Chapter 4. Seasonal Distributions of $PM_{2.5}$ Aerosol Mass Concentrations

In the previous chapters we focused only on the annual mean concentrations of several key aerosol species. However, the seasonality of aerosol concentrations can be significant depending on species and region and is a function of the source emissions, meteorological parameters, and local and long-range transport. Examining aerosol concentrations on a regional basis, rather than a site-specific basis, can lead to insights regarding air quality issues on regional scales. In this chapter we examine the differences in the regional seasonal signatures of major aerosol species for rural and urban regions.

IMPROVE and CSN data were grouped and monthly averaged according to previously defined regions. When a specific region is used in this report, it refers to an IMPROVE or CSN region as defined in Figure 1.2 or Figure 1.9, respectively (Chapter 1), not a commonly-used geographical region. For example, the IMPROVE "Northwest" region refers to a specific group of sites, not to the area of the country typically considered as "northwestern United States". We used 35 of the 41 predefined IMPROVE regions (see Table 1.1 and Figure 1.2 in Chapter 1), 28 of which were rural and an additional seven that corresponded to a single urban site per region. Of the rural sites, three regions included only one site (Death Valley, Virgin Islands, and Ontario). The IMPROVE regions were semi-empirically defined based on site location and the seasonal distribution of aerosol concentrations for major species (e.g., Sisler et al., 1993; Sisler et al., 1996; Malm et al., 2000; Malm et al., 2004; Debell, 2006). We did not investigate the variability in the species composition between sites in a given region, nor did we take into account differences in elevation.

We used 29 of the 31 semi-empirically defined regions for the CSN sites based on seasonal distribution of aerosol concentrations. For comparison purposes, we grouped sites in regions similar to those defined for the IMPROVE network. Of the 29 regions, eight had only one site per region. A list of CSN regions and the comprised sites can be found in Chapter 1 (Table 1.8 and Figure 1.9).

We analyzed the monthly and annual mean concentrations of $PM_{2.5}$ ammonium sulfate (AS), ammonium nitrate (AN), particulate organic matter (POM), light absorbing carbon (LAC), soil, sea salt and gravimetric fine mass (FM) and coarse mass (CM). We also evaluated the seasonal distribution in relative contribution (the percent contribution of a species' mass to reconstructed fine mass, RCFM). The evaluation of both the absolute and relative concentrations highlights the importance of the behavior of species mass concentrations relative to each other. For example, a given species might vary on a relative basis although its absolute concentrations are steady (or vice versa), solely based on the seasonal behavior of other species.

The monthly mean IMPROVE and CSN regional data are presented as stacked bar charts. Monthly means are depicted with the first letter of the month, followed by an "A" for annual mean. Seasonality is defined as the ratio of the maximum to minimum monthly mean concentrations for a given region. Seasonal periods correspond to winter (December, January and February) spring (March, April and May), summer (June, July and August), and fall (September, October, and November). Stacked bar charts for monthly mean concentrations are grouped into figures corresponding to four sections of the country: northwestern, southwestern, eastern, and OCONUS (outside the contiguous United States, e.g., Hawaii, Alaska, and Virgin Islands)

United States. Stacked bar charts for monthly mean mass fractions for were also created. Sections 4.1–4.8 present the regional seasonality for the above listed species; a discussion of results is provided in Section 4.9.

4.1 $PM_{2.5}$ AMMONIUM SULFATE MASS CONCENTRATIONS

The IMPROVE maximum 2005–2008 regional monthly mean ammonium sulfate (AS) concentration of 11.29 μg m^{-3} occurred at the urban site of Baltimore in July. The highest concentration in nonurban regions corresponded to the Appalachia region in August (9.94 μg m^{-3}). In fact, bar charts presented in Figure 4.1.1 depict that most of the regions in the eastern United States corresponded to higher AS concentrations in summer, especially the Ohio River Valley, Northeast, East Coast, and Mid South regions. The similar seasonal pattern suggested regional sources of AS. Notice that the scales for each regional bar plot in Figure 4.1.1 (and subsequent figures) are different. The minimum monthly mean AS concentrations occurred in the Oregon/Northern California region in December (0.17 μg m^{-3}). Most regions in the northwestern United States had relatively low AS concentrations compared to other species (typically less than 1 μg m^{-3}) and less-defined summer peaks in concentration (see Figure 4.1.2). AS concentrations in the southwestern United States (Figure 4.1.3) were also low but higher than in the northwestern United States and also demonstrated more of a summer peak (e.g., see the Southern California, Death Valley, and West Texas regions). AS monthly mean concentrations in Alaska and the Virgin Islands were fairly low (less than 2 μg m^{-3}, see Figure 4.1.4) with peaks in the spring. Concentrations of AS in the Hawaii region were very different with higher concentrations (typically greater than 1μg m^{-3}), especially in spring, and lower concentrations in summer.

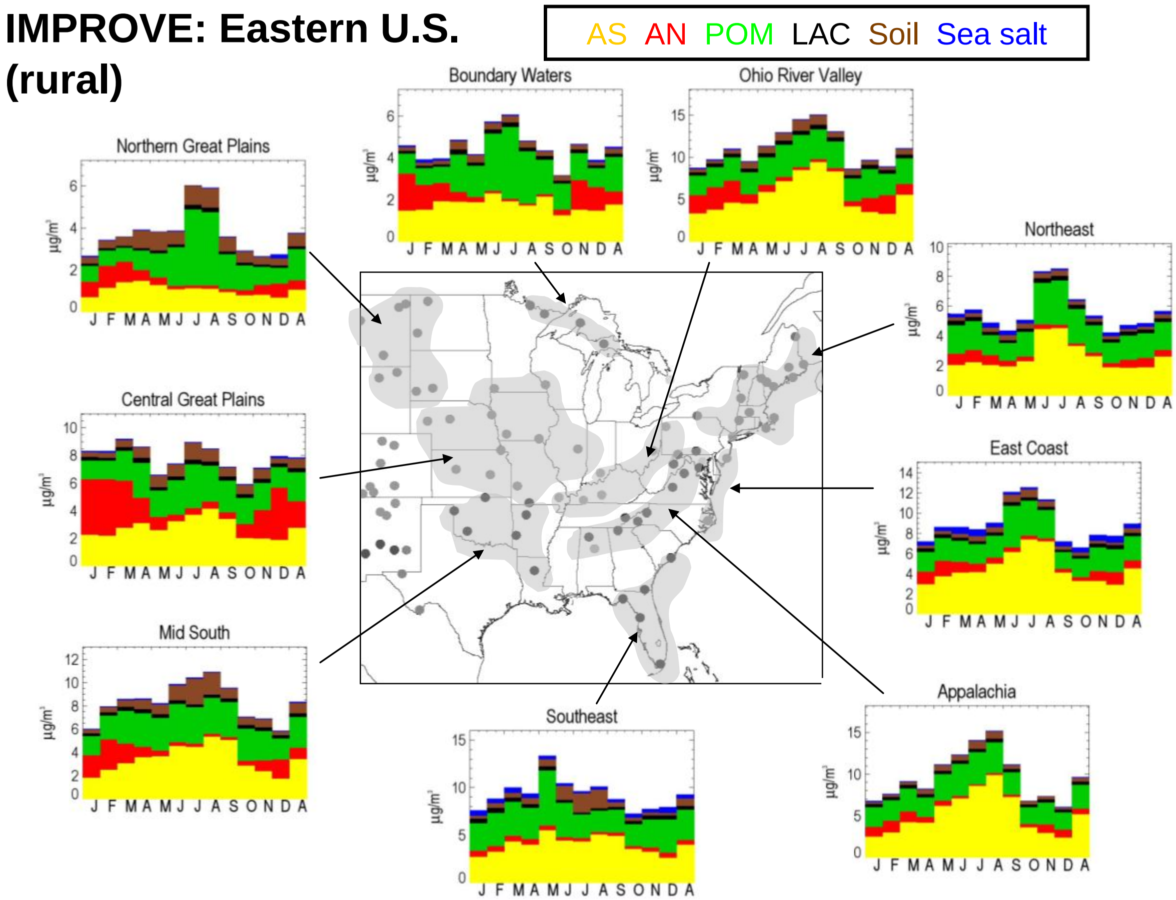

Figure 4.1.1. IMPROVE 2005–2008 regional monthly mean $PM_{2.5}$ mass concentrations (μg m^{-3}) for the eastern United States. The letters on the x-axis correspond to the month and "A" corresponds to "annual" mean. Ammonium sulfate (AS) in yellow, ammonium nitrate (AN) in red, particulate organic matter (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.

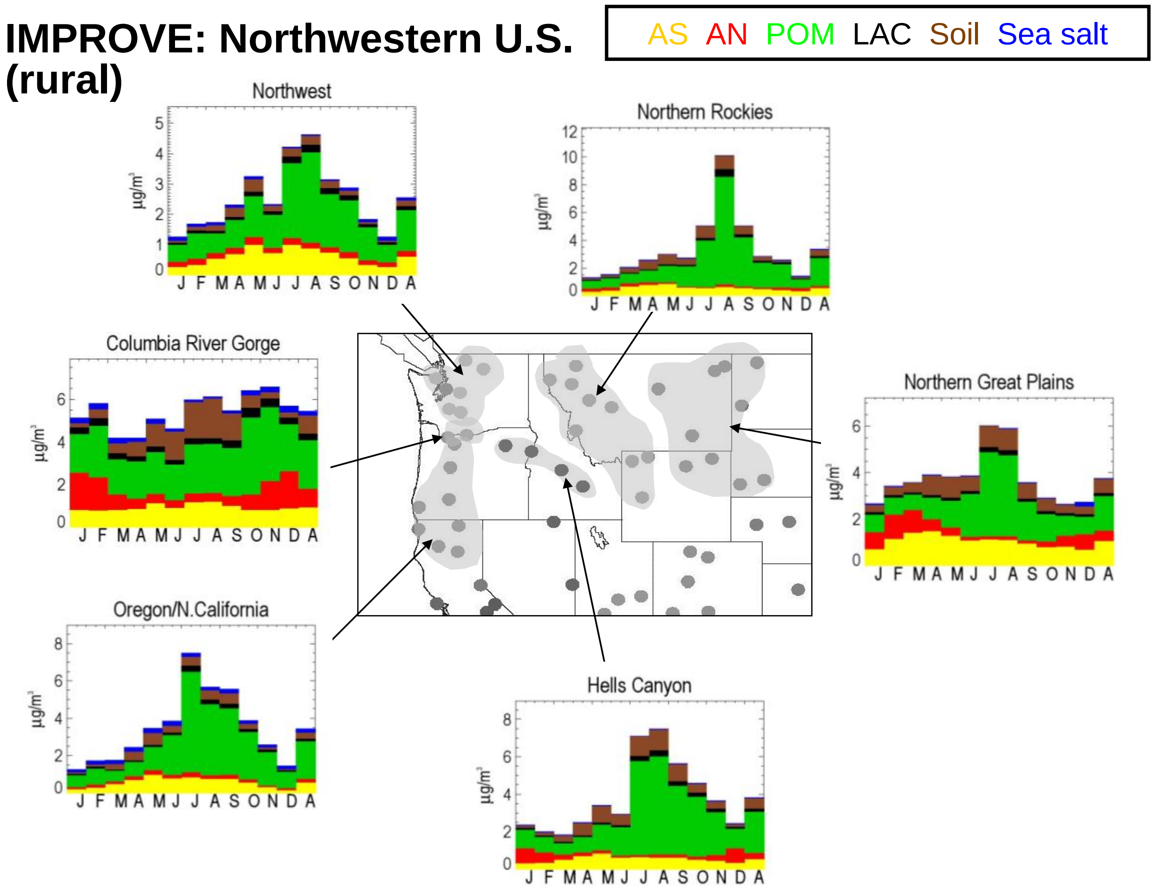

Figure 4.1.2. IMPROVE 2005–2008 regional monthly mean $PM_{2.5}$ mass concentrations (µg m^{-3}) for the northwestern United States. The letters on the x-axis correspond to the month and "A" corresponds to "annual" mean. Ammonium sulfate (AS) in yellow, ammonium nitrate (AN) in red, particulate organic 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.

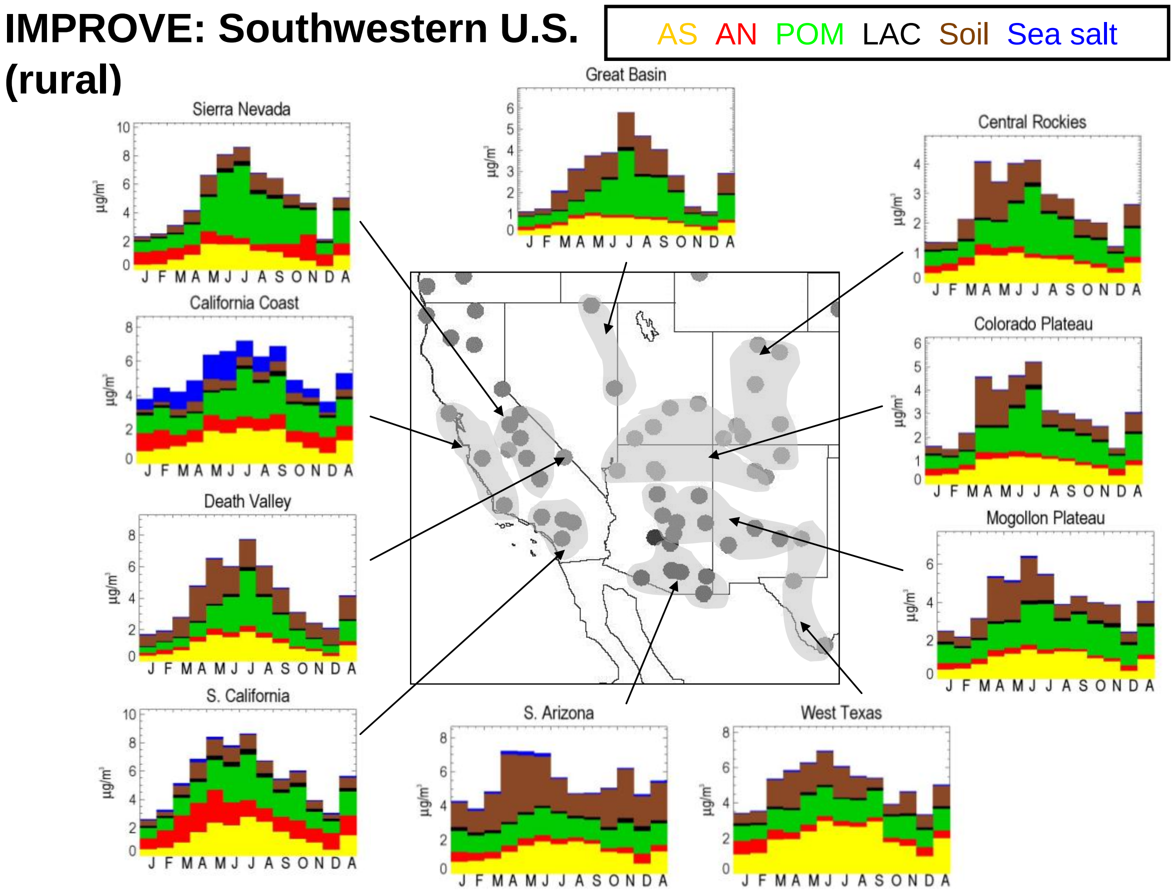

Figure 4.1.3. IMPROVE 2005–2008 regional monthly mean $PM_{2.5}$ mass concentrations (µg m^{-3}) for the southwestern United States. The letters on the x-axis correspond to the month and "A" corresponds to "annual" mean. Ammonium sulfate (AS) in yellow, ammonium nitrate (AN) in red, particulate organic 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.

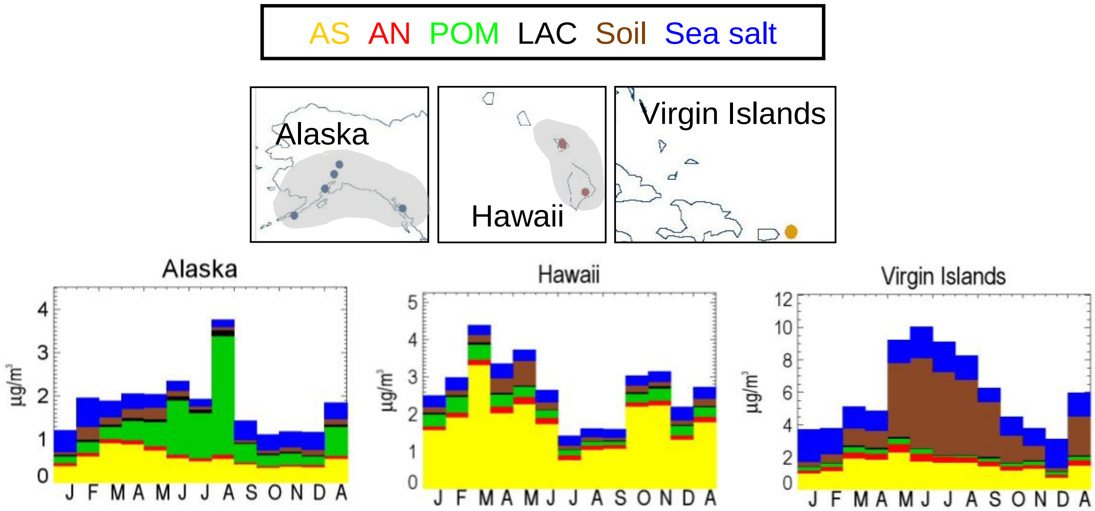

Figure 4.1.4. IMPROVE 2005–2008 regional monthly mean $PM_{2.5}$ mass concentrations (µg m^{-3}) for Hawaii, Alaska, and the Virgin Islands. The letters on the x-axis correspond to the month and "A" corresponds to "annual" mean. Ammonium sulfate (AS) in yellow, ammonium nitrate (AN) in red, particulate 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 seasonality of AS is summarized in Figure 4.1.5. 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 mean concentration such that large triangles represent larger degrees of seasonality. Keep in mind that the location of the triangle represents the region and may not be placed directly over a specific site location. Only three IMPROVE regions had ratios of AS monthly maximum to minimum mean concentrations less than 2, demonstrating a high degree of seasonality (Figure 4.1.5). The highest ratio was computed for the Sierra Nevada region, where the maximum was over six times greater than the minimum, compared to the lowest ratio in the Columbia River Gorge region (maximum was 1.5 times the minimum). The maximum AS mass concentrations predominantly occurred in the summer, especially in the regions in the eastern and southwestern United States and in the Southern California region. In the northwestern United States, the maximum occurred in the spring for many regions. Consistent with the bar charts presented in Figure 4.1.4, the maximum monthly mean concentrations in the OCONUS regions occurred in the spring. The minimum season for almost all regions occurred in winter; fall minimums occurred in the Boundary Waters, Baltimore, Northeast, and Alaska regions. Summer minimum occurred in Hawaii and spring minimum occurred in the Sierra Nevada region.

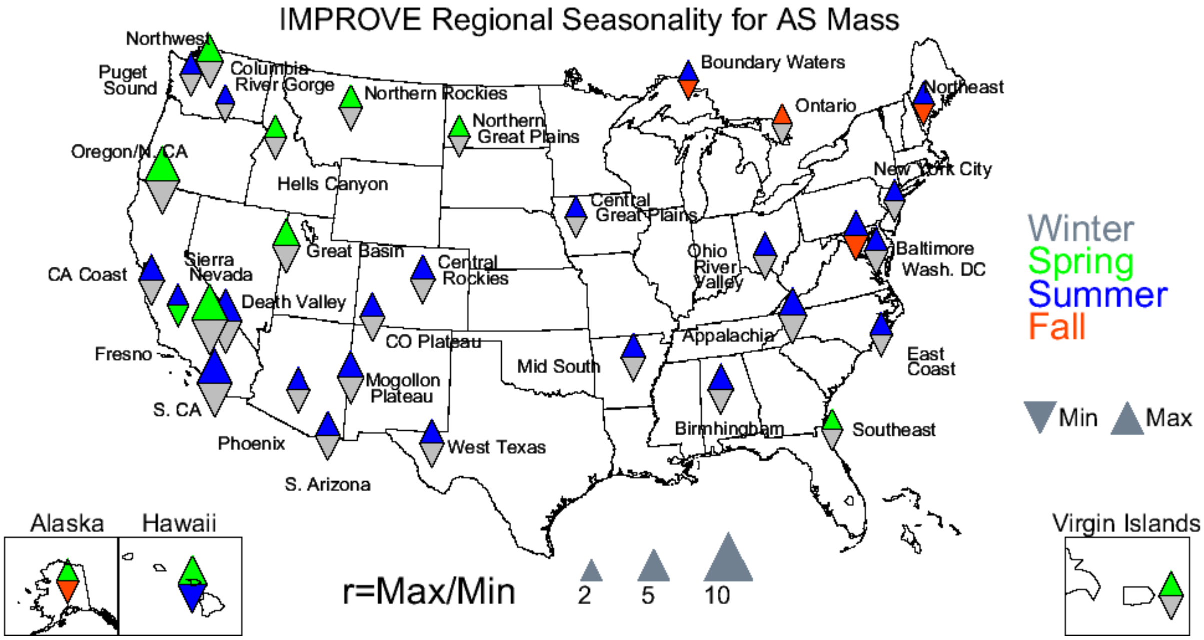

Figure 4.1.5. Seasonal variability for IMPROVE 2005–2008 monthly mean ammonium sulfate (AS) mass concentrations. The color of the upward pointing triangle refers to the season with the maximum monthly mean concentration and the downward pointing triangle refers to the season with the minimum monthly 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 monthly mean concentration was 10.82 μg m^{-3} in the Washington D.C./Philadelphia Corridor region in July. Similar to the IMPROVE regions, the CSN regions in the eastern United States corresponded to higher AS monthly mean concentrations that peaked typically in the summer, especially at the Ohio River Valley, Northeast, New York City, Southeast, and Mid South regions, among others (see Figure 4.1.6). The similarity in seasonal patterns of AS concentrations in the eastern United States pointed to regional sources of AS that impact urban and rural regions alike (compare Figures 4.1.1 and 4.1.6). The minimum CSN monthly mean mass concentration was 0.42 μg m^{-3} in the Northwest Nevada region in December (see Figure 4.1.7). The urban AS concentrations in the southwestern United States were lower than in the eastern United States but still peaked in summer for most regions (Figure 4.1.7). In general the southwestern urban concentrations were higher than rural concentrations (compare Figures 4.1.7 and 4.1.3). Regional AS concentrations in the northwestern United States were also lower than in the eastern United States and displayed less of a summer peak (Figure 4.1.8). Urban AS monthly mean concentrations in Alaska were higher than rural concentrations (see Figure 4.1.9) and peaked in winter with a summer minimum. Regional urban concentrations in Hawaii were similar to rural concentrations and demonstrated a similar summer minimum.

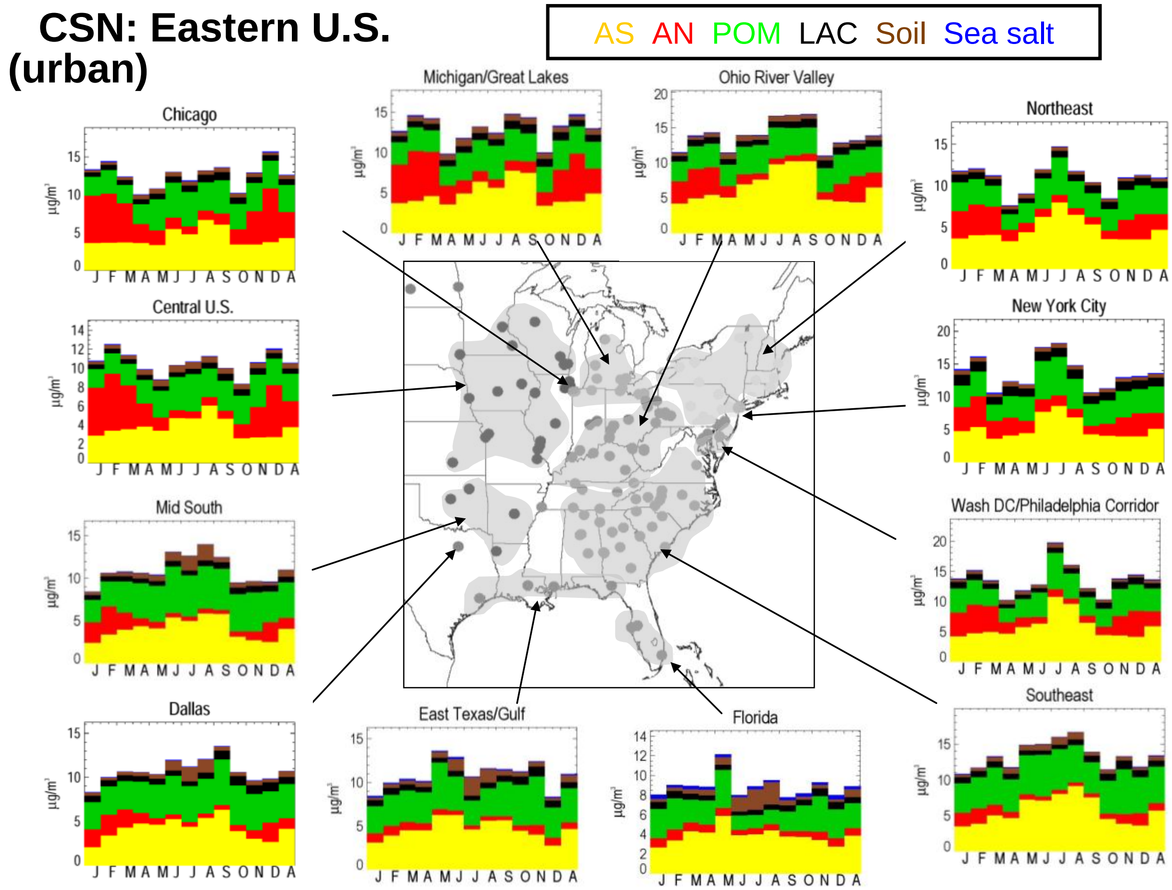

Figure 4.1.6. CSN 2005–2008 regional monthly mean $PM_{2.5}$ mass concentrations (µg m^{-3}) for the eastern United States. The letters on the x-axis correspond to the month and "A" corresponds to "annual" mean. Ammonium sulfate (AS) in yellow, ammonium nitrate (AN) in red, particulate organic matter (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.

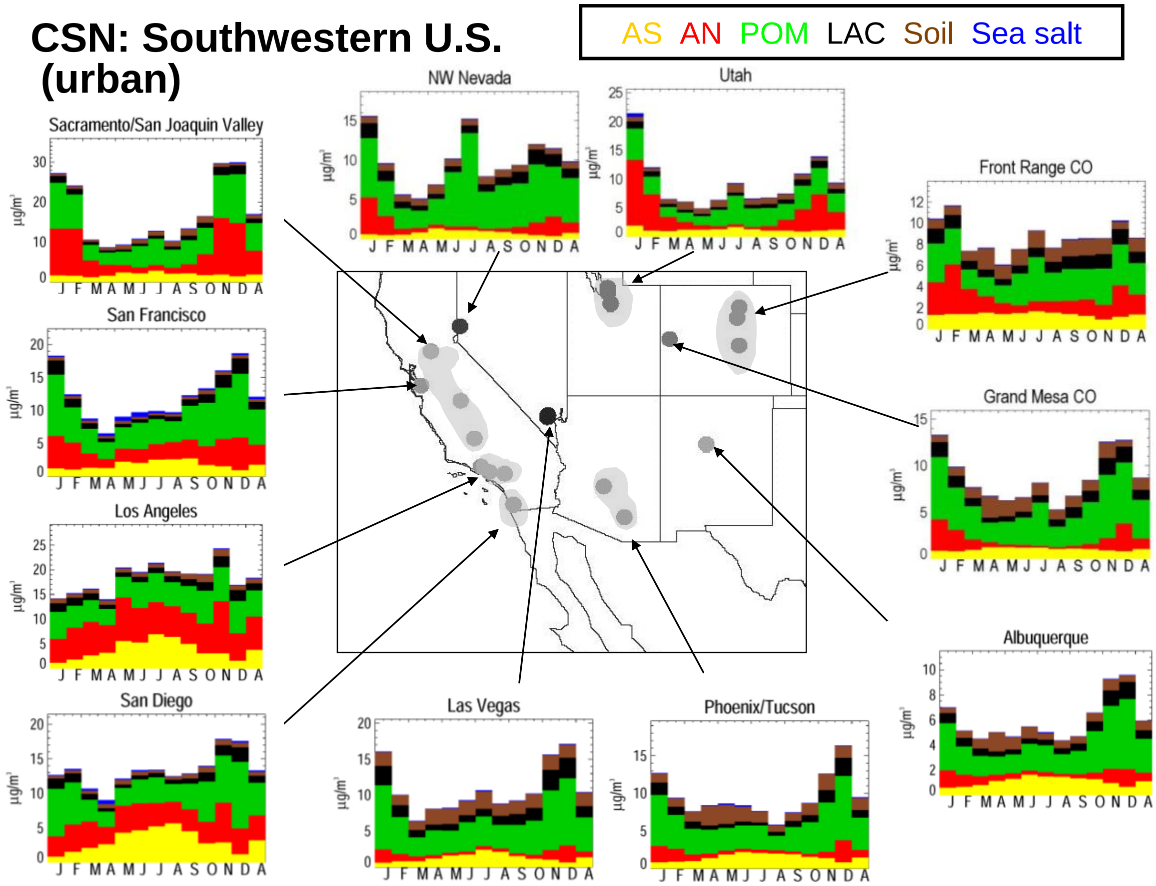

Figure 4.1.7. CSN 2005–2008 regional monthly mean $PM_{2.5}$ mass concentrations (µg m^{-3}) for the southwestern United States. The letters on the x-axis correspond to the month and "A" corresponds to "annual" mean. Ammonium sulfate (AS) in yellow, ammonium nitrate (AN) in red, particulate organic matter (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.

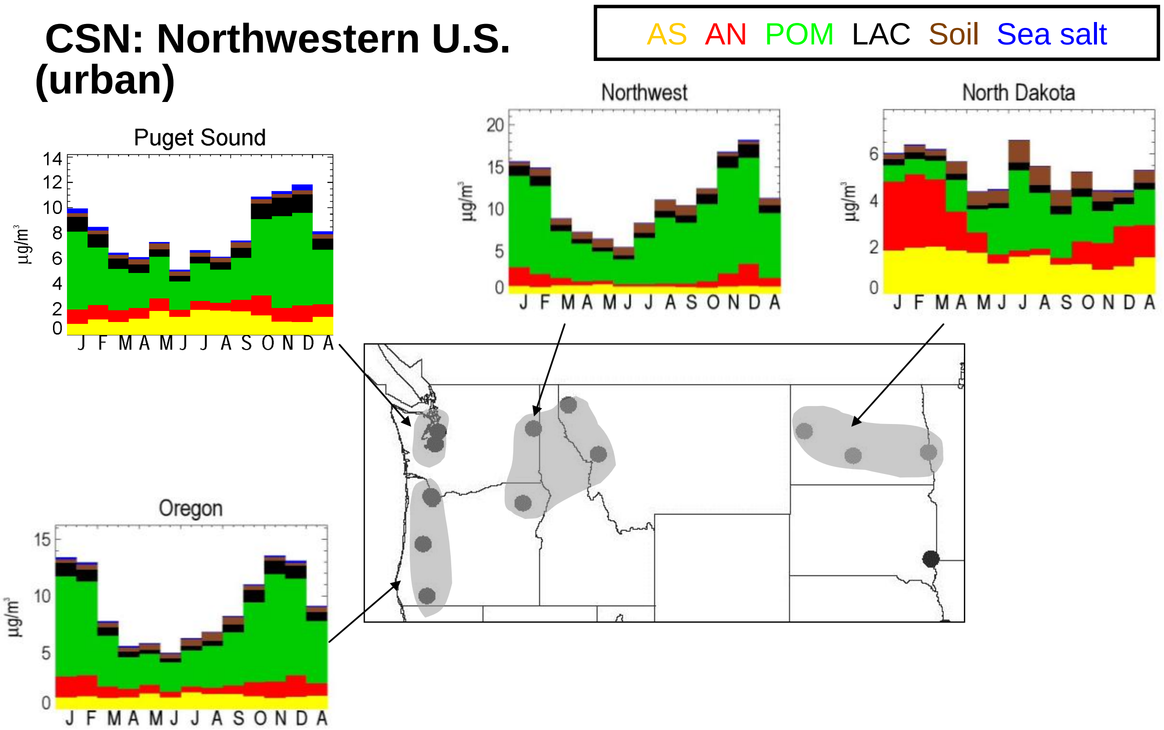

Figure 4.1.8. CSN 2005–2008 regional monthly mean $PM_{2.5}$ mass concentrations (µg m^{-3}) for the northwestern United States. The letters on the x-axis correspond to the month and "A" corresponds to "annual" mean. Ammonium sulfate (AS) in yellow, ammonium nitrate (AN) in red, particulate organic matter (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.

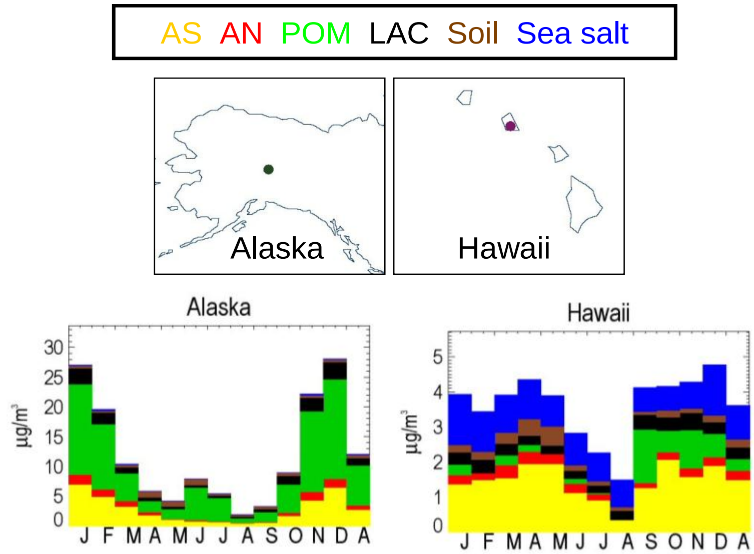

Figure 4.1.9. CSN 2005–2008 regional monthly mean $PM_{2.5}$ mass concentrations ($\mu g\ m^{-3}$) for Hawaii and Alaska. The letters on the x-axis correspond to the month and "A" corresponds to "annual" mean. Ammonium sulfate (AS) in yellow, ammonium nitrate (AN) in red, particulate organic matter (POM) 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.

Urban regions were somewhat less seasonal than rural regions. Six CSN regions had maximum to minimum ratios less than 2, with the highest and lowest seasonality corresponding to the Alaska (14.6) and Oregon (1.4) regions, respectively. As shown in Figure 4.1.10, there was a higher degree of seasonality in southern part of California, with a summer maximum and winter minimum. Many regions had minimums in the fall (e.g., Central U.S., North Dakota, Utah, Northwest, Oregon, and Michigan/Great Lakes). Regions in the northwestern United States had spring maxima, similar to the IMPROVE regions (see Figure 4.1.5). Spring minima occurred at the Sacramento/San Joaquin Valley, Chicago, Northeast, and New York City regions.

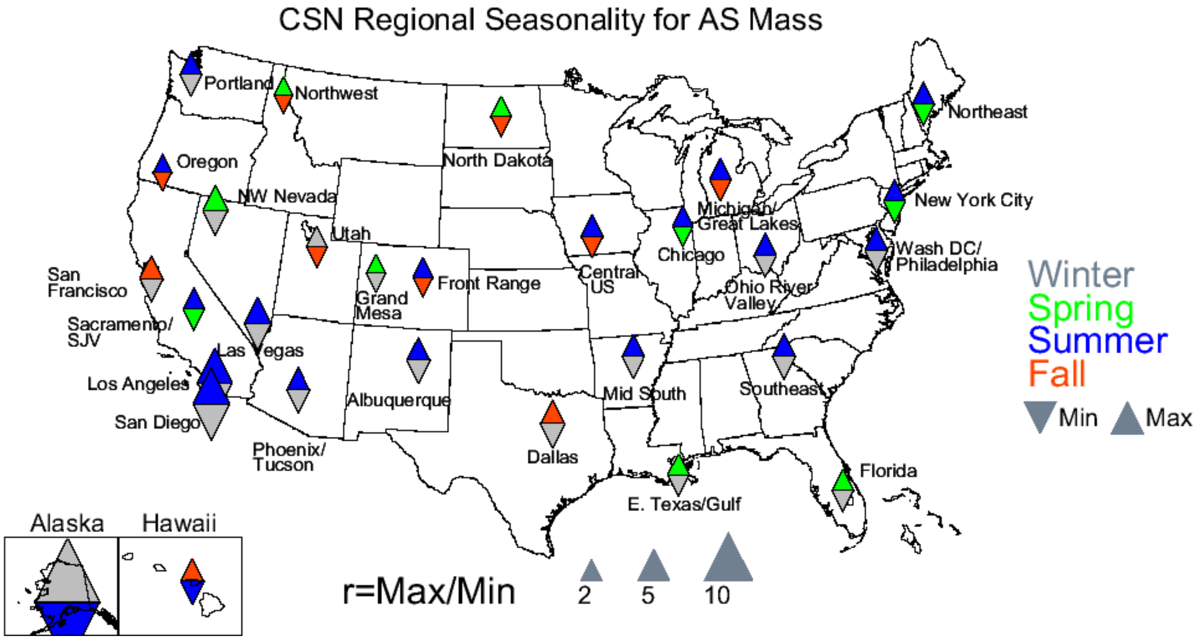

Figure 4.1.10. Seasonal variability for CSN 2005–2008 monthly mean ammonium sulfate (AS) mass concentrations. The color of the upward pointing triangle refers to the season with the maximum monthly mean concentration and the downward pointing triangle refers to the season with the minimum monthly mean concentration. The size of the triangles refers to the magnitude of the ratio of maximum to minimum monthly mean mass concentration.

IMPROVE regional percent contributions of AS to RCFM ranged from 3.9% in Phoenix in December to 75.7% in the Hawaii region in March. AS mass dominated RCFM in summer at many of the rural regions. For example, regions in the eastern United States typically had AS concentrations that contributed 40% or more to RCFM (See Figure 4.1.11) and reached up to 60% in summer (e.g., the Ohio River Valley and East Coast regions). In contrast, contributions of AS to RCFM were typically 20% or less in the northwestern United States (Figure 4.1.12) and did not demonstrate a summer mass fraction maxima; in fact, AS contributed the least to RCFM in the summer in the northwestern United States at many regions (e.g., Northern Rocky Mountains, Northern Great Plains, and Hells Canyon). In the southwestern United States (Figure 4.1.13), the contributions were somewhat higher (20–40%) and often were the highest during summer at regions such as Southern Arizona and West Texas. However, other regions in the southwestern United States, such as Death Valley and Central Rocky Mountains, corresponded to fairly flat seasonal contributions of AS to RCFM. The OCONUS region (Figure 4.1.14) demonstrated different patterns. AS was a large contributor to RCFM in the Hawaii region year round, with 60% or greater contributions and fairly flat seasonal patterns. AS contributions ranged from 20 to 50% and 20 to 40% in the Alaska and Virgin Islands regions, respectively, and peaked in spring months.

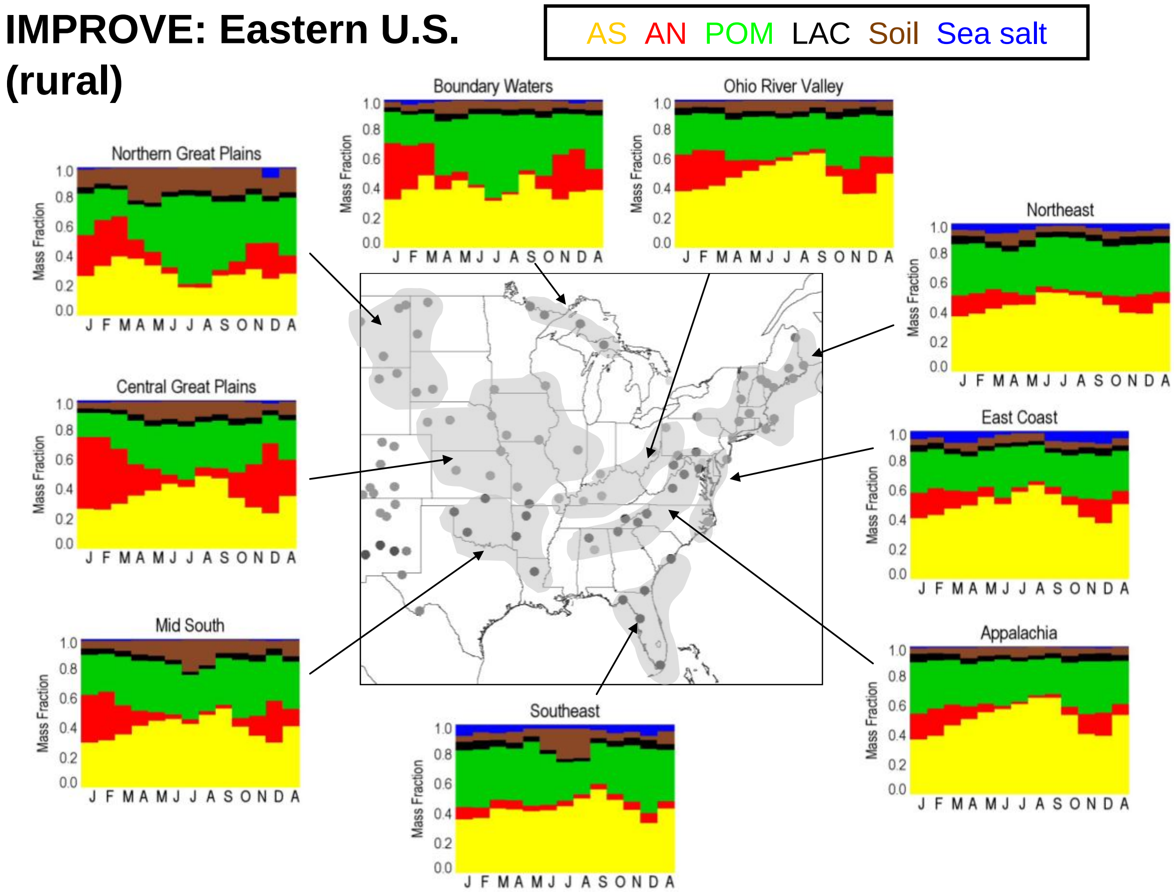

Figure 4.1.11. IMPROVE 2005–2008 regional monthly mean $PM_{2.5}$ reconstructed fine mass fractions for the eastern United States. The letters on the x-axis correspond to the month and "A" corresponds to "annual" mean. Ammonium sulfate (AS) in yellow, ammonium nitrate (AN) in red, particulate organic 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.

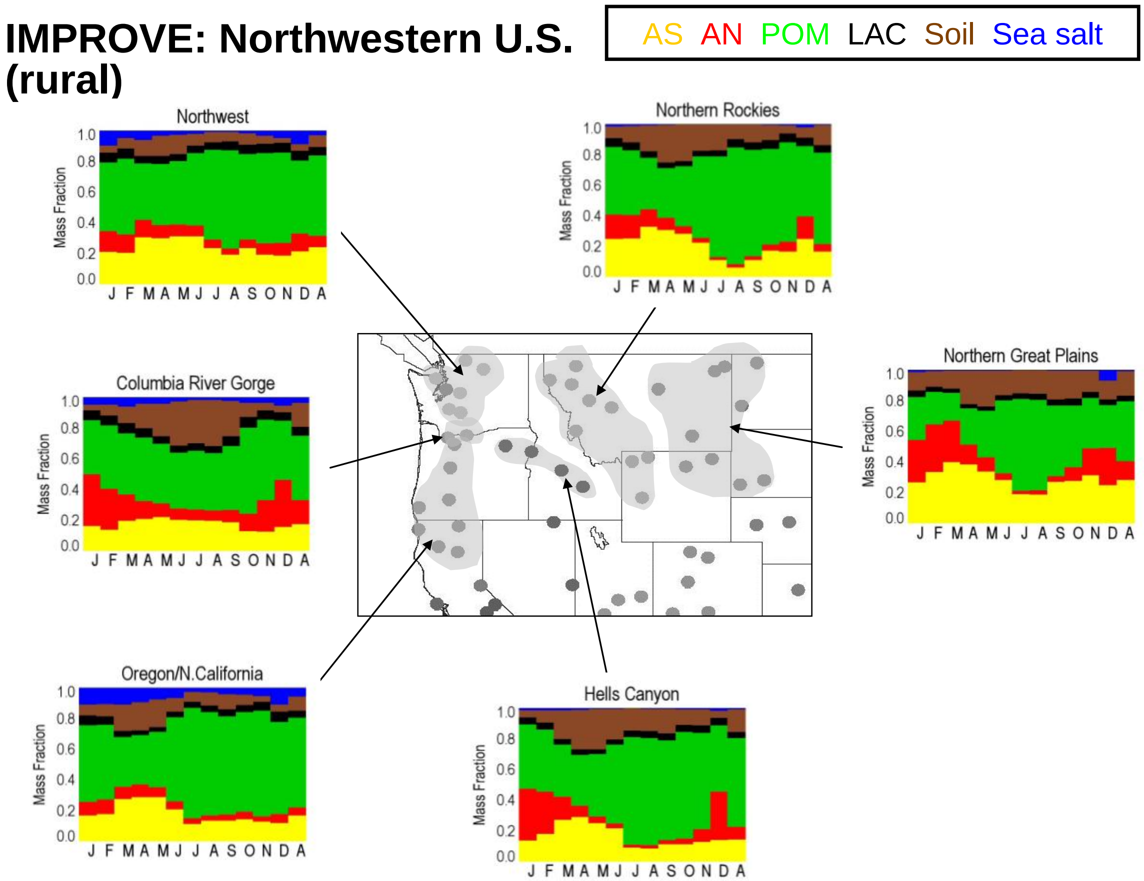

Figure 4.1.12. IMPROVE 2005–2008 regional monthly mean $PM_{2.5}$ reconstructed fine mass fractions for the northwestern United States. The letters on the x-axis correspond to the month and "A" corresponds to "annual" mean. Ammonium sulfate (AS) in yellow, ammonium nitrate (AN) in red, particulate organic 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.

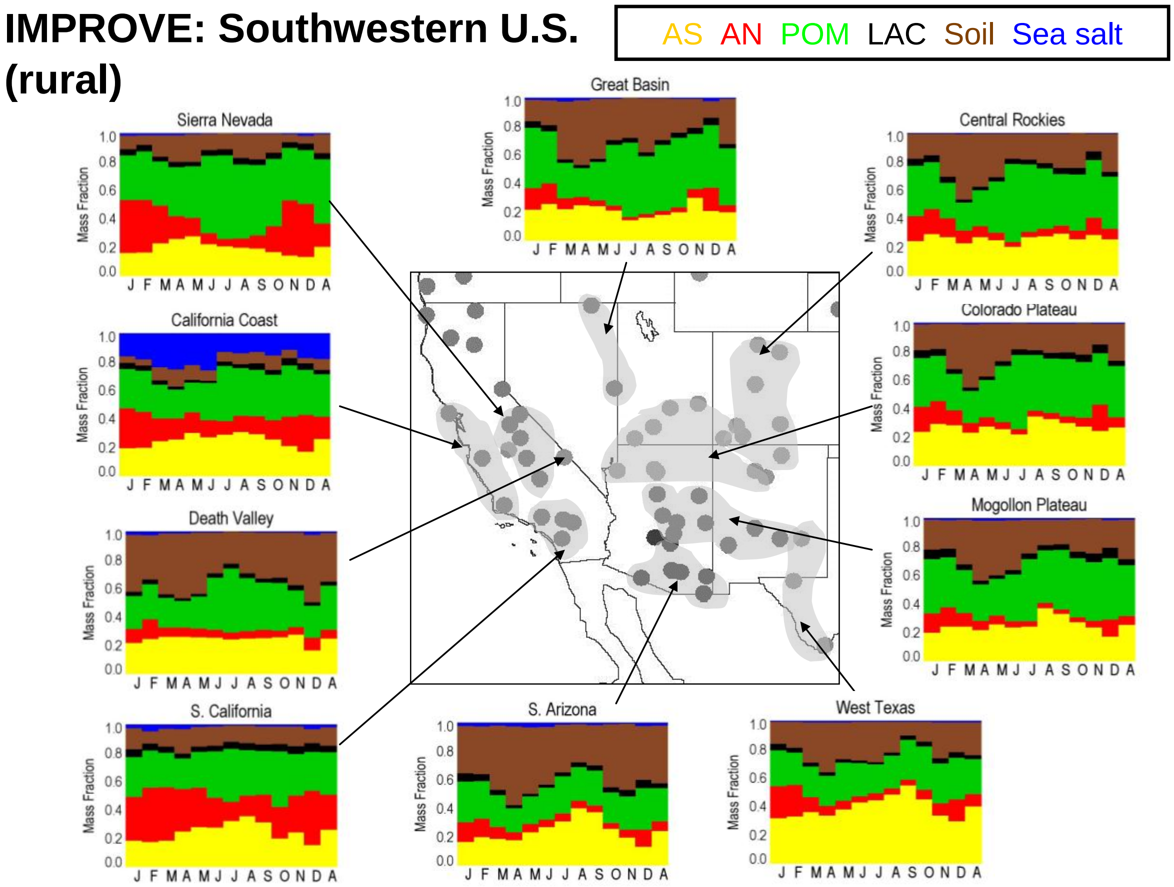

Figure 4.1.13. IMPROVE 2005–2008 regional monthly mean $PM_{2.5}$ reconstructed fine mass fractions for the southwestern United States. The letters on the x-axis correspond to the month and "A" corresponds to "annual" mean. Ammonium sulfate (AS) in yellow, ammonium nitrate (AN) in red, particulate organic 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.

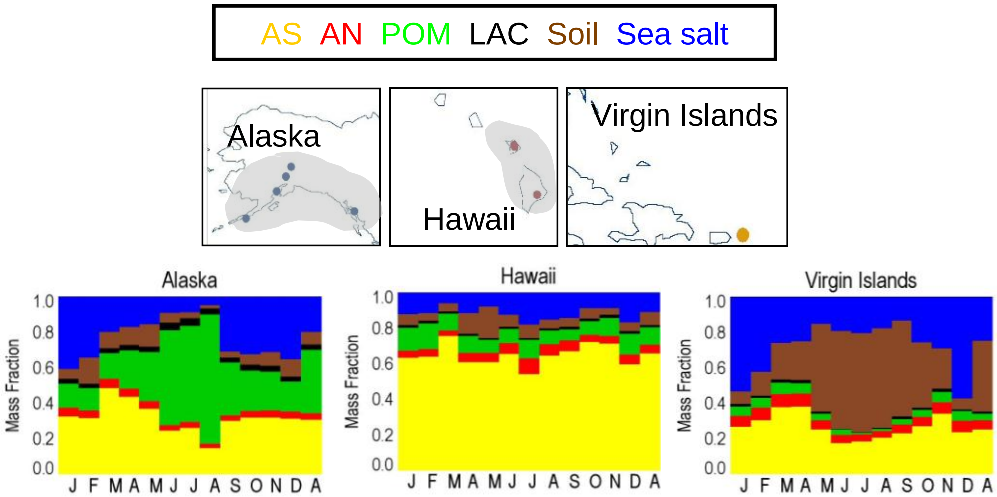

Figure 4.1.14. IMPROVE 2005–2008 regional monthly mean $PM_{2.5}$ reconstructed fine mass fractions for Hawaii, Alaska,and the Virgin Islands. The letters on the x-axis correspond to the month and "A" corresponds to "annual" mean. Ammonium sulfate (AS) in yellow, ammonium nitrate (AN) in red, particulate 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.

Almost half of all the IMPROVE regions demonstrated a small degree of seasonality in which the maximum percent contribution of AS to RCFM was less than twice the minimum percent contribution (Figure 4.1.15). The Hawaii region had the lowest ratio (1.4), suggesting that AS was a consistent contributor to fine mass year round in that region. The largest rural ratio occurred for the Northern Rocky Mountains region, where the maximum percent contribution was 5.2 times larger than the minimum percent contribution. The seasons that corresponded to maximum and minimum were different for mass fractions compared to mass concentrations (compare Figure 4.1.15 to Figure 4.1.5). For example, in the Ohio River Valley region the maximum mass fraction occurred during fall (as did the minimum) while the maximum monthly mean concentration occurred in the summer. Many regions in the southwestern United States had similar seasonality in concentration and mass fraction, such as the Phoenix site and Southern Arizona and Mogollon Plateau regions. In many regions the degree of seasonality for AS mass fractions was less than for mass concentrations (e.g., regions in California and the eastern United States).

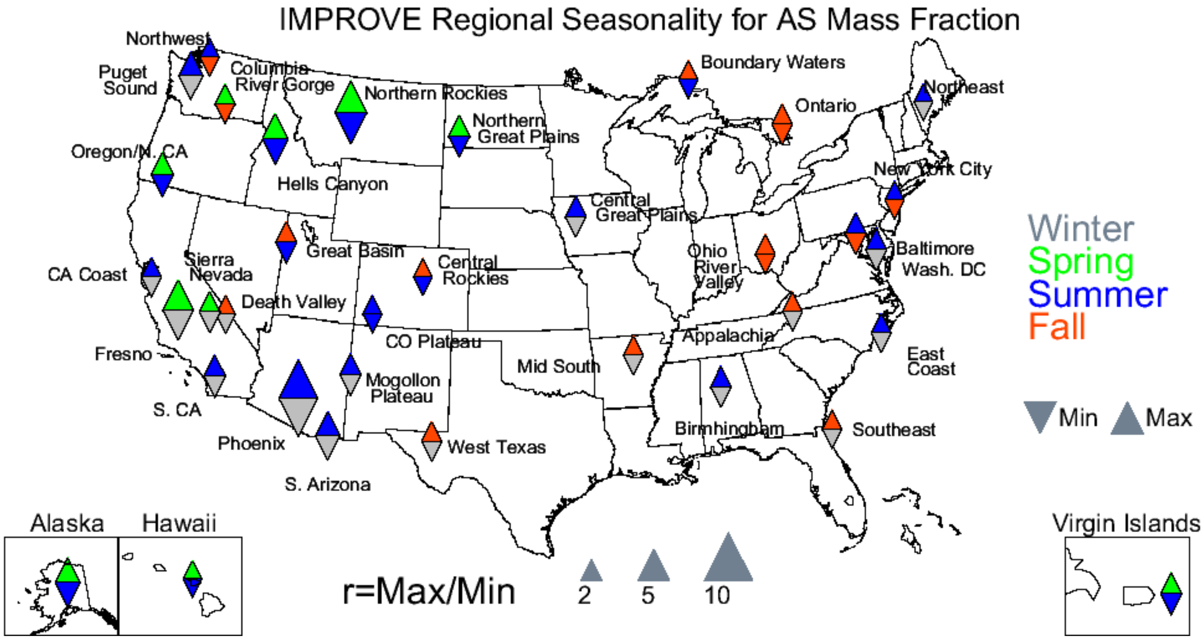

Figure 4.1.15. Seasonal variability for IMPROVE 2005–2008 monthly mean ammonium sulfate (AS) reconstructed fine mass fractions. The color of the upward pointing triangle refers to the season with the maximum monthly mean concentration and the downward pointing triangle refers to the season with the minimum monthly mean concentration. The size of the triangles refers to the magnitude of the ratio of maximum to minimum monthly mean mass concentration.

The CSN AS regional percent contribution to RCFM ranged from 3.6% in the Northwest Nevada region in December to 61.1% in the Ohio River Valley region in August. The Ohio River Valley region was typical of other regions in the eastern United States where AS typically contributed 40% or more to RCFM (see Figure 4.1.16). In the summer relative contributions of AS in many regions almost reached 60%. In contrast, regions in the northwestern United States had AS contributions that were typically 20–30% of RCFM in spring and summer (see Figure 4.1.17). The North Dakota region was the exception, with a fairly flat seasonal pattern in mass fraction. Regions in the southwestern United States exhibited low AS contributions to RCFM (less than 20–30%) and the seasonal pattern showed maxima in the summer (see Figure 4.1.18). Slightly higher contributions were observed in the Alaska region (20–40%) but with a summer minimum (Figure 4.1.19 for OCONUS regions). The Hawaii region had a fairly steady contribution of ~40% to RCFM, with a notable decrease in August.

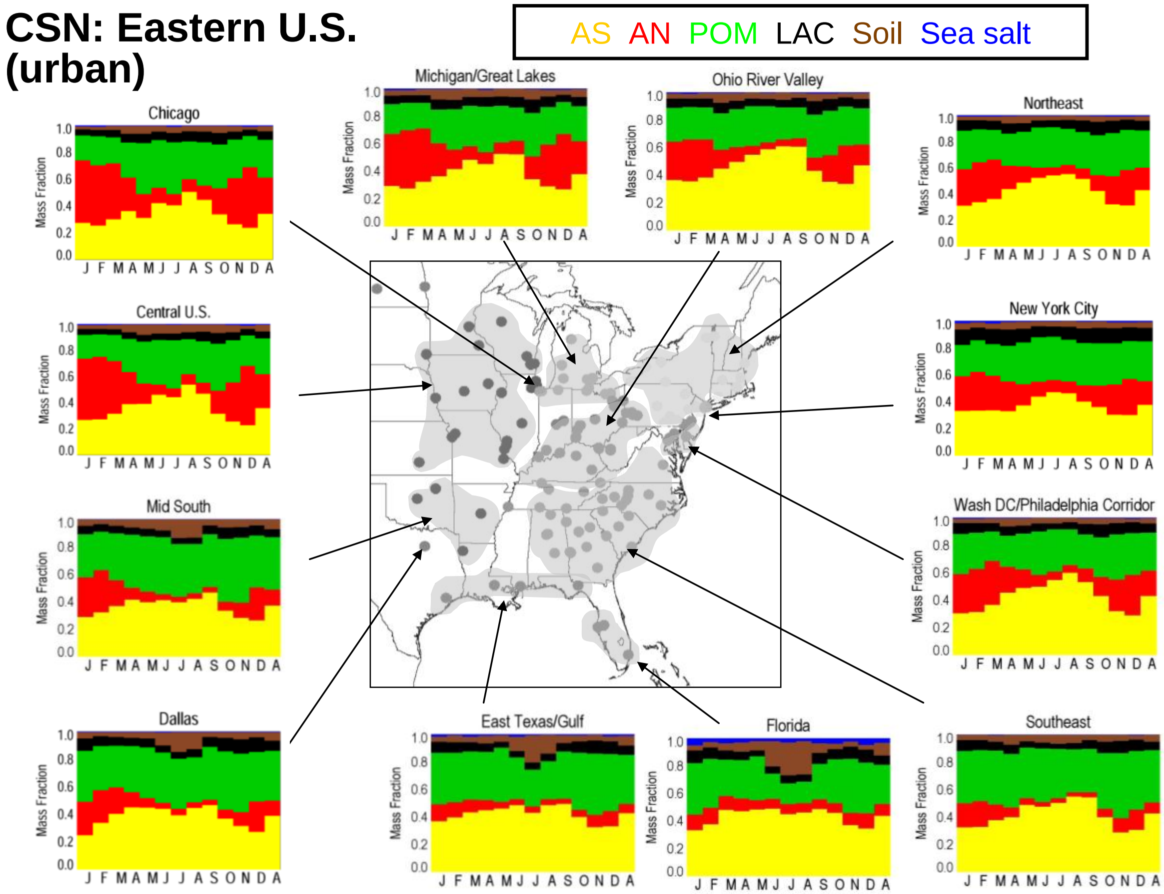

Figure 4.1.16. CSN 2005–2008 regional monthly mean $PM_{2.5}$ reconstructed fine mass fractions for the eastern United States. The letters on the x-axis correspond to the month and "A" corresponds to "annual" mean. Ammonium sulfate (AS) in yellow, ammonium nitrate (AN) in red, particulate organic matter (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.

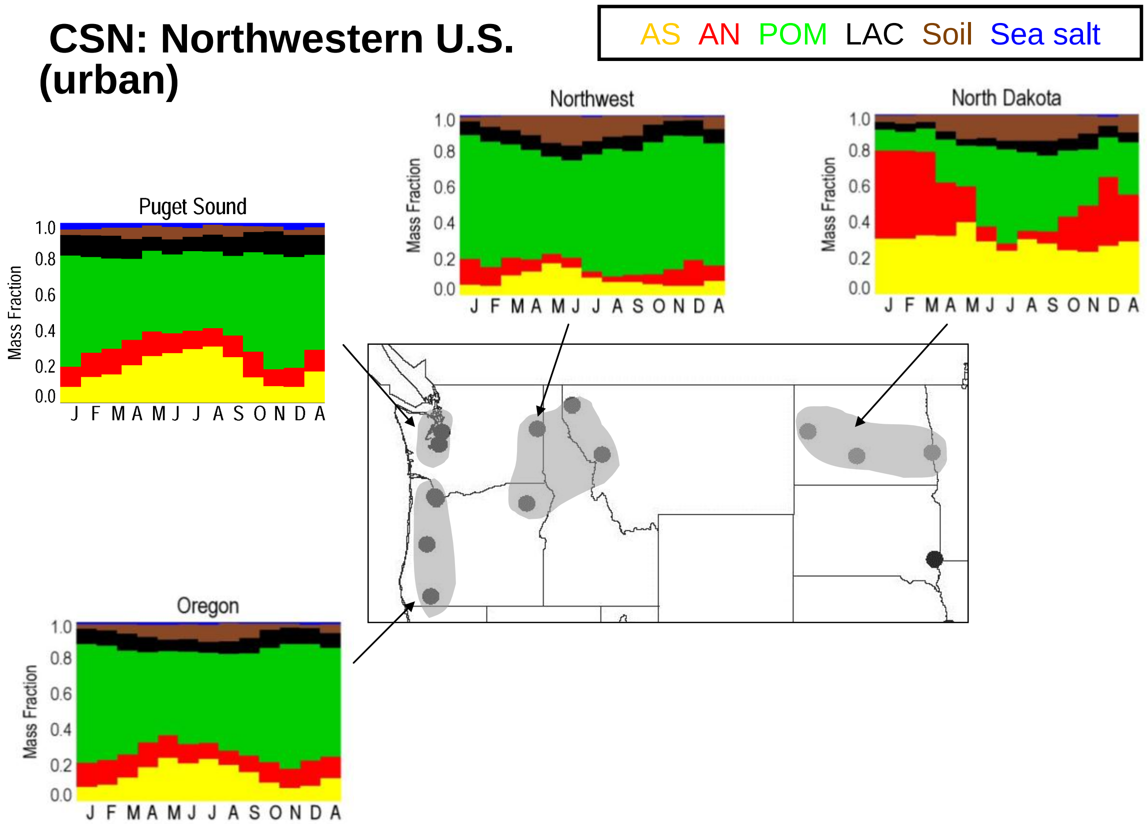

Figure 4.1.17. CSN 2005–2008 regional monthly mean $PM_{2.5}$ reconstructed fine mass fractions for the northwestern United States. The letters on the x-axis correspond to the month and "A" corresponds to "annual" mean. Ammonium sulfate (AS) in yellow, ammonium nitrate (AN) in red, particulate organic 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.

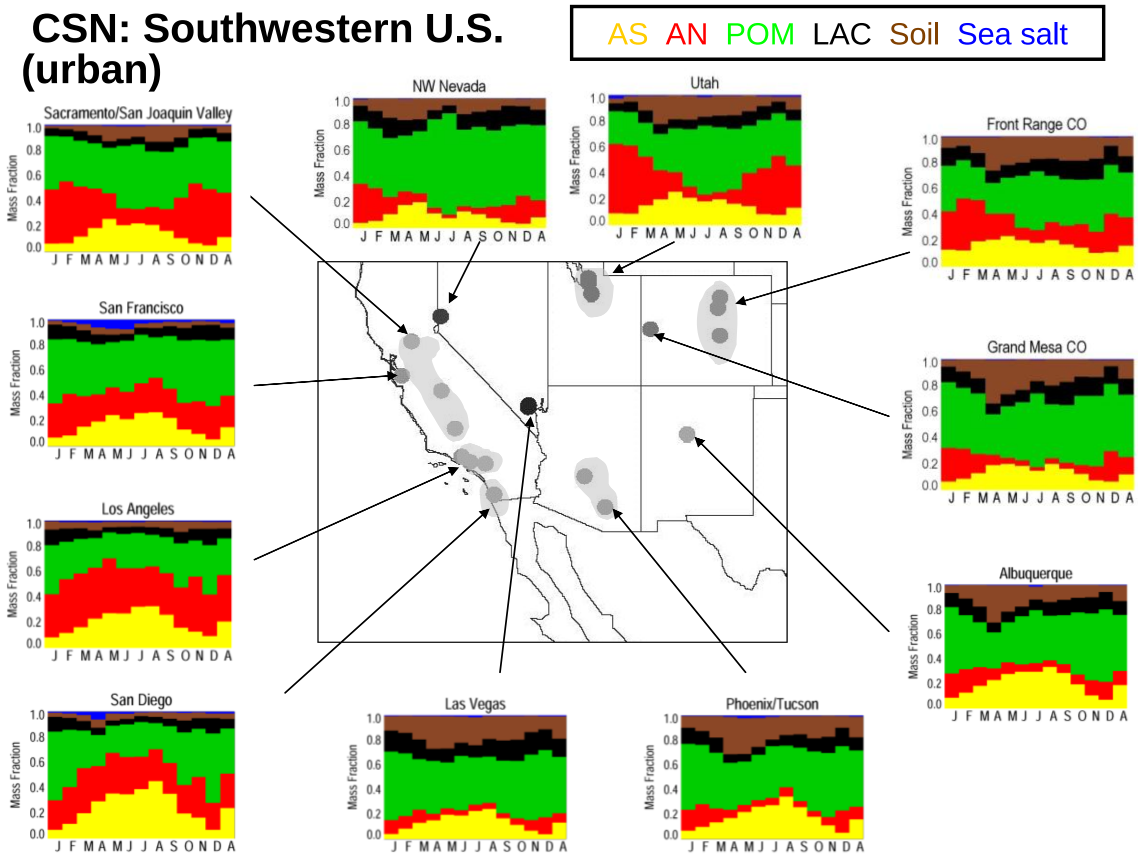

Figure 4.1.18. CSN 2005–2008 regional monthly mean $PM_{2.5}$ reconstructed fine mass fractions for the southwestern United States. The letters on the x-axis correspond to the month and "A" corresponds to "annual" mean. Ammonium sulfate (AS) in yellow, ammonium nitrate (AN) in red, particulate organic 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.

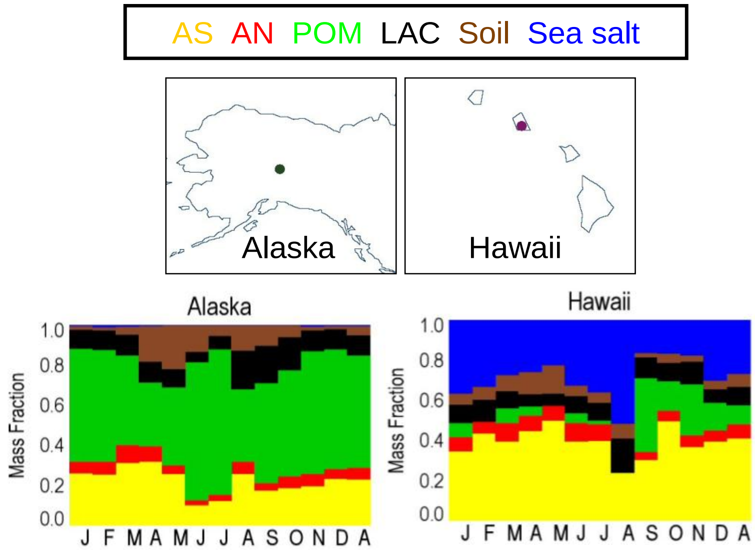

Figure 4.1.19. CSN 2005–2008 regional monthly mean $PM_{2.5}$ reconstructed fine mass fractions for Hawaii and Alaska. The letters on the x-axis correspond to the month and "A" corresponds to "annual" mean. Ammonium sulfate (AS) in yellow, ammonium nitrate (AN) in red, particulate organic matter (POM) 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.

In contrast to the IMPROVE regions, the seasonality in the CSN mass fraction of AS was actually greater than the seasonality in AS concentration for many regions in the western United States (see Figure 4.1.20). For example, Albuquerque, Phoenix/Tucson, and regions in California had many similar seasons for the maxima and minima in mass fractions compared to concentrations, but the degree of seasonality was greater for the relative contribution (compare Figure 4.1.10 and 4.1.20). Regions in the eastern United States depicted a different scenario, with many regions having lower seasonality in mass fractions compared to concentration and with different seasons corresponding to maxima and minima as well (e.g., the Mid South and Southeast). This lower degree of seasonality for AS mass fractions in the eastern United States suggested AS was a steady contributor to RCFM year round. The seasonality in relative contribution ranged from 1.5 in the East Texas/Gulf region to 6.7 in San Diego.

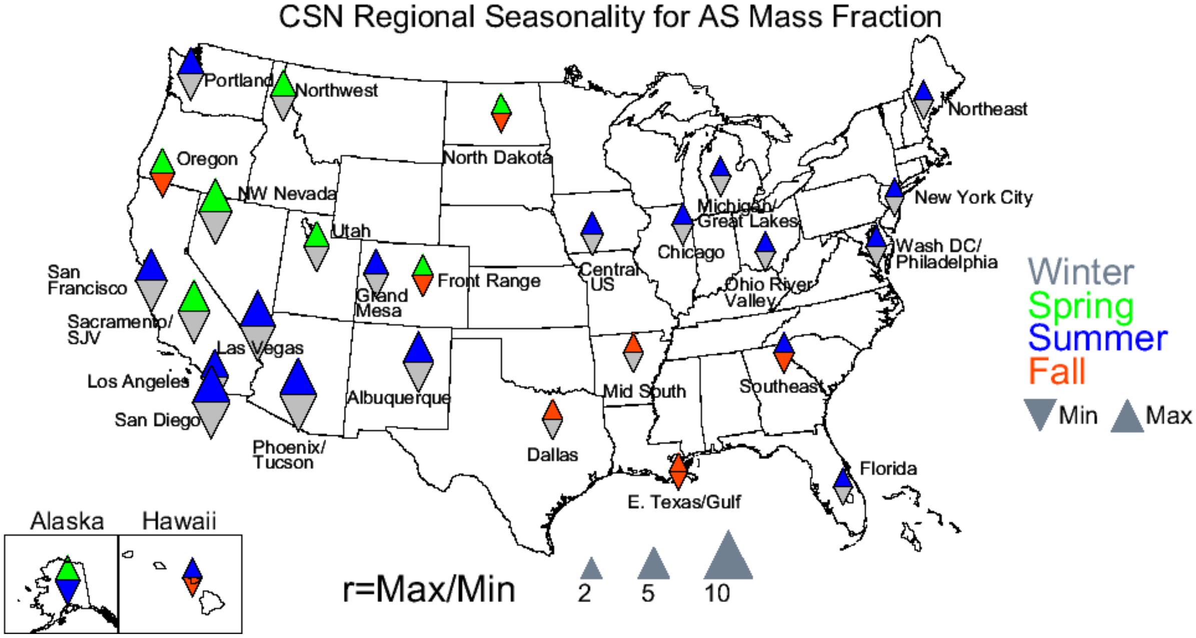

Figure 4.1.20. Seasonal variability for CSN 2005–2008 monthly mean ammonium sulfate (AS) reconstructed fine mass fractions. The color of the upward pointing triangle refers to the season with the maximum monthly mean concentration and the downward pointing triangle refers to the season with the minimum monthly mean concentration. The size of the triangles refers to the magnitude of the ratio of maximum to minimum monthly mean mass concentration.

4.2 $PM_{2.5}$ AMMONIUM NITRATE MASS CONCENTRATIONS

The IMPROVE 2005–2008 regional maximum monthly mean ammonium nitrate (AN) mass concentration (16.19 µg m^{-3}) corresponded to the urban site of Fresno in November and was four times larger than the highest nonurban region (4.08 µg m^{-3}) of the Central Great Plains region in February. A minimum concentration of 0.04 µg m^{-3} was observed in Alaska in October. In regions in the eastern United States, the concentrations were relatively low (see the earlier bar chart in Figure 4.1.1). As one moves west from the east coast, the AN concentrations increased, especially in winter. Other regions of high AN concentrations occurred in the Southern California region in the southwestern United States (see Figure 4.1.3). Concentrations were fairly steady year round in this region. The California Coast and Sierra Nevada regions also corresponded to higher AN concentrations. However, other regions in the southwestern United States had lower concentrations, such as the Colorado Plateau and Mogollon Plateau regions. In the northwestern United States, the Columbia River Gorge and Northern Great Plains regions corresponded to relatively higher concentrations, especially in winter (see Figure 4.1.2). Other regions, such as the Northern Rocky Mountains, had very low concentrations. OCONUS regions all had very low concentrations year round (Figure 4.1.4).

As evidenced from the data presented in these figures, AN concentrations were typically higher in winter due to more favorable conditions of nitrate particle formation in that season. The winter maxima at most regions were very obvious from the depiction of seasonality in Figure 4.2.1. Most of the regions had high seasonality, with only three regions having maximum to minimum ratios less than 2. The maximum ratio was computed for the Boundary Waters region (20.0) and the minimum at the California Coast region (1.7). Several regions in the southwestern

United States had fall minima (e.g., Phoenix, Southern Arizona, and West Texas), and many regions had spring maxima (e.g., Central Rocky Mountains, Colorado Plateau, Mogollon Plateau, Southern California, and Death Valley). Many regions in California had fall maxima and summer minima. In the northwestern United States, most regions corresponded to maxima and minima that occurred in winter and summer, respectively. OCONUS regions had low seasonality. Hawaii and Alaska had spring maxima and fall minima, while the Virgin Islands had a spring maximum and a winter minimum.

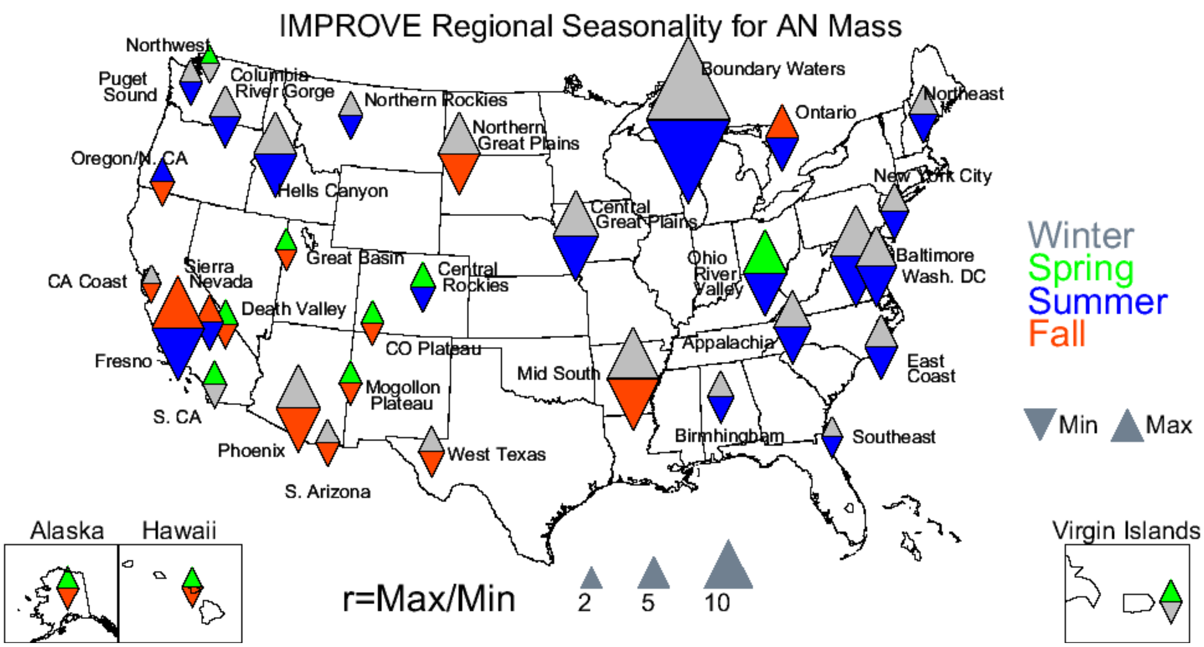

Figure 4.2.1. Seasonal variability for IMPROVE 2005–2008 monthly mean ammonium nitrate (AN) mass concentrations. The color of the upward pointing triangle refers to the season with the maximum monthly mean concentration and the downward pointing triangle refers to the season with the minimum monthly mean concentration. The size of the triangles refers to the magnitude of the ratio of maximum to minimum monthly mean mass concentration.

The maximum CSN monthly mean concentration (14.09 μg m^{-3}) occurred at the Sacramento/San Joaquin Valley region in November. Several regions in the southwestern United States had high AN concentrations, especially compared to IMPROVE regions in this same area (see Figure 4.1.7). Many of the regions in this section showed pronounced winter maxima (e.g., Utah, Sacramento/San Joaquin Valley, and the Front Range CO and Grand Mesa CO regions), while in the southern part of California several regions had fairly flat seasonal AN concentrations. In the northwestern United States, the concentrations decreased but still showed winter maxima, especially in the North Dakota, Northwest, and Oregon regions (Figure 4.1.8). Many regions in the eastern United States had high AN concentrations, especially compared to IMPROVE regions. Winter maxima were obvious at the Chicago, Central U.S., Michigan/Great Lakes, and other regions (Figure 4.1.6). Other regions, such as East Texas/Gulf and Florida, had relatively low concentrations that were fairly flat across all months. The AN concentrations at the Alaska and Hawaii regions were also fairly low and relatively flat year round (Figure 4.1.9). In fact, the minimum regional monthly mean AN concentration occurred at the Alaska region in August (0.11 μg m^{-3}).

CSN regions demonstrated a strong seasonality in AN mass concentrations, with only one region having a maximum to minimum ratio less than or equal to 2 (Florida, 2.0) (see Figure 4.2.2). The largest seasonality was observed in the Utah region (max/min = 32.6). The maximum monthly mean AN concentration occurred in winter for the majority of regions. More urban regions corresponded to winter maxima compared to the IMPROVE regions and were subject to a higher degree of seasonality. Regions in the western United States had a higher seasonality than in the eastern United States, especially in Colorado, Utah, and Nevada. Many regions had minimum concentrations in the fall (e.g., Las Vegas, Phoenix/Tucson, Mid South, East Texas/Gulf, Florida, New York City, and Hawaii).

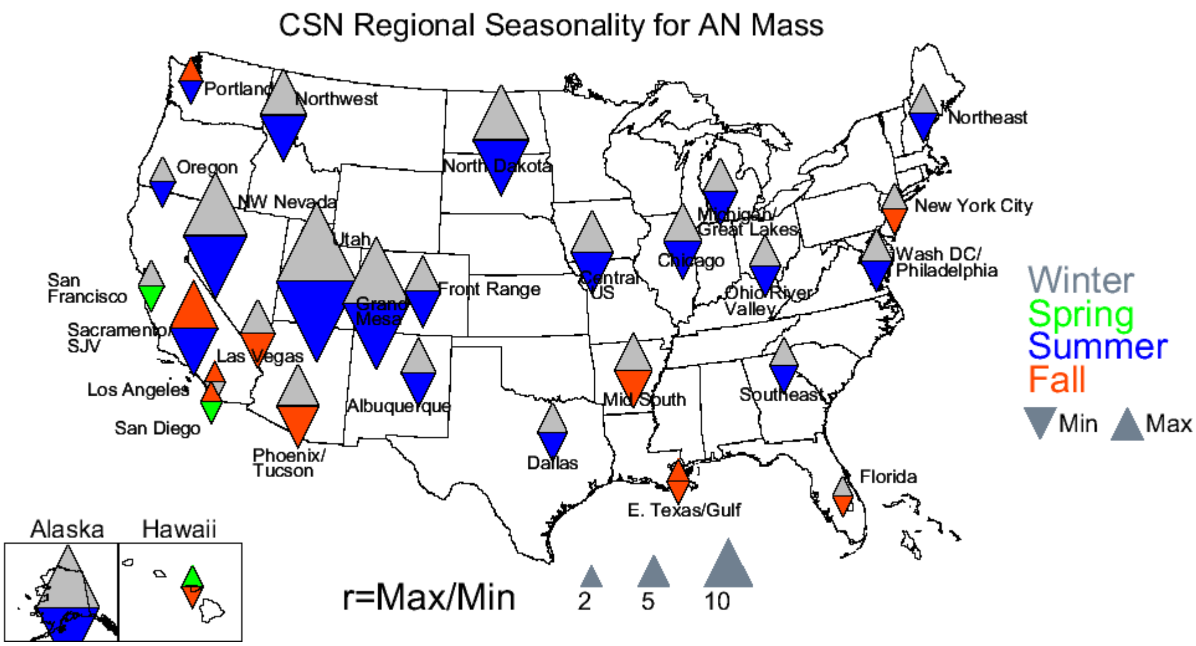

Figure 4.2.2. Seasonal variability for CSN 2005–2008 monthly mean ammonium nitrate (AN) mass concentrations. The color of the upward pointing triangle refers to the season with the maximum monthly mean concentration and the downward pointing triangle refers to the season with the minimum monthly mean concentration. The size of the triangles refers to the magnitude of the ratio of maximum to minimum monthly mean mass concentration.

Rural IMPROVE mass fractions for AN ranged from 1.5% in the Appalachia region in July to 49.1% in the Central Great Plains region in February, similar to the maximum urban IMPROVE site in Fresno in November (50.4%). Many IMPROVE regions on the eastern coast corresponded to fairly low relative contributions (~20% or less), and this contribution was largest in winter when the AS contributions were lower (see Figure 4.1.11). Moving west, the AN mass fraction increased up to 50% in the Central Great Plains region in winter. Other regions, such as Boundary Waters, Northern Great Plains, Mid South, and Ohio River Valley, corresponded to higher contributions compared to coastal regions. These spatial patterns were probably due to the proximity to sources as well as a decrease in AS as the dominant contributor to RCFM. A few regions in the northwestern United States (Figure 4.1.12) also corresponded to considerable AN contributions to RCFM, especially at the Northern Great Plains, Columbia River Gorge, and Hells Canyon regions. Farther west, the contributions of AN decreased, with the exception of the Columbia River Gorge region. In contrast, many regions in the southwestern United States, especially in California, showed considerable AN contributions in winter (4.1.13), such as the

Southern California, Sierra Nevada, and California Coast regions. Regions in Nevada and the Four Corners area tended toward lower AN contributions but still demonstrated winter maxima. The West Texas region had slightly higher contributions. Contributions were low (less than 10%) in the OCONUS region year round (Figure 4.1.14).

As was suggested by the preceding discussion, significant seasonality in AN contributions was observed at IMPROVE regions around the United States (Figure 4.2.3). Only two sites had a ratio of maximum to minimum percent contribution less than 2 (Virgin Islands and Puget Sound). The maximum ratio occurred in the Boundary Waters region (21.0) compared to the minimum in Puget Sound (1.8). Most of the regions had higher AN contributions in winter and lower contributions in summer, following the seasonal pattern of AN concentrations and the formation mechanisms that favor AN formation in winter. Two sites in the eastern United States, Baltimore and Washington, D.C., had spring maxima, and several regions in the western United States corresponded to fall minima. Some California regions had fall maxima and summer minima. The lowest seasonality occurred for regions in the southwestern and northwestern United States.

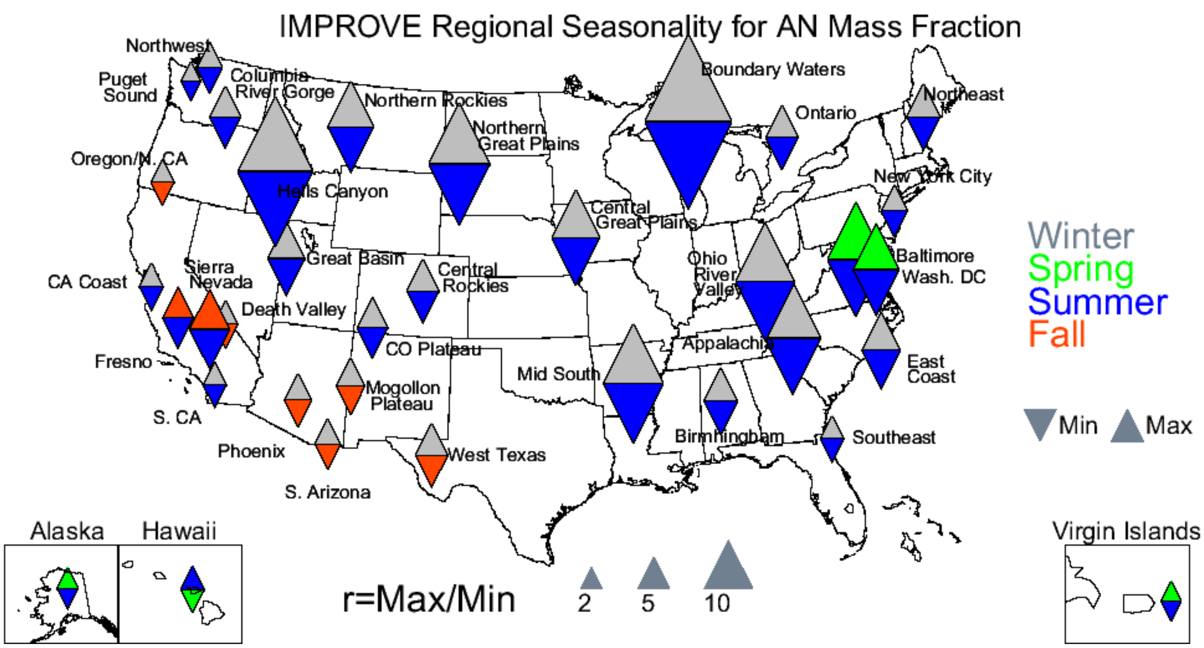

Figure 4.2.3. Seasonal variability for IMPROVE 2005–2008 monthly mean ammonium nitrate (AN) reconstructed fine mass fractions. The color of the upward pointing triangle refers to the season with the maximum monthly mean concentration and the downward pointing triangle refers to the season with the minimum monthly mean concentration. The size of the triangles refers to the magnitude of the ratio of maximum to minimum monthly mean mass concentration.

CSN regional monthly mean AN percent contributions to RCFM ranged from 2.7% in Alaska in June to 53.4% in Utah in January. The southwestern United States included regions with very different seasonal patterns (Figure 4.1.18). For example, the Utah region corresponded to large contributions of AN to RCFM in winter, similar to most regions in Colorado, New Mexico, Arizona, and Nevada but at lower magnitudes. In contrast, regions in the southern part of California corresponded to significant but fairly flat seasonal contributions. At the regions in the northwestern United States, the contributions were fairly flat, except at North Dakota, where a strong winter maximum and high contributions were observed (Figure 4.1.17). In the eastern United States, AN contributions ranged up to 40% at some regions (Chicago, Central U.S., Michigan/Great Lakes) with strong winter maxima (Figure 4.1.16). Toward the eastern coast, the magnitude of the relative contribution decreased, especially at southern regions like the East Texas/Gulf and Florida regions. This general pattern was also observed with the IMPROVE data. AN contributions at the Hawaii and Alaska regions were also low (~10% or less) and fairly flat seasonally (Figure 4.1.19).

A somewhat higher number of CSN regions demonstrated low seasonality in AN mass fractions compared to the rural regions (six compared to two). The highest ratio corresponded to North Dakota (12.5) compared to the minimum at Los Angeles (1.4), consistent with the monthly mean mass fractions shown in Figure 4.1.18. All of the regions with percent contribution ratios less than 2, with the exception of Florida, corresponded to the western coast (Figure 4.2.4). Most regions corresponded to winter maxima and summer minima, with the exception of several regions with fall minima (Dallas, East Texas/Gulf, Phoenix/Tucson, San Francisco, and Puget Sound). San Diego and Washington D.C./Philadelphia Corridor were the only regions with spring maxima. Overall, regions in the western and central United States had higher seasonality than regions in the eastern United States.

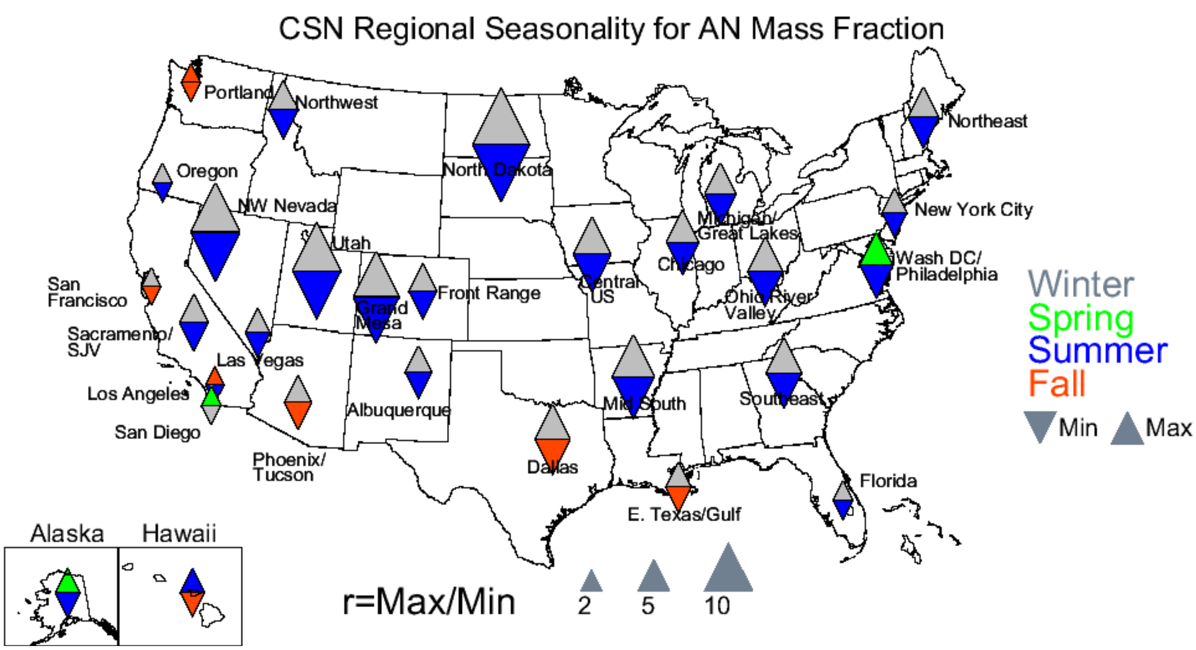

Figure 4.2.4. Seasonal variability for CSN 2005–2008 monthly mean ammonium nitrate (AN) reconstructed fine mass fractions. The color of the upward pointing triangle refers to the season with the maximum monthly mean concentration and the downward pointing triangle refers to the season with the minimum monthly mean concentration. The size of the triangles refers to the magnitude of the ratio of maximum to minimum monthly mean mass concentration.

4.3 $PM_{2.5}$ PARTICULATE ORGANIC MATTER MASS CONCENTRATIONS

IMPROVE 2005–2008 regional monthly mean particulate organic matter (POM) concentrations ranged from 0.08 μg m^{-3} at Virgin Islands in July to 13.02 μg m^{-3} in the urban location of Fresno in December. The maximum nonurban POM concentration was 7.72 μg m^{-3} in the Northern Rocky Mountains region in August. Most of the regions in the northwestern United States corresponded to significant POM concentrations, especially in summer (e.g., Northern Rocky Mountains, Northwest, Northern Great Plains, Hells Canyon, and Oregon/Northern California, see Figure 4.1.2), most likely associated with biomass burning emissions. More northerly regions in the southwestern United States had similar patterns (e.g., Great Basin and Sierra Nevada), but the magnitude of the concentrations and degree of seasonality decreased moving south (e.g., Southern Arizona and West Texas) (see Figure 4.1.3). For most regions in the eastern United States, POM concentrations were comparable to AS, particularly in non-summer months (e.g., Ohio River Valley, Northeast, East Coast, Appalachia, and Southeast, see Figure 4.1.1). POM monthly mean concentrations were higher in Alaska and peaked in summer, but were relatively low in the Hawaii and Virgin Island regions (Figure 4.1.4).

Most of the IMPROVE regions demonstrated a high level of seasonality with only 6 regions having ratios of maximum to minimum mass concentrations less than 2 (Figure 4.3.1). The largest ratio occurred in the Alaska region (16.9) and the lowest ratio occurred in the Southern Arizona region (1.6). The western United States corresponded to much higher seasonality in POM concentrations compared to the eastern United States, probably because of the impacts from biomass burning in summer. Most western regions had summer maxima and winter minima, with the exception of the urban sites of Fresno, Phoenix, and Puget Sound, all of which had winter maxima. A few regions had spring minima, such as California Coast, Fresno, Oregon and Northern California, Hells Canyon, and Northern Great Plains. In the eastern United States the maxima predominantly occurred in summer, but minima occurred during all seasons. Maximum and minimum both occurred during fall months in Baltimore.

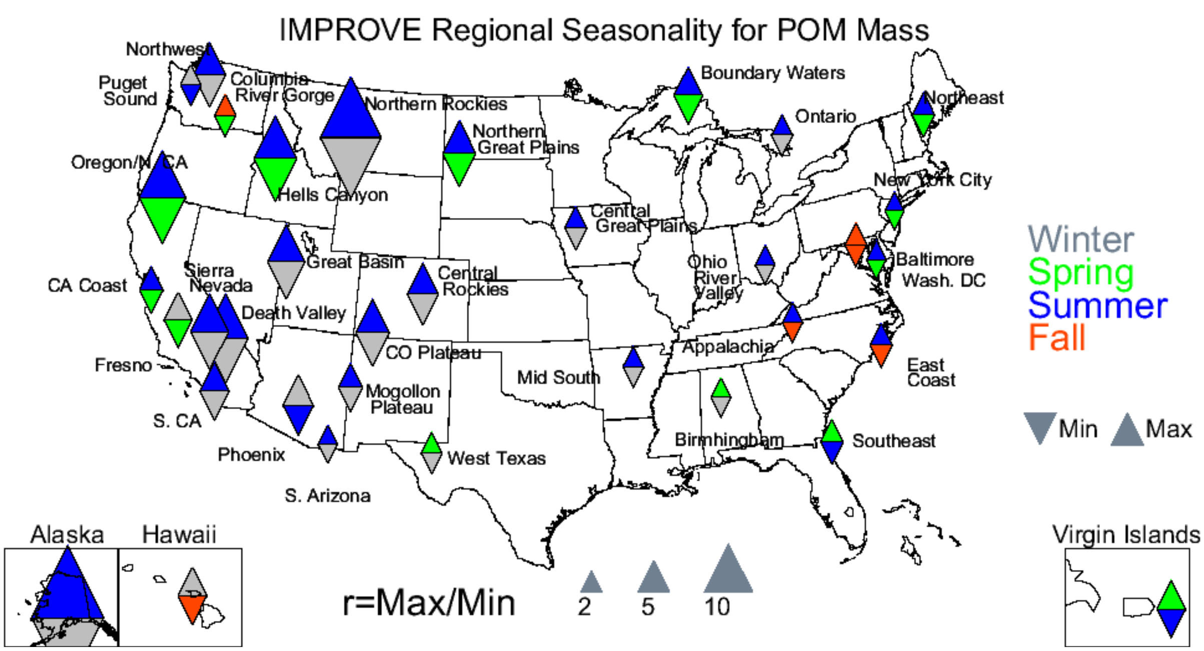

Figure 4.3.1. Seasonal variability for IMPROVE 2005–2008 monthly mean particulate organic matter (POM) mass concentrations. The color of the upward pointing triangle refers to the season with the maximum monthly mean concentration and the downward pointing triangle refers to the season with the minimum 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 POM regional monthly mean mass concentrations ranged from 0.66 μg m^{-3} in the North Dakota region in February to 16.74 μg m^{-3} in the Alaska region in December. Eastern regions had comparable POM mass concentrations that were generally seasonally flat (Figure 4.1.6) and comparable in magnitude to AS concentrations, especially in non-summer months. In contrast, POM concentrations were much higher in the northwestern United States (Figure 4.1.8), especially in winter (with the exception of North Dakota). In the Northwest region POM concentrations were much higher than AS concentrations; similar patterns occurred in the Puget Sound and Oregon regions as well. POM concentrations were also larger than AS concentrations in the southwestern United States (Figure 4.1.7). In regions such as Northwest Nevada, Las Vegas, Front Range CO, and others, the POM concentrations were considerably higher than AS concentrations and tended to peak in winter. High POM concentrations were also observed in the Alaska region (Figure 4.1.9), especially in winter. In contrast, concentrations were low in Hawaii although they increased during the fall and early winter.

