Project Title: Tools for Estimating Contributions of Wildland and Prescribed Fires to Air Quality in the Southern Sierra Nevada, California

Project Number: 05-3-1-03

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I. Abstract

A better understanding is needed of the contribution of wild-land fires vs. various anthropogenic activities (agriculture, traffic, etc.) to air quality from a perspective of exceedances of federal and state standards and a possibility of using prescribed fires as the fuel management tool. For that reason a comprehensive network for monitoring ambient ozone (O_3), nitrogen dioxide (NO_2), ammonia (NH_3), gaseous nitric acid (HNO_3) and particulate matter (PM) in the southern Sierra Nevada was established. The project was a joint effort between the USDA Forest Service, the National Park Service, the University of Houston, Michigan State University and University of California in Merced. This network of passive and active monitors allowed for the estimation of spatial and temporal distributions of air pollutants resulting from urban and agricultural activities. During fire events, the network and mobile instruments helped to characterize effects of fires on the ground-level concentrations of O_3, N air pollutants, and PM concentrations. Based on those data maps of ambient O_3, NH_3 and HNO_3 concentrations were developed. In addition to the Sierra Nevada research, a case study on the effects of the October 2007 fires on ambient air quality in southern California was conducted.

The BlueSky dynamic modeling system was adapted and run for the southern Sierra Nevada conditions providing forecasts of PM concentrations resulting from forest fires. A statistical model for forecasting next day O_3 levels (with specified precisions) were developed based on ground monitoring data, meteorological conditions, estimated background O_3 distribution, and predicted contributions of fires from the BlueSky model. The precision of the BlueSky PM forecasts were also studied.

Results from our three year study in the Sierra Nevada indicated the occurrence of significant increases in average O_3 levels with increasing fire activity in a given region. However, the overall effect on diurnal O_3 levels seems to be small (~2% of the variability) when compared with the amount of variability attributed to sources other than fire. For the 3 years in the study and at 4 sites in the Sierra with continuous O_3 monitors, the increase in ozone that we were able to attribute to fire was less than 0.5 ppb in 95% of the cases and less than 1.6 ppb in 99% of cases. In addition, increased fire activity seemed to elevate ambient concentrations of HNO_3, while its effects on NH_3 was unclear and is still analyzed.

During the California wildland fires of October 2007, combustion emissions, closure of a major transportation routes, and the Santa Ana winds had pronounced effects on ambient O_3 in southern California. At a rural receptor site located among several large fires, during the initial phase of the fires (strong, dry northerly and northeasterly Santa Ana winds and greatly reduced traffic), daytime O_3 concentrations were reduced, and nighttime O_3 levels were abnormally elevated. During the second phase of the fires (no Santa Ana winds present, resumed traffic, and air filled with smoke), daytime O_3 concentrations steadily increased and reached values exceeding the federal standard of 75 ppb as the 8 h average, and nighttime values returned to normal. After six days of the fires, O_3 diurnal concentrations returned to the pre-fire patterns and levels. Additionally, concentrations of NO_2, NH_3 and HNO_3 during the fires were elevated compared to the pre-fire conditions.

II. Background and Purpose

Smoke from wildland and prescribed fires have been increasing during the past decade. There is a growing awareness that smoke from fires can expose individuals and populations to hazardous air pollutants. As a result, EPA in cooperation with federal land managers, States and Tribes issued the Interim Air Quality Policy on Wildland and Prescribed Fire (EPA, 1998) to protect public health and welfare by mitigating the impacts of air pollutant emissions from wildland fires on air quality.

Prescribed fires, as well as natural fires, produce gases and aerosols that have instantaneous and long-term effects on air quality (Fang, 1999). Extend of these effects depends on fire size, fuel composition, physical and chemical characteristics of the events (Kasischke and Penner, 2004). Fires are complex combustion processes that involve several categories of fuel, and fire behavior that change over time depending on available fuel and weather conditions. Smoke from fire is composed of hundreds of chemicals in gaseous, liquid, and solid forms that undergo complex chemical reactions and transformations (Ottmar, 2000; Urbanski et al., 2009). As a result, substantial concentrations of elemental carbon, volatile organic compounds (VOCs), carbon monoxide (CO), carbon dioxide (CO_2), nitrogen oxides (NO_x), ozone (O_3) and particulate matter (PM) may be found downwind of the fires (Cheng, 1998). Some of these compounds are classified criteria pollutants (pollutants with established air quality standards) under the Clean Air Act, and these include O_3, nitrogen dioxide (NO_2) and PM. In addition, ammonia (NH_3) is also released from fires mainly during their smoldering phase, while gaseous nitric acid (HNO_3) is produced photochemically downwind of the fires. Both NH_3 and HNO_3 are important components of N deposition with strong ecological effects in forest and other ecosystems. Ozone threatens public and forests health, while PM affects human health and causes visibility reduction (Billington et al, 2000). One region that is, perhaps, most susceptible to air pollution impact of wildland fires is the San Joaquin Valley and the Sierra Nevada in California. The San Joaquin Valley is recognized as one the most polluted areas in the United States where federal standards for O_3 and PM are violated (American Lung Association, 2004). Similar problems exist also in the downwind Class I and II federally managed lands in the southern Sierra Nevada. In 2003, Sequoia and Kings Canyon National Park recorded 72 days (April to October) of exceedances of the 8-hour health standards for O_3 (NPS-Air Resources Division 2003 Annual Data Summary). Because wildland fires produce PM and O_3 precursors, the effect of fires on air quality in the southern Sierra Nevada and its vicinity is a serious air quality management issue.

Because of the above, the San Joaquin Valley Air Pollution Control District (Valley Air District) is increasingly regulating all sources of PM emissions, including agricultural and prescribed fires. The ability of wildland fire managers to reduce fuels using prescribed fire is at risk due to the lack of forecasting models for smoke that has resulted in conservative policies the Valley Air District uses to protect valley air quality conditions. Consequently, it is more difficult and expensive to conduct prescribed fires, and wildland use fires have largely been banned.

At present there is no comprehensive air quality monitoring network in the Sierra Nevada. Information on O_3 is based on sparsely located monitoring stations equipped with active monitors operated by NPS (Sullivan et al., 2001) and other networks. This gap is partially filled by information on weekly or bi-weekly O_3 concentration from passive sampler networks. Such networks have been in operation for several years in Yosemite and Sequoia and Kings Canyon NP (NPS-ARD website). In 1999, a study on air quality with use of passive and active monitors was performed in Sequoia NP (Bytnerowicz et al., 2002). Also in 1999, O_3 distribution was measured with passive samplers in the entire Sierra Nevada (Arbaugh and Bytnerowicz, 2003). This study resulted in production of maps of two-week long averages of O_3 distribution (Frączek et al., 2003; Preisler and Schilling, 2003). Monitoring of $PM_{2.5}$ in the Sierra Nevada is even more limited than of that of O_3. To better understand the magnitude of the problem created by smoke from prescribed and wildfire on $PM_{2.5}$ concentrations, the Fire Management and the Air Program in the Southern Sierra Nevada Region 5 purchased several air quality instruments to monitor particulate matter located in the Sequoia, Sierra, Inyo and Stanislaus National Forests.

Quantitative tools to assess fire emissions and their contributions to local and regional air quality are desperately needed by fire management officers if prescribed fire is to be continued as a viable method of fuels reduction in the southern Sierra Nevada. Three components that are necessary to provide these tools are 1) an adequate network of air monitoring stations 2) a tool for modeling air transport from specific sources of pollution (e.g., fires) 3) statistical models for testing and predicting contributions of fires on air quality in the presence of other sources of pollutants and variable weather conditions.

The current project was designed to address these issues. In particular, the project was designed to fill in the measurement network gap in the southern Sierra Nevada and use observations from the proposed and existing monitoring network to evaluate the dynamic smoke and PM transport model BlueSky[1] and incorporate its output in a statistical model for estimating and forecasting contributions of wildfires to ambient O_3 levels.

The purpose of the present study was to:

- Expand existing local networks of air pollution monitors into 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 pollutant production from multiple fires.
- Implement BlueSky dynamic modeling system for the southern Sierra Nevada using local topography, weather conditions and fire history.
- Develop a statistical model to evaluate the BlueSky model as a forecasting tool for particulate matter from fires and to estimate the precision of its outcome.
- Develop a statistical model to forecast (with specified precisions) next day or next week prescribed fire effects on regional air pollution (O_3 and PM).

[1]BlueSky was developed by the USDA Forest Service, with funding from the National Fire Plan, and in cooperation with the US Environmental Protection Agency (EPA)

III. Study Description and Location

Monitoring networks

Ozone and N pollutants. A network of fifty sites for monitoring O_3, NH_3 and HNO_3 concentrations with passive samplers was established in the southern Sierra Nevada. Passive samplers provided 2-week long averages of O_3 concentrations. In addition, on the subset of sites the 2B Technology and Monitor Lab UV-absorption instruments produced real time O_3 concentrations. The network incorporated the existing passive sampler networks in the Kings River Project in the Sierra National Forest that had been operational since 2002 and the Sequoia/Kings Canyon and Yosemite National Parks monitoring sites. About thirty passive samplers were added in the locations of the 1999 Sierra Nevada O_3 study in order to reliably cover the entire study area (Frączek et al., 2003). Information on real-time concentrations of O_3 was also obtained from the existing O_3 monitors (CASTNET, NADP and ARB networks) (Figure 1). These monitoring efforts allowed developing O_3 distribution surfaces that describe the general spatial patterns of O_3 in the Sierra Nevada (see below).

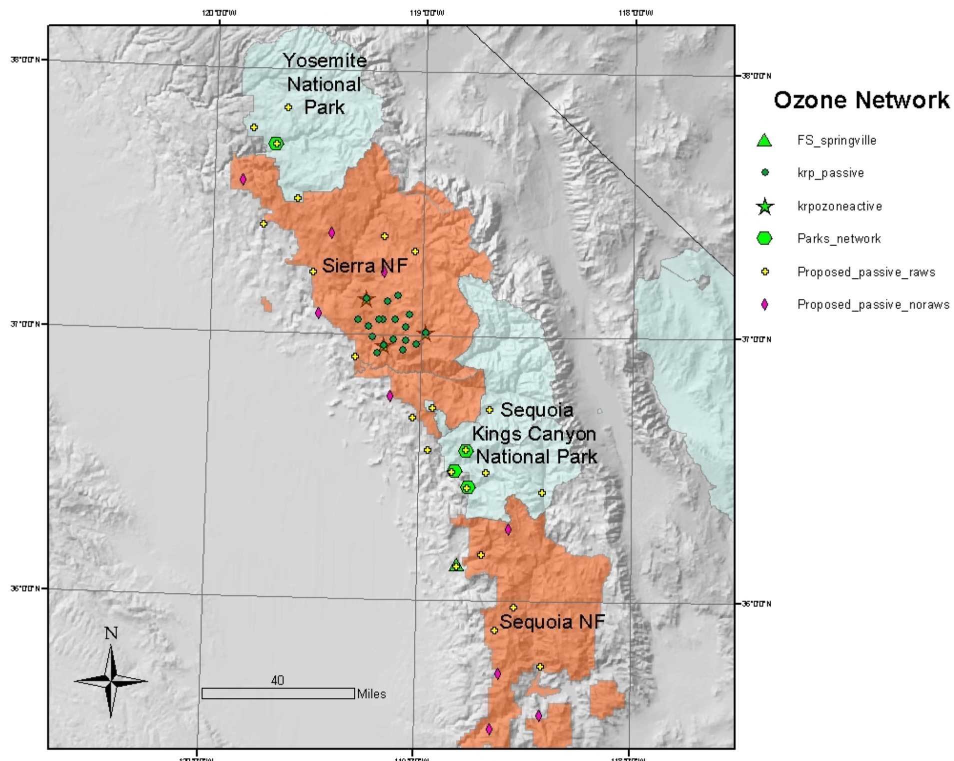

Figure 1. Location of monitoring sites for active O_3 monitors and O_3, NH_3 and HNO_3 passive samplers in 2006 and 2007. Explanation of acronyms: FS – Forest Service; krp – Kings River Project; raws – remote automated weather stations.

Additionally, a study was conducted in the 2008 summer season to better understand movement and distribution of O_3, NO_2, NH_3, HNO_3 across the Sierra Nevada and along the Owens Valley (Figure 2).

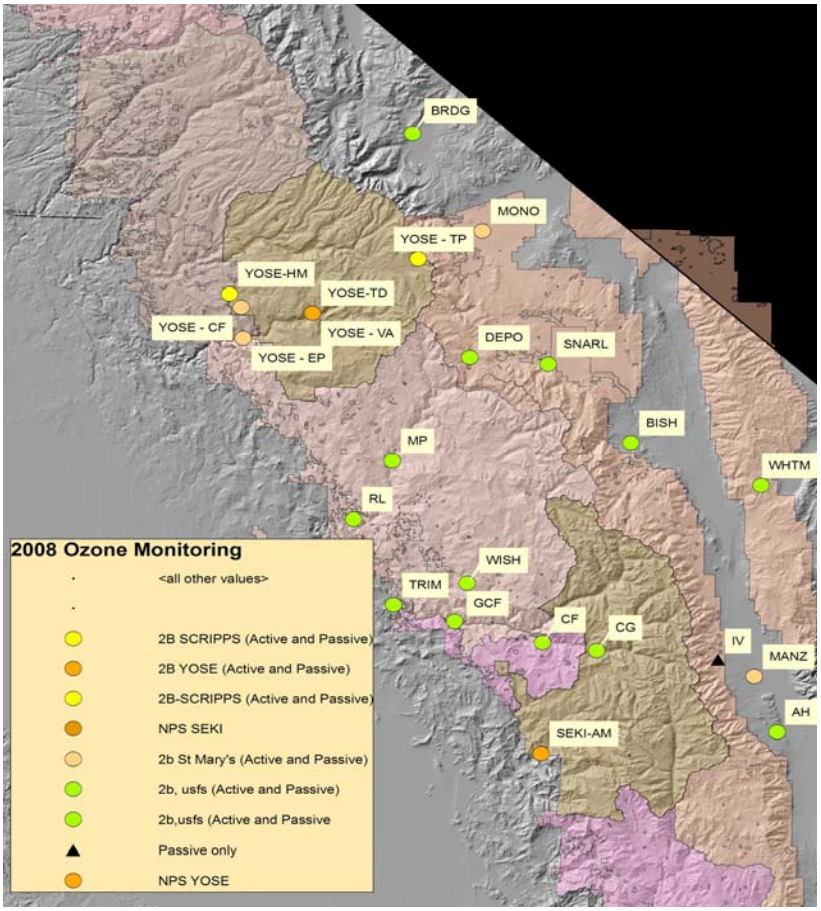

Figure 2. Location of O_3 active monitors and O_3, NO_2, NH_3, HNO_3 passive samplers in 2008.

Particulate matter. The U.S. Forest Service Region 5 established a network of particulate matter (PM) monitors in the southern Sierra Nevada in 2004 as part of the Sierra Nevada Smoke Monitoring Pilot Project (Trent Procter, Region 5 Air Program Manager). The PM monitors were distributed in Sequoia National Forest, Sierra National Forest, Stanislaus National Forest, and Inyo National Forest and consisted of 3 BAM 1020 and 9 EBAM (Met One Instruments, Inc). Both types of instruments work on the principle of beta attenuation. The BAM 1020 is a federal reference instrument that requires ambient temperature control. The EBAM is not a federal reference, portable air monitor with no need for ambient temperature control. The BAM 1020 is equipped with wind speed/wind direction, air temperature, relative humidity, barometric pressure, solar radiation and precipitation. The EBAM is equipped with the same meteorological parameters except for solar radiation and precipitation.

The BAM 1020 instruments were located in fixed locations in Kernville, Springville and Pinehurst (Sequoia National Forest) and were operated all year round. The EBAMs are distributed as follow: two in Stanislaus NF, two in Sierra NF, one in Inyo NF and four in Sequoia NF. The two EBAMs in the Sierra NF (in Trimmer and North Fork) collected data all year round. The EBAMs in Stanislaus and Inyo NF were operational during prescribed fires and the wildfire season only. In the Sequoia NF, the four EBAMs were operated during fire season only.

In addition, nine E-Samplers (Met One Instruments, Inc.) particulate matter instruments were purchased to add to the existing network (Fig. 2). These instruments were operated seasonally from April through October. The E-Sampler is a portable instrument based on the principle of near-forward light scattering, and incorporates a gravimetric filter device that can be used to improve the accuracy of the concentrations. E-Sampler compares reasonably well with the Federal Reference Method (Trent 2003). Intercalibration of BAM 1020, EBAM and E-Samplers assured compatibility of the $PM_{2.5}$ data.

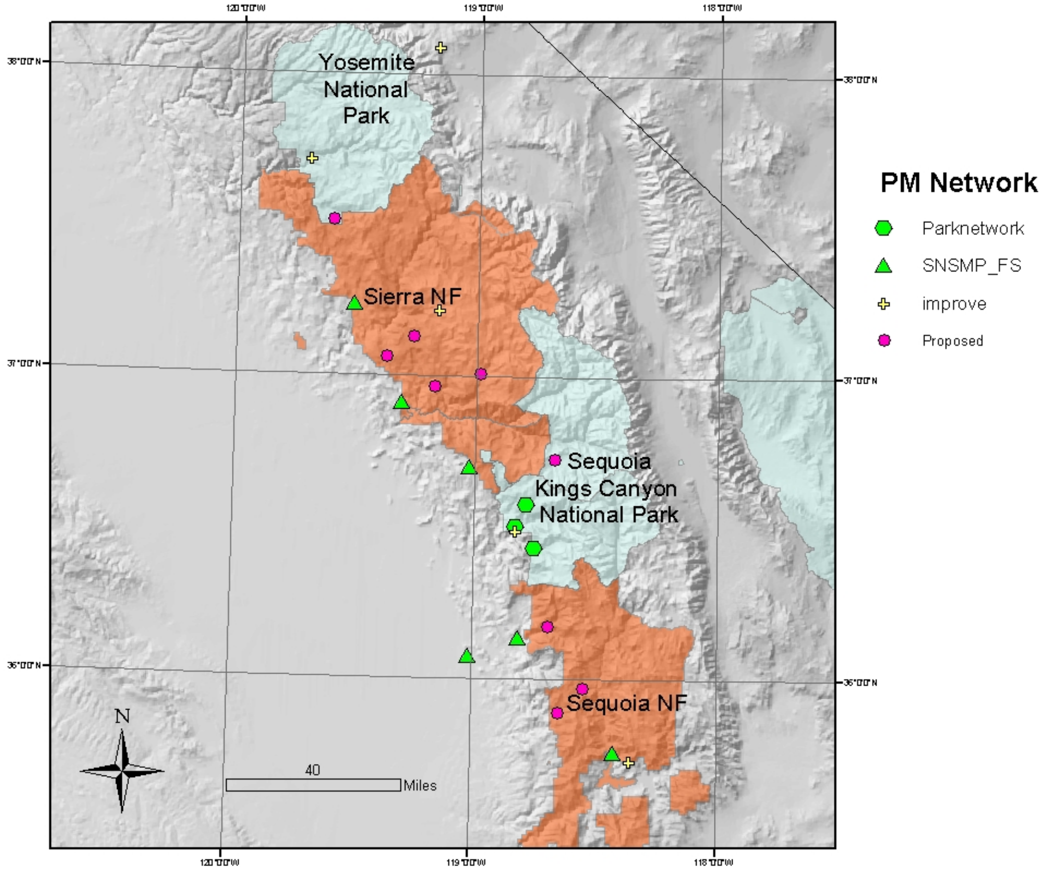

Figure 2. Location of the existing and added (on the legend - proposed) $PM_{2.5}$ monitoring sites in the study area. SNSMP – Sierra Nevada Smog Monitoring Project, Forest Service.

Mobile air pollution laboratories

Three of the EBAMs from the Smoke Monitoring Pilot Project are powered with solar systems. Similarly, several 2B Technology O_3 monitors are battery-operated and may also be powered by solar panels. Three complete mobile systems equipped with solar panels, energy storage, EBAM and 2B Technology monitors will be housed in 16 feet flat trailers that can be pulled with a regular ½ ton truck. Whenever a wildland fire event occurred, these instruments supplemented the fixed air monitoring network and were deployed around the fire area.

Historical ozone data

Observational data from four continuous monitoring sites operated by the National Park Service were used to develop the statistical forecasting model and to estimate the contribution of wildland fires on ambient O_3 levels. Two of the four sites were located in the Sequoia Kings Canyon National Park (Ash Mountain and Lower Kaweah sites) and two were in the Yosemite National Park (Turtleback Dome and Yosemite Valley sites). Twenty years of historic hourly O_3 data and three years of meteorological data from the four stations listed above were used to develop the statistical forecasting model and quantify the contribution of fire to O_3 concentrations.

IV. Key Findings

1. ***Contribution of fires to ambient ozone***: Results from our 3 year study indicated the occurrence of significant increases in average ozone levels with increasing fire activity in a given region. However, the overall effect on diurnal ozone levels seems to be small (~2% of the variability) when compared with the amount of variability attributed to sources other than fire. For the 3 years in the study and at 4 sites in the Sierra with continuous ozone monitors, the increase in ozone that we were able to attribute to fire was less than 0.5 ppb in 95% of the cases and less than 1.6 ppb in 99% of cases (Preisler et. al. submitted 2009)

2. ***Forecasting Hourly Ozone levels***: We were able to develop a statistical model for predicting hourly ozone levels during fire seasons in the Sierra Nevada. The forecasts were able to explain 68% of the variability in next day's hourly ozone levels and the 99th percentile of the forecasted values appear to give a good coverage of the next day observed ozone levels (Figure 1a&b in uploaded Powerpoint I & Preisler et al. submitted 2009).
   The hourly forecasts can also be used to predict next-day 8-hr moving average levels. California ambient air quality standard for ozone is 70 ppb for the forth highest 8 hr concentration averaged over three years. Our next-day 50th and 95th percentiles of the predicted 8-hr average levels appeared to give a good fit when compared to the actual observed levels (Figures 2 in uploaded Powerpoint I & Preisler et al submitted 2009).

3. ***Evaluation of BlueSky Smoke Dispersion Modeling Framework***: Comparisons of the BlueSky output with the extensive data set (from surface PM concentrations and satellite smoke plume imaged collected during two fire events) provided insight into the accuracy of the BlueSky predictions of smoke plumes and surface concentrations in regions of highly complex terrain. Results show that BlueSky can predict the trajectories and aerial coverage of the smoke plumes reasonably well. The timing and magnitude of predicted increase in surface PM2.5 concentrations are comparable to the observed at most locations, but BlueSky appear to fail to capture all of the observed increases in surface concentration. The study points to a need to improve quantitative prediction of surface concentration. However, BlueSky outputs were useful for the statistical forecasting model as a surrogate for the amount of ozone precursors being transported to given location. The latter depends on the timing and magnitude of predicted increases in PM concentration which BlueSky appears to predict usefully. (Fusina et al. 2007-2008; Fusina 2008; Lu et al 2008)

4. ***The impact of complex terrain and associated atmospheric processes on the transport and dispersion of smoke***: A series of sensitivity experiments were designed to examine how the complex topography in the region affects local and regional atmospheric circulations and what the subsequent impacts of these circulations are on smoke transport and dispersion under different synoptic weather conditions. This work helps identify uncertainties and biases of these state-of-art prognostic smoke prediction models when applied to complex terrain settings. Programs have already been developed but the simulations are still on-going.

5. ***PM2.5 background concentrations in southern Sierra Nevada***: Particulate Matter with an aerodynamic diameter less than 2.5 μm (PM2.5) concentrations in the Southern Sierra Nevada are estimated to be 5 mg/m^3. Concentrations of PM2.5 at high elevation sites are lower than at low elevation sites closer to urban areas. High

^{3} in those sites.
In the low elevation sites PM2.5 concentrations are highest in winter.

6. ***Maps describing patterns of pollutions in the Sierra Nevada***: Maps produced from the air pollution monitoring network deployed in the Sierra Nevada during 2006-2008 fire seasons helped our understanding of the spatial distribution patterns of O_3, nitric acid (HNO_3), ammonia (NH_3). We are still in the process of producing similar maps for PM.

7. ***Effects of wildland fires and a major freeway closure on ambient ozone concentrations:*** The 2007 southern California wildland fires, Santa Ana winds and freeway closures had pronounced impact on concentrations and the diurnal characteristics of O_3 at the remote rural receptor site. During the initial phase of the fires (strong, dry northerly and northeasterly Santa Ana winds and greatly reduced traffic), daytime O_3 concentrations were reduced, and nighttime O_3 levels were abnormally elevated. During the second phase of the fires (no Santa Ana winds present, resumed traffic, and air filled with smoke), daytime O_3 concentrations steadily increased and reached values exceeding the federal standard of 75 ppb as the 8 h average, and nighttime values returned to normal. After six days of the fires, O_3 diurnal concentrations returned to the pre-fire patterns and levels. Increased levels of NO_2, HNO_3 and NH_3 during the fires were also observed at the studied site.

V. Management Implications

As a result of our studies we now have a much better, holistic, understanding of the contribution of wildland fires vs. various anthropogenic activities (agriculture, traffic, etc.) to air quality from a perspective of exceedances of federal and state standards, and a possibility of using prescribed fires as the fuel management tool are still needed. Following are some more specific implication to management.

1. The statistical model and computer program developed for forecasting hourly ozone levels is easy to use and to run. It requires minimum input data and hence can be used to support decision making by land and air resource managers regarding air quality and prescribed burns in the Class-I areas of the Sierra Nevada and other sensitive areas.

2. Results of the BlueSky evaluation done as part of this project points to a need to improve quantitative predictions of surface concentration. Desert Research Institute in Nevada is already working on a new version of BlueSky (version III) taking into account the results from our study.

3. Maps of distribution patterns of air pollutants indicated a strong effect of air pollution generated in the California Central Valley on air quality on the western slopes of the Sierra Nevada. Concentrations of O_3, HNO_3 and NH_3 were elevated in the western Sierra Nevada and much lower in the eastern Sierra due to the topographic barrier of the high elevation ranges. However, at certain periods, during the prevailing SW winds, polluted air masses moved across the Sierra Nevada along the valleys and canyons resulting in high levