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Regional Pollution Potential in the Northwestern United States

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Abstract

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The potential for air pollution from industrial sources to reach wilderness areas throughout the Northwestern United States is approximated from monthly mean emissions, along with wind speeds and directions. A simple index is derived to estimate downwind concentration. Maps of pollution potential were generated for each pollution component (particulates, sulfur oxides, nitrogen oxides, and ammonia), months representing each season (January, April, July, and October), and each of three vertical levels: surface, 850 mb, and 700 mb. Mixing heights for the last 40 years are used to help determine which trajectory levels best represent each month. Wind frequencies for the same period help show variability and inherent uncertainty in using mean monthly data for pollution-potential estimates.

Keywords: Pollution, pollution trajectory, mixing height, steering wind, Columbia River basin, industrial emissions.

Introduction

The Northwestern United States has some of the cleanest air in the world and contains some of the most beautiful landscapes. Pristine vistas, however, easily are corrupted by air pollution. Also, sensitive plants and animals in the region are being impacted by air pollutants (Shoettle et al. 1999). Many federal land agencies in the region are responsible for monitoring and protecting air quality over the land they manage. To do so, they need to know if, when, and how frequently pollutants from industrial sources reach protected lands. A number of numerical air quality models are available to calculate trajectories and concentrations. The computational expense of running these models, however, has limited their use to individual case studies and small domains. This has prevented their use in the larger scale regional assessments needed for land management planning.

In 1993, the Interior Columbia Basin Ecosystem Management Project (ICBEMP) began compiling industrial source emission and climate data for their reports on air quality (Shoettle et al. 1999) and air quality climate (Ferguson 1998). We use the compiled data from both studies to estimate the potential for air pollution to reach class I areas (fig. 1). Surface winds, upper-air winds, and mixing heights are used to estimate mean monthly trajectories. Average monthly emissions from industrial sources are assumed to decrease linearly with distance downwind as a function of wind speed. Concentrations of converging trajectories are added together.

Polygons of protected lands are shown with maps of pollution trajectories so managers easily can see monthly averaged pollution concentration levels and from where the pollution originates. Land managers might use the maps to help decide where to install monitoring sites, when to limit or encourage prescribed fire activities, or whether more realistic dispersion modeling is needed for regulatory or negotiating purposes.

Emissions

Reported annual emissions from each Northwestern state and British Columbia were divided by 12 to estimate mean monthly emission rate. Trajectories were determined only for emissions greater than a certain threshold value (table 1) as suggested by Miller (1997) based on U.S. Environmental Protection Agency (EPA 1990) guidelines. The year of each emissions report differs by state and province from 1985 for British Columbia to 1993 for Montana and Idaho. Figure 1 shows all reporting industrial sources, boundaries for class I areas, and the ICBEMP assessment boundary.

Steering Winds

Winds at three altitudes are used to estimate pollution trajectories corresponding to heights at the 700 and 850 mb atmospheric pressure levels and at the surface (10 m above ground level [agl]). Mandatory measurements are required from all National Weather Service (NWS) radiosonde observation stations at the 700- and 850-mb pressure surfaces. Therefore, wind data are readily available from these heights. The height of the 700-mb pressure surfaces usually varies around 3000 m above sea level (asl), and the 850-mb pressure surface usually varies around 1500 m asl. Only a few observations are needed to determine the characteristics of upper-air wind because atmospheric patterns usually change slowly over space and time above the influence of topography. The observation data are linearly interpolated to determine the wind within 10 km of each stack. Then trajectories are assumed to follow a straight line from the stack. This is not entirely realistic because monthly averaged upper-air winds show a slight curvature. The approximation, however, is well within the standard deviation of mean monthly wind directions.

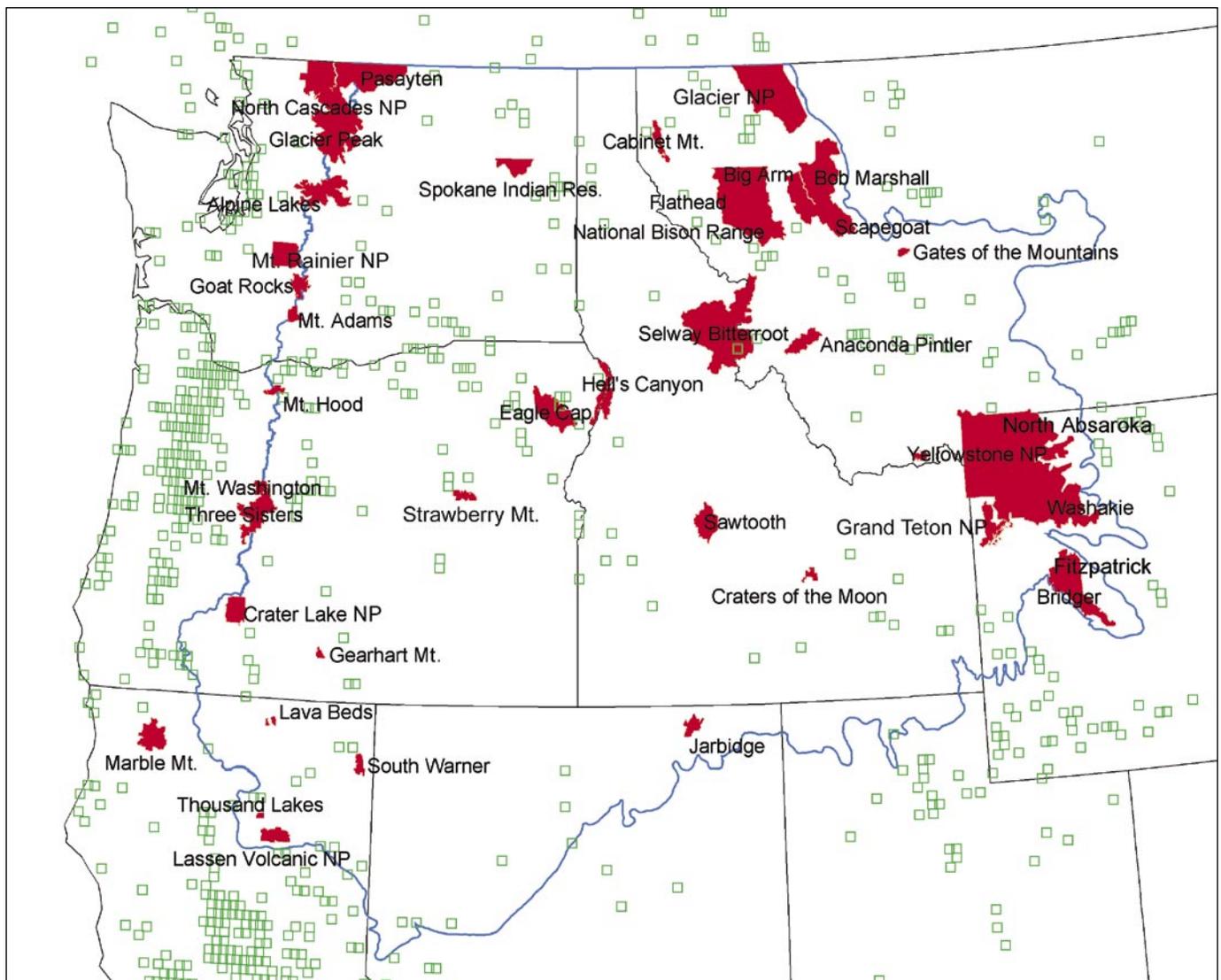


Figure 1—The Northwestern United States. The Interior Columbia Basin Ecosystem Management Project boundary is shown in blue, class I wilderness areas are red, and open green squares show point-source emission locations.

Table 1—Threshold emission rates for each pollutant

Pollutant	Threshold emission rate
	<i>Tons per month</i>
Total particulates	1.25
Sulfur oxides	3.00
Nitrous oxides	3.00
Ammonia	3.00

Source: Miller 1997.

Although surface winds also are mandatory measurements at radiosonde observation sites and other primary NWS observation stations, they are strongly influenced by small undulations in topography and cannot be linearly interpolated with reasonable accuracy in regions of complex terrain. Therefore, a simple mesoscale wind model was adapted to generate surface winds at a 5-minute latitude-longitude (about 10 km) horizontal resolution (Mass and Dempsey 1985). Modeled surface winds are approximated at 10 m agl and follow the terrain.

Wind speed and direction observed over Spokane, Washington, illustrate the variability of wind and corresponding uncertainty in monthly mean trajectories. At the 700-mb level, winds prevail from the west-southwest every season but January, which represents winter, when winds prevail from the west (fig. 2). At 850 mb, wind directions prevail from the southwest most of the time (fig. 3). In any month of the year, however, wind directions can vary by as much as 360°. Table 2 summarizes the percentage of wind directions during each season that are within 22.5° and 45° of prevailing direction.

At 100 km from a source, plume trajectories could be as much as 40 km off target if wind directions varied by 22.5° from the monthly mean wind because upper-air trajectories are assumed to be straight lines. Twice that error could be expected for variations near 45°.

Closer to the surface, winds are more likely to be influenced by topography. For example, nearly 30 percent of all surface winds at Spokane are from the northeast or southwest directions (fig. 4) because the observations are collected from a site that is in a broad southwest-to-northeast sloping valley. These subtle changes in wind direction at the surface, however, affect how plumes are carried downstream. Frequency distributions of wind at each grid cell are needed to determine the true variance of surface trajectories, but this information currently is not available. Suffice it to say that variation around the monthly mean surface wind trajectories could be as much as or more than those at upper levels of the atmosphere.

Mixing Heights

Mixing height is a level in the atmosphere above which vertical exchange of air is inhibited. As such, average monthly mixing heights can be used to approximate the maximum elevation at which pollutants will disperse downwind. Because the atmosphere is relatively consistent horizontally for hundreds of kilometers between frontal systems and within general climate zones, one may expect the mixing height to represent a somewhat constant level, like a planar surface that can dissect mountain ranges. Therefore, estimated heights of trajectory winds on the western side of the high-elevation Rocky Mountains should be similar to those in the lower elevations of the Columbia plateau because they both fall within a relatively consistent climate zone of the Columbia River basin. Heights measured on the Oregon and Washington coasts, in Nevada, or eastern Montana, however, represent different air masses than inside the basin. Therefore, trajectories may follow different paths from sources outside the basin than from sources inside the basin.

Afternoon radiosonde observations (RAOBs) were used to approximately coincide with the time of maximum daily surface temperature. Afternoon RAOBs occur near 0000 Universal Time Coordinated, which coincides with 1600 Pacific Standard Time and 1700 Mountain Standard Time in the Columbia River basin. Data include about 1,000 RAOBs taken over a 23-year period, from 1966 to 1989. Afternoon mixing heights were calculated by the Western Regional Climate Center. Note that diurnal variation in mixing height could significantly alter plume trajectories. Morning heights usually are much lower than afternoon heights.