The seasonality of POM monthly mean concentrations was much different for urban CSN regions compared to rural IMPROVE regions. Lower seasonality was observed in general (eight CSN regions maximum to minimum ratios less than 2) and the winter minima/summer maxima that occurred in most western IMPROVE regions (and Alaska) were replaced with nearly the opposite: winter maxima and spring and summer minima (Figure 4.3.2). In the eastern United States the seasonality varied per region, with several summer maxima and winter and spring minima. Several regions along the eastern coast corresponded to similar summer maxima/spring minima and degree of seasonality as the rural regions. The largest ratio occurred at the Alaska region (24.6) and the lowest in the Southeast region (1.5).

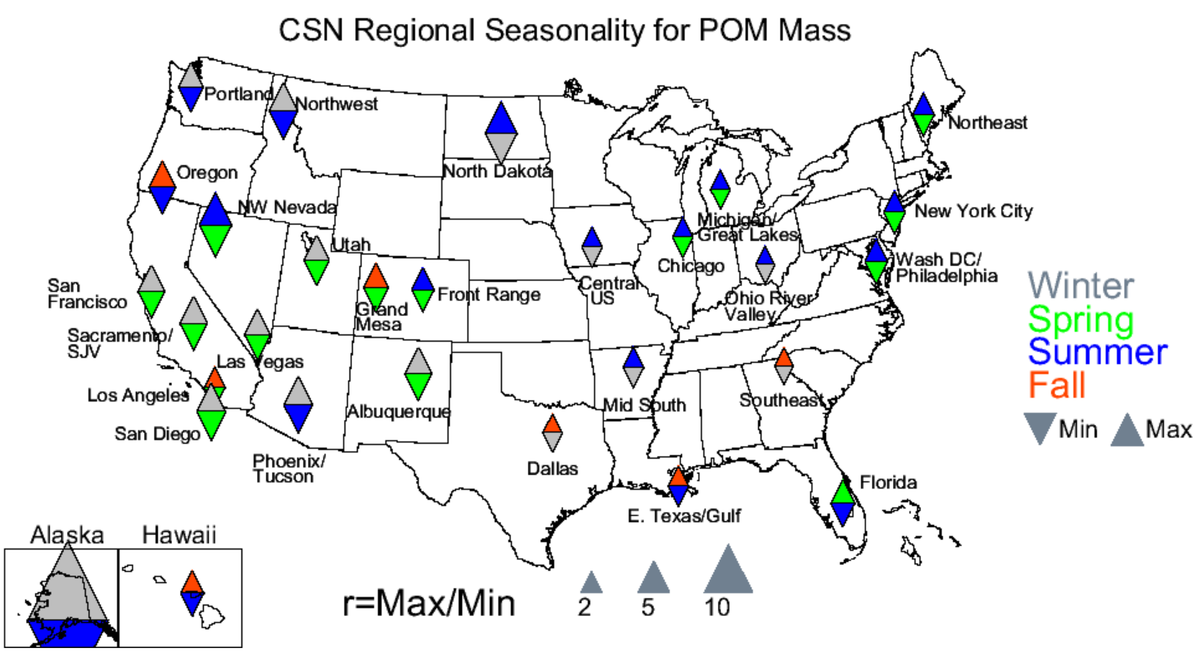

Figure 4.3.2. Seasonal variability for CSN 2005–2008 monthly mean particulate organic matter (POM) mass concentrations. The color of the upward pointing triangle refers to the season with the maximum monthly mean concentration and the downward pointing triangle refers to the season with the minimum monthly mean concentration. The size of the triangles refers to the magnitude of the ratio of maximum to minimum monthly mean mass concentration.

The lowest IMPROVE rural regional monthly mean mass fraction occurred in the Virgin Islands in July (0.9%), compared to the highest (76.3%) in the Northern Rocky Mountains region in August. POM contributions dominated the RCFM in the northwestern United States. Contributions were typically 40–60% and generally higher in summer (see Figure 4.1.12). In the southwestern United States the magnitude and seasonality of POM contributions decreased somewhat (Figure 4.1.13). Contributions were 15–20% at many regions throughout the year (e.g., West Texas, Southern Arizona, and Southern California). In the eastern United States POM relative contributions typically ranged from 20 to 40%, although higher mass fractions occurred at the Boundary Waters and Northern Great Plains regions (Figure 4.1.11). Of the OCONUS regions, Alaska had the highest POM contributions, especially in summer (Figure 4.1.14).

Summer maxima in mass fractions of POM were common for IMPROVE regions. As seen in Figure 4.3.3, most western regions corresponded to summer maxima and spring minima, with the exception of a few regions, such as Puget Sound, Columbia River Gorge, and Southern California. In the eastern United States, many regions had fall maxima, with varying seasons for minima. Relative contributions of POM demonstrated a low degree of seasonality (much lower than POM concentrations), suggesting that the level of contributions of POM to RCFM were fairly steady at most regions. Nearly half of all IMPROVE regions had minimal seasonality (max/min < 2). The maximum ratio occurred at Virgin Islands (7.1) and the lowest occurred at New York City (1.3).

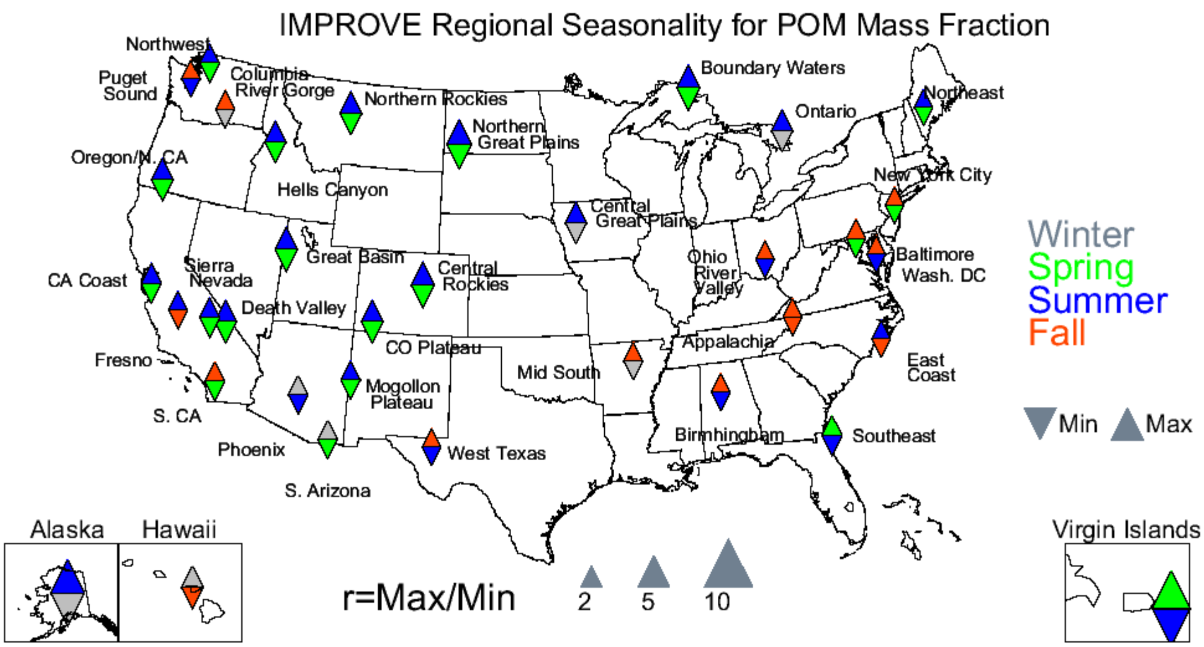

Figure 4.3.3. Seasonal variability for IMPROVE 2005–2008 monthly mean particulate organic matter (POM) reconstructed fine mass fractions. The color of the upward pointing triangle refers to the season with the maximum monthly mean concentration and the downward pointing triangle refers to the season 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.

A CSN urban maximum POM mass fraction of 77.8% occurred in the Northwest Nevada region in July compared to a minimum of 10.3% in North Dakota in February. Most regions in the northwestern United States had high POM contributions (see Figure 4.1.17). The seasonal pattern at North Dakota was markedly different than the other regions in this area. Contributions were largest during winter (70–80%) for Puget Sound, Northwest, and Oregon regions, but at North Dakota the POM contributions were highest in summer. Moving south, the POM contributions decreased to around 40%, depending on region. Northwest Nevada had the highest contributions of POM to RCFM of any region in the southwestern United States (Figure 4.1.18). The contributions of POM to RCFM decreased even further in the eastern United States. Relative contributions of 20–40% were typical at many regions (see Figure 4.1.16) and fairly flat seasonally. Alaska had much higher contributions (60% or more), with the largest in summer. The Hawaii region had a very low POM contribution, but it increased in the fall (Figure 4.1.19).

POM mass fractions in CSN regions were somewhat less seasonal than IMPROVE regions, with 21 of all urban regions having ratios less than 2. The maximum ratio occurred in North Dakota (5.1) compared to the lowest in the Northwest region (1.4). The seasonality also reflected different seasons corresponding to maxima and minima compared to IMPROVE regions, with fewer summer maxima and spring minima in the western United States (Figure 4.3.4). In the northwestern United States the maximum contributions occurred mainly in summer and fall, farther south winter maxima in Arizona, New Mexico, and the southern part of California occurred. In the eastern United States the maxima occurred in the fall for many regions, with minima in the summer for the Southeast, East Texas/Gulf, and Florida regions.

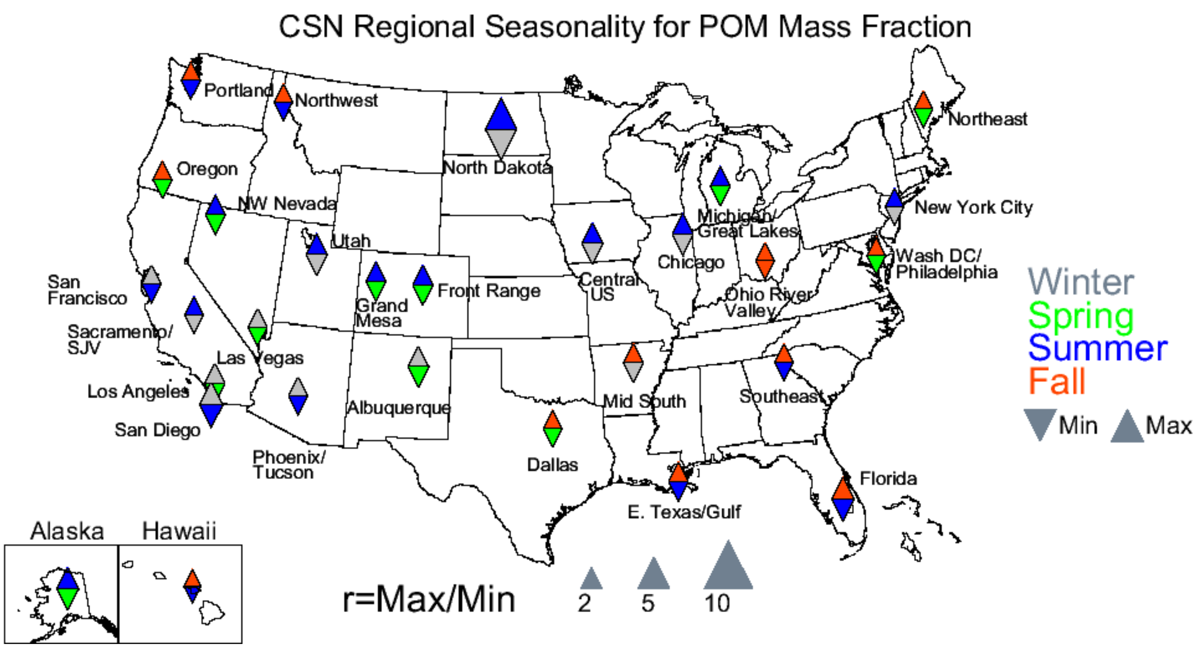

Figure 4.3.4. Seasonal variability for CSN 2005–2008 monthly mean particulate organic matter (POM) reconstructed fine mass fractions. The color of the upward pointing triangle refers to the season with the maximum monthly mean concentration and the downward pointing triangle refers to the season with 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.

4.4 $PM_{2.5}$ LIGHT ABSORBING CARBON MASS CONCENTRATIONS

The IMPROVE 2005–2008 maximum regional monthly mean light absorbing carbon (LAC) mass concentration of 2.69 μg m^{-3} occurred in the urban location of Phoenix in December and 0.56 μg m^{-3} in the nonurban locations of the Northern Rocky Mountains region in August. The minimum regional monthly mean mass concentration occurred at the Hawaii region in July (0.012 μg m^{-3}). Compared to other aerosol species, LAC concentrations were so relatively low that they are difficult to discern on bar charts from the eastern (Figure 4.1.1), southwestern (4.1.3), and OCONUS (4.1.4) regions of the United States. Somewhat higher concentrations occurred in the northwestern United States (Figure 4.1.12). For example, the Northern Rocky Mountains, Northwest, and Columbia River Gorge regions had somewhat higher concentrations (i.e., viewable on the charts), especially in summer.

Although difficult to see on the bar charts because of relatively low LAC concentrations compared to other species, IMPROVE LAC concentrations corresponded to some degree of seasonality, although less than POM concentrations. Regions in the western United States had higher seasonality compared to the eastern regions (Figure 4.4.1). Many regions in the western United States corresponded to summer maxima and winter minima. Similar to POM concentrations, some of the urban IMPROVE sites had the opposite seasonality (winter maxima/summer minima), such as Puget Sound and Phoenix. Several eastern regions corresponded to fall maxima. Thirteen regions had maximum to minimum ratios less than 2. The highest ratio in LAC maximum/minimum concentrations occurred at the Northern Rocky Mountain region (7.3) compared to the lowest for the Ohio River Valley region (1.3).

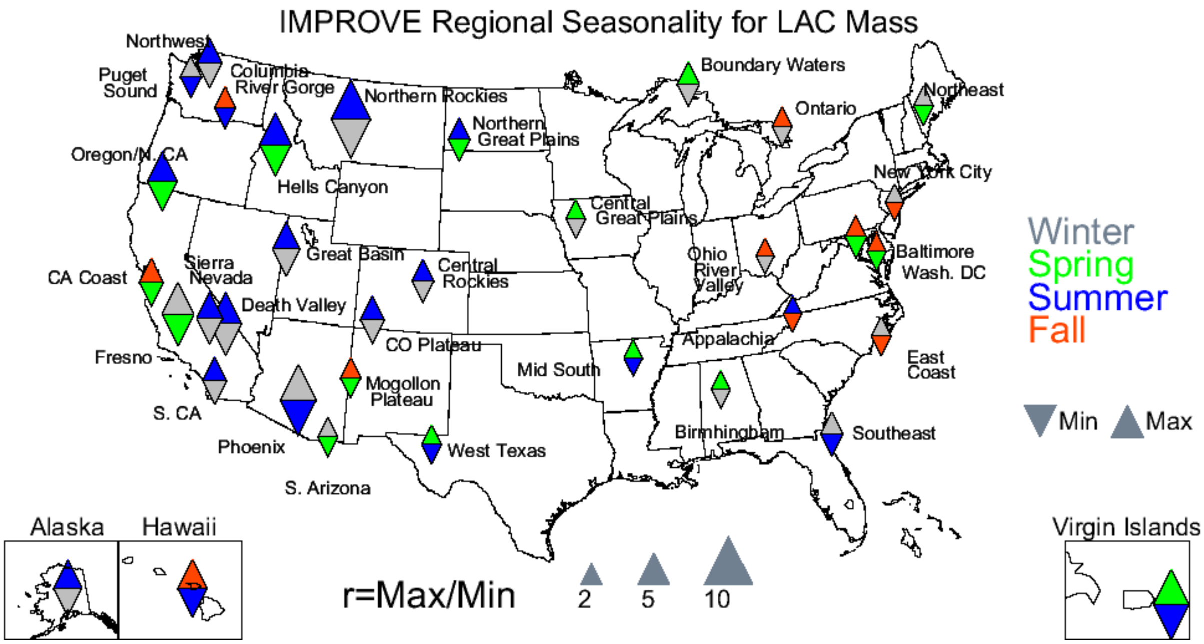

Figure 4.4.1. Seasonal variability for IMPROVE 2005–2008 monthly mean light absorbing carbon (LAC) mass concentrations. The color of the upward pointing triangle refers to the season with the maximum monthly mean concentration and the downward pointing triangle refers to the season with the minimum monthly 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 LAC concentrations ranged from 0.16 μg m^{-3} in North Dakota in May to 2.91 μg m^{-3} in the Alaska region in December. The CSN LAC concentrations were much higher than concentrations in rural IMPROVE regions. For example, eastern U.S. LAC concentrations are visible on the bar charts in Figure 4.1.6, especially at some locations like New York City. In some southwestern regions the urban LAC concentrations were much larger than rural regions (compare Figure 4.1.7 to 4.1.3). Winter concentrations were higher than during other months at several regions in the southwestern United States, such as Las Vegas, Phoenix/Tucson, San Francisco, Grand Mesa CO, and Albuquerque. Higher LAC concentrations, especially in winter, were observed in the northwestern United States (e.g., Puget Sound region). Higher CSN concentrations were also observed in the Alaska and Hawaii regions (Figure 4.1.9) compared to IMPROVE OCONUS regions.

CSN LAC concentrations demonstrated a similar degree of seasonality as POM concentrations but with different seasons corresponding to maximum and minimum, especially in the eastern United States (Figure 4.4.2 compared to Figure 4.3.2). Several western regions corresponded to winter maxima and spring minima and higher seasonality compared to eastern U.S. regions. In contrast, several eastern regions had fall maxima and summer minima. There were 11 regions with maximum to minimum ratios less than 2 for the CSN network, with the Alaska region demonstrating the highest seasonality (8.0) compared to New York City, which demonstrated the least (1.4).

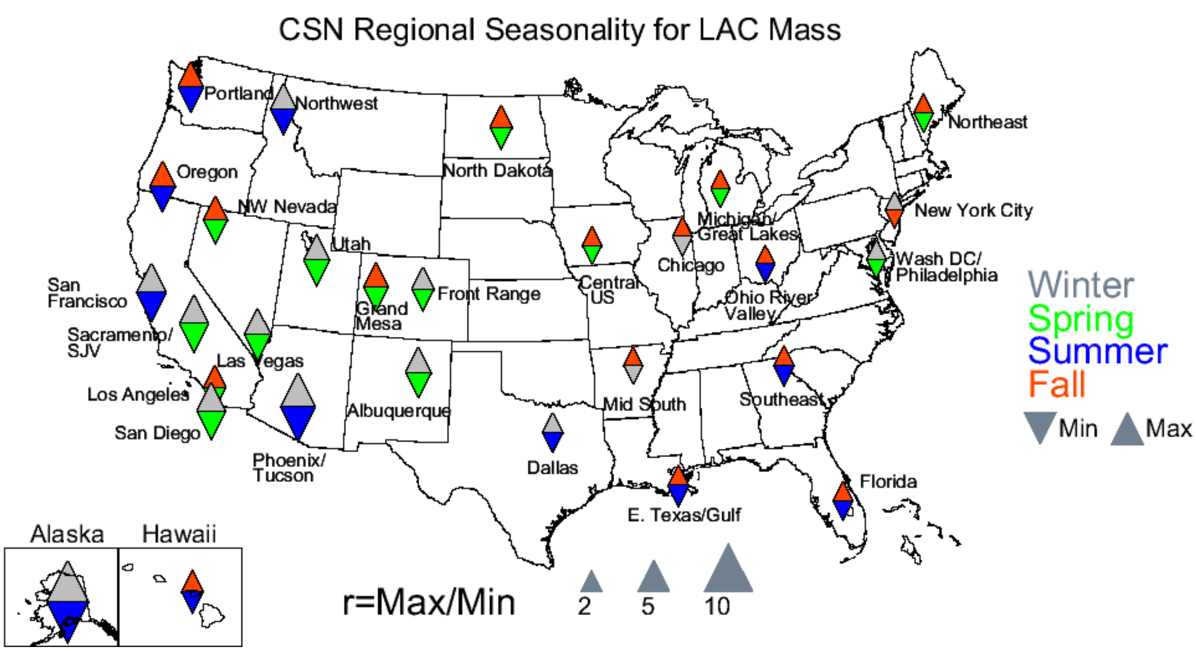

Figure 4.4.2. Seasonal variability for CSN 2005–2008 monthly mean light absorbing carbon (LAC) mass concentrations. The color of the upward pointing triangle refers to the season with the maximum monthly mean concentration and the downward pointing triangle refers to the season with the minimum monthly mean concentration. The size of the triangles refers to the magnitude of the ratio of maximum to minimum monthly mean mass concentration.

As expected from the IMPROVE rural LAC concentrations discussed previously, the relative contribution of LAC to RCFM was low; these low contributions were especially obvious in the eastern United States (see Figure 4.1.11). Somewhat higher contributions occurred in the northwestern United States (e.g., Columbia River Gorge, Northwest, Northern Rocky Mountains, and Oregon/Northern California regions, see Figure 4.1.12). Relative contributions of LAC were low in the southwestern United States also, although they were slightly higher during winter months at some locations (e.g., Colorado Plateau and Mogollon Plateau, see Figure 4.1.13). LAC relative contributions were higher at Alaska compared to other OCONUS regions (Figure 4.1.14). Rural IMPROVE regional LAC mass fractions ranged from 0.17% in the Virgin Islands to 7.5% in the Mogollon Plateau in December. The maximum monthly mean mass fraction for IMPROVE urban region corresponded to 13.3% in Puget Sound in January.

The IMPROVE LAC mass fractions did not exhibit a high degree of seasonality, with 24 regions having ratios of maximum to minimum mass fractions less than 2. The largest occurred in the Virgin Islands (11.6) compared to the Northwest region (1.4). Relative LAC contributions were lowest in the spring and highest in winter in many western regions. However, in the eastern regions the minimum relative contribution occurred in summer, with maxima in fall and winter (Figure 4.4.3). The seasons corresponding to maxima and minima were quite different for LAC and POM mass fractions, although the degree of seasonality was similar (compare Figures 4.4.3 to 4.3.3).

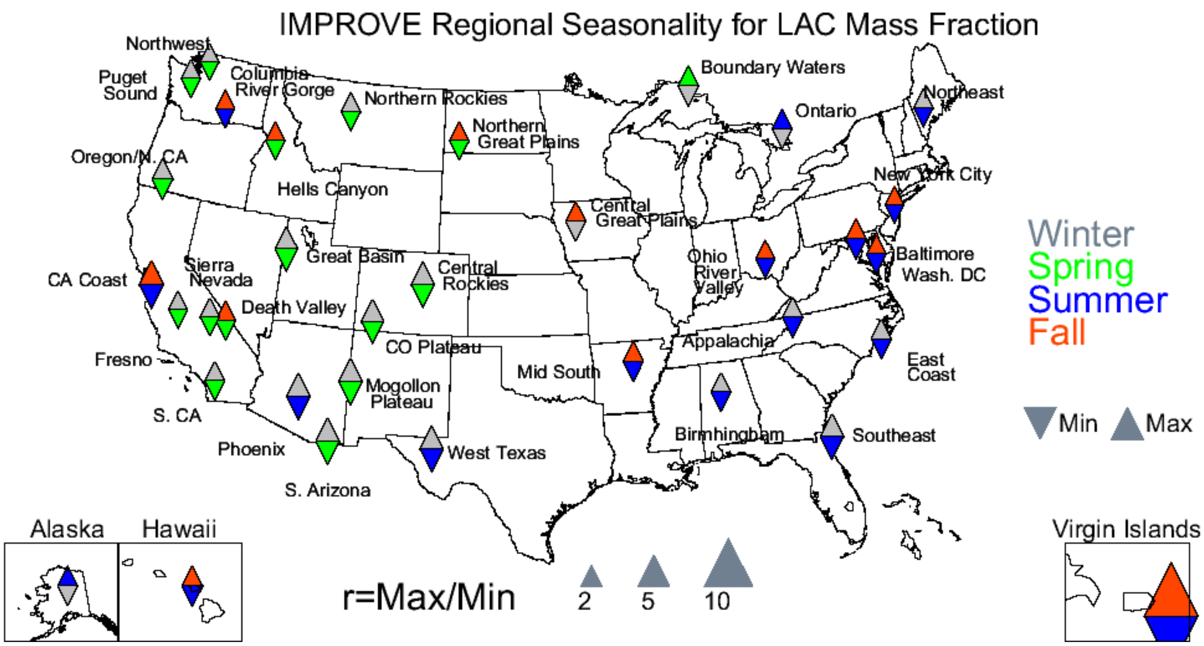

Figure 4.4.3. Seasonal variability for IMPROVE 2005–2008 monthly mean light absorbing carbon (LAC) reconstructed fine mass fractions. The color of the upward pointing triangle refers to the season with the maximum monthly mean concentration and the downward pointing triangle refers to the season with 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 regional mass fractions ranged from 3.6% in North Dakota in May to 19.4% in Alaska in August. As seen in Figure 4.1.19, the CSN Hawaii region also corresponded to relatively large LAC mass fractions compared to the IMPROVE Hawaii region (compare Figure 4.1.14). Urban relative contributions were also higher in the northwestern United States (compare Figure 4.1.17 to Figure 4.1.12). For these regions, Puget Sound had the highest LAC mass fractions year round. Relative contributions of urban LAC in the southwestern United States were also higher than rural regions (Figure 4.1.18). Specifically, regions such as Northwest Nevada, Front Range CO, and Phoenix/Tucson corresponded to higher LAC mass fractions compared to nearby rural regions (compare Figure 4.1.18 to Figure 4.1.13). LAC contributions in the eastern United States appeared somewhat larger than rural regions, but not to the degree as in the western United States (compare Figure 4.1.16 to 4.1.11).

In most CSN regions, LAC did not appear to have a high degree of seasonality. In fact, roughly half (14) of all CSN regions had maximum to minimum mass fraction ratios less than 2. The maximum occurred in Alaska (3.7) compared to the minimum in the Northwest region (1.4). Several regions corresponded to fall maxima, both in the eastern and western United States. However, in the southwestern United States and Dallas, several regions corresponded to winter maxima. Spring and summer minima occurred for most regions around the country, with the exception of winter minima in the Utah, Central U.S., Chicago, and Michigan/Great Lakes regions. LAC relative contributions generally had the same degree of seasonality as POM mass fractions, but maxima and minima seasons differed for most regions (compare Figures 4.3.4 and 4.4.4).

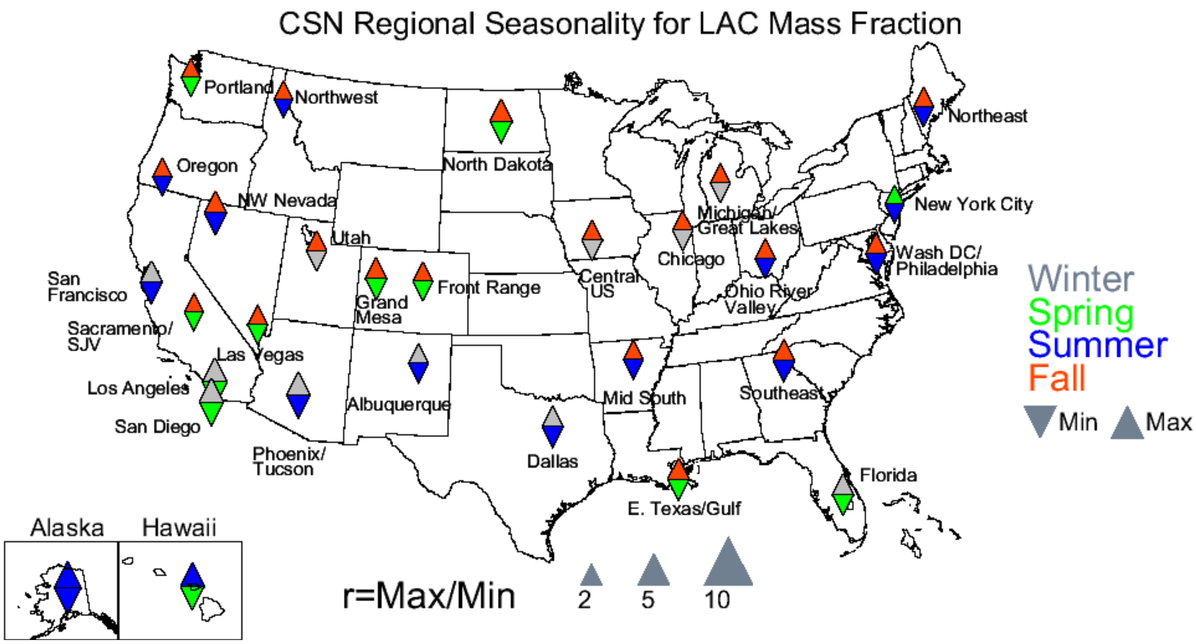

Figure 4.4.4. Seasonal variability for CSN 2005–2008 monthly mean light absorbing carbon (LAC) reconstructed fine mass fractions. The color of the upward pointing triangle refers to the season with the maximum monthly mean concentration and the downward pointing triangle refers to the season with the minimum monthly mean concentration. The size of the triangles refers to the magnitude of the ratio of maximum to minimum monthly mean mass concentration.

4.5 $PM_{2.5}$ SOIL MASS CONCENTRATIONS

A maximum 2005–2008 regional monthly mean IMPROVE soil mass concentration of 5.54 μg m^{-3} was observed in June at Virgin Islands, a site known to have impacts from North African dust transport, especially during summer. The minimum concentration was observed in Alaska in September (0.05 μg m^{-3}) (see Figure 4.1.4). Soil concentrations were highest in the southwestern United States (Figure 4.1.3). Most regions in this area, with the exception of some regions along the coast in California, corresponded to relatively high soil concentrations, such as spring concentrations in the regions of Death Valley, Central Rocky Mountains, Colorado Plateau and Mogollon Plateau, and Southern Arizona. Large differences in monthly concentrations were observed at some regions, such as Great Basin, where winter soil concentrations were quite low. Concentrations were lower in the northwestern United States and peaked in summer rather than spring but were also quite low in winter (Figure 4.1.2). Concentrations in the eastern United States were also comparatively low compared to the southwestern United States (Figure 4.1.1) and typically were higher in summer for some regions (e.g., Mid South and Southeast regions).

As could be seen in many of the bar charts, IMPROVE soil concentrations were highly seasonal, with only four regions having maximum to minimum ratios less than 2 (all urban regions), consistent with the often episodic impacts of soil emissions. The largest ratio occurred at Virgin Islands (28.9) and the lowest at New York City (1.6) (Figure 4.5.1). Maxima occurred primarily in the spring in the western and southwestern United States and in summer in the most northwestern and eastern regions, and minima often occurred in winter. Southern Arizona and Phoenix were the only regions with summer minima in the country.

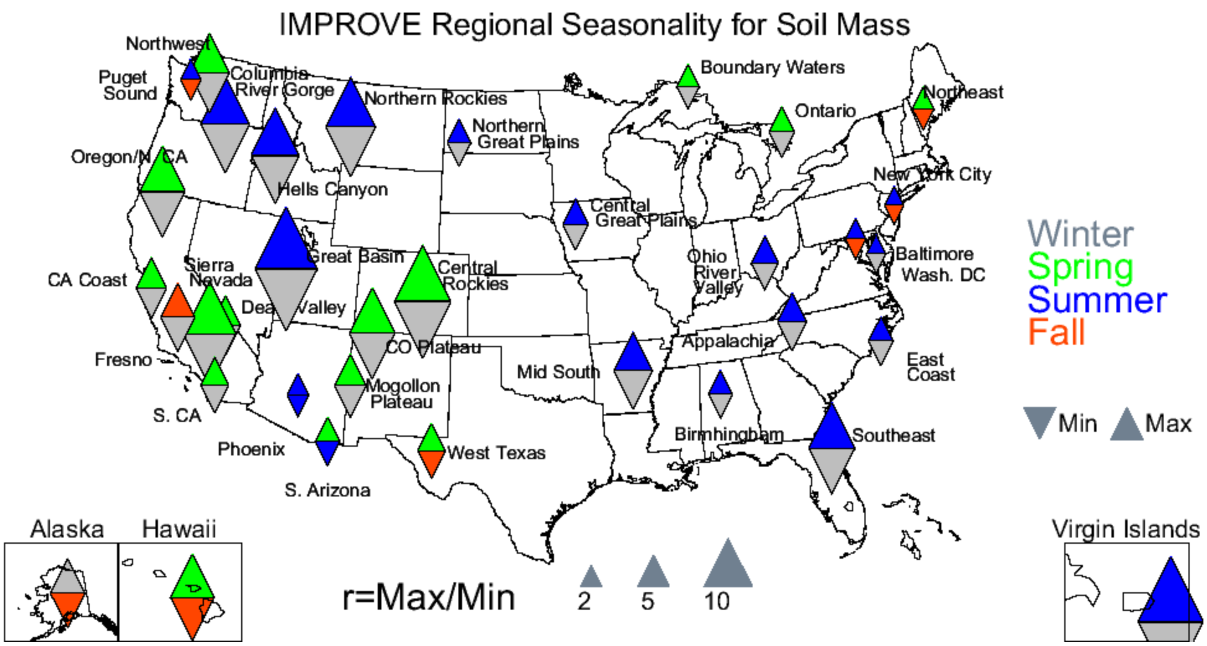

Figure 4.5.1. Seasonal variability for IMPROVE 2005–2008 monthly mean fine soil mass concentrations. The color of the upward pointing triangle refers to the season with the maximum monthly mean concentration and the downward pointing triangle refers to the season with the minimum monthly mean concentration. The size of the triangles refers to the magnitude of the ratio of maximum to minimum monthly mean mass concentration.

Unlike other species, CSN soil concentrations were generally lower than IMPROVE soil concentrations, although recall the relative bias between IMPROVE and CSN data, with higher IMPROVE soil concentrations at collocated sites (Table 1.9). However, spatial patterns in CSN soil concentrations differed from the rural concentrations as demonstrated by data at regions in the southwestern United States. CSN concentrations were noticeably lower than IMPROVE (compare Figure 4.1.7 to 4.1.3) and demonstrated less seasonality, although concentrations increased in spring and summer (e.g., Phoenix/Tucson and Grand Mesa CO). CSN concentrations also were low in the northwestern United States and also increased in summer and spring (Figure 4.1.8). Low soil concentrations were also characteristic of most eastern urban regions (Figure 4.1.6). Southern regions, such as Florida, East Texas/Gulf, Dallas, and Mid South, had the highest concentrations. The low urban soil concentrations observed in most of the continental United States was also characteristic of the Alaska and Hawaii regions (Figure 4.1.9). The lowest and highest soil concentrations both occurred in summer months in Alaska, while the highest concentrations in Hawaii occurred in spring (Figure 4.1.9). The maximum CSN soil mass concentration was 2.55 μg m^{-3} in Phoenix/Tucson in April, compared to a low value of 0.09 μg m^{-3} in Hawaii in September.

CSN urban regions experienced a much lower degree of seasonality compared to IMPROVE rural regions. (Compare Figure 4.5.2 and 4.5.1), especially in the western United States. While the seasons corresponding to maxima and minima were similar, the range in concentration between minimum and maximum months was much lower. More regions in California had fall maxima compared to spring maxima at IMPROVE regions. Seven regions had maximum to minimum ratios less than 2. The largest ratio occurred in Florida (8.2), perhaps associated with transport of North African dust. The lowest ratio (1.6) occurred in New York City.

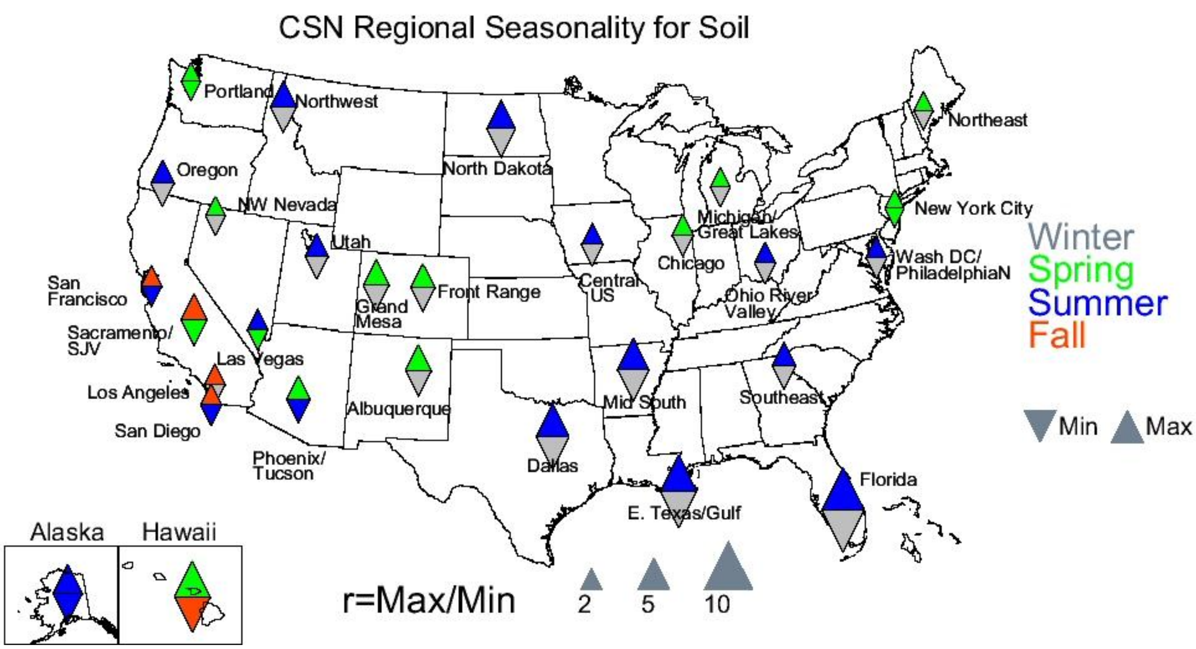

Figure 4.5.2. Seasonal variability for CSN 2005–2008 monthly mean fine soil mass concentrations. The color of the upward pointing triangle refers to the season with the maximum monthly mean concentration and the downward pointing triangle refers to the season with the minimum monthly mean concentration. The size of the triangles refers to the magnitude of the ratio of maximum to minimum monthly mean mass concentration.

Soil mass contributions to RCFM for the IMPROVE rural regions ranged from 1.9% in Alaska in August to 56.3% in the Virgin Islands in August. Given the previous discussions of other aerosol species, it is not surprising that the soil was not a major contributor to RCFM in most eastern regions. However, at the Southeast, Northern Great Plains, and Mid South regions, the relative contributions reached as high as 20% in summer (Figure 4.1.11). The Southeast region most likely experienced the impacts of North African dust transport in summer, as indicated by the high soil mass fractions at the Virgin Islands in summer also (Figure 4.1.14).

The relative contribution of soil to RCFM in the southwestern United States was noticeably higher than in the eastern United States (Figure 4.1.13). Many regions (e.g., Southern Arizona and Death Valley) had contributions of 40% or greater during certain months. The only regions with lower relative contributions were Southern California, California Coast, and Sierra Nevada. Most of the northwestern regions corresponded to ~20% relative contributions of soil (Figure 4.1.12). Soil mass fractions were highest in spring for these regions, with the exception of Columbia River Gorge, which experienced an increase in soil contributions in summer.

IMPROVE soil mass fractions were fairly seasonal for most regions, with only four regions having ratios less than 2 (Figure 4.5.3). The regions with the highest ratios were the urban site of Fresno (12.8) and the rural Virgin Island site (9.2). The lowest ratios occurred at the urban New York City site (1.7) and the rural East Coast region (1.9). Most of the maxima in soil contributions occurred in spring, especially in the western, northern, and eastern areas of the United States. The central and southern United States corresponded to maximum contributions in summer. Winter minima were common for most regions around the country, although there were exceptions (e.g., summer in Phoenix and Death Valley, fall in West Texas and other regions, and spring in Baltimore).

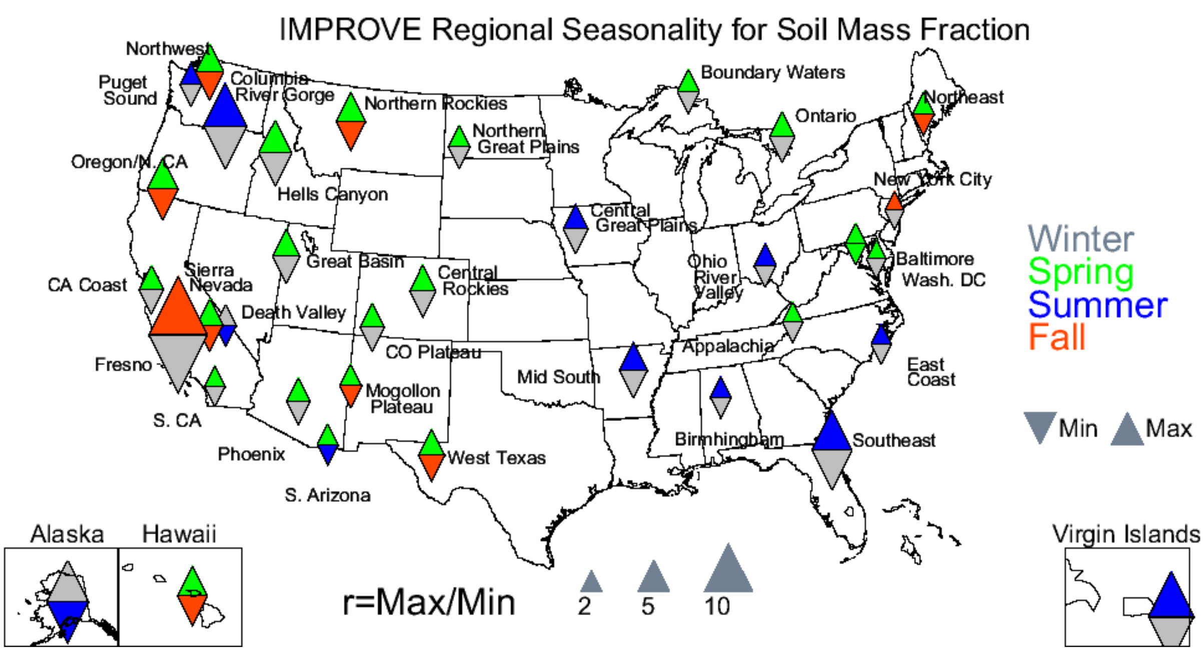

Figure 4.5.3. Seasonal variability for IMPROVE 2005–2008 monthly mean fine soil reconstructed fine mass fractions. The color of the upward pointing triangle refers to the season with the maximum monthly mean concentration and the downward pointing triangle refers to the season with the minimum monthly mean concentration. The size of the triangles refers to the magnitude of the ratio of maximum to minimum monthly mean mass concentration.

The maximum CSN urban mass fraction was lower than for the maximum IMPROVE rural region (33.5% at Grand Mesa CO in April compared to 56.3% in Virgin Islands in August, respectively), but the minimum mass fraction was similar for the rural CSN and IMPROVE regions (1.4% in Alaska in December to 1.9% in Alaska in August, respectively). Low urban soil contributions were observed in the eastern United States (Figure 4.1.16). Contributions of ~10% were common, with exceptions at the Florida and East Texas/Gulf regions in summer. Relative contributions of soil increased in summer at the Mid South and Dallas regions although to a lesser degree. Contributions of soil to RCFM at urban regions in the southwestern United States were larger than in the eastern regions but lower than many rural regions in the same vicinity (compare Figure 4.1.18 to 4.1.13). Higher contributions in the spring and summer were common for many regions (e.g., Phoenix/Tucson, Albuquerque, and Grand Mesa CO), but regions near to the coast had lower relative contributions with less of a seasonal impact (Figure 4.1.18). In the northwestern United States the urban soil contributions were lower than rural regions and reached up to 10–20% in the North Dakota region and the Northwest region in fall and summer, respectively. Contributions were relatively low in the Puget Sound and Oregon regions (Figure 4.1.17). Relative soil contributions reached up to 20% in the urban Alaska region in spring but were typically lower in Hawaii (Figure 4.1.19).

Most CSN regions experienced some degree of seasonality in soil mass fractions, with only one region having a ratio less than 2 (New York City, 1.6). The maximum ratio occurred in Alaska (15.4). The urban regions mainly experienced spring maxima and winter minima, although, summer maxima occurred in the northwestern, southern, and southeastern United States. The only summer minima occurred in Los Angeles, San Diego, and New York City.

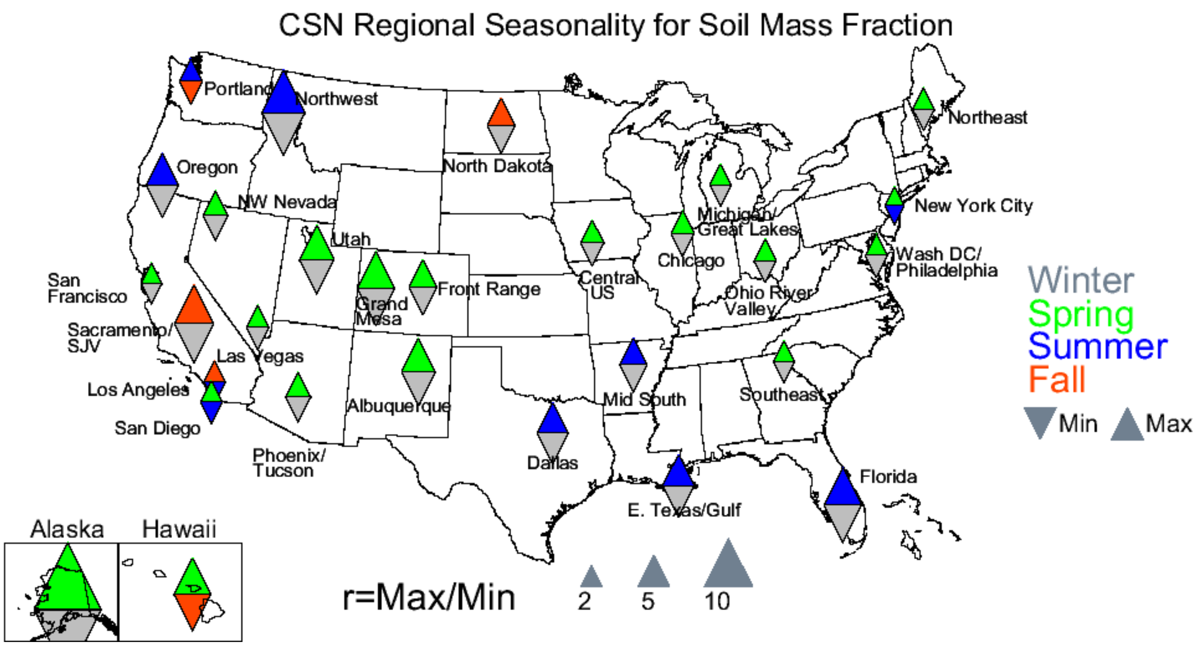

Figure 4.5.4. Seasonal variability for CSN 2005–2008 monthly mean fine soil reconstructed fine mass fractions. The color of the upward pointing triangle refers to the season with the maximum monthly mean concentration and the downward pointing triangle refers to the season with the minimum monthly mean concentration. The size of the triangles refers to the magnitude of the ratio of maximum to minimum monthly mean mass concentration.

4.6 $PM_{2.5}$ SEA SALT MASS CONCENTRATIONS

Estimates of sea salt concentrations were derived from chloride ion (IMPROVE) (White, 2008) and chlorine (CSN) mass concentrations. Because of this difference, the two estimates may not be directly comparable but are the closest approximations available for the two networks. In fact, IMPROVE estimates were biased high relative to CSN estimates at collocated sites (Table 1.9). In addition, it is well known that chloride concentrations in particle phase can be depleted by a gas-particle exchange of chloride to the atmosphere; estimates of sea salt discussed here are possibly an underestimate. The 2005–2008 regional monthly mean sea salt concentration for the IMPROVE regions ranged from 0.003 $\mu g\ m^{-3}$ at the Central Rocky Mountain region in November to 1.98 $\mu g\ m^{-3}$ at the Virgin Islands site in January. Sea salt concentrations were visible on the monthly bar charts relative to other species for only a few regions. In the eastern United States, coastal regions such as Northeast, East Coast, and Southeast had noticeable sea salt concentrations relative to other species (Figure 4.1.1). In the northwestern United States, sea salt was noticeable at Columbia River Gorge and Oregon/Northern California (Figure 4.1.2). Higher sea salt concentrations at the California Coast region were obvious in Figure 4.1.3, and non-negligible concentrations occurred at the OCONUS regions (Figure 4.1.4).

IMPROVE sea salt concentrations were highly seasonal, with only three regions (Appalachia, Hawaii, and Oregon/Northern California) having maximum to minimum ratios less than 2 (Figure 4.6.1). Part of the reason for high seasonality of sea salt is its low concentrations in most regions. Many regions corresponded mainly to spring and winter maxima. Spring maxima occurred at regions in the western and coastal (east and west) United States. Winter maxima occurred in the northwestern United States and a few eastern U.S. regions such as Baltimore, Washington D.C., Appalachia, and the Southeast. A few regions corresponded to summer maxima (Oregon/Northern California, California Coast, and Phoenix). Fall minima occurred mainly in the central and southwestern United States and in California.

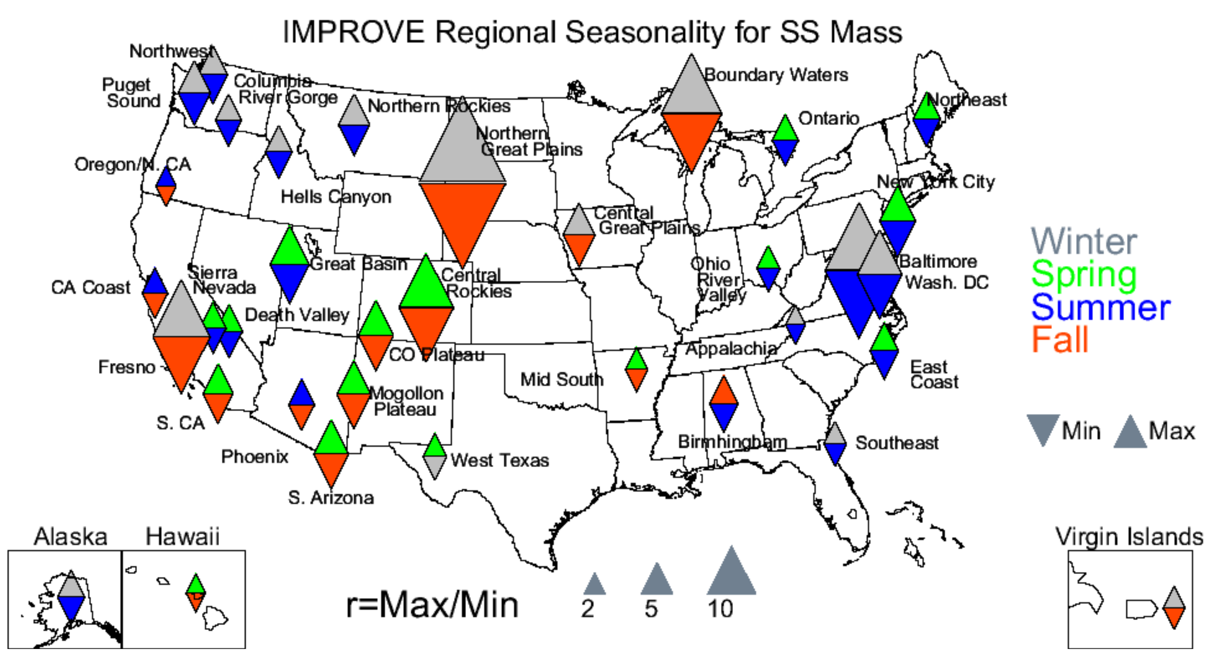

Figure 4.6.1. Seasonal variability for IMPROVE 2005–2008 monthly mean sea salt (SS) mass concentrations. The color of the upward pointing triangle refers to the season with the maximum monthly mean concentration and the downward pointing triangle refers to the season with the minimum monthly mean concentration. The size of the triangles refers to the magnitude of the ratio of maximum to minimum monthly mean mass concentration.

Because the relative concentrations of sea salt to other urban aerosols were so low, sea salt concentrations were difficult to discern in all of the CSN bar charts with the exception of Puget Sound (Figure 4.1.8), Florida (Figure 4.1.6), San Francisco, and San Diego (Figure 4.1.7). However, sea salt concentrations were higher in the Hawaii region relative to other species (Figure 4.1.9). CSN sea salt concentrations ranged from 0.0016 $\mu g\ m^{-3}$ at the North Dakota region in September to 1.44 $\mu g\ m^{-3}$ at Hawaii in January.

Sea salt concentrations in urban CSN regions were also highly seasonal, with only one region (Southeast) with maximum to minimum ratios less than 2. The maximum ratio of monthly mean sea salt concentrations occurred at Alaska (94.9) compared to the Southeast (1.9). Western regions corresponded to higher seasonality compared to eastern regions (Figure 4.6.2). Many regions, especially in the northern United States, had winter maxima that were perhaps associated with road salt applied during winter months. Summer and spring maxima were common for southern regions (e.g., Las Vegas, San Diego, Phoenix/Tucson, Albuquerque, Dallas, and East Texas/Gulf). Minima occurred for all seasons, although many northern regions corresponded to summer minima.

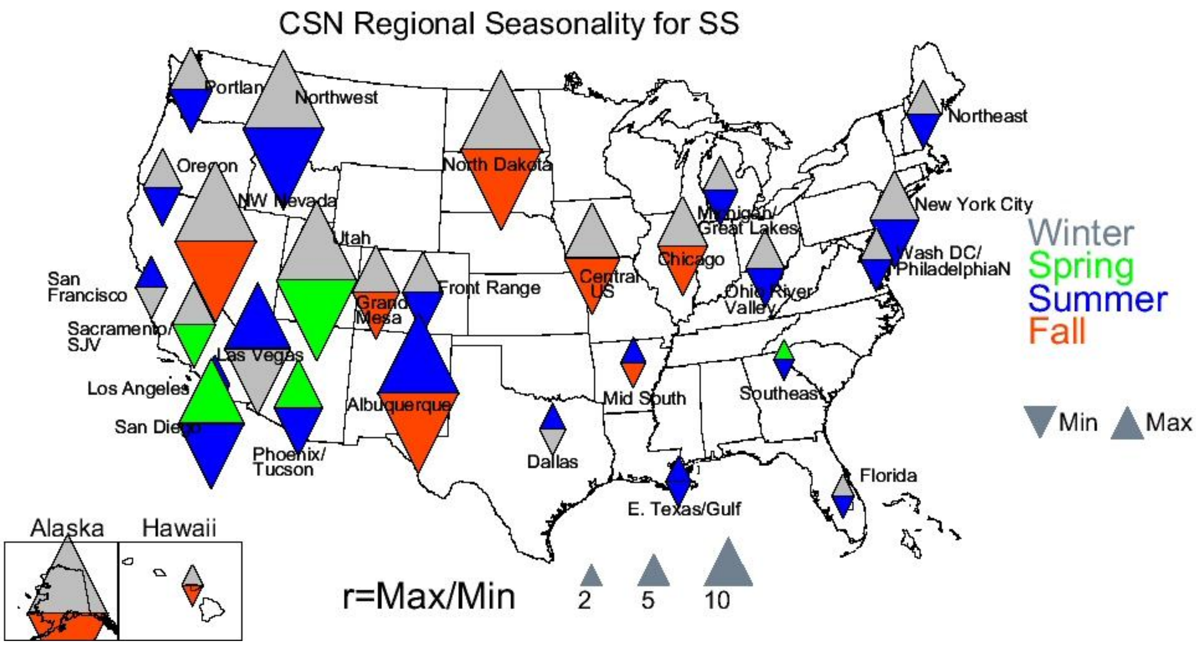

Figure 4.6.2. Seasonal variability for CSN 2005–2008 monthly mean sea salt (SS) mass concentrations. The color of the upward pointing triangle refers to the season with the maximum monthly mean concentration and the downward pointing triangle refers to the season with the minimum monthly mean concentration. The size of the triangles refers to the magnitude of the ratio of maximum to minimum monthly mean mass concentration.

Because of the low concentrations of sea salt relative to other species, its contributions were more easily viewed as mass fractions. IMPROVE sea salt mass fractions ranged from 0.11% in the Northern Rocky Mountains region in August to 57.2% in the Virgin Islands in December. The only eastern regions with noticeable contributions of sea salt to RCFM were the Northeast, East Coast, and Southeast (all coastal regions) (Figure 4.1.11). Other coastal regions in the northwestern United States had noticeable sea salt contributions, such as the Northwest, Columbia River Gorge, and Oregon/Northern California regions. Interestingly, Northern Great

Plains showed contributions of sea salt in December, possibly associated with long-range transport of sea salt (White et al., 2010) (Figure 4.1.12). The California Coast region had the highest contribution of sea salt to RCFM of any southwestern region; mass fractions of 20% or less were typical year round (Figure 4.1.13). The regions of Alaska, Hawaii, and the Virgin Islands all corresponded to higher sea salt mass fractions also. The Hawaii region experienced year-round contributions of 10–20%, and the Alaska and Virgin Island regions had typical contributions of 40–50%, with higher values in winter (Figure 4.1.14).

The contribution of sea salt to fine mass at IMPROVE regions was highly seasonal, with only one region with a ratio less than 2 (West Texas, 1.7). The maximum ratio occurred in the Northern Great Plains region (36.1). Relative contributions of sea salt had greater seasonality than sea salt concentrations (compare Figures 4.6.3 to 4.6.1), with many western regions having high seasonality. The seasons corresponding to maxima and minima were similar for mass fractions and mass concentrations for most regions, with the exception of some regions on the western coast.

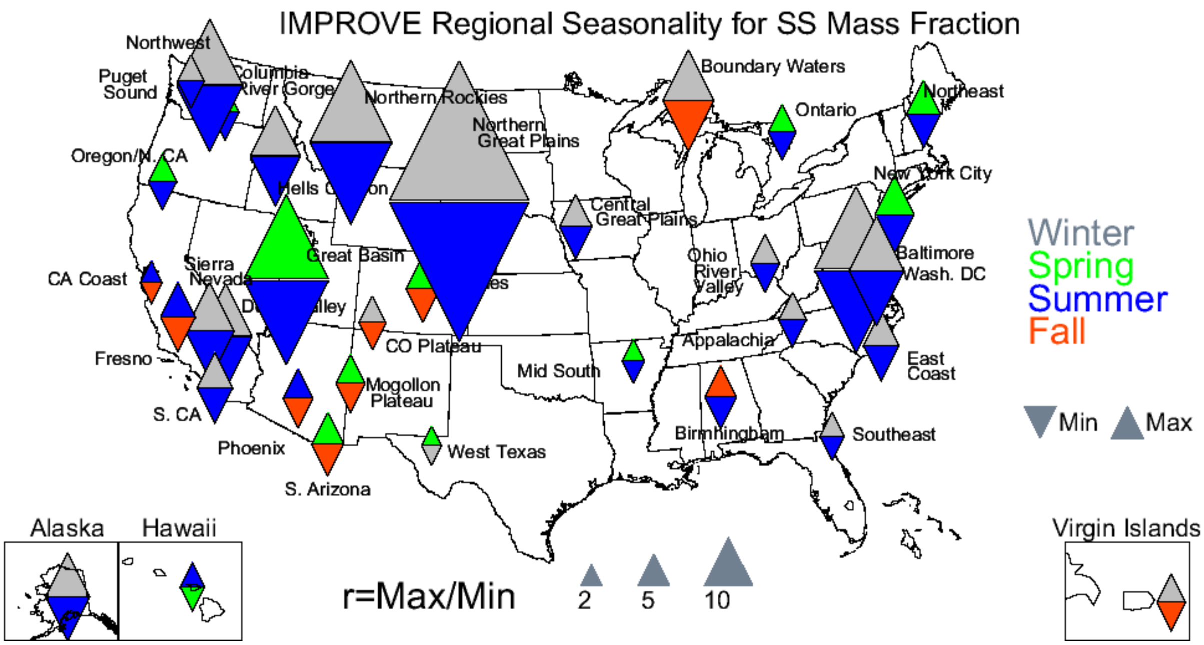

Figure 4.6.3. Seasonal variability for IMPROVE 2005–2008 monthly mean sea salt (SS) reconstructed fine mass fractions. The color of the upward pointing triangle refers to the season with the maximum monthly mean concentration and the downward pointing triangle refers to the season with the minimum monthly mean concentration. The size of the triangles refers to the magnitude of the ratio of maximum to minimum monthly mean mass concentration.

The range of sea salt contributions to RCFM were similar for the urban CSN regions compared to rural regions, with a high of 51.5% in Hawaii in August and a low of 0.04% in North Dakota in September. The CSN regions with noticeable sea salt contributions were San Diego and San Francisco in the southwestern United States (Figure 4.1.18), Puget Sound in the northwestern United States (Figure 4.1.17), and the Florida region in the eastern United States (Figure 4.1.16). In contrast to the rural Alaska regions, the urban Alaska regions corresponded to only negligible contributions from sea salt. However, the CSN Hawaii region had much higher sea salt contributions compared to the IMPROVE Hawaii region (Figure 4.1.19).

The seasonal patterns of CSN sea salt mass fractions were very similar to sea salt mass concentrations (compare Figures 4.6.4 to 4.6.1). Mass fractions had a slightly lower degree of seasonality for many regions, but overall they were comparable. The seasons corresponding to maxima and minima varied for some regions, such as the Northeast, New York City, Mid South, Phoenix/Tucson, and Sacramento/San Joaquin Valley, to name a few. No regions had ratios less than 2, suggesting all CSN regions experienced seasonal contributions of sea salt to RCFM.

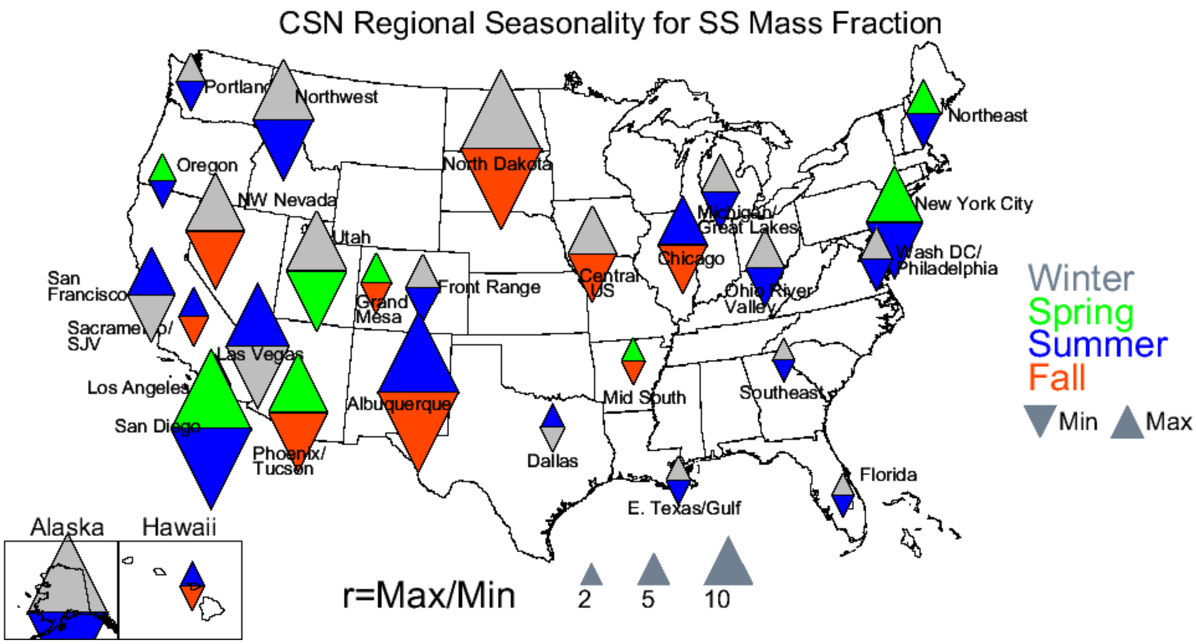

Figure 4.6.4. Seasonal variability for CSN 2005–2008 monthly mean sea salt (SS) reconstructed fine mass fractions. The color of the upward pointing triangle refers to the season with the maximum monthly mean concentration and the downward pointing triangle refers to the season with the minimum monthly mean concentration. The size of the triangles refers to the magnitude of the ratio of maximum to minimum monthly mean mass concentration.

4.7 $PM_{2.5}$ GRAVIMETRIC FINE MASS CONCENTRATIONS

IMPROVE regional monthly mean gravimetric $PM_{2.5}$ fine mass (FM) concentrations ranged from 0.93 $\mu g\ m^{-3}$ in the Great Basin region in January to 26.0 $\mu g\ m^{-3}$ in the urban site of Fresno in November. The highest concentrations in a nonurban region occurred at the Appalachian region in August (16.41 $\mu g\ m^{-3}$). Most of the regions corresponded to summer maxima and winter minima, with the exception of several regions along the eastern coast that had summer maxima and fall minima (Figure 4.7.1). Western summer maxima were most likely associated with the seasonal dominance of POM concentrations in the northwestern and southwestern United States (see Figures 4.1.2 and 4.1.3, respectively). Regional maxima in the eastern United States were most likely associated with summer peaks in AS concentrations (see Figure 4.1.1). There was less seasonality in FM compared to individual species, with nine regions having maximum to minimum ratios less than 2. The maximum ratio occurred at the Northern Rocky Mountains region (7.3) compared to the minimum region at Ontario (1.3). Higher seasonality occurred in the western compared to the eastern United States.

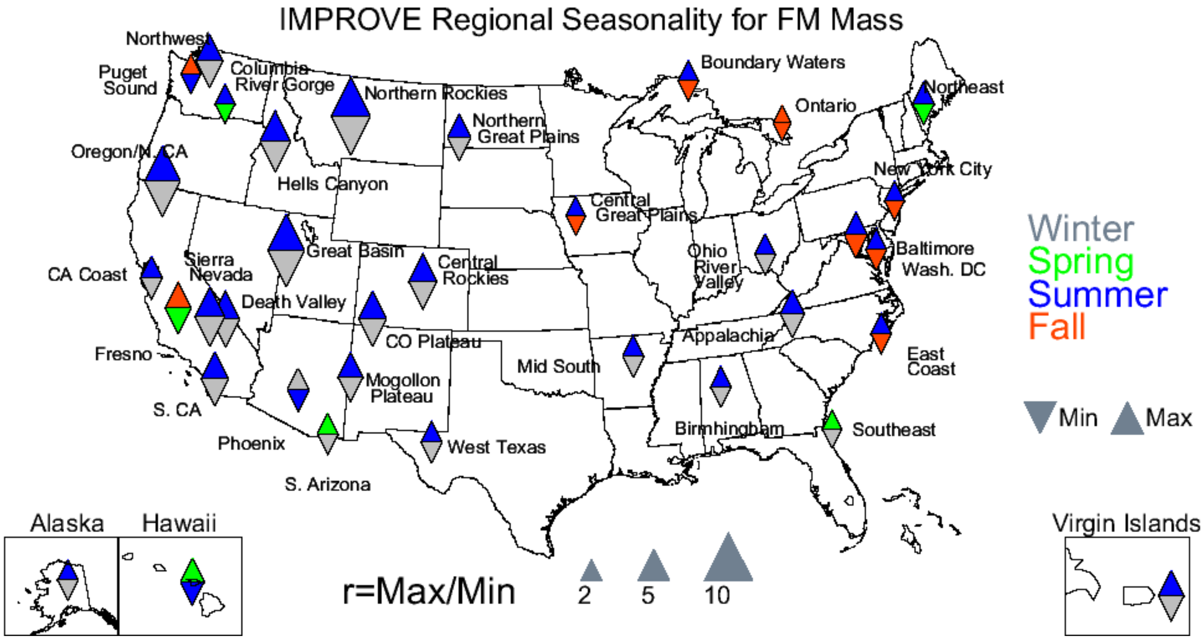

Figure 4.7.1. Seasonal variability for IMPROVE 2005–2008 monthly mean $PM_{2.5}$ gravimetric fine mass (FM) concentrations. The color of the upward pointing triangle refers to the season with the maximum monthly mean concentration and the downward pointing triangle refers to the season with the minimum monthly mean concentration. The size of the triangles refers to the magnitude of the ratio of maximum to minimum monthly mean mass concentration.

FM concentrations were higher at the CSN urban regions, ranging from 3.52 µg m^{-3} in Alaska in August to 34.1 µg m^{-3} in Sacramento/San Joaquin Valley in December. In contrast to the IMPROVE network, many regions corresponded to winter maxima and spring minima. The regional seasonal patterns of CSN FM concentrations were very different from the IMPROVE regional seasonal patterns (Figure 4.7.2). Many western U.S. regions corresponded to winter maxima and spring minima, most likely due to the prevalence of peaks in AN and POM concentrations in winter (see Figures 4.1.7 and 4.1.8). Regions in the East corresponded to summer maxima and winter and fall minima, and probably were associated with summer peaks in AS concentrations since it dominates FM in summer in this area (Figure 4.1.6). In general the urban regions demonstrated a lower degree of seasonality compared to FM concentrations in the rural regions. Fifteen regions had maximum to minimum ratios less than 2; the maximum ratio occurred at Alaska (7.5), compared to the minimum at the Central U.S. region (1.5).

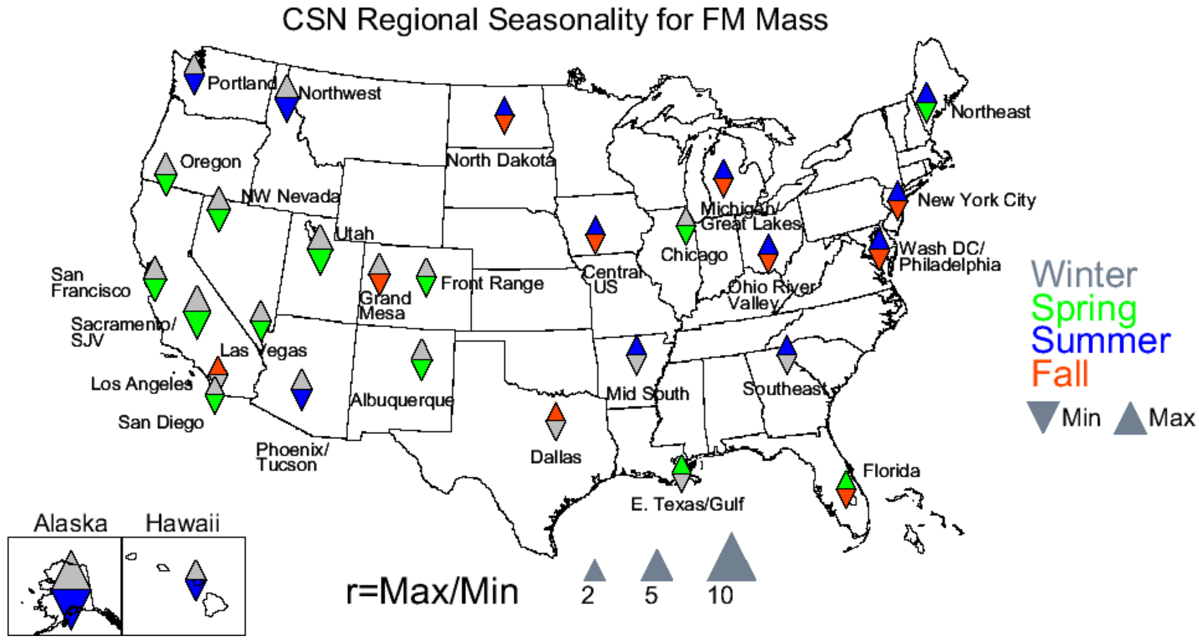

Figure 4.7.2. Seasonal variability for CSN 2005–2008 monthly mean $PM_{2.5}$ gravimetric fine mass (FM) concentrations. The color of the upward pointing triangle refers to the season with the maximum monthly mean concentration and the downward pointing triangle refers to the season with the minimum monthly mean concentration. The size of the triangles refers to the magnitude of the ratio of maximum to minimum monthly mean mass concentration.

4.8 COARSE MASS CONCENTRATIONS

IMPROVE 2005–2008 regional monthly mean coarse mass (CM) concentrations ranged from 0.46 µg m^{-3} in the Northwest region in December to 19.56 µg m^{-3} in the rural site of Virgin Islands in July and 39.79 µg m^{-3} in the urban Fresno site in September. The seasonal distribution of coarse mass concentrations was fairly similar for northwestern regions (see Figure 4.8.1). Although the magnitude of coarse mass concentrations varied, they were highest in July and August for all of the regions in the northwestern United States, with the exception of the Oregon/Northern California region. The Columbia River Gorge region had the highest concentration in the northwestern United States, compared to the lowest concentrations in the Northwest region. In the southwestern United States the summer maxima associated with the Sierra Nevada and Great Basin regions shifted toward the spring months for regions farther south (e.g., Colorado Plateau, Southern Arizona, and West Texas, see Figure 4.8.2). A bimodal distribution corresponding to peaks in concentration in spring/summer and late fall was associated with the Southern Arizona, West Texas, and Mogollon Plateau regions, perhaps related to soil, as dust source regions in Mexico and predominant meteorological conditions correspond to dust episodes in those seasons (Rivera Rivera et al., 2008). The Great Basin, Central Rocky Mountains, and Colorado Plateau and Mogollon Plateau regions corresponded to the lowest monthly mean CM concentrations in the southwestern United States, compared to the regions farther south and in California, where the peak concentrations were twice as high.

IMPROVE: Northwestern U.S. (rural)

Coarse Mass Concentration (µg m^{-3})

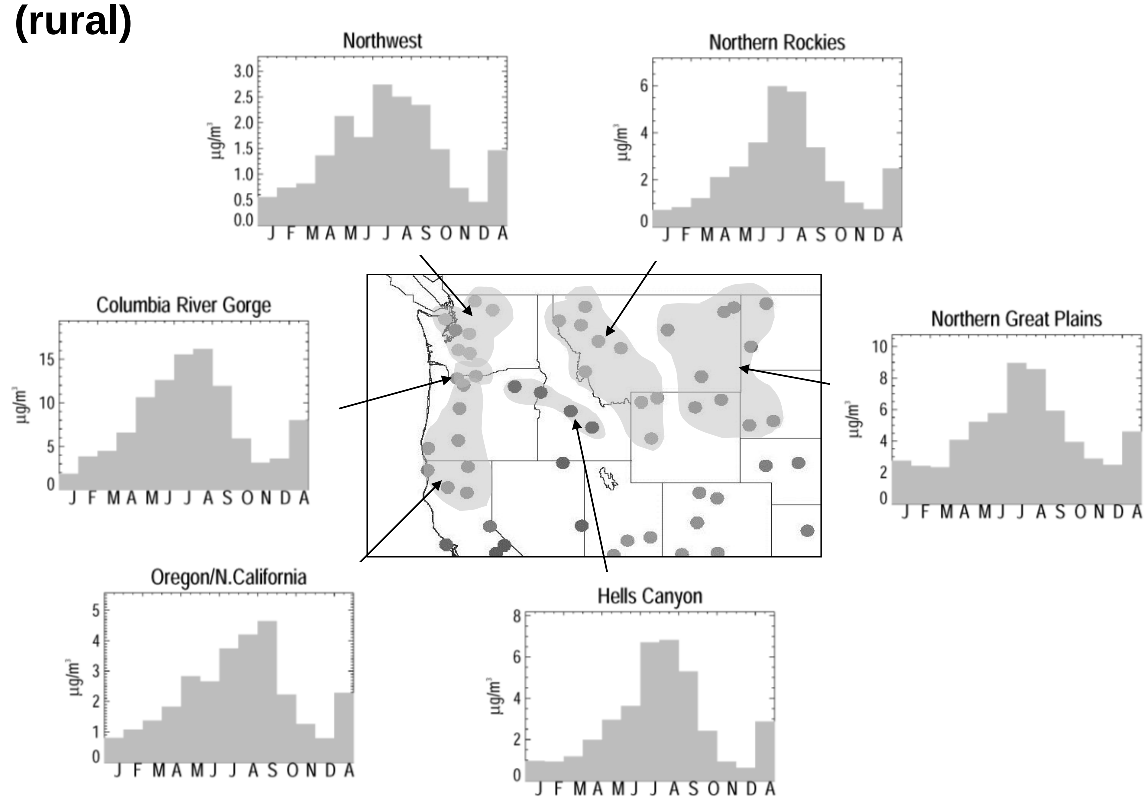

Figure 4.8.1. IMPROVE 2005–2008 regional monthly mean coarse mass concentrations (µg m^{-3}) for the northwestern United States. The letters on the x-axis correspond to the month and "A" corresponds to "annual" mean. The shaded area corresponds to the regions that comprise the sites used in the analysis, shown as dots.

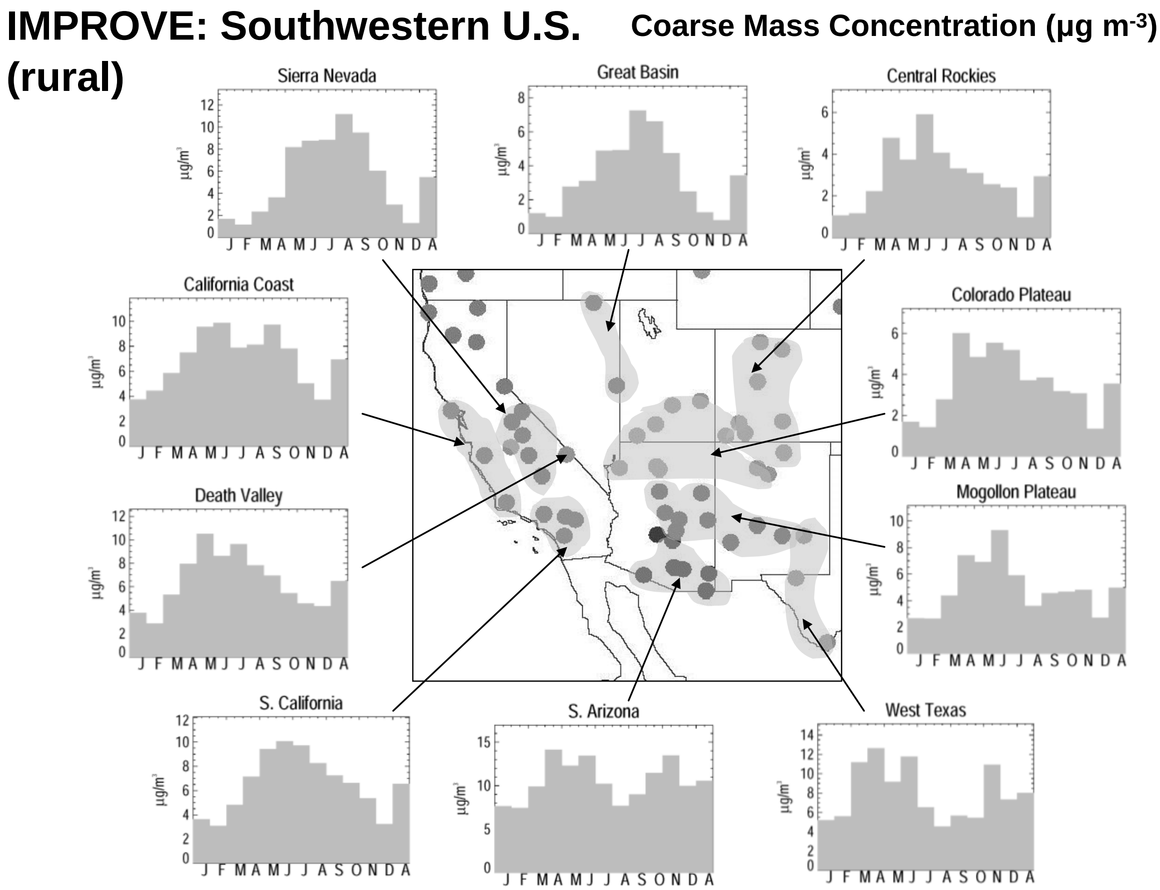

Figure 4.8.2. IMPROVE 2005–2008 regional monthly mean coarse mass concentrations (µg m^{-3}) for the southwestern United States. The letters on the x-axis correspond to the month and “A” corresponds to “annual” mean. The shaded area corresponds to the regions that comprise the sites used in the analysis, shown as dots.

CM concentrations increased during summer months at regions in the eastern United States, such as Northeast, East Coast, Appalachia, and Ohio River Valley (see Figure 4.8.3). Regions toward the central United States were associated with summer peaks. CM concentrations were fairly well distributed across months in the eastern compared to the western United States, with less-defined peaks of concentrations in any one month. The Virgin Island site corresponded to a large peak in CM concentration in summer months compared to other months (Figure 4.8.4) that was probably associated with the transport of North African dust. The CM concentrations at the Virgin Islands region were nearly ten times greater than the other OCONUS regions of Hawaii and Alaska. Those regions did not exhibit strong peaks in monthly concentrations, but concentrations did increase somewhat in spring months.

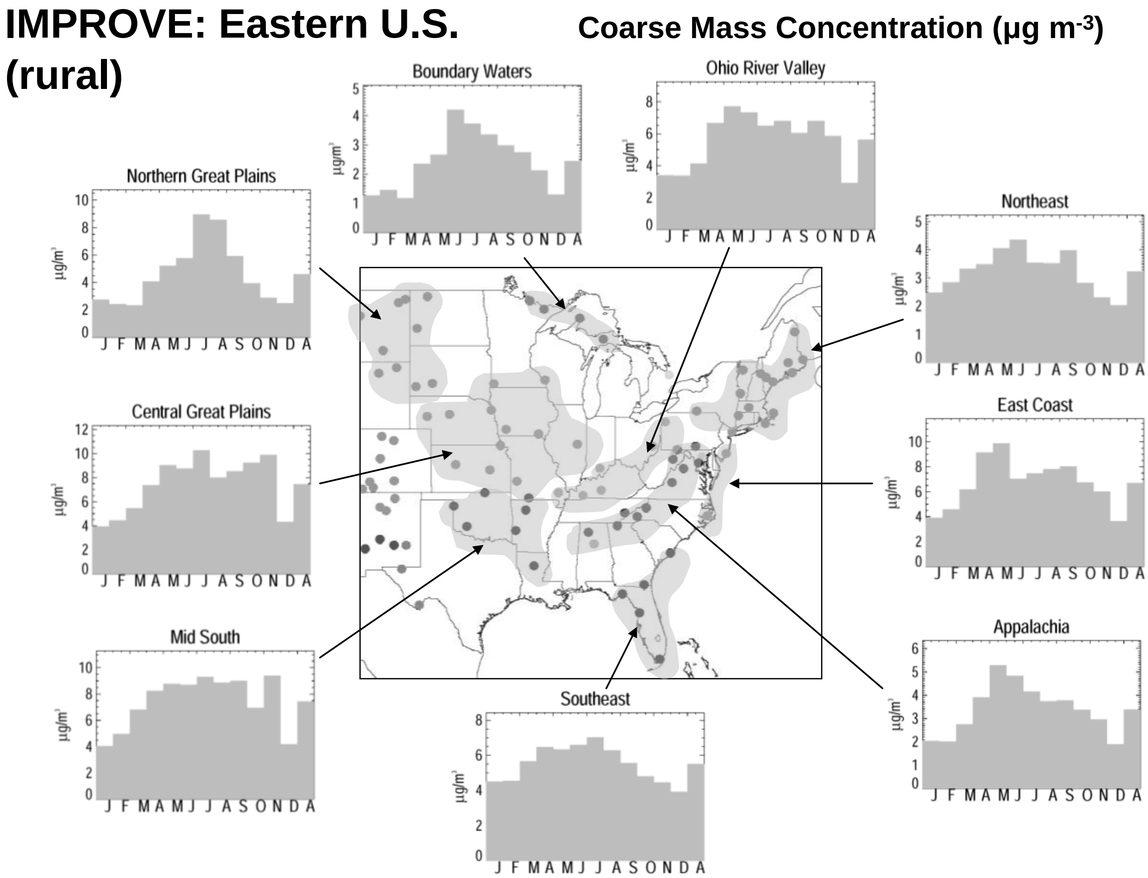

Figure 4.8.3. IMPROVE 2005–2008 regional monthly mean coarse mass concentrations (µg m^{-3}) for the eastern United States. The letters on the x-axis correspond to the month and "A" corresponds to "annual" mean. The shaded area corresponds to the regions that comprise the sites used in the analysis, shown as dots.

Coarse Mass Concentration (µg m^{-3})

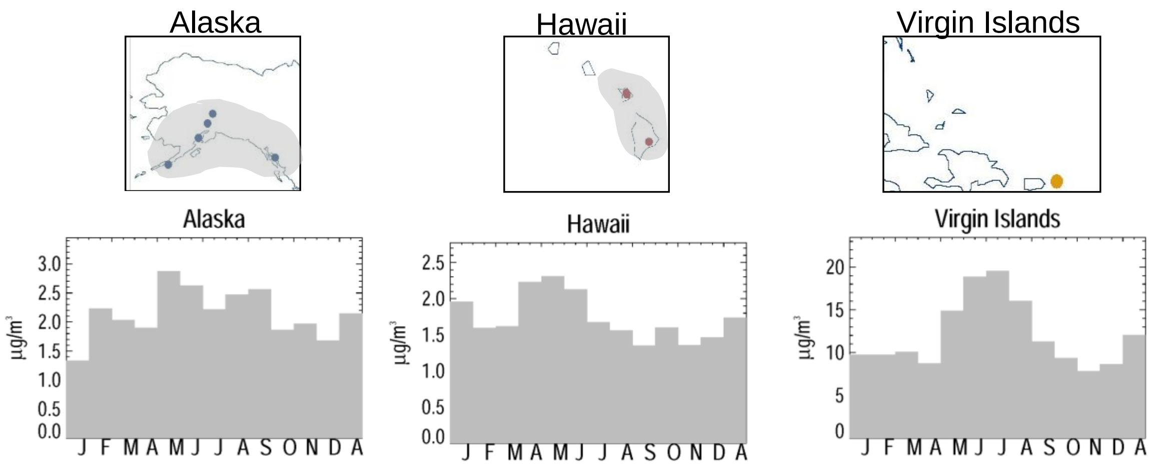

Figure 4.8.4. IMPROVE 2005–2008 regional monthly mean coarse mass concentrations (µg m^{-3}) for OCONUS U.S. The letters on the x-axis correspond to the month and "A" corresponds to "annual" mean. The shaded area corresponds to the regions that comprise the sites used in the analysis, shown as dots.

Most regions demonstrated some seasonality in monthly mean CM concentrations, with only four regions having maximum to minimum ratios less than 2. The highest ratio occurred at Hells Canyon (11.0) and the lowest was in Washington, D.C. (1.6). The seasonality was higher in the western United States. Most regions corresponded to winter minima, with the exception of a few regions (e.g., West Texas, Puget Sound, Northern Great Plains, Boundary Waters, and Washington, D.C., see Figure 4.8.5). Summer maxima occurred for over half of the regions and many of them were located in the northwestern United States, in California, and in the Southeast region. Spring maxima occurred for many eastern U.S. regions, as well as Southern Arizona, West Texas, and the Colorado Plateau.

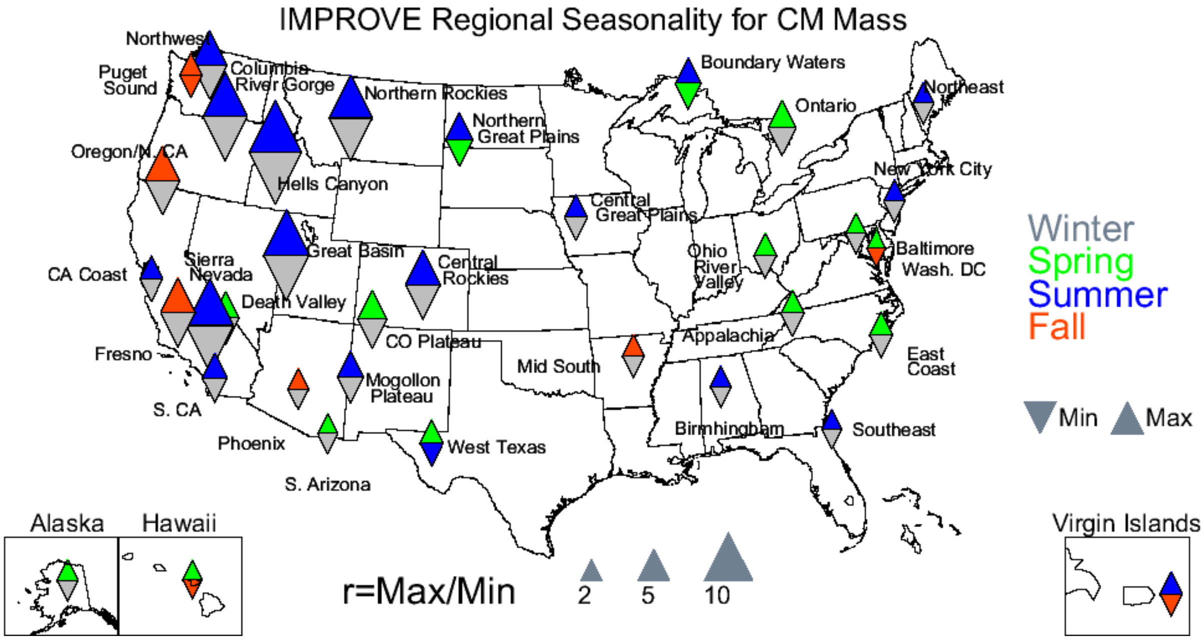

Figure 4.8.5. Seasonal variability for IMPROVE 2005–2008 monthly mean coarse mass (CM) concentrations. The color of the upward pointing triangle refers to the season with the maximum monthly mean concentration and the downward pointing triangle refers to the season with the minimum monthly mean concentration. The size of the triangles refers to the magnitude of the ratio of maximum to minimum monthly mean mass concentration.

4.9 DISCUSSION

The differences observed in the seasonal and spatial patterns in species concentrations for the rural regions of the IMPROVE network and the urban/suburban locations in the CSN network were indicative of the spatial extent of aerosol sources, atmospheric processes, regional transport, and sinks. For example, AS seasonal patterns and concentrations were similar for both the IMPROVE rural and CSN urban regions, with summer maxima in the eastern half of the country. This pattern reflected the higher emissions of SO_2 in this region and favorable conditions for aerosol formation in summer. Seasonal patterns in AN were consistent between CSN and IMPROVE regions. Winter maxima were observed for urban locations and in the central United States, demonstrating the regional impacts of agricultural sources in that area and favorable aerosol formation conditions during that season. CSN urban nitrate concentrations were considerably higher than rural IMPROVE concentrations. Maximum contributions of AN to fine mass occurred in winter for both rural and urban regions.

The strong summer maxima in POM concentrations at western rural regions (Figure 4.3.1) contrasted with the summer/fall/winter maxima observed at CSN urban regions (Figure 4.3.2), suggesting that wildfire activity is a major contributor to POM concentrations in rural areas especially in the western and northwestern United States in summer. Biogenic secondary organic aerosol also could have contributed significantly to high summer POM concentrations as well. Winter urban maxima at some urban regions were probably due in part to meteorological conditions but also to local sources. LAC concentrations followed similar patterns as POM concentrations, although summer maxima rural LAC concentrations were not as dominant as POM concentrations. CSN LAC concentrations corresponding to fall/winter urban maxima were probably associated with local sources like residential heating and transportation. Both CSN POM and LAC concentrations were considerably higher than those measured in rural IMPROVE regions. The maximum percent contribution of POM to RCFM was highest in summer for most rural regions compared to both summer and fall in urban regions. LAC percent contributions displayed a somewhat different seasonal pattern compared to POM. LAC maximum percent contributions at rural regions occurred in winter, while regional urban maximum contributions occurred in fall, followed by winter.

Soil concentrations were influenced by both local and long-range transport. Major regions of higher dust concentrations were evident in the urban and rural regions, especially in the southwestern United States in spring/summer and IMPROVE Southeast and CSN East Texas/Gulf regions in summer. Both networks had many “hot spots” of high soil that were similar in some seasons and not others, suggesting fairly localized fugitive dust sources (Kavouras et al., 2007; 2009). The maximum contributions of soil to fine mass occurred in spring for many rural and urban regions, perhaps associated with agricultural sources. While the seasons corresponding to maxima and minima for CM and fine soil concentrations agreed in some regions (e.g., in the northwestern United States, see Figures 4.5.1 and 4.8.1), for most regions these seasons did not coincide. One would expect that if soil was the main contributor to CM, their seasonality would be similar. However, based on work by Malm et al. (2007), who investigated the speciation of CM at select IMPROVE sites for a year, the speciation of CM varied significantly depending on region and month. For example, the Mount Rainier site corresponded to POM-dominated CM either year round or for select months, as did the sites at Sequoia National Park in California, Bridger Wilderness Area in Wyoming, Bondville, Illinois, and Great Smoky Mountains National Park in Tennessee. The only regions with consistent seasonal maxima and minima between soil and CM were Columbia River Gorge, Hells Canyon, Northern Rocky Mountains, Great Basin, Death Valley, and the Colorado Plateau. It is possible and probably quite likely that the seasonality of CM was impacted by the variability of species other than soil.

Sea salt concentrations and percent contributions were negligible at most regions for both the urban and rural networks. Coastal regions (including both the east and west coasts, including OCONUS regions) were the only regions to correspond to non-negligible impacts from sea salt on RCFM. Sea salt corresponded to a high degree of seasonality, probably in part because of its very low concentrations.

FM concentrations were noticeably higher in urban regions than rural regions. The highest concentrations of FM for the CSN network occurred in California, in the Sacramento/San Joaquin Valley region during December, where AN and POM composed the majority of the RCFM. Similarly, the urban IMPROVE site of Fresno had the highest FM concentrations in November, again dominated by AN and POM. The highest IMPROVE nonurban FM concentration corresponded to the Appalachia region in August, where AS dominated the RCFM composition in summer.

Tables with regional monthly mean concentrations listed a function of species, month and region are provided in Appendix D.1 for IMPROVE and CSN values. Regional monthly mean mass fractions are listed in Appendix D.2 for IMPROVE and CSN. Stacked bar charts of monthly mean concentrations for individual sites for IMPROVE and the CSN are provided in Appendix D.3, while mass fractions for IMPROVE and the CSN are provided in Appendix D.4.

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