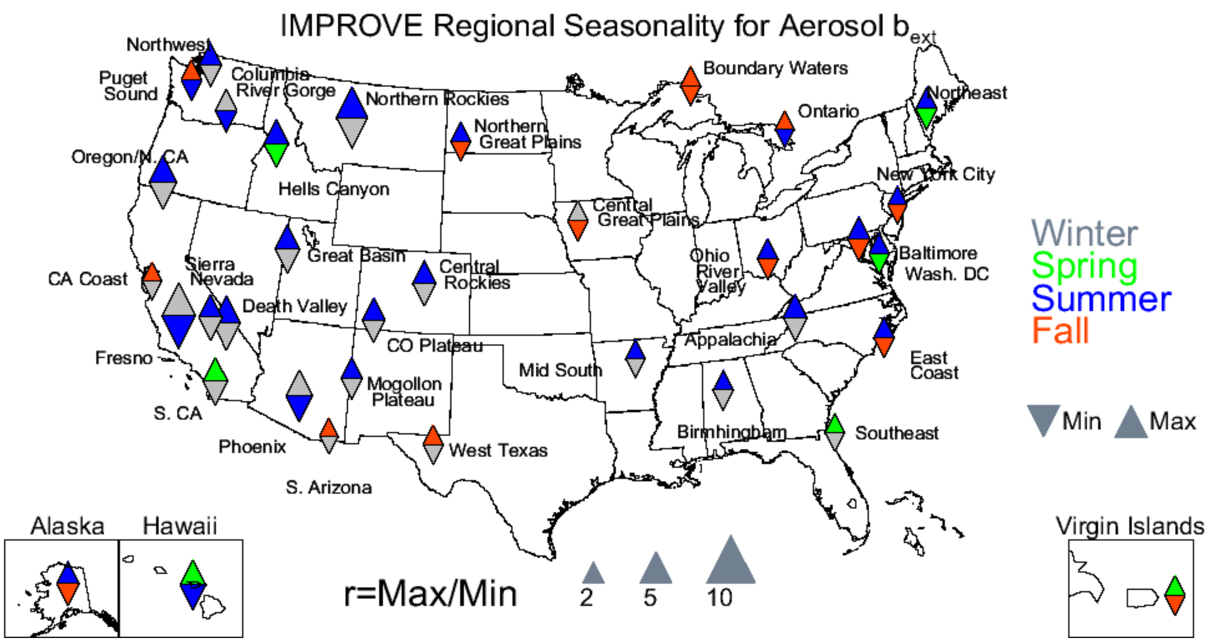

Figure 5.7.1. Seasonal variability for IMPROVE 2005–2008 monthly mean regional $PM_{2.5}$ aerosol light extinction coefficients (b_{ext}). The color of the upward pointing triangle refers to the season with the maximum monthly mean concentration and the downward pointing triangle refers to the season with the minimum monthly mean concentration. The size of the triangles refers to the magnitude of the ratio of maximum to minimum monthly mean mass concentration.

The urban CSN regional mean b_{ext_aer} ranged from 12.43 Mm^{-1} in the Alaska region in August to 204.41 Mm^{-1} in the Sacramento/San Joaquin Valley region in December, most likely from AN. In contrast to rural regions, most urban regional maxima occurred in winter, consistent with winter peaks in AN and POM (Figure 5.7.2). Spring minima were common for many U.S. regions. Summer minima occurred at the Puget Sound, Northwest, Oregon, Phoenix/Tucson, Hawaii, Alaska, Grand Mesa CO, and Florida regions, while summer maxima occurred for many regions along the eastern coast. Eleven regions had maximum to minimum ratios less than 2, suggesting that many regions experienced some degree of seasonality; these regions were predominantly in the western United States. The seasonality in urban b_{ext_aer} was greater for urban compared to rural regions. The highest ratio occurred at the Alaska region (13.7) compared to the lowest in the Florida region (1.4).

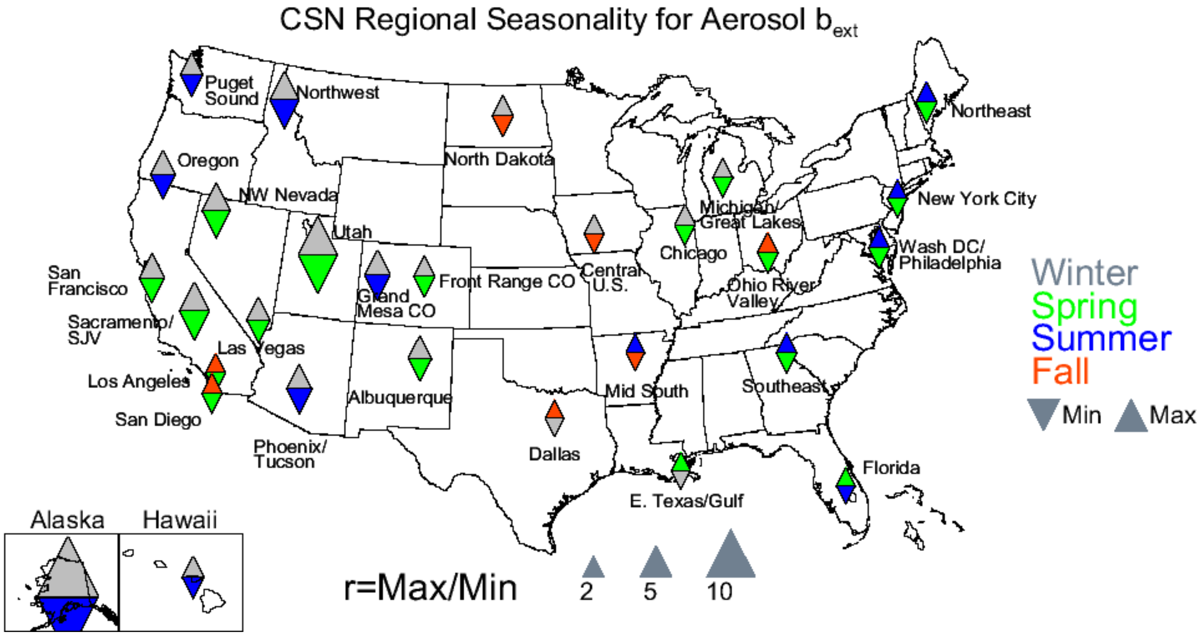

Figure 5.7.2. Seasonal variability for CSN 2005–2008 monthly mean regional $PM_{2.5}$ aerosol light extinction coefficients (b_{ext}). The color of the upward pointing triangle refers to the season with the maximum monthly mean concentration and the downward pointing triangle refers to the season with the minimum monthly mean concentration. The size of the triangles refers to the magnitude of the ratio of maximum to minimum monthly mean mass concentration.

5.8 COARSE MASS LIGHT EXTINCTION COEFFICIENTS

Coarse mass (CM=PM_{10} - $PM_{2.5}$) concentrations are measured routinely by the IMPROVE network only; therefore this discussion covers only IMPROVE 2005–2008 regional monthly mean light extinction coefficients from CM (b_{ext_CM}). The extinction efficiency for CM is 0.6 m^2 g^{-1}, and since CM is considered nonhygroscopic, b_{ext_CM} is scaled to CM concentrations (see section 3.1). Values of regional b_{ext_CM} ranged from 0.31 Mm^{-1} in the Northwest region in December to 11.73 Mm^{-1} in the Virgin Islands in June (rural) and 23.87 Mm^{-1} in Fresno in September (urban). The high b_{ext_CM} in the Virgin Islands was consistent with the high b_{ext_SS} observed for that location during that same month, suggesting that the CM contributions to b_{ext} were mostly likely sea salt, and perhaps soil, related. High extinction due to CM at the Virgin Islands site was roughly ten times greater than other OCONUS sites and corresponded to a more defined seasonal peak (see Figure 5.8.1). Well-defined seasonal peaks were also common for northwestern U.S regions, usually in summer (Figure 5.8.2). The exception was the Oregon/Northern California region, which was associated with a peak in b_{ext_CM} in fall. The Columbia River Gorge region corresponded to the highest b_{ext_CM} in that area and was roughly double or greater than at other areas.

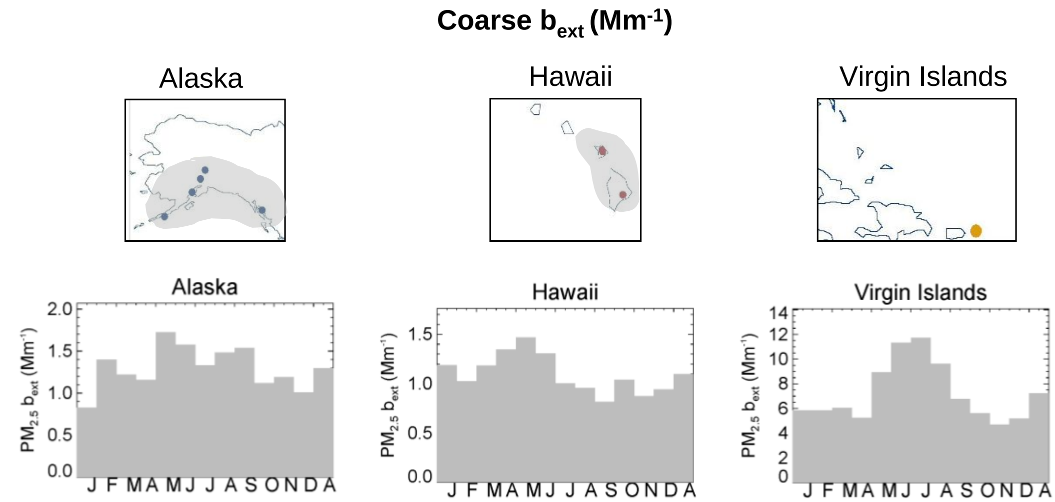

Figure 5.8.1. IMPROVE 2005–2008 regional monthly mean coarse mass reconstructed light extinction coefficients (b_{ext}, Mm^{-1}) for Hawaii, Alaska and the Virgin Islands. The letters on the x-axis correspond to the month and "A" corresponds to "annual" mean. The shaded area corresponds to the regions that comprise the sites used in this analysis, shown as dots. The "modified original" IMPROVE algorithm was used (see text). Wavelength corresponds to 550 nm.