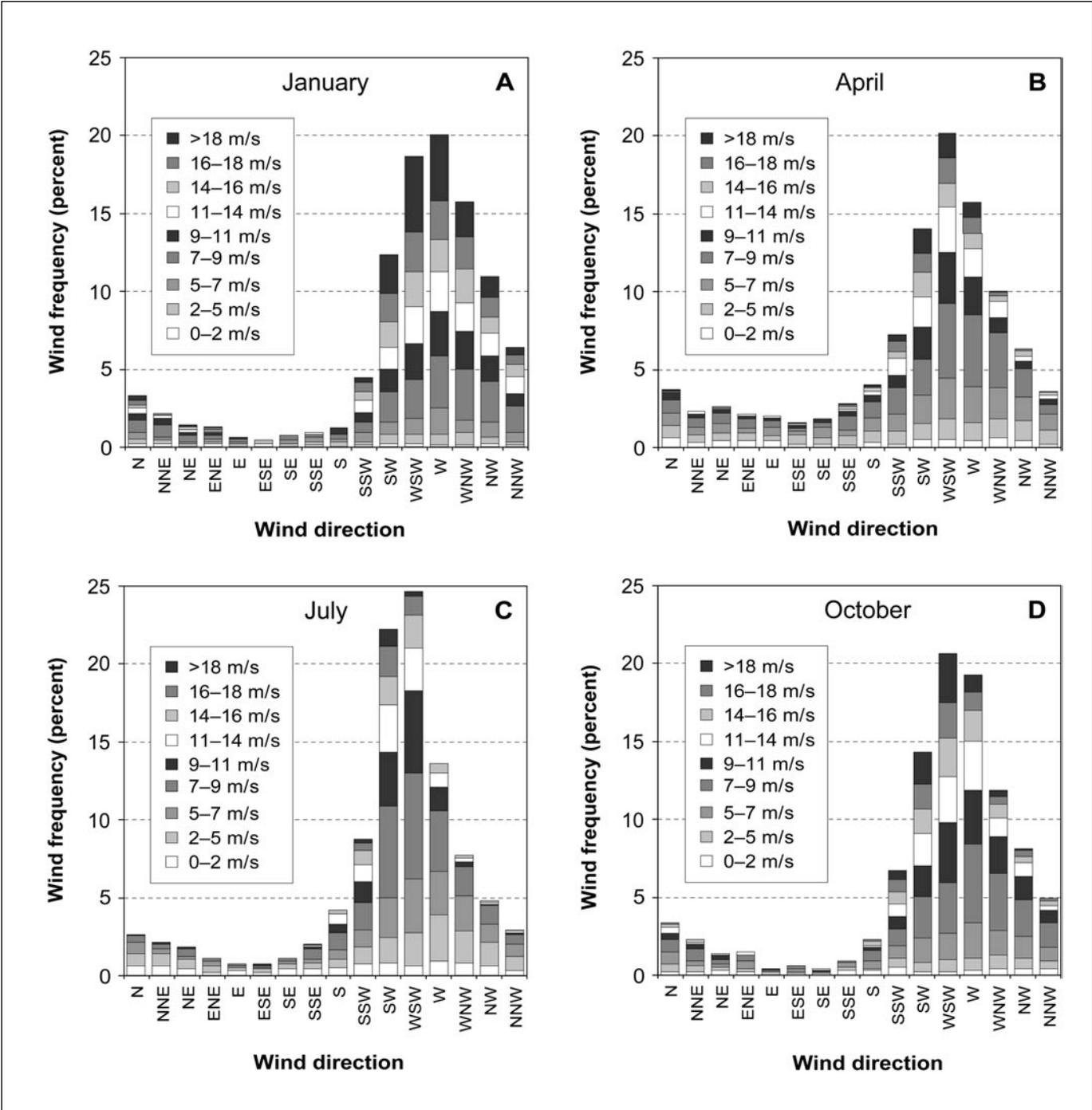


Figure 2—Histogram of 700-mb winds at Spokane, Washington, for (A) January, (B) April, (C) July, and (D) October. Classes are in meters per second (m/s).

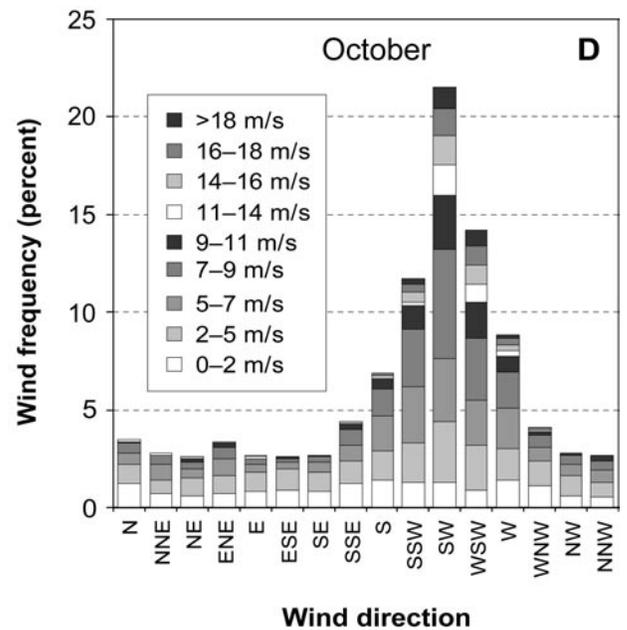
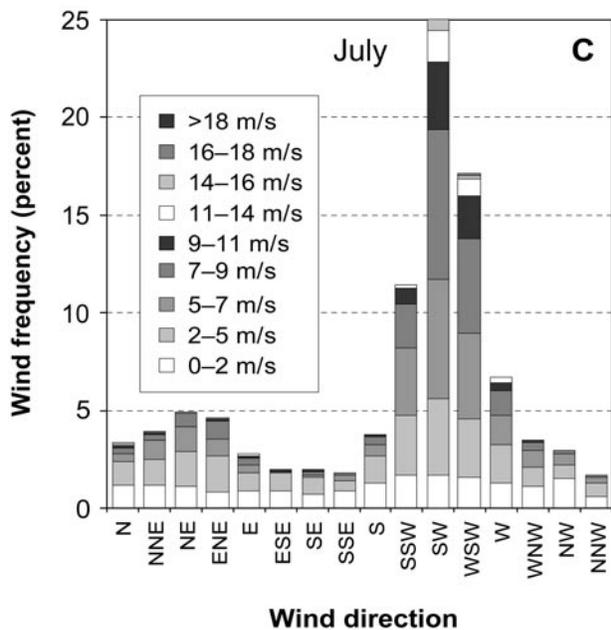
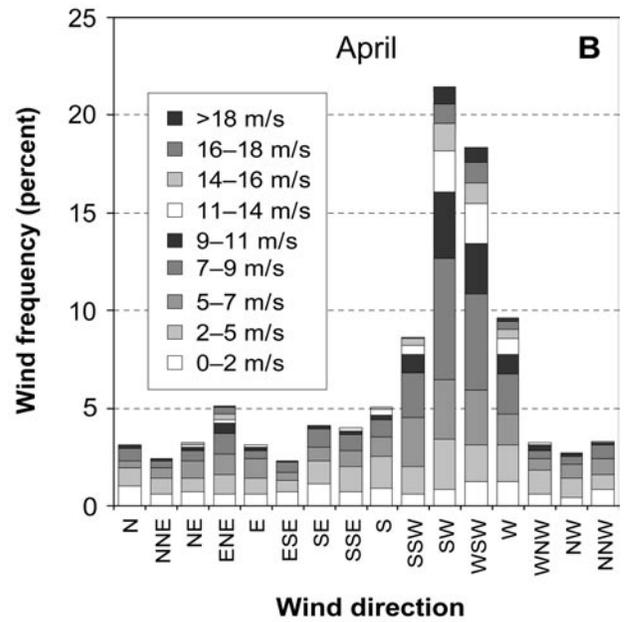
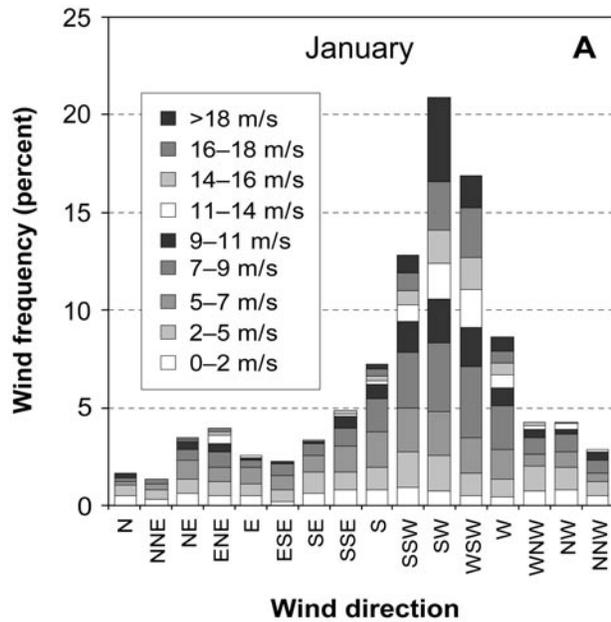


Figure 3—Histogram of 850-mb winds at Spokane, Washington, for (A) January, (B) April, (C) July, and (D) October. Classes are in meters per second (m/s).

Table 2—Percentage of time within the months of January, April, July, and October that winds at 700- and 850-mb pressure levels are within $\pm 22.5^\circ$ and $\pm 45^\circ$ of the prevailing direction over Spokane, Washington

Month	Prevailing direction ^a		$\pm 22.5^\circ$ of prevailing direction		$\pm 45^\circ$ of prevailing direction	
	700 mb	850 mb	700 mb	850 mb	700 mb	850 mb
----- Percentage of time -----						
January	W	SW	54.3	49.8	77.5	65.4
April	WSW	SW	49.8	48.3	67.0	62.9
July	WSW	SW	47.2	54.7	63.4	65.3
October	WSW	SW	54.9	49.6	73.7	65.5

^aW = west, WSW = west southwest, and SW = southwest.

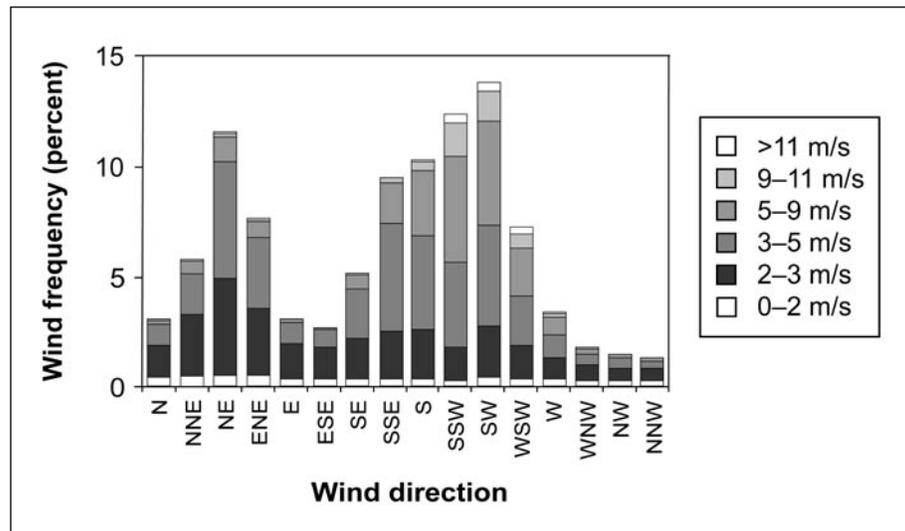


Figure 4—Histogram of surface winds at Spokane, Washington, for all months. Classes are in meters per second (m/s).

The stations analyzed included Quillayute, Washington (58 m elevation), the only station on the Pacific coast; Salem, Oregon (61 m), and Medford, Oregon (421 m), between the Coast and Cascade Ranges; Spokane, Washington (722 m), and Boise, Idaho (871 m), inside the basin; and Winnemucca, Nevada (1310 m), just south of the basin in northern Nevada. The stations represent three distinctive climate zones, maritime (Quillayute, Salem, and Medford), continental (Winnemucca), and transitional (Spokane and Boise). Figures 5 through 8 show the frequency distribution of mixing heights from each station for 4 months that represent each season.

In winter, mixing heights remain below about 300 m agl in most places (fig. 5). This implies that pollutants often may stay relatively close to the ground and might frequently follow surface winds during winter. Occasional higher mixing heights, which rarely exceed 900 m agl (or about 1600 m asl) inside the basin, may allow pollutants to follow 850-mb-level winds at times during winter.

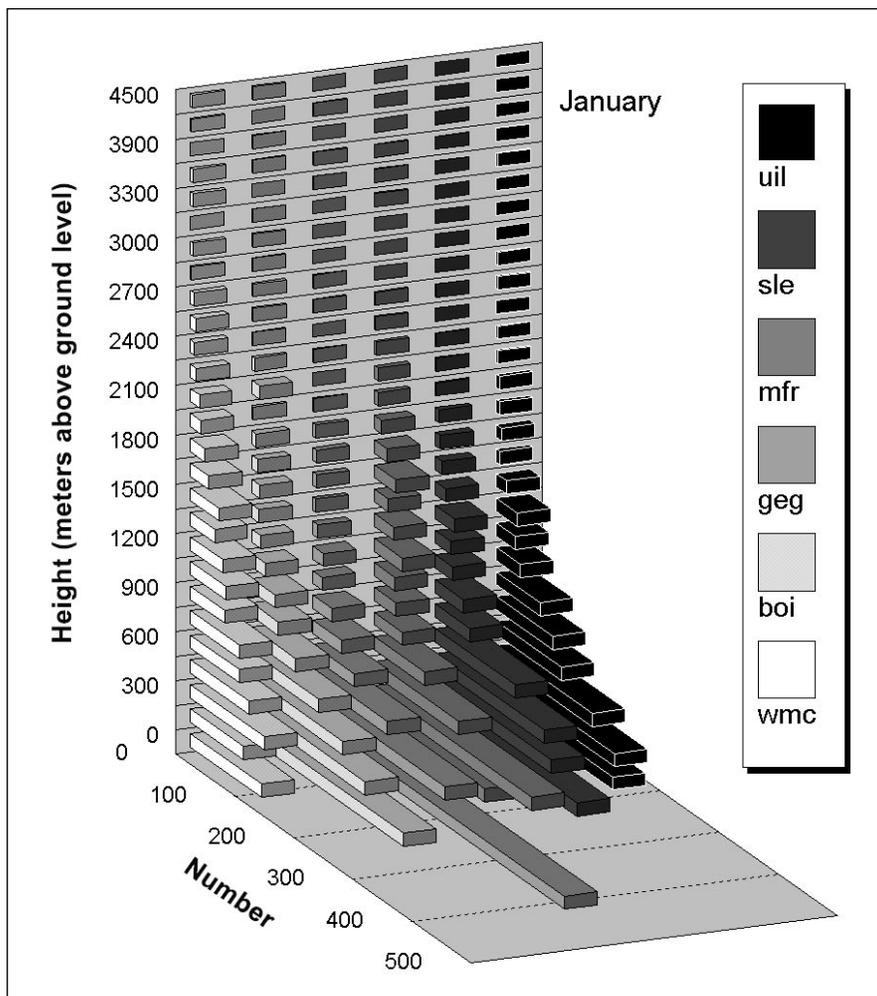


Figure 5—Frequency of January mixing heights for uil (Quillayute, Washington, at 58 m elevation); sle (Salem, Oregon, at 61 m); mfr (Medford, Oregon, at 421 m); geg (Spokane, Washington, at 722 m); boi (Boise, Idaho, at 871 m); and wmc (Winnemucca, Nevada, at 1310 m).

