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Following the Smoke Trail

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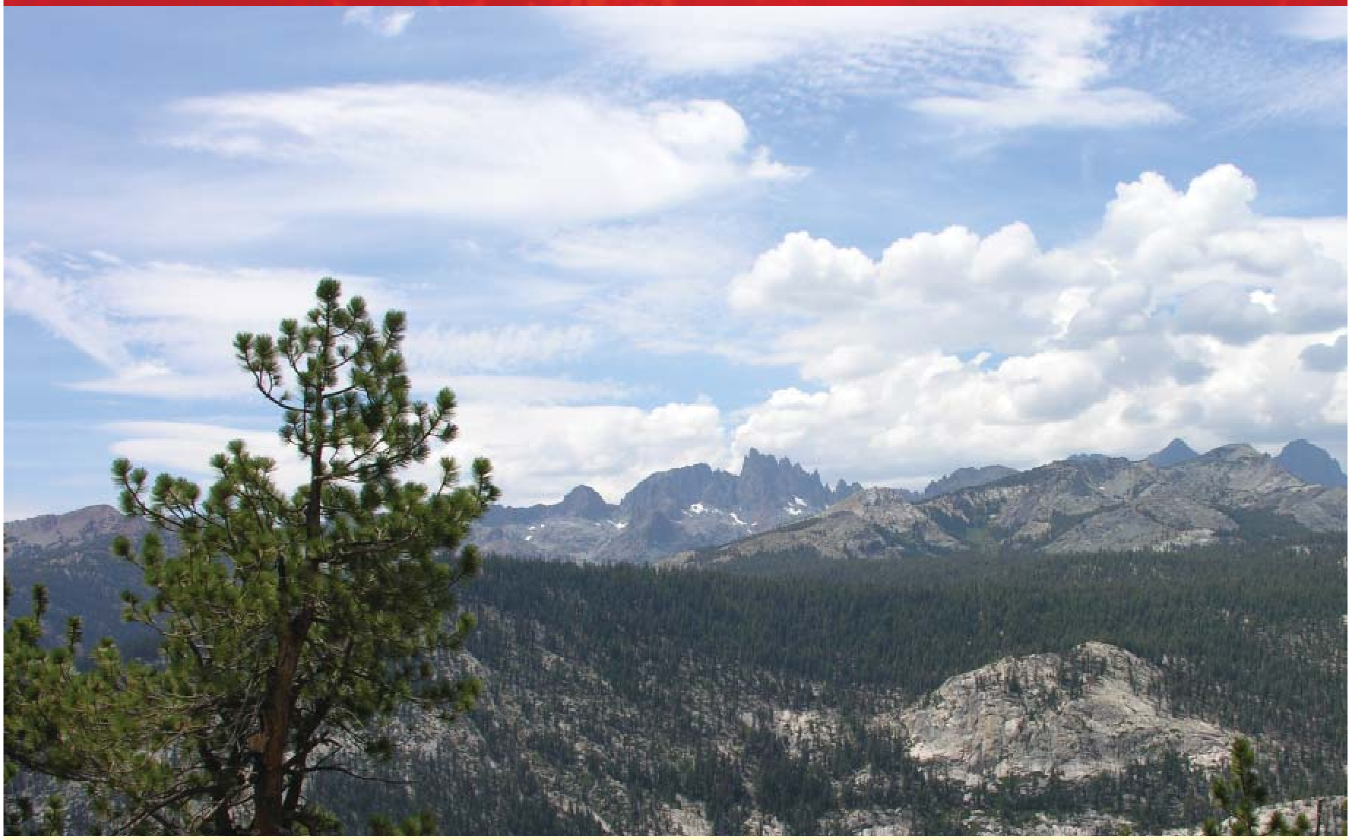
RESEARCH SUPPORTING SOUND DECISIONS



Even the pristine eastern Sierra Nevada can be affected by
air pollution episodes in the San Joaquin Valley, across the mountains.

Following the Smoke Trail

Summary

Public land administrators and air quality managers need better information on the potential contribution of wildland fires vs. anthropogenic sources on possible exceedances of air quality standards. To obtain more precise information in California, a composite network was established for monitoring ozone (O_3), nitrogen dioxide (NO_2), ammonia (NH_3), gaseous nitric acid (HNO_3) and particulate matter (PM). The network was located in the Sierra Nevada region of central California.

The network provided data for estimates of distribution of air pollutants from urban and agricultural activities, and measured contributions of area wildland fires on ground levels of pollutants. Information was also gathered during the southern California wildland fires of October 2007, in periods of closure of major transportation routes and Santa Ana winds. Research indicated increased O_3 levels during periods of fire activity, but overall effects on diurnal O_3 levels appear to be minor compared with the amount of variability attributed to other sources. Particulate matter levels appeared to be the pollutant most influenced by wildland fires.

Key Findings

- With both wildfires and prescribed burns in the Southwest, usually the greatest concern from an air quality standpoint is elevated levels of particulate matter. This was confirmed by an extensive air quality monitoring project in the Sierra Nevada.
- Prescribed burns are normally conducted at times of year when emissions have minimal impact on the production of photochemical smog. This is often not the case with wildfires.
- The BlueSky monitoring framework generates forecasting results that generally are consistent with field measurements. However, refinements in BlueSky data elements will improve its forecasting accuracy.
- Strong southwest winds have potential to drive elevated air pollution levels from the San Joaquin Valley up the western slope of the Sierra Nevada and over to the eastern slope.
- Elevated levels of particulates resulting from prescribed burns may limit future burns in the Sierra Nevada. However, this may have the long-term effect of raising fuel levels and increasing the likelihood of more frequent and intense wildfire events, resulting in significantly greater air quality consequences.

Wildland fire and air quality

Over the last two decades, smoke from both wildfires and prescribed fires in California has increased. During that same period, there has been growing concern that smoke from wildland fires might contribute to increased levels of hazardous air pollutants. As a result, the U.S. Environmental Protection Agency (EPA), in cooperation with federal land managers, states, and tribes, issued the Interim Air Quality Policy on Wildland and Prescribed Fires.

Wildland fires of all kinds produce gases and aerosols that influence air quality. The extent of those effects depends on fire size, fuel composition, and the characteristics of the fire events themselves. Smoke is composed of hundreds of chemicals that undergo complex chemical reactions and transformations. Critical pollutants include O_3, NO_2, and particulate matter (PM), as well as other compounds of concern including carbon monoxide (CO), carbon dioxide (CO_2), nitrogen oxides (NO_x), and volatile organic compounds (VOC).

The Valley and the Sierra Nevada

The San Joaquin Valley comprises the southern half of the Central Valley and is located north of Los Angeles and southeast of San Francisco. Because it is hemmed in by mountains and frequently does not have sufficient winds to disperse pollutants, it often has high air pollution levels. The sources of these pollutants include agricultural operations, road transportation, household emissions, and some industrial operations. To the east of the Valley is the Sierra Nevada range, which in this area encompasses numerous national park and national forest areas.

The San Joaquin Valley is recognized as one of the most polluted areas in the U.S. Related air quality problems reach into federally managed lands in the Sierra Nevada, including Yosemite and Sequoia and Kings Canyon National Parks, and several national forests. In 2003, these areas experienced 72 days of exceedances of the 8-hour health standard for O_3. Because wildland fires can contribute to high levels of O_3 and PM, the additive effect of fires in these areas is an air quality management issue.

Map shows the location of the San Joaquin Valley relative to the Sierra Nevada range, and other California reference points.

Need to know the numbers

Because of the pollution levels and the need to control them, the San Joaquin Valley Air Pollution Control District (Valley Air District) is increasingly regulating all sources of PM emissions, including agricultural and prescribed fires. Because of a lack of forecasting models for smoke, wildland fire managers have had to follow conservative practices to protect air quality. This has impaired their ability to reduce fuel levels using prescribed fire.

Part of the difficulty has sprung from lack of a complete monitoring network in the Sierra Nevada area. Information on O_3 levels was based on sparsely located monitoring stations operated by the National Park Service (NPS). Monitoring of particulate matter with an aerodynamic diameter less than 2.5 microns ($PM_{2.5}$) was even more limited.

In order to collect more complete air quality information and to study data to develop correlations with wildland fire events, a research project was developed. A key to the project was collaboration between NPS and the Forest Service monitoring networks, with supplementary monitoring stations established to fill in gaps in the Sierra Nevada area. Principal investigators were Dr. Andrzej Bytnerowicz and Dr. Haiganoush Preisler, both of the Forest Service Pacific Southwest Research Station. Co-investigators were Dr. Sharon Zhong of Michigan State University and Dr. Ricardo Cisneros of Region 5 Forest Service. The research was sponsored in part by the Joint Fire Science Program (JFSP).

Project is developed

The goals of the research were as follows:

- Expand existing networks of air pollution monitors to create a regional network useful for spatial modeling of O_3 and PM concentrations in the southern Sierra Nevada region.
- Develop and implement mobile monitoring systems to measure ground level pollution from multiple fires.
- Develop a statistical model to evaluate the BlueSky model as a forecasting tool for particulate matter from fires and to estimate the precision of this process.
- Develop a statistical model forecast for next-day or next-week fire effects on regional air pollution (O_3 and PM).

Establishing monitoring networks

A key step was establishing coordinated monitoring networks for monitoring various air pollutant levels within the Sierra Nevada. Many of the monitoring stations also collected meteorological data to assist in placing pollution data in a weather context.

Ozone and nitrogen pollutant monitoring

Networks of passive samplers for monitoring O_3, NH_3 and HNO_3 were already established in the Kings River Project in the Sierra National Forest and in Sequoia/Kings Canyon and Yosemite National Parks. These samplers provided data on two-week average O_3 concentrations. These were supplemented with 30 additional passive monitoring stations. A smaller network of active monitors collected data on real-time O_3 concentrations in the study area.

This monitoring improved understanding of O_3 distribution patterns in the Sierra Nevada. A special study was conducted in the 2008 summer season to better understand movement of O_3, NO_2, NH_3 and HNO_3 across the Sierra Nevada and into Owens Valley, the deep rift valley east of the Sierra Nevada.

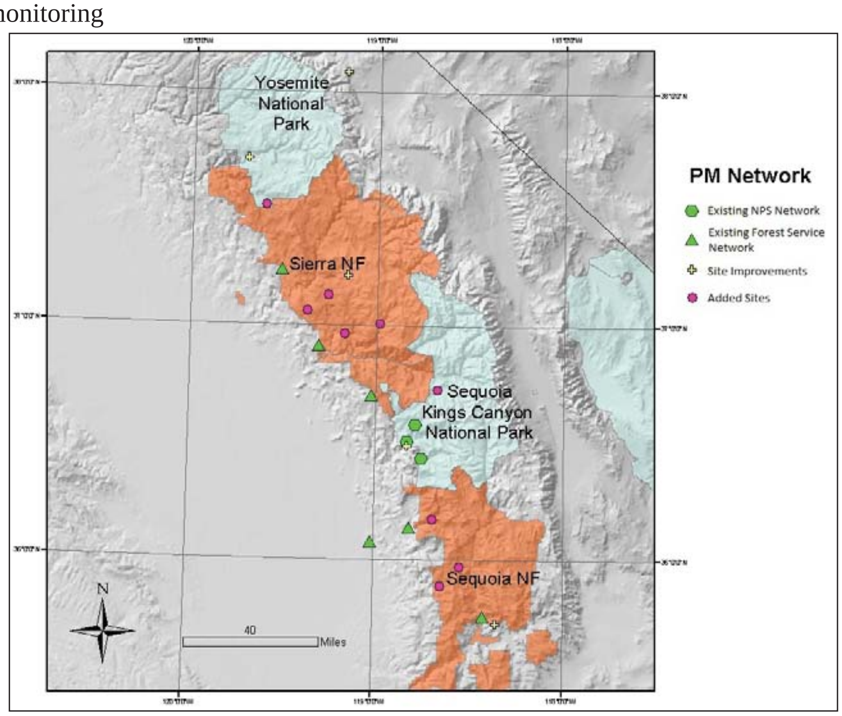
Researchers change passive samplers for O_3, NO_2, NO, NH_3 and HNO_3 at the White Mountains monitoring location.

Using historical ozone data

Observational data from four continuous monitoring sites operated by the Park Service were used to develop the statistical forecasting model and to estimate the contribution of wildland fires on O_3 levels.

Particulate matter monitoring

The Forest Service had established a network of $PM_{2.5}$ monitoring stations in 2004 as part of the Sierra Nevada Smoke Monitoring Pilot Project. These were located in Sequoia, Sierra, Stanislaus and Inyo National Forests and consisted of 12 instruments, some of which operated only seasonally and some year-round. These systems include meteorological data monitoring for wind speed/direction, air temperature, relative humidity and barometric pressure.



Locations of existing, improved, and added particulate monitoring sites in the Sierra Nevada Smog Monitoring Project.

In addition to these monitors, nine mobile particulate monitoring instruments were purchased to add to the existing network. Three of the mobile particulate monitoring systems were equipped with solar panels and energy storage.

Study findings

Data collected in this study were useful in increasing and improving the understanding of the role of wildland fire on air pollution level near the fire and in nearby populated regions.

Contribution of fire to ozone levels

Monitoring over the three-year study period indicated an increase in O_3 levels with increasing fire activity. However, the overall contribution of fire to daily ozone levels appears to be small compared to contributions from other sources.

Developing model for ozone forecasting

With this data, researchers were able to develop a statistical model for predicting hourly ozone levels during fire seasons in the Sierra Nevada. These forecasts can be used to predict next-day eight-hour moving average levels.

BlueSky framework evaluated

BlueSky is a modeling framework that links a number of independent modeling tools and is used for studying wildland fire smoke generation. Information from the Sierra Nevada research project included comparisons of field $PM_{2.5}$ measurements with BlueSky outputs. Results showed that BlueSky can successfully predict trajectories and aerial coverage of smoke plumes. The actual timing and approximate magnitude of increases in surface $PM_{2.5}$ were quite comparable to the BlueSky modeled levels. However, BlueSky appeared to fail to capture all of the observed increases in pollutant surface concentration.

The role of terrain

One of the challenges in understanding pollutant transport and the role of atmospheric processes in the Sierra Nevada is the complexity of the terrain. A series of sensitivity experiments in the research project examined how the topography affects regional atmospheric circulation patterns, and what the impacts of those patterns are on smoke transport. Programs are being developed to improve the models for these areas, and simulations are still ongoing.

$PM_{2.5}$ concentrations

The study found that $PM_{2.5}$ concentrations in the southern Sierra Nevada at high elevations are lower than at lower elevation sites that are closer to urban areas. Concentrations in the lower elevation sites are higher in winter.

Pollution mapping developed

The results developed with the pollution monitoring network have been used to develop maps showing spatial distribution of O_3, HNO_3, and NH_3. Similar maps on the distribution of particulate matter are being developed.

How does this information help?

Dr. Bytnerowicz believes that as a result of these studies, researchers have achieved a better, more holistic understanding of the contribution to air quality of wildfires compared to other human sources. The study has also produced a statistical model and computer program for forecasting hourly ozone levels. The model requires minimum input data and can be used to support decision making by land and air resource managers regarding air quality and prescribed burns in the Sierra and other similar, sensitive areas.

Data from the coordinated monitoring network in the Sierra Nevada improves the understanding of the effects of wildland fire on air pollution levels. Photo shows plume from a wildfire in Humboldt-Toiyabe National Forest in 2002.

An important aspect of the work was the correlation of the results with those forecasted using the BlueSky monitoring framework. Bytnerowicz explains, “Our study shows that the BlueSky tool worked reasonably well in predicting PM concentrations. BlueSky outputs were also useful for the statistical forecasting model as a surrogate for the amount of ozone precursors being transported to a given location. Currently there is more ongoing work on these issues.”

Desert Research Institute in Reno, Nevada is using the results of the Sierra Nevada research to develop a new version of BlueSky (Version III) that will become available to land and air quality managers.

Mapping documents pollution trends

Mapping done as part of the research project demonstrated the strong effect of air pollution in the Central Valley on air quality on the western slopes of the Sierra Nevada. This included elevated levels of O_3, HNO_3 and NH_3 in the western Sierra Nevada and much lower levels in the eastern Sierra. This is attributed to the topographic barrier of the high elevation ranges.

However, research indicated that during conditions of southwest winds, polluted air masses could move across the Sierra Nevada along canyons and valleys, resulting in high levels of O_3 on the eastern side of the range.

Particulate emissions greater problem

Despite the large size of the 2007 southern California fires, the federal O_3 standard was exceeded only on single days at two air quality monitoring sites in the San Diego areas.

Dr. Bytnerowicz says, "Our results, based mostly on analysis of wildfires in the entire Sierra Nevada, indicate quite clearly that small size prescribed fires should not significantly increase ambient ozone concentrations. However prescribed fires may still be a source of particulate matter for the downwind areas." That is part of the challenge facing managers.

Compliance with $PM_{2.5}$ standards is apparently a more serious issue than with ozone. Managers need to be concerned that compliance with air quality standards during prescribed burning could significantly restrict this practice, thus crippling its potential to mitigate subsequent more severe impacts from catastrophic wildfires.

The results of this study compliment other air quality monitoring network efforts conducted by the Forest Service and other agencies in the West. Specifically, it increases the field of information on air pollution distribution in forests and areas of complex mountain topography.

Taking results to other areas

Dr. Bytnerowicz explains, "We feel the information we have gathered should be transferrable to other western areas of similar terrain and elevations, although Sierra Nevada is unique due to the proximity to the California Central Valley, one of the most polluted areas in the United States." The results of this study also combine with research by Pfister et al. to provide new perspectives on the effects of the 2007 southern California wildfires on air quality, especially in remote sites.

Overall, the study helps to explain the role of wildland fire in the larger field of air quality management. Dr. Bytnerowicz notes, "Particulate matter seems to be the most important pollutant from the human health point of view. Ozone and nitrogen oxides could also affect human health."

Although the research team is not involved in any follow-up studies in the southern Sierra Nevada, other studies including an analysis of 2010 air quality monitoring in the Lake Tahoe Basin, central Sierra Nevada, are in progress. This will include consideration of the effects of wildland fires.

Management Implications

- An improved understanding of the potential effects of prescribed burns and wildfire on air quality has been achieved.
- The study suggested that in the Sierra Nevada, the influence of air pollution from the Central Valley is significant, and needs to be considered as a major additive factor in evaluating potential air quality impacts of prescribed burns.
- The seasons in which prescribed burns are normally conducted in these areas normally do not coincide with times of the highest potential of photochemical smog. However, wildfires often occur during times of high photochemical smog potential.
- The greatest potential air quality impact of both prescribed burns and wildfires is commonly in increased levels of particulates.
- The western slope of the Sierra Nevada, because of its exposure to Central Valley anthropogenic-source pollutants, normally has the highest exposure to elevated levels of ozone and other pollutants. However under certain wind conditions the eastern slope also can be exposed to elevated levels of air pollutants.
- Particulate emissions are specific concern and may reduce the ability to use prescribed burns. However, additional restrictions on the use of prescribed burns for fuel reduction may have the long-term effect of increasing the frequency, duration and intensity of wildfires. These resulting wildfires may cause far greater air pollution problems.

Further Information: Publications and Web Resources

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Scientist Profile

Dr. Andrzej Bytnerowicz is a Senior Scientist at the USDA Forest Service Pacific Southwest Research Station in Riverside, CA. His leading scientific work has related to understanding the chemical environment in forest stands, ecosystems, landscapes and regions. His research interests include evaluation of air pollution distribution in complex mountain terrain, development of methodologies for estimates of N deposition to forests and other ecosystems, and understanding the effects of wildfires on air quality and forest management options.

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Results presented in JFSP Final Reports may not have been peer-reviewed and should be interpreted as tentative until published in a peer-reviewed source.

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