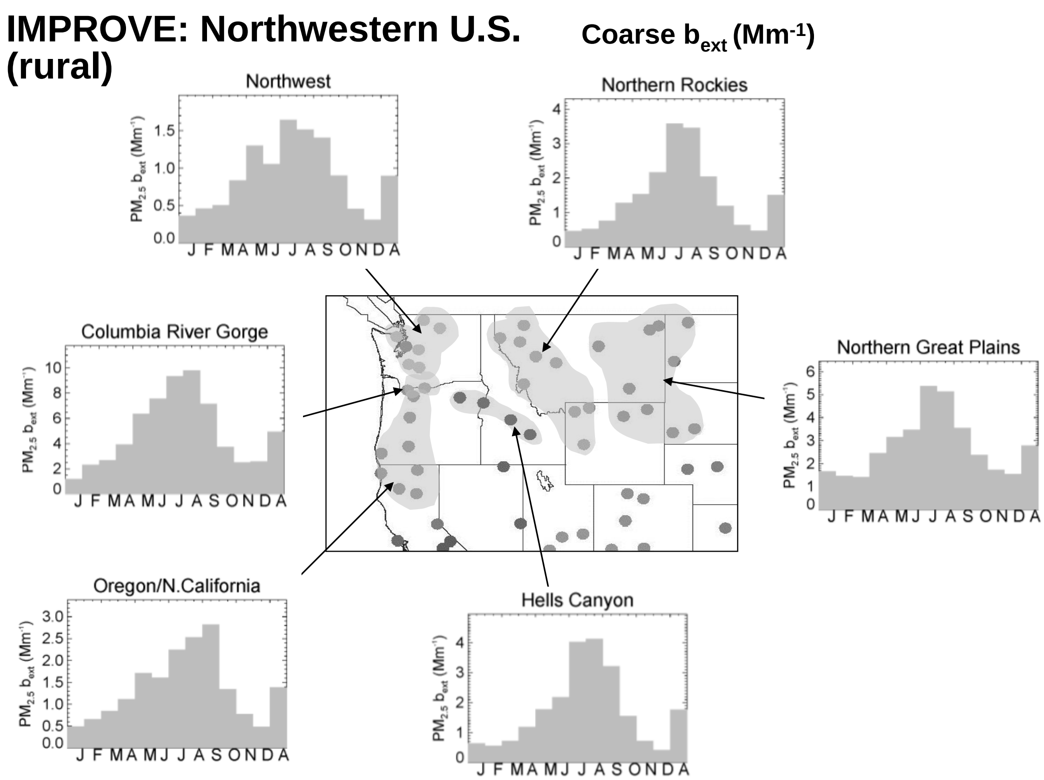

Figure 5.8.2. IMPROVE 2005–2008 regional monthly mean coarse mass reconstructed light extinction coefficients (b_{ext}, Mm^{-1}) for the northwestern United States. The letters on the x-axis correspond to the month and "A" corresponds to "annual" mean. The shaded area corresponds to the regions that comprise the sites used in this analysis, shown as dots. The "modified original" IMPROVE algorithm was used (see text). Wavelength corresponds to 550 nm.

Peaks in b_{ext_CM} during summer also occurred for southwestern U.S. regions that were typically located farther north (e.g., Sierra Nevada and Great Basin; see Figure 5.8.3). Most of the other regions were associated with spring peaks in b_{ext_CM} that were generally well defined. Bimodal distributions in seasonal b_{ext_CM} (spring and fall) occurred at the Southern Arizona, West Texas, and Mogollon Plateau regions. The Sierra Nevada, Southern Arizona, and West Texas regions were associated with the highest values of b_{ext_CM} in the southwestern United States. Seasonal distributions of b_{ext_CM} in the eastern United States were broader than most U.S. regions. Light extinction coefficients from CM peaked in spring for regions such as the Northeast, East Coast, Appalachia and Ohio River Valley regions. Toward the central United States, the peak months shifted toward summer months (see Figure 5.8.4).

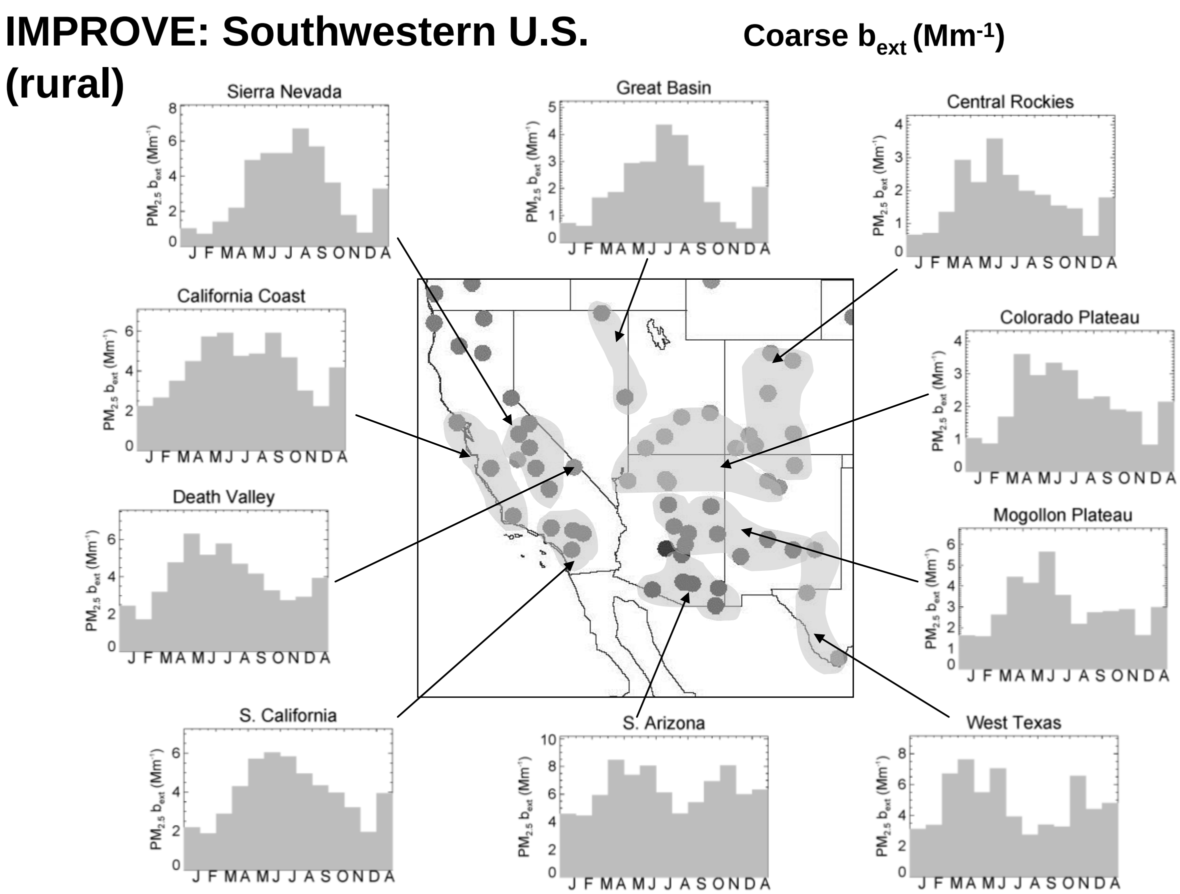

Figure 5.8.3. IMPROVE 2005–2008 regional monthly mean coarse mass reconstructed light extinction coefficients (b_{ext}, Mm^{-1}) for the southwestern United States. The letters on the x-axis correspond to the month and "A" corresponds to "annual" mean. The shaded area corresponds to the regions that comprise the sites used in this analysis, shown as dots. The "modified original" IMPROVE algorithm was used (see text). Wavelength corresponds to 550 nm.