During spring, mixing heights are much more varied than during winter (fig. 6). April mixing heights average about 2300 m asl (1500 m agl at Spokane and Boise) within the basin, about 1500 m asl on the coast, and near 3500 m asl (2400 m agl at Winnemucca) south and east of the basin. Therefore, 850-mb winds may steer trajectories most often from sources inside the basin and from emissions west of the Cascade Range. Pollutants originating from south and east of the basin, however, may be steered by 700-mb winds. Because mixing heights at all sites vary by about ± 500 m, however, there are numerous times when lower or higher level winds may be influential.

During summer, Winnemucca experiences consistently high mixing heights because the summer sunshine efficiently warms the inland continent (fig. 7). Within the basin, the mean summer mixing height is about 1800 m agl at Spokane and Boise. The range of mixing heights, however, includes levels below 900 m agl, especially at Boise

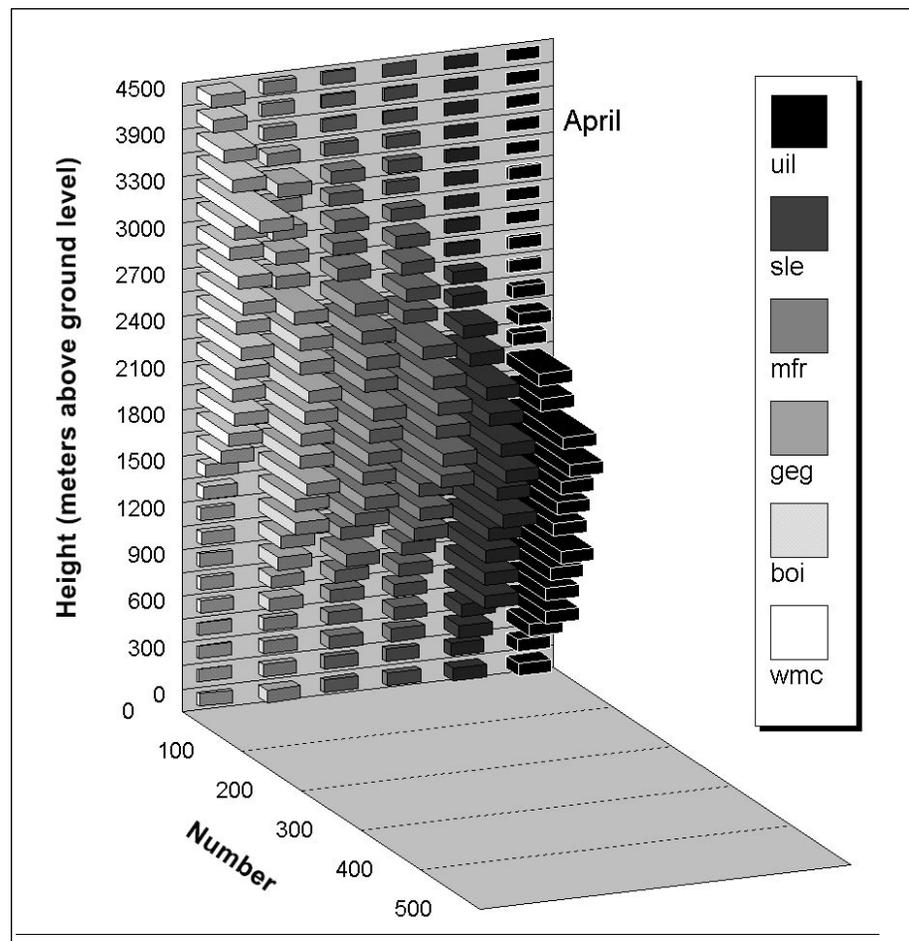


Figure 6 —Frequency of April mixing heights for uil (Quillayute, Washington, at 58 m elevation); sle (Salem, Oregon, at 61 m); mfr (Medford, Oregon, at 421 m); geg (Spokane, Washington, at 722 m); boi (Boise, Idaho, at 871 m); and wmc (Winnemucca, Nevada, at 1310 m).

where topographic constraints from the Snake River valley can be more dominant than the overall basin topography. Even so, most steering winds during summer could be from the 700-mb level. Stations west of the Cascade crest are influenced by frequent intrusions of marine clouds that increase atmospheric stability, so pollutants emanating from the Willamette Valley and Puget Sound may be steered by 850-mb winds at times during summer. Directly along the coast, the marine influence is more dramatic (e.g., Quillayute, uil in fig. 7), and pollutants from these places frequently may be steered by summer surface winds.

In autumn, mixing heights are much lower than in spring but not as low as in winter. They frequently drop below 900 m agl at west-side and basin interior stations (fig. 8). This means that surface and 850-mb winds most commonly steer monthly mean pollution trajectories from inside the basin and west of the Cascade Range. Mixing heights also begin to lower at Winnemucca, and pollutants emanating from south and east of the basin may be steered by 700-mb winds as well as 850-mb winds.

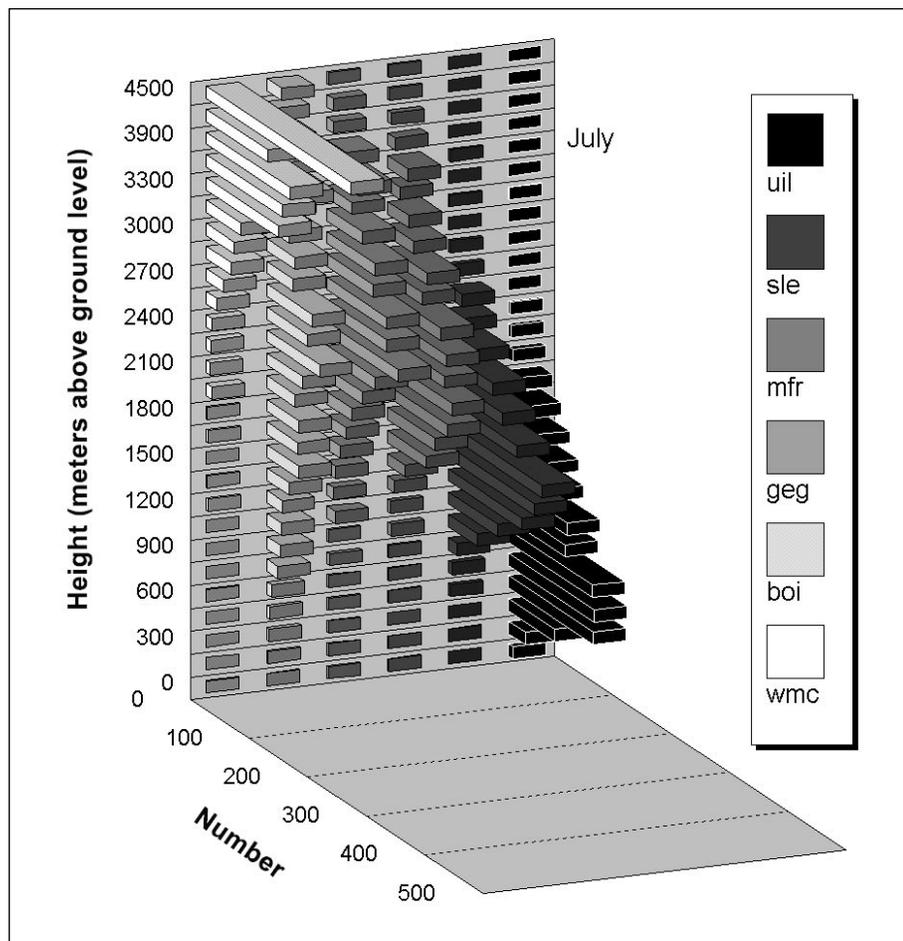


Figure 7—Frequency of July mixing heights for uil (Quillayute, Washington, at 58 m elevation); sle (Salem, Oregon, at 61 m); mfr (Medford, Oregon, at 421 m); geg (Spokane, Washington, at 722 m); boi (Boise, Idaho, at 871 m); and wmc (Winnemucca, Nevada, at 1310 m).

If the mixing height collapses at night, which commonly occurs, pollutants emitted during the day may be decoupled from the surface wind at night. This may cause lingering pollutants from daytime emissions to continue on trajectories steered by upper-air winds while new pollutants emitted at night may follow surface-level winds.

Also, the type and location of a source might influence its plume trajectory. For example, sources with tall stacks, such as power plants, may be more influenced by upper-air winds than sources with relatively short stacks. Likewise, sources that begin at high elevations may be more influenced by upper-air winds than sources at lower elevations. Finally, because the center of mass of a plume rarely reaches the top of a mixing layer, use of 700-mb trajectories should be limited.

Dispersion Index

To avoid the computational requirements of a fully physical dispersion model, a simple index was applied to approximate depleting concentrations downwind of a source. Most Gaussian dispersion models estimate downwind concentrations to be proportional to the emission rate and inversely proportional to the wind speed and distance from

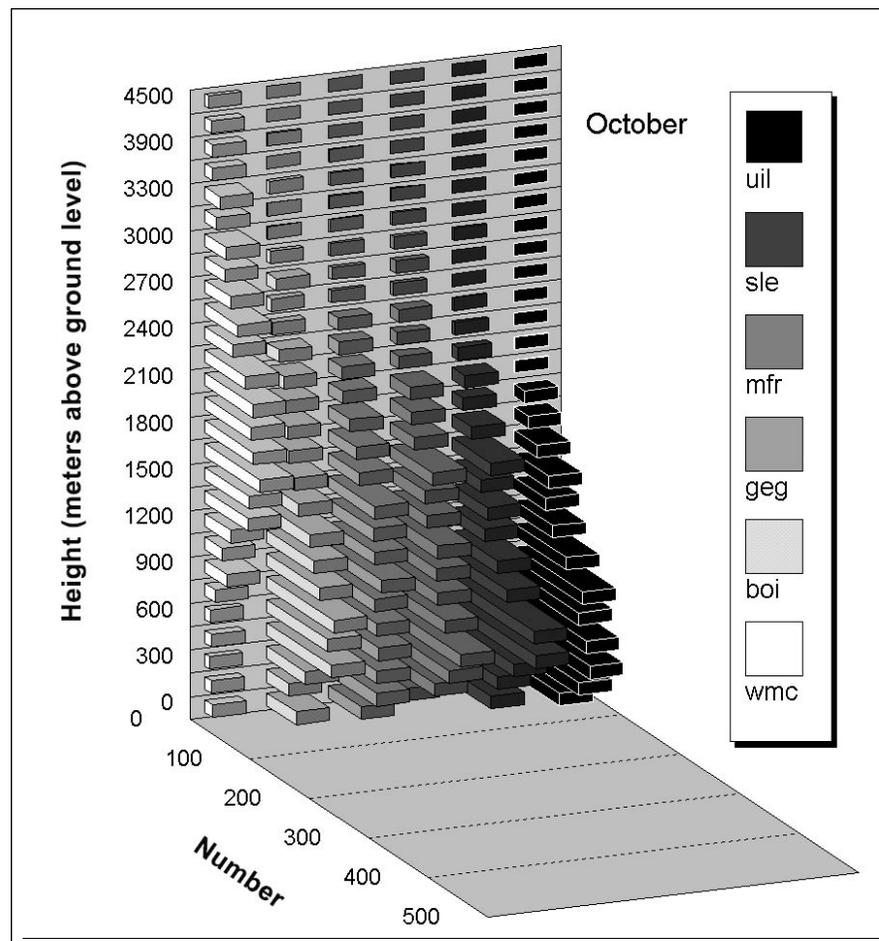


Figure 8—Frequency of October mixing heights for uil (Quillayute, Washington, at 58 m elevation); sle (Salem, Oregon, at 61 m); mfr (Medford, Oregon, at 421 m); geg (Spokane, Washington, at 722 m); boi (Boise, Idaho, at 871 m); and wmc (Winnemucca, Nevada, at 1310 m).

the source (e.g., Beychok 1994, Scire and others 1995, Sestak and Riebau 1988). Other factors like horizontal and vertical diffusion and exponential decay rates significantly influence downwind concentrations, but these are ignored in the present index. Also, more fully physical dispersion models assume constants that may or may not be realistic for monthly averaged conditions. Therefore, our index (I) takes the following form:

$$I = \frac{q}{W_s \times d},$$

where q is the concentration of emissions in tons at the source, W_s is the monthly mean wind speed in meters per second, and d is the distance in meters from the source.

We used the same index scale (0 to >32) for each map for each component. The scale is roughly logarithmic because most plumes retain relatively low concentrations of pollutants. Whenever trajectories intersect, their separate indices are added together.

Only the centerline of each trajectory is mapped. Lateral dispersion should be expected, however, at rates approximated by a Gaussian (bell-shaped distribution). Pasquill (1961) estimated horizontal spread in four classes of stability, from very stable to highly unstable. The spread distance is from points on either side of the centerline having concentrations that are 10 percent of centerline concentrations and defined by the angle of spread. For example, at 10 km downwind from a source in light winds, a horizontal spread angle of 28° might be expected in an unstable atmosphere and 13° in a stable atmosphere, which would suggest that concentrations of about 10 percent of those at the centerline could be found at distances of about 2.5 and 1.1 km from the centerline. At 100 km from the source, in strong winds, spread angles of 20° and 10° might occur in unstable and stable atmospheres, respectively. This suggests that 10-percent concentration levels may be found within 18 km from the centerline during unstable conditions and 9 km from the centerline in stable conditions.

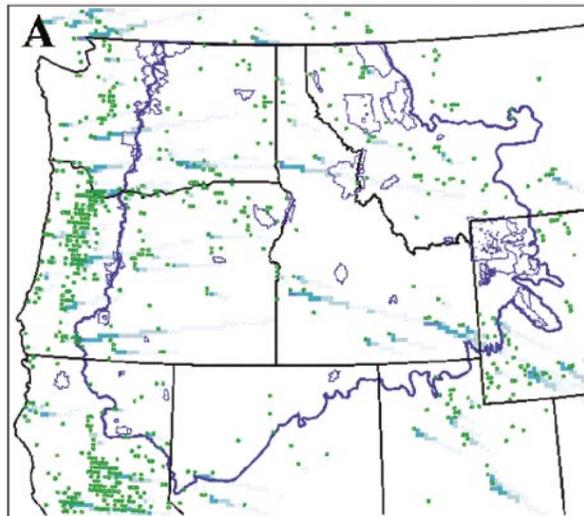
Results

Figures 9 through 12 show pollution potential trajectories at the 700-mb level. At this level, winds are relatively strong so plumes are dispersed within reasonably short distances downwind of each source. This is particularly true in winter. Although months representing each season are shown, the 700-mb trajectories are most appropriate during summer (fig. 11). At this time, the prevailing direction is from the southwest. Particulate matter (PM) emissions are relatively low compared to the gas constituents, and the most susceptible regions appear to be the Alpine Lakes Wilderness in Washington, the Sawtooth Wilderness in Idaho, and Wyoming's Fitzpatrick and Bridger Wildernesses (fig. 11a). In addition, because of the wide range of monthly winds, it appears that all the protected areas in the southern Washington and Oregon Cascade Range and the Flathead Indian Reservation in Montana can be impacted by PM emissions.

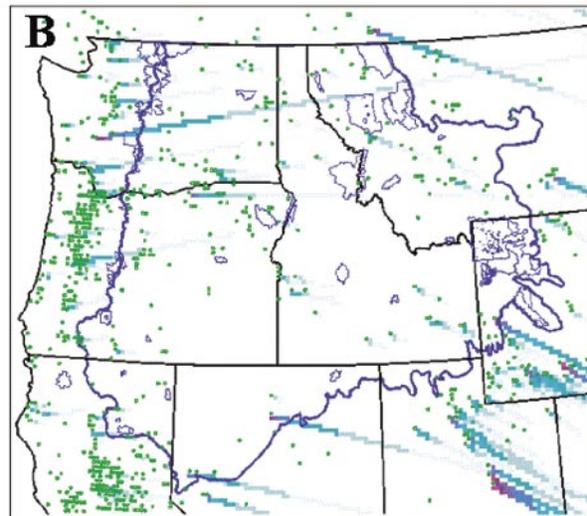
Most nitrogen oxide (NO_x) emissions that affect Northwest class I and nonattainment areas come from industrial sources in the Puget Sound and Willamette Valley regions of Washington and Oregon (fig. 11b). The greatest sources of NO_x emissions, however, are near Centralia, Washington, impacting the Alpine Lakes Wilderness and Mount Rainier National Park, and near Bondurant, Wyoming, which impacts the Fitzpatrick and Bridger Wildernesses. The spurious looking plume from sources in California is the result of weak winds in that region, which allow the index to remain relatively high for long distances. It is reasonable to suspect, however, that NO_x from the California plumes will disperse laterally or fall out as deposits before reaching as far into the basin as the mapped trajectory implies.

Sulfur oxide (SO_x) emission patterns are similar to NO_x emissions (fig. 11c). The Fitzpatrick and Bridger Wildernesses, however, are much more greatly impacted by SO_x sources in Idaho, near Pocatello and Soda Springs. There are relatively few sources of ammonia (NH₃) in the basin, and it appears that only North Cascades National Park may be affected by NH₃ emissions (fig. 11d).

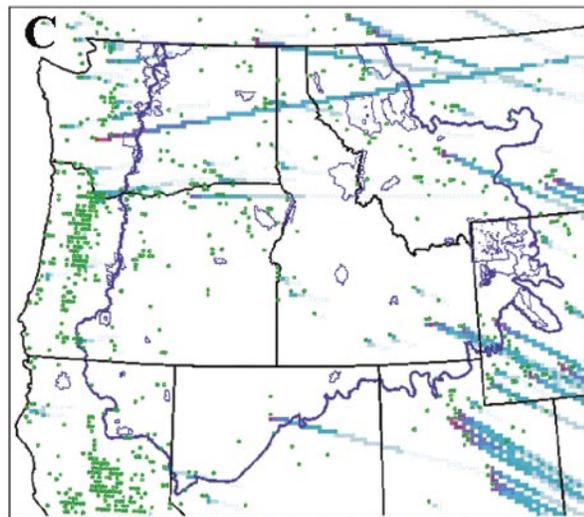
Pollution trajectories at the 850-mb level are shown in figures 13 through 16. Slightly weaker winds at this level allow concentrations to be carried somewhat farther downwind than those traveling at the 700-mb level. Months representing each season are shown, but trajectories at the 850-mb level are most appropriate for spring and autumn because mixing heights at these times of year are most commonly around 1500 m asl, the average height of the 850-mb pressure surface.



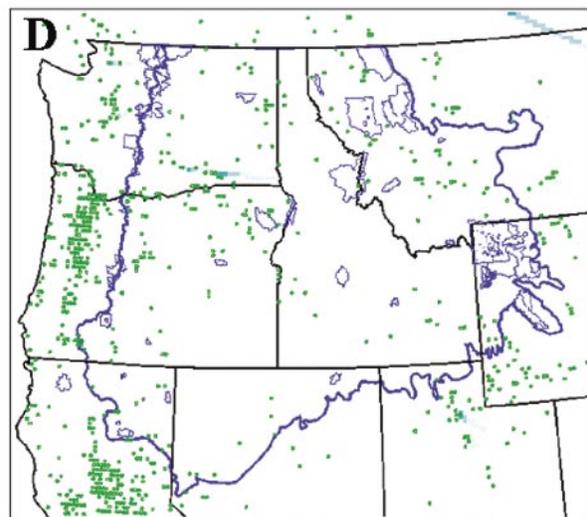
Particulate matter



Nitrogen oxides



Sulfur oxides



Ammonia

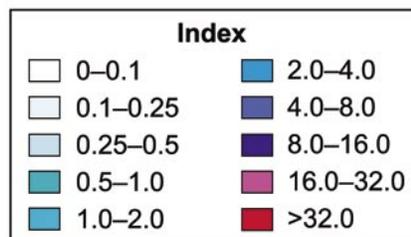
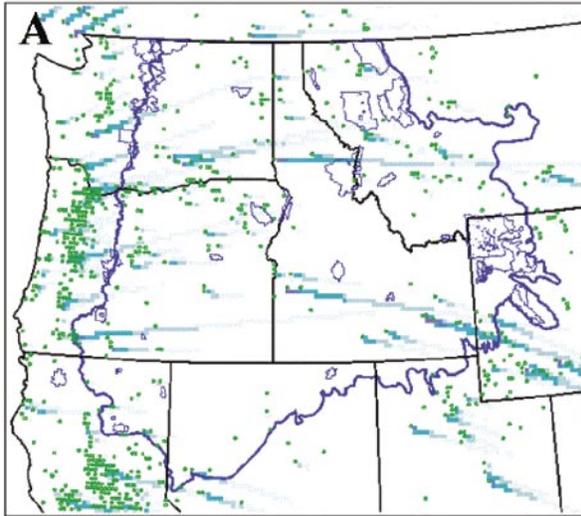
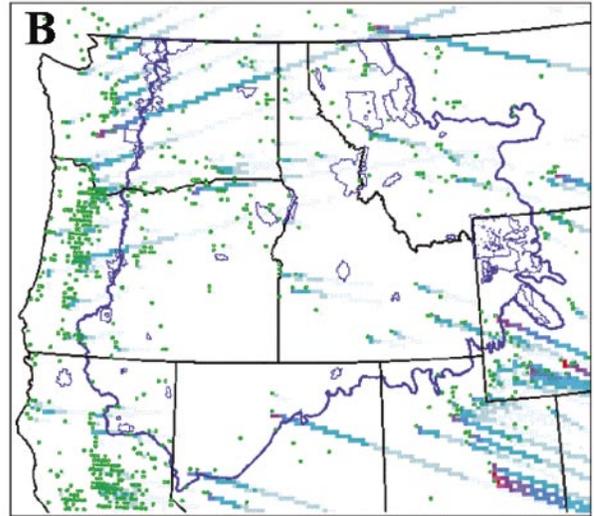


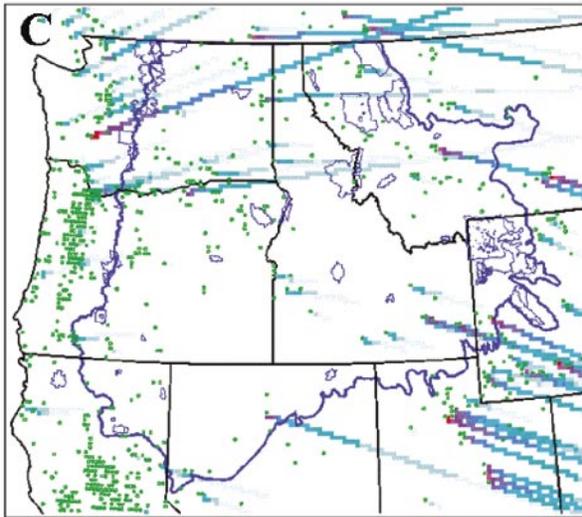
Figure 9—Potential pollution trajectories at 700 mb in January for (A) total particulates, (B) nitrogen oxides, (C) sulfur oxides, and (D) ammonia. Colors indicate the value of an index, which is based on the value of emission concentrations at the source divided by wind speed and distance from the source. Class I areas are outlined, and green squares show point source emission locations.



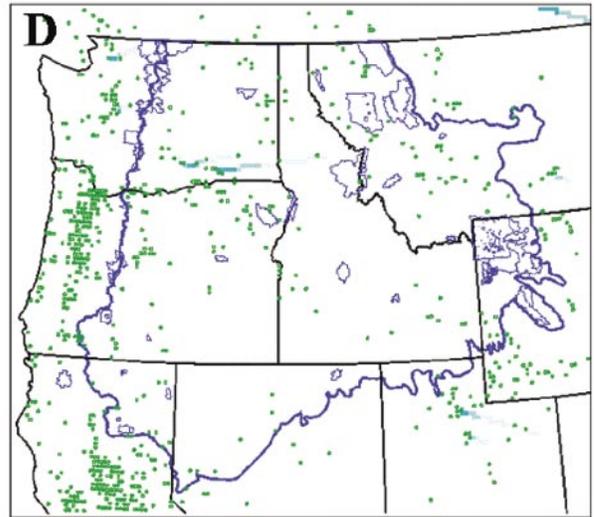
Particulate matter



Nitrogen oxides



Sulfur oxides



Ammonia

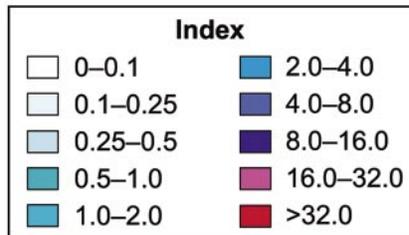
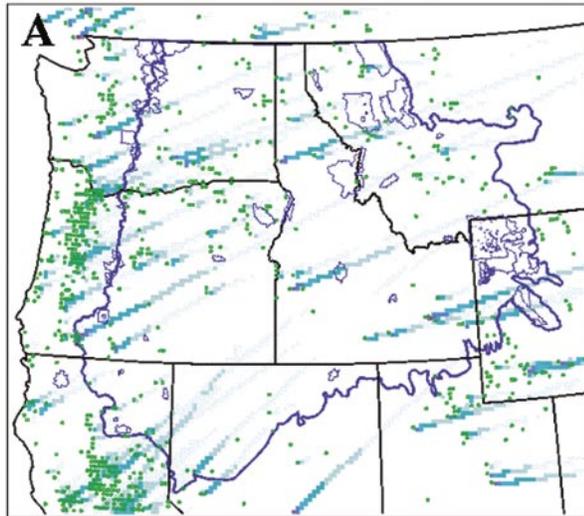
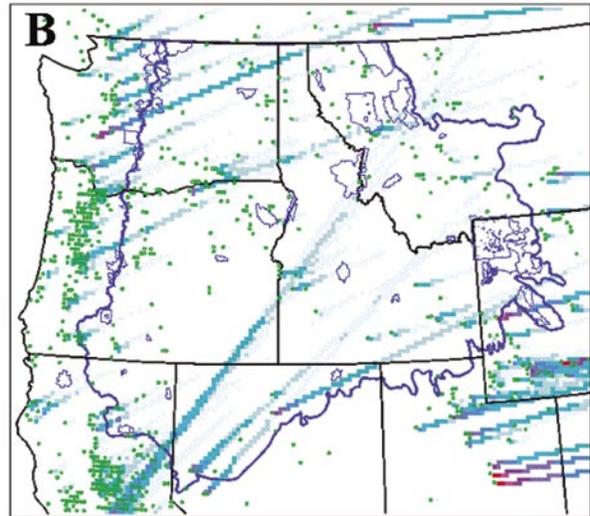


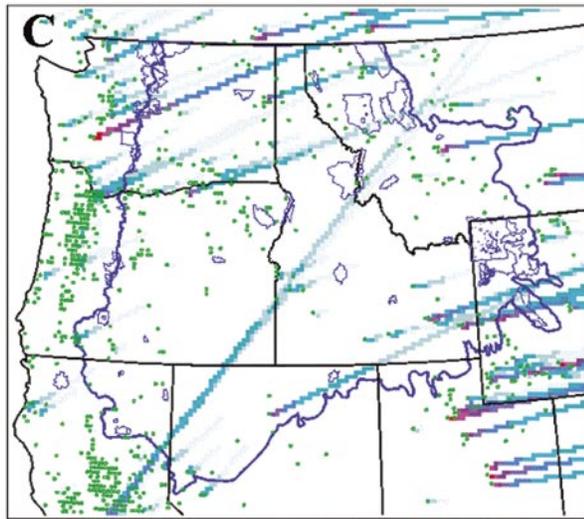
Figure 10—Potential pollution trajectories at 700 mb in April for (A) total particulates, (B) nitrogen oxides, (C) sulfur oxides, and (D) ammonia. Colors indicate the value of an index, which is based on the value of emission concentrations at the source divided by wind speed and distance from the source. Class I areas are outlined, and green squares show point source emission locations.



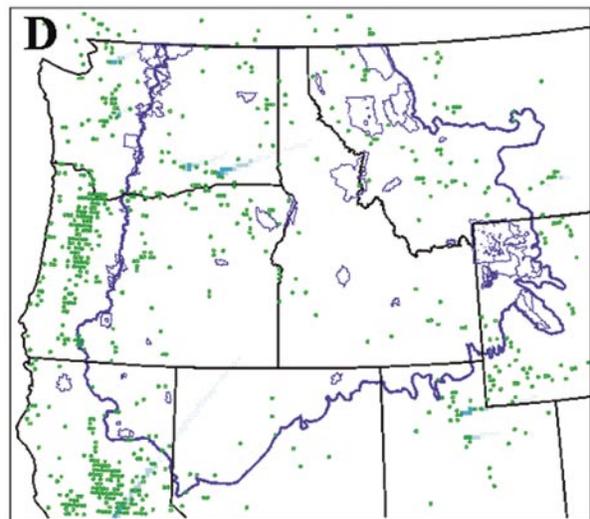
Particulate matter



Nitrogen oxides



Sulfur oxides



Ammonia

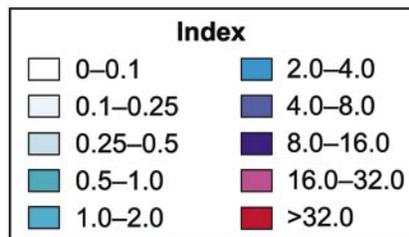
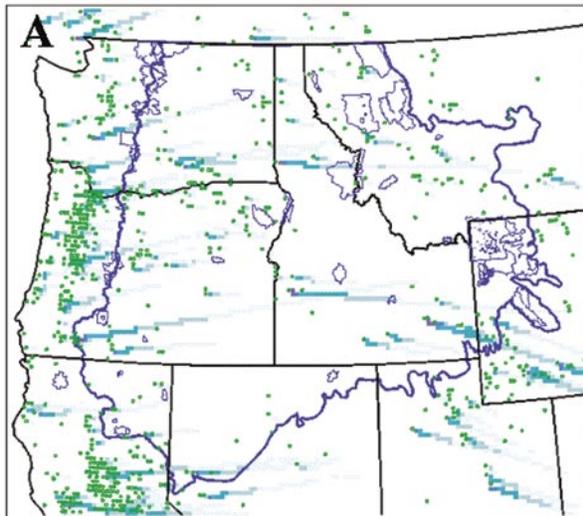
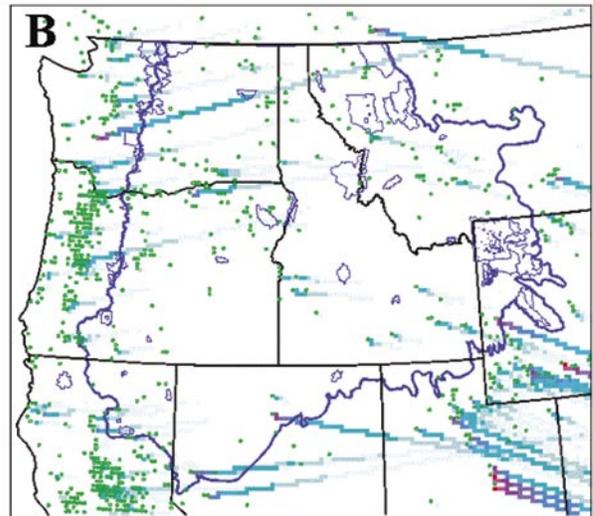


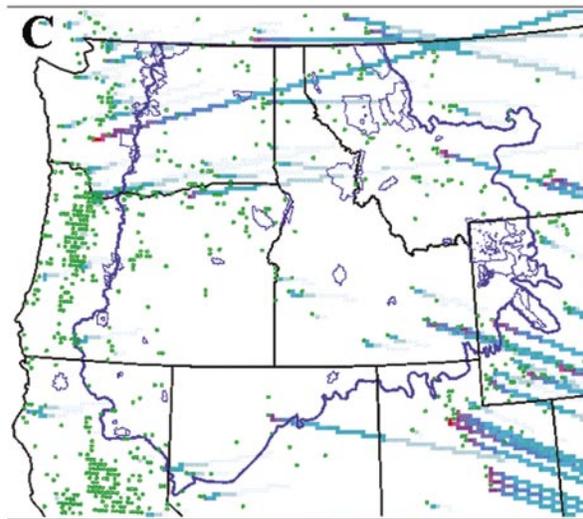
Figure 11 —Potential pollution trajectories at 700 mb in July for (A) total particulates, (B) nitrogen oxides, (C) sulfur oxides, and (D) ammonia. Colors indicate the value of an index, which is based on the value of emission concentrations at the source divided by wind speed and distance from the source. Class I areas are outlined, and green squares show point source emission locations.



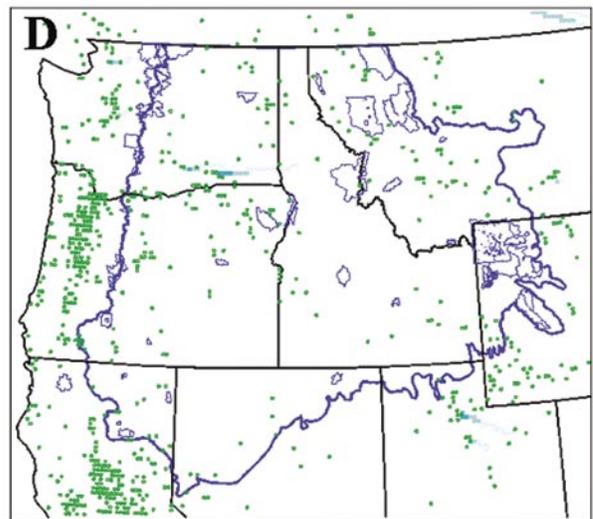
Particulate matter



Nitrogen oxides



Sulfur oxides



Ammonia

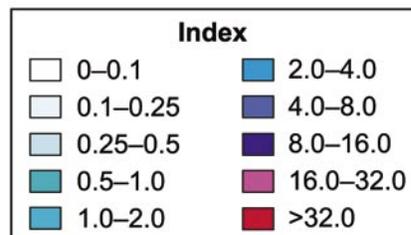
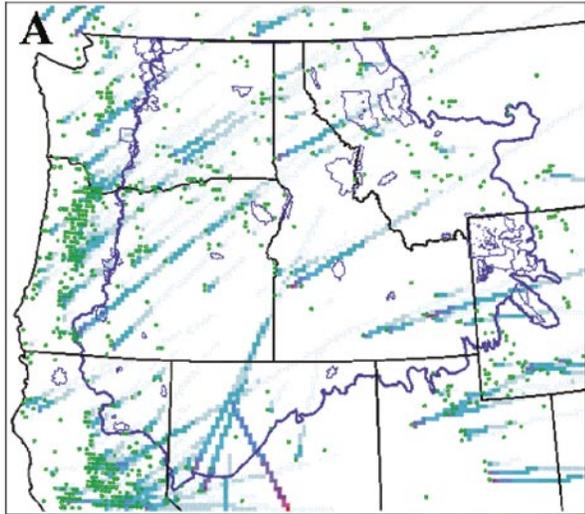
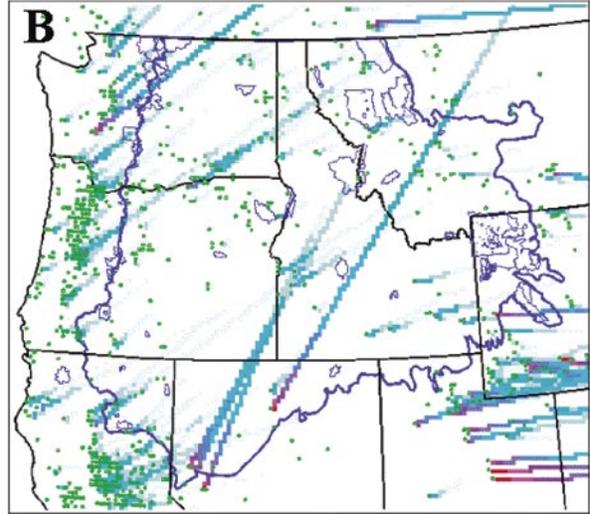


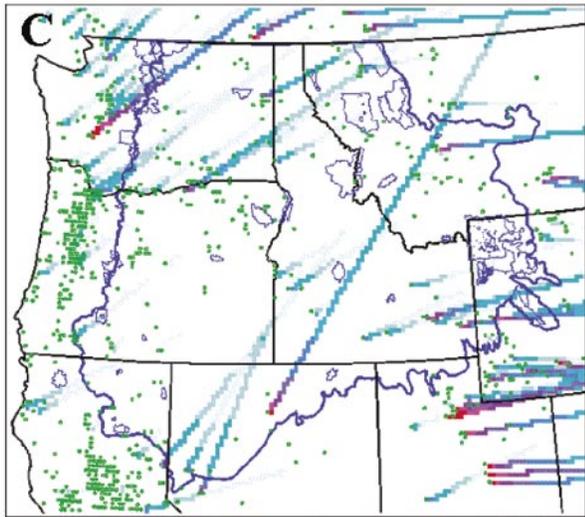
Figure 12 —Potential pollution trajectories at 700 mb in October for (A) total particulates, (B) nitrogen oxides, (C) sulfur oxides, and (D) ammonia. Colors indicate the value of an index, which is based on the value of emission concentrations at the source divided by wind speed and distance from the source. Class I areas are outlined, and green squares show point source emission locations.



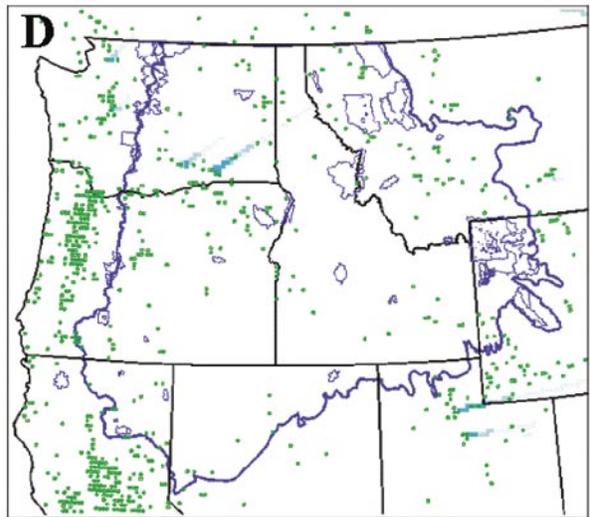
Particulate matter



Nitrogen oxides



Sulfur oxides



Ammonia

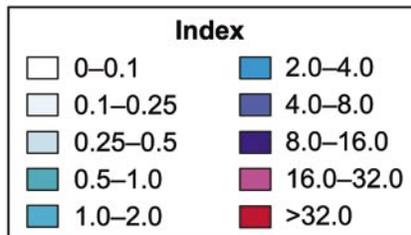
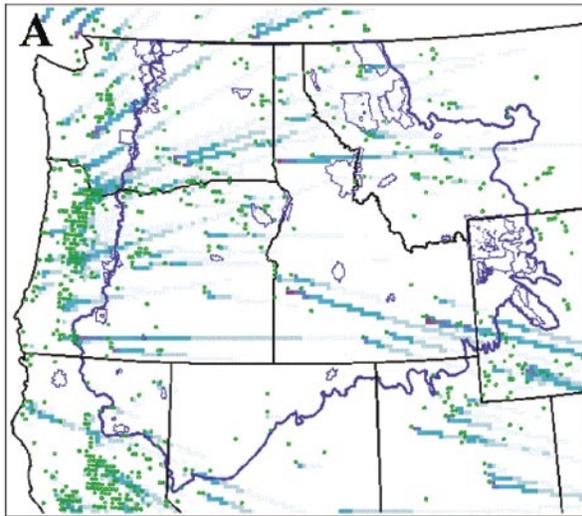
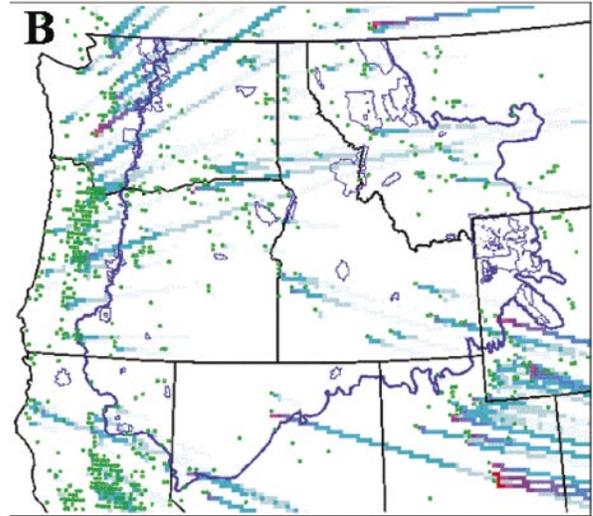


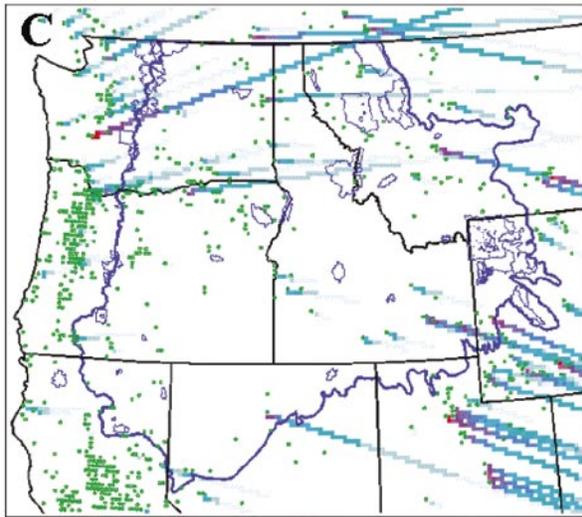
Figure 13—Potential pollution trajectories at 850 mb in January for (A) total particulates, (B) nitrogen oxides, (C) sulfur oxides, and (D) ammonia. Colors indicate the value of an index, which is based on the value of emission concentrations at the source divided by wind speed and distance from the source. Class I areas are outlined, and green squares show point source emission locations.



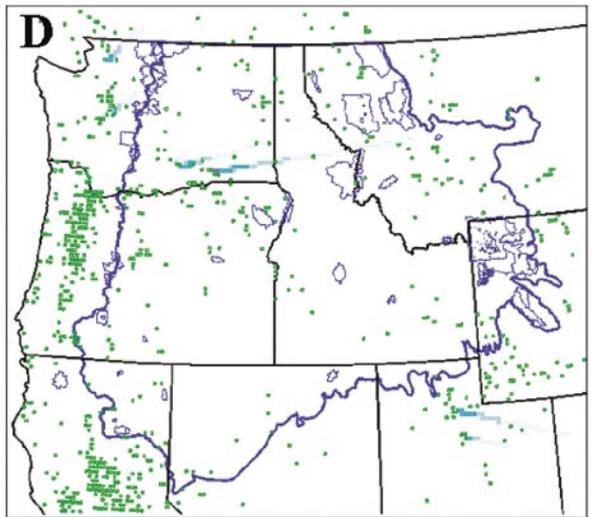
Particulate matter



Nitrogen oxides



Sulfur oxides



Ammonia

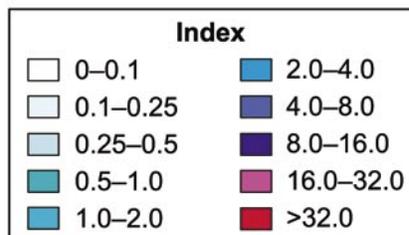
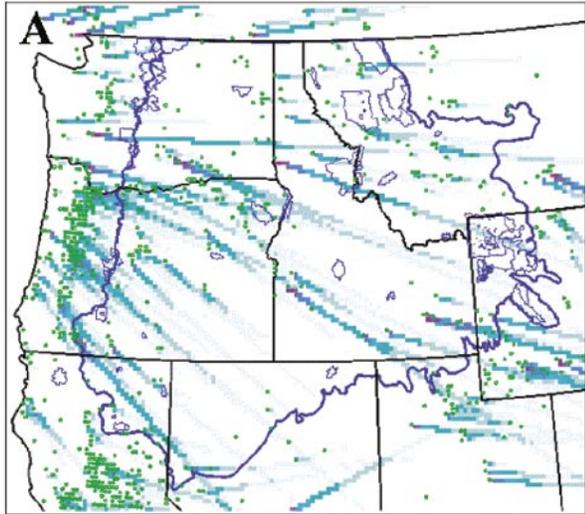
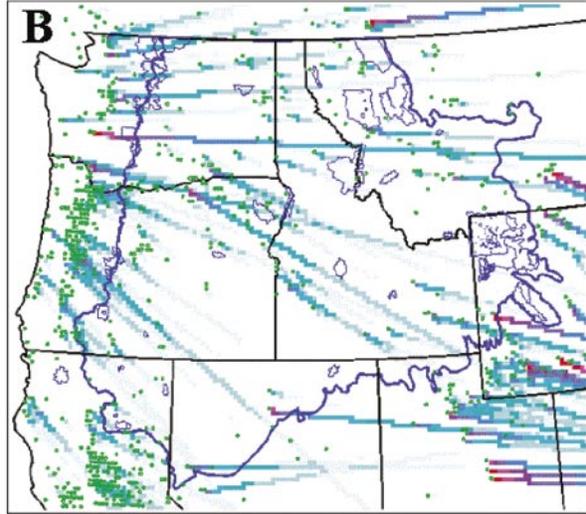


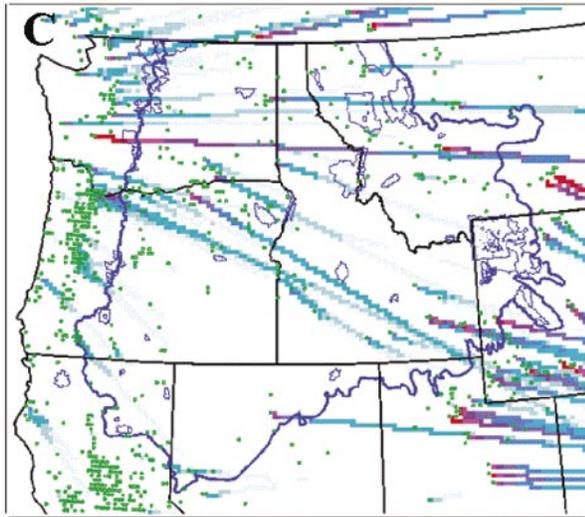
Figure 14—Potential pollution trajectories at 850 mb in April for (A) total particulates, (B) nitrogen oxides, (C) sulfur oxides, and (D) ammonia. Colors indicate the value of an index, which is based on the value of emission concentrations at the source divided by wind speed and distance from the source. Class I areas are outlined, and green squares show point source emission locations.



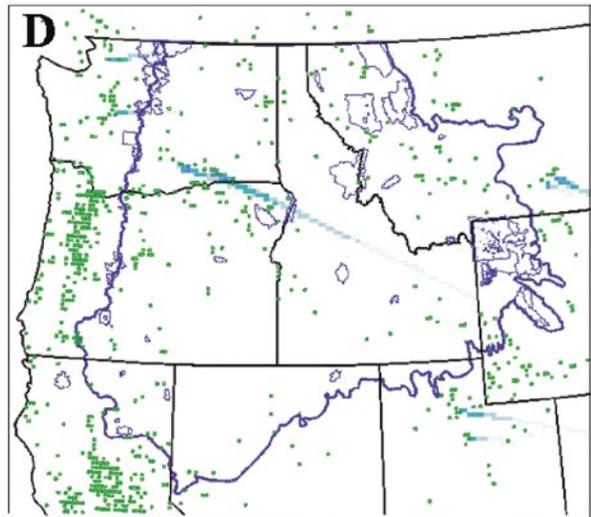
Particulate matter



Nitrogen oxides



Sulfur oxides



Ammonia

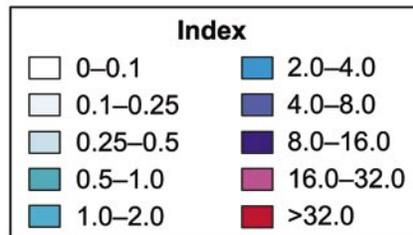
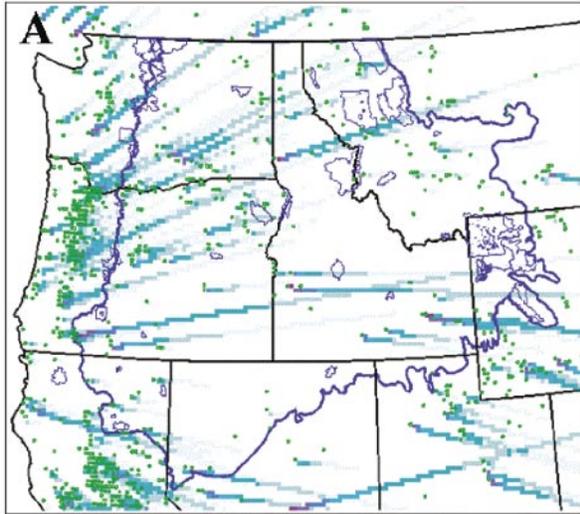
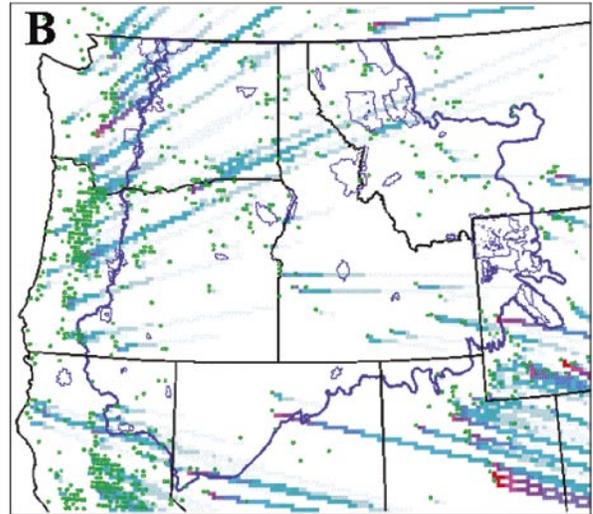


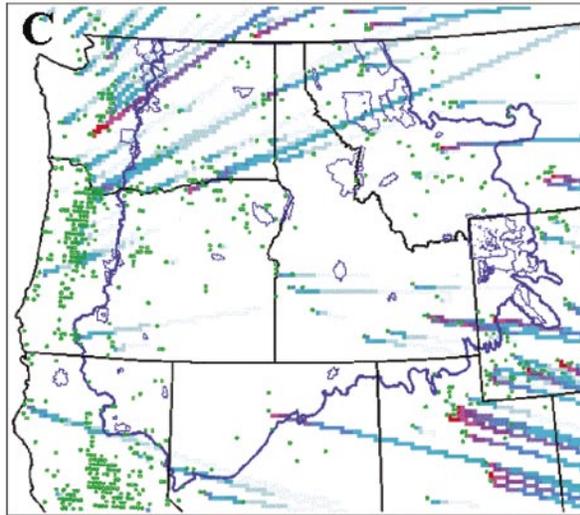
Figure 15—Potential pollution trajectories at 850 mb in July for (A) total particulates, (B) nitrogen oxides, (C) sulfur oxides, and (D) ammonia. Colors indicate the value of an index, which is based on the value of emission concentrations at the source divided by wind speed and distance from the source. Class I areas are outlined, and green squares show point source emission locations.



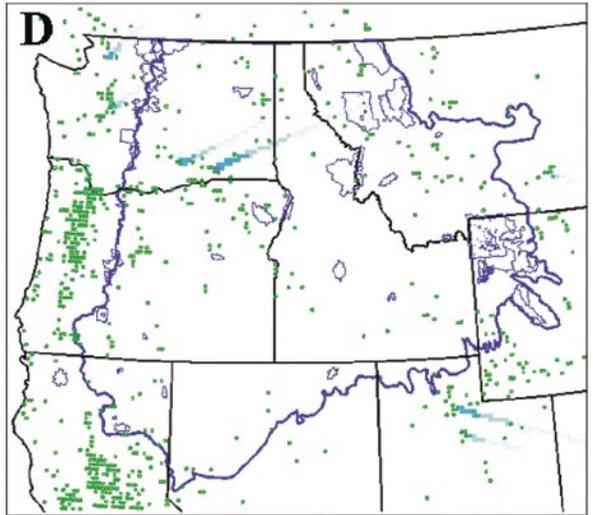
Particulate matter



Nitrogen oxides



Sulfur oxides



Ammonia

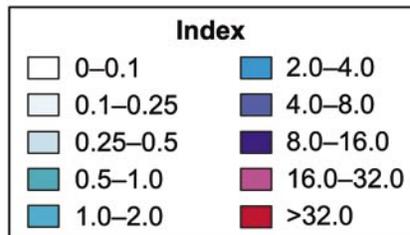


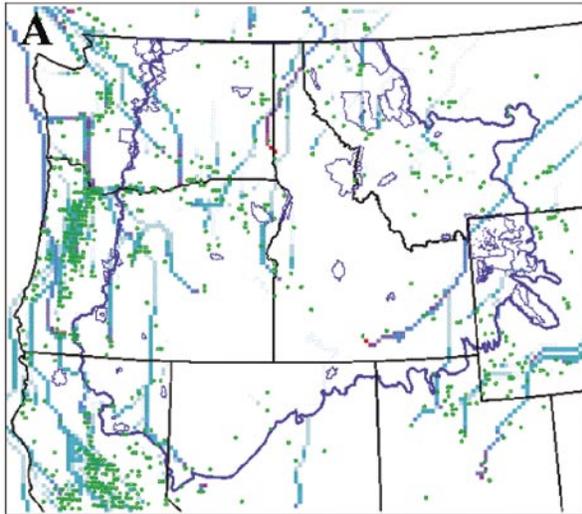
Figure 16—Potential pollution trajectories at 850 mb in October for (A) total particulates, (B) nitrogen oxides, (C) sulfur oxides, and (D) ammonia. Colors indicate the value of an index, which is based on the value of emission concentrations at the source divided by wind speed and distance from the source. Class I areas are outlined, and green squares show point source emission locations.

In April, 850-mb winds prevail from the southwest to west in the northern part of the basin and from the west to northwest in the southern part of the basin (fig. 14). This means that pollution impacts during spring are very similar to summer impacts in the northern part of the basin, except that the Selway Bitterroot Wilderness appears more susceptible to pollution sources near Lewiston, Idaho, because April winds have a more westerly component in that region. Also, in the southern basin the shift in spring to northwesterly winds helps to carry pollutants away from the Fitzpatrick and Bridger Wildernesses, places that are strongly impacted by 700-mb July trajectories.

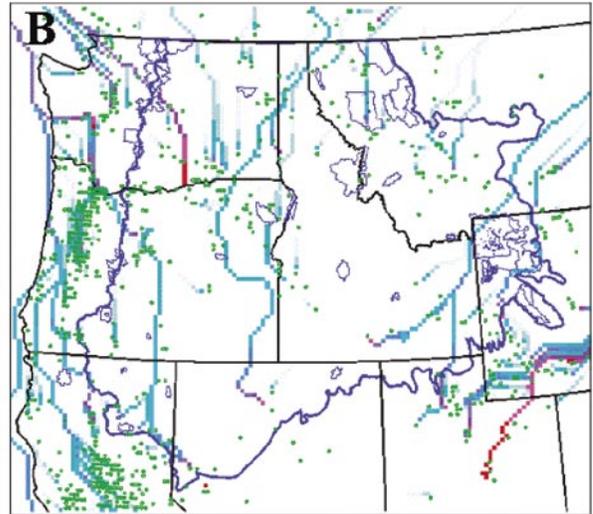
Winds in October are slightly weaker than those in January and April. Therefore, pollution concentrations can be carried somewhat farther downwind (fig. 16). For example, it appears that the Flathead Indian Reservation and Scapegoat Wilderness in Montana are impacted by sources over 300 km away near Lewiston, Idaho, and that the Fitzpatrick and Bridger Wildernesses are impacted by sources 600 km away near Boise, Idaho. Along both trajectories, however, mountains that range well over the 1500-m average height of the 850-mb pressure surface may block pollutants. Therefore, the very long mapped trajectories may not show realistic concentrations.

Trajectories following surface winds are shown in figures 17 through 20. Because very low mixing heights are most common during winter, it is during this season that surface trajectories are most applicable (fig. 17). Surface winds in winter are nearly opposite to surface winds in other seasons and to upper-air winds in all seasons. This is because a temperature inversion persists in the basin during winter, which not only causes low mixing heights but also causes surface pressures to be relatively high. This helps set up a pressure gradient force that causes easterly winds to prevail over the western half of the basin and south to southwesterly winds in the eastern half of the basin. In addition, because winds follow surface terrain, some dominant topographic features can control trajectories. For example, pollution trajectories from east of the Cascade Range are funneled through Stevens Pass, Snoqualmie Pass, the Columbia River Gorge, and Santiam Pass, barely impacting the adjacent class I areas. Other places, however, are impacted more significantly during winter than at other seasons. Glacier National Park, for instance, is impacted by PM, NO_x, and SO_x sources from near Kalispell and Missoula (figs. 17a, 17b, and 17c, respectively). The Flathead Indian Reservation also is impacted by PM and NO_x sources from near Missoula. In addition, the Three Sisters Wilderness appears impacted by a PM source near Klamath Falls, Oregon, and Yellowstone National Park may see some impact from sources in Idaho's Snake River valley.

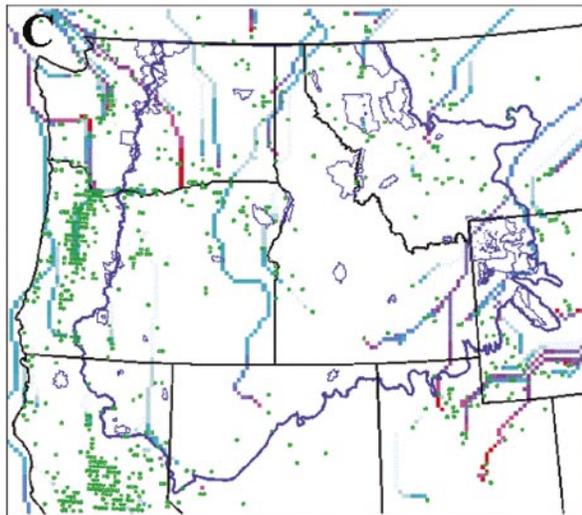
In all maps, wind direction can vary over 45° from the monthly mean. Variations in speed also can lengthen or shorten trajectories by tens of kilometers. In addition, mixing heights vary each month and are different for air masses inside the basin than those outside the basin. Therefore, plumes may follow significantly different trajectories during any given month than those described above. Also, plumes from sources west of the Cascade Range may follow lower trajectories than inside the basin. Likewise, plumes from sources east of the Rocky Mountains and south of the basin may follow higher trajectories than inside the basin.



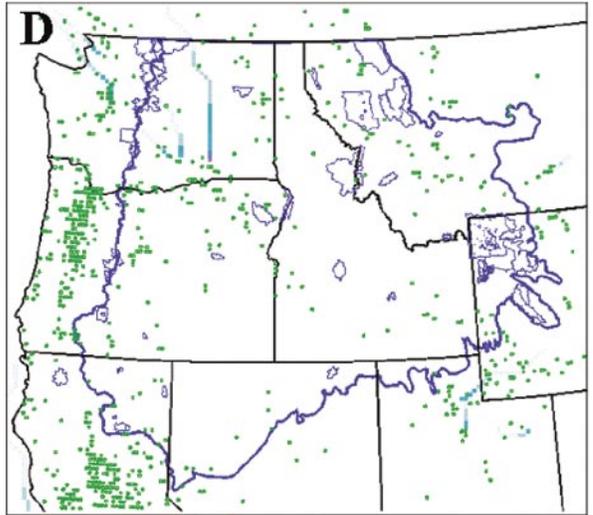
Particulate matter



Nitrogen oxides



Sulfur oxides



Ammonia

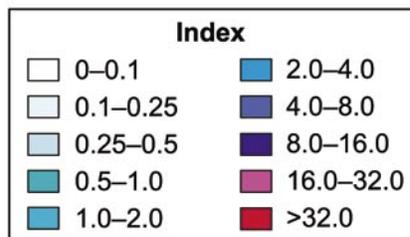
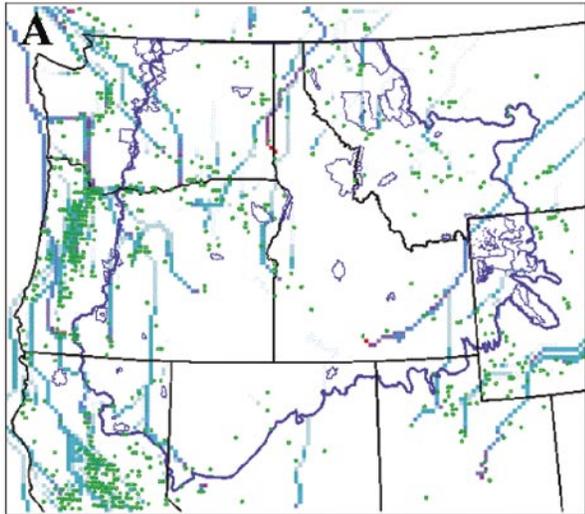
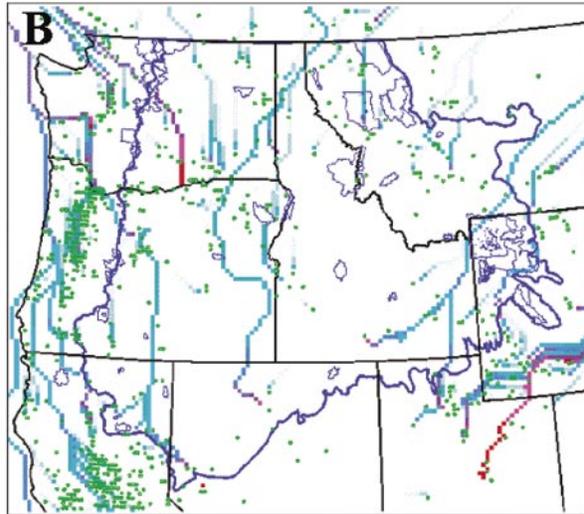


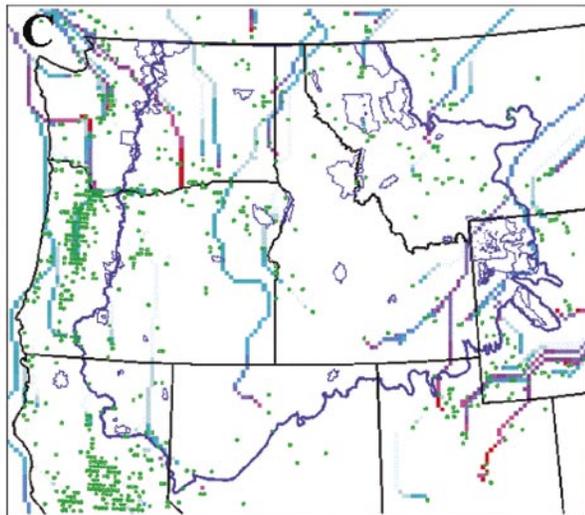
Figure 17—Potential pollution trajectories at the surface in January for (A) total particulates, (B) nitrogen oxides, (C) sulfur oxides, and (D) ammonia. Colors indicate the value of an index, which is based on the value of emission concentrations at the source divided by wind speed and distance from the source. Class I areas are outlined, and green squares show point source emission locations.



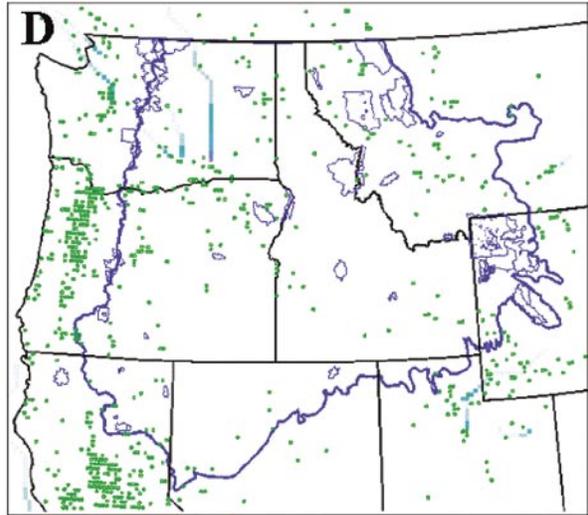
Particulate matter



Nitrogen oxides



Sulfur oxides



Ammonia

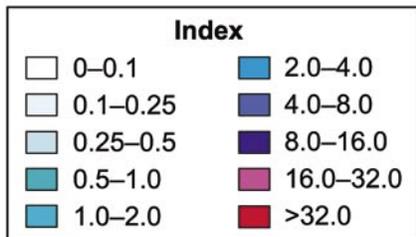
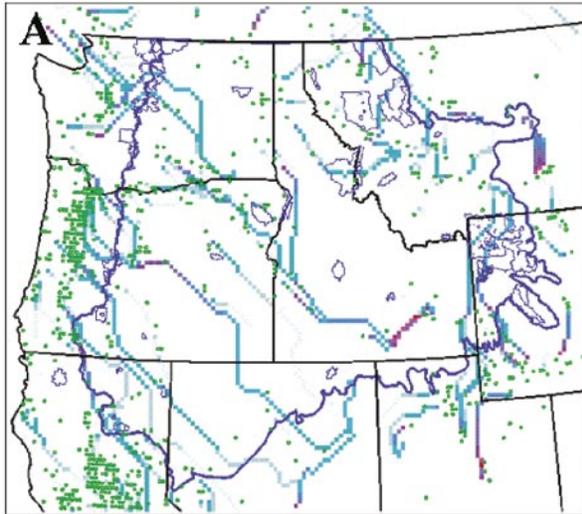
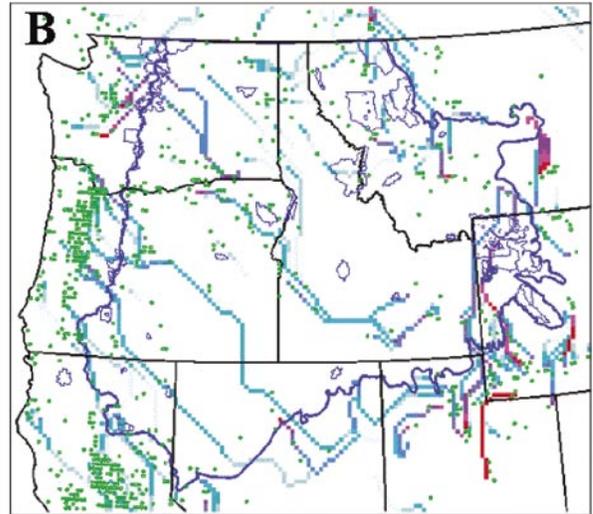


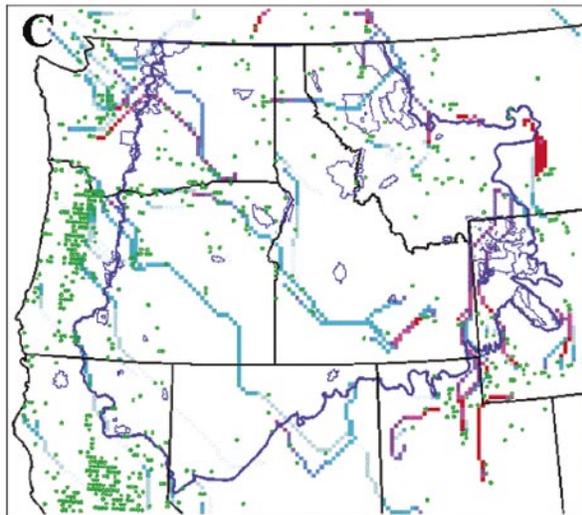
Figure 18—Map of potential pollution trajectories at the surface in April for (A) total particulates, (B) nitrogen oxides, (C) sulfur oxides, and (D) ammonia. Colors indicate the value of an index, which is based on the value of emission concentrations at the source divided by wind speed and distance from the source. Class I areas are outlined, and green squares show point source emission locations.



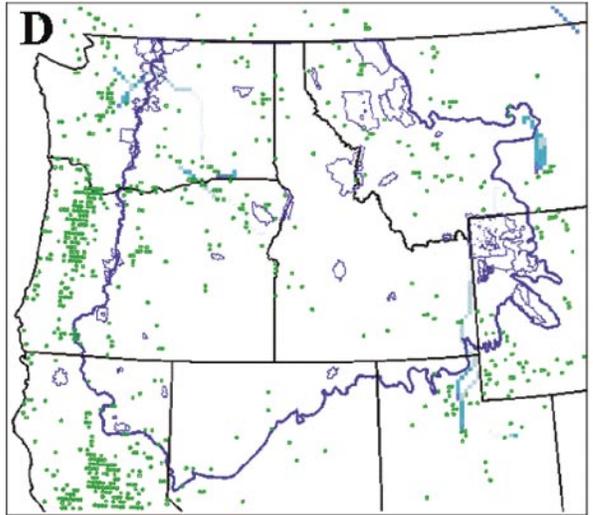
Particulate matter



Nitrogen oxides



Sulfur oxides



Ammonia

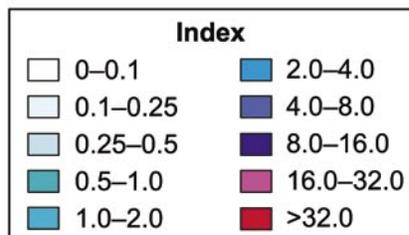
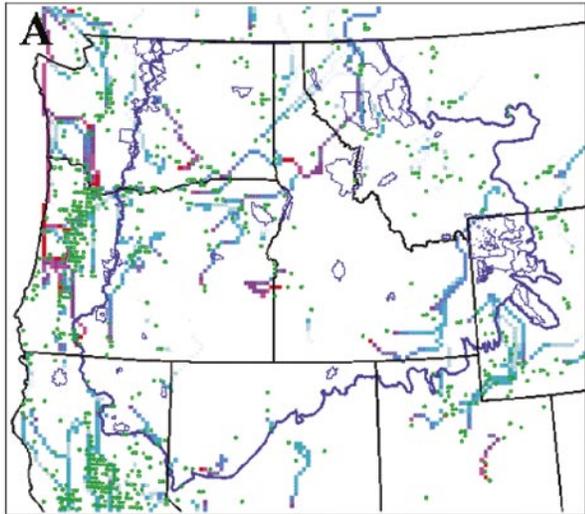
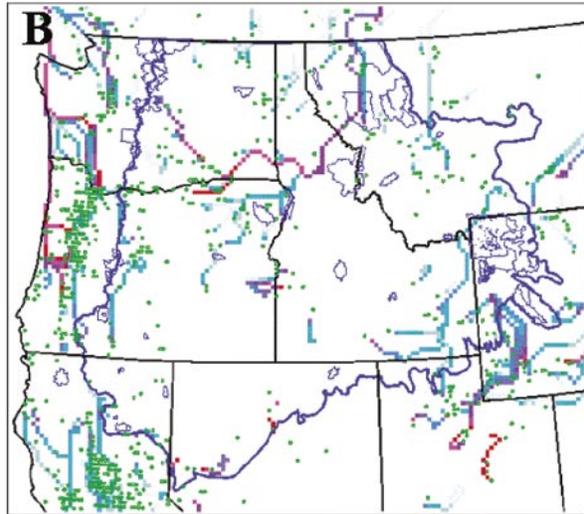


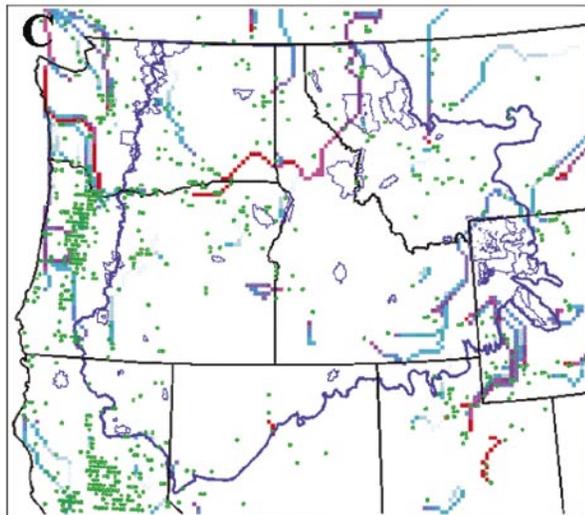
Figure 19—Potential pollution trajectories at the surface in July for (A) total particulates, (B) nitrogen oxides, (C) sulfur oxides, and (D) ammonia. Colors indicate the value of an index, which is based on the value of emission concentrations at the source divided by wind speed and distance from the source. Class I areas are outlined, and green squares show point source emission locations.



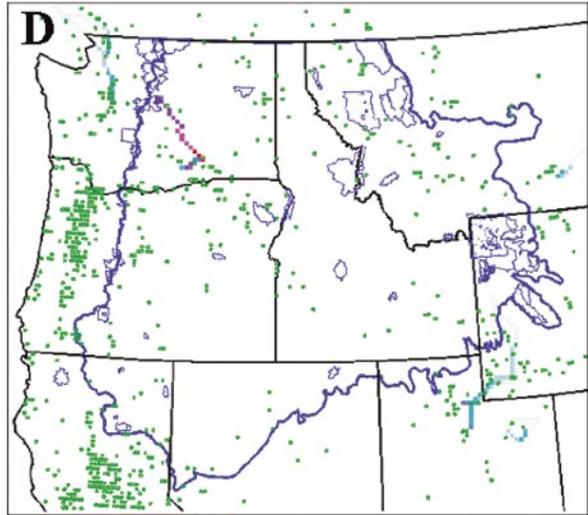
Particulate matter



Nitrogen oxides



Sulfur oxides



Ammonia

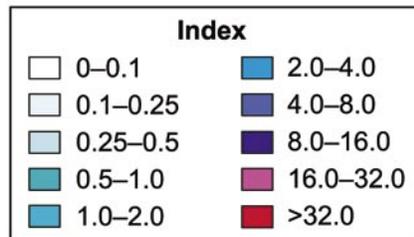


Figure 20—Potential pollution trajectories at the surface in October for (A) total particulates, (B) nitrogen oxides, (C) sulfur oxides, and (D) ammonia. Colors indicate the value of an index, which is based on the value of emission concentrations at the source divided by wind speed and distance from the source. Class I areas are outlined, and green squares show point source emission locations.

Conclusion

A simple dispersion index was used with monthly mean wind directions to estimate the potential for pollutants reaching class I areas in the Northwestern United States. It showed that impacts from existing pollution sources are seasonal and that many parts of the Columbia River basin are affected from a variety of sources. Although some mapped trajectories indicate impacts from sources that are a long distance from class I areas, topography of the region and simplicity of the indexing scheme suggest that nearby sources present the greatest threats.

Because of the large uncertainty in the mapped trajectories, they should only be used as initial guidance in planning. To gain more complete knowledge of the impact from an individual source, other tools must be used. For example, more fully physical dispersion models can be used to identify impacts from specific events, or models can be run over long periods to gain a statistical sampling of impact events. Tools like the pollution exposure index model also can be used to estimate the probability of impacts (Miller 1997). Despite the limitations of the regional pollution-potential approach, it can provide useful information about the density of pollution and seasonal variation of trajectories.

Acknowledgments

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English Equivalents

When you know:	Multiply by:	To find:
Meters (m)	3.28	Feet
Kilometers (km)	.62	Miles
Millibars (mb)	.0295	Inches of mercury
Meters per second (m/s)	2.24	Miles per hour
Meters per second (m/s)	1.94	Knots

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