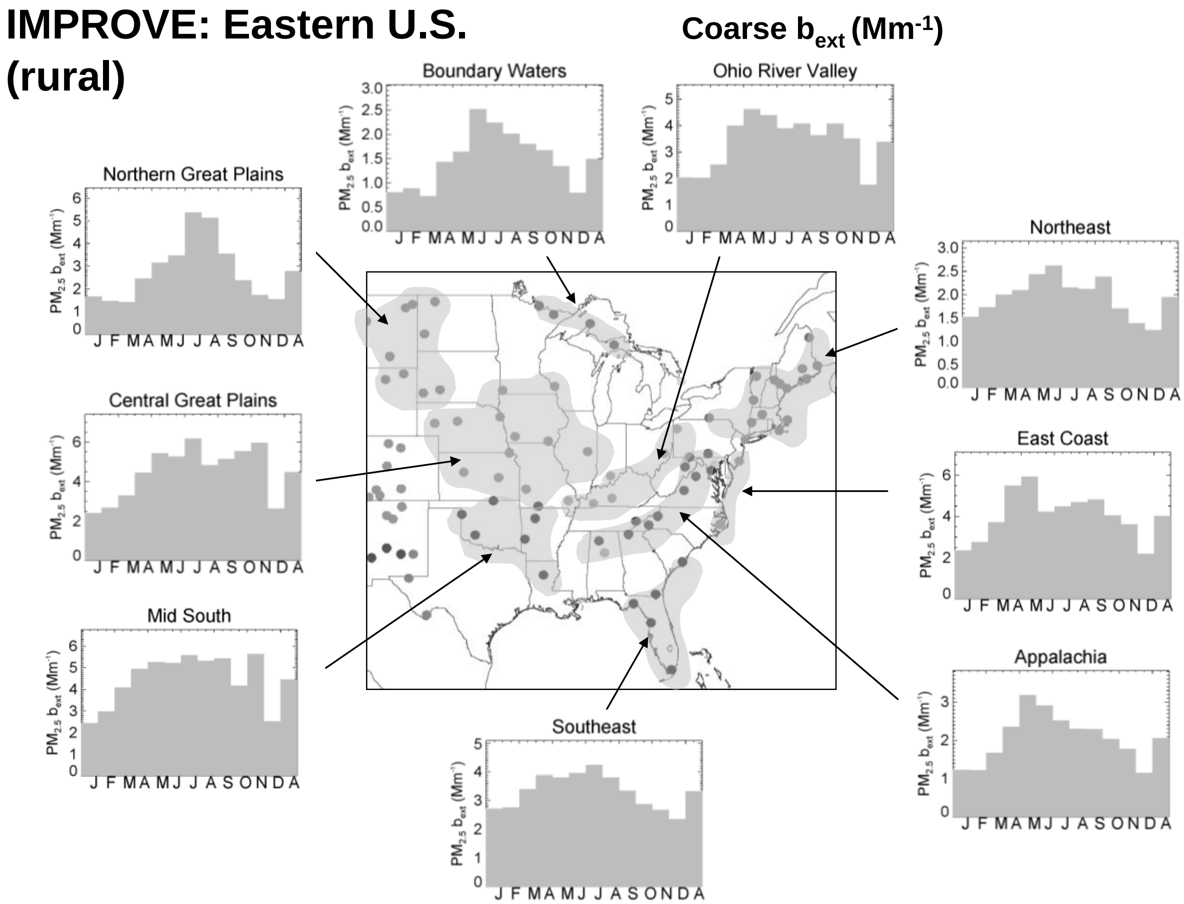

Figure 5.8.4. IMPROVE 2005–2008 regional monthly mean coarse mass reconstructed light extinction coefficients (b_{ext}, Mm^{-1}) for the eastern United States. The letters on the x-axis correspond to the month and "A" corresponds to "annual" mean. The shaded area corresponds to the regions that comprise the sites used in this analysis, shown as dots. The "modified original" IMPROVE algorithm was used (see text). Wavelength corresponds to 550 nm.

The majority of IMPROVE regions had maximum b_{ext_CM} in summer. Many regions corresponding to summer maxima were in the western United States, and spring maxima were common in the northeastern United States and some southwestern regions (e.g., Death Valley, Colorado Plateau, Southern Arizona, West Texas, Hawaii, and Alaska, Figure 5.8.5). Winter minima were common for many regions, although a few regions corresponded to fall minima (e.g., Hawaii, Virgin Islands, Puget Sound, and Washington, D.C., regions). Because CM could be associated with a variety of species (e.g., soil, sea salt, POM, and coarse nitrate species), it is difficult to comment specifically on sources without additional information. Most regions exhibited strong seasonality, with only four regions having ratios less than 2. The highest occurred in the Hells Canyon region (9.9) compared to the lowest at the Washington, D.C. (1.6), and Southeast regions (1.8).

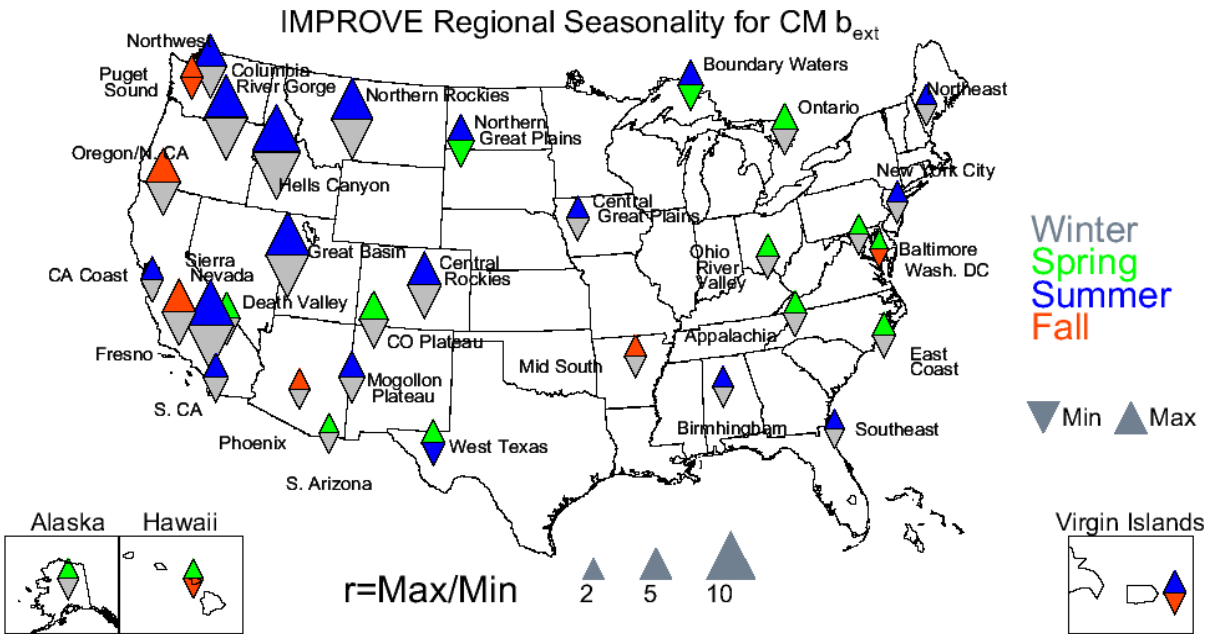

Figure 5.8.5. Seasonal variability for IMPROVE 2005–2008 monthly mean regional coarse mass (CM) light extinction coefficients (b_{ext}). The color of the upward pointing triangle refers to the season with the maximum monthly mean concentration and the downward pointing triangle refers to the season with the minimum monthly mean concentration. The size of the triangles refers to the magnitude of the ratio of maximum to minimum monthly mean mass concentration.

5.9 $PM_{2.5}$ DECIVIEW

Recall from section 3.1 that the estimates of deciview (dv) take into account the site-specific Rayleigh scattering coefficient and CM scattering coefficients and therefore were computed for IMPROVE data only. Because of these additions, the regions corresponding to maximum and minimum dv may differ from b_{ext_aer} described in the previous section. The seasons corresponding to maximum and minimum did in fact shift from b_{ext_aer} to dv (e.g., the Alaska, Virgin Islands, Columbia River Gorge, California Coast, Fresno, Southern Arizona, West Texas, Central Great Plains, Boundary Waters, Ontario, Southeast, Baltimore, New York City, and Northeast regions; see Figure 5.9.1). The regional IMPROVE dv ranged from 3.16 in the Central Rocky Mountains region in December to 24.45 in the rural Ohio River Valley region in August and 30.26 in the urban region of Fresno in December. The maximum values in the Ohio River Valley and Fresno regions were probably due to AS and AN, respectively. Maximum dv occurred in summer for most of the IMPROVE regions, but winter maxima also occurred (e.g., the Fresno, Phoenix, Boundary Waters, New York City, and Ontario regions), as did spring maxima (the Hawaii, Southern California, Central Great Plains, and Southeast regions). Fall maxima occurred only at the Puget Sound region. Winter and fall minima were common for most regions. The seasonality in dv was generally low.

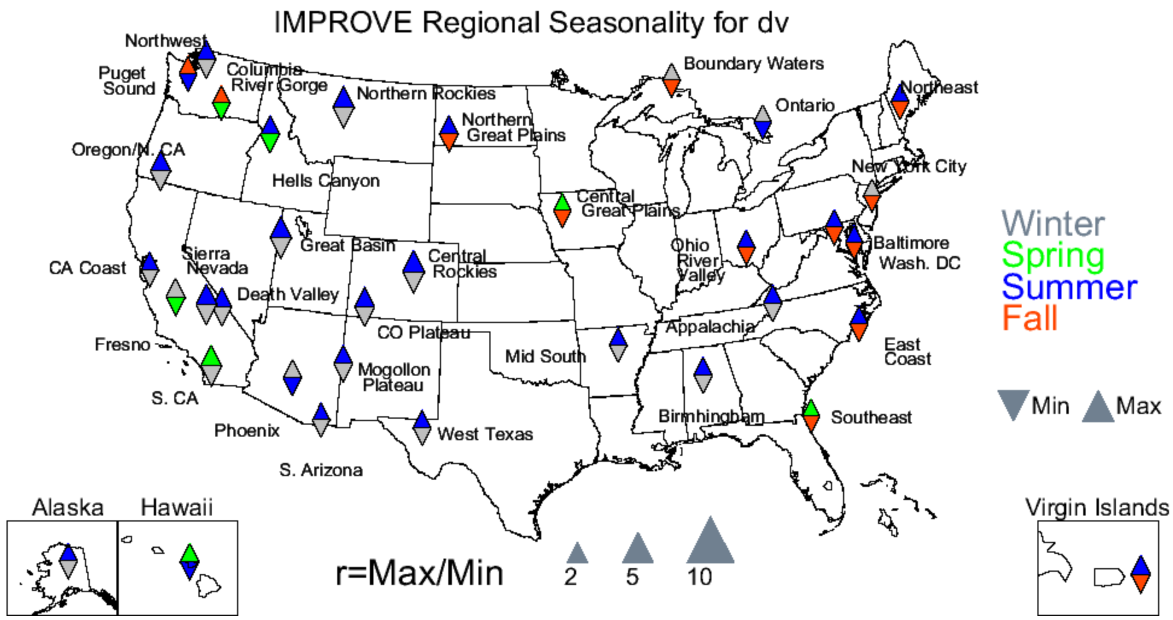

Figure 5.9.1. Seasonal variability for IMPROVE 2005–2008 monthly mean regional deciview (dv) light extinction coefficients (b_{ext}). The color of the upward pointing triangle refers to the season with the maximum monthly mean concentration and the downward pointing triangle refers to the season with the minimum monthly mean concentration. The size of the triangles refers to the magnitude of the ratio of maximum to minimum monthly mean mass concentration.

5.10 SUMMARY

The seasonal patterns in light extinction coefficients corresponding to major aerosol species were similar to the seasonal distributions in mass concentrations presented in the Chapter 4. This similarity was expected for most species because mass concentrations were converted to b_{ext}, with mass extinction efficiencies that essentially just scaled the values to inverse megameter units. However, for AS, AN, and sea salt, the conversion to b_{ext} accounted for relative humidity effects and hygroscopic growth that can be considerable in environments with high relative humidity. No significant differences were observed between the seasonal distributions in mass compared to b_{ext}. Occasionally, the season that corresponded to the majority of the maximum and minimum regional absolute b_{ext} or relative b_{ext} changed for many of the species examined here. In addition, some species that were important for their contributions to RCFM were less important in reconstructed b_{ext} (e.g., soil), while others became more important (e.g., LAC, POM, and hygroscopic species).

Appendices associated with this chapter include tables of regional monthly mean b_{ext} for IMPROVE and the CSN (E.1), and tables of relative b_{ext} for IMPROVE and the CSN (E.2). Figures include monthly mean b_{ext} bar charts for individual IMPROVE sites and CSN sites (E.3), as well as individual site bar charts of relative b_{ext} for IMPROVE and CSN sites (E.4).

REFERENCES

White, W. H., B. P. Perley, R. L. Poirot, T. F. Dann, and E. Dabek-Zlotorzynska, 2010, Continental-scale transport of sea salt aerosol, Abstract A43C-0245 presented at the 2010 Fall Meeting, AGU, San Francisco, California, 13-17 December 2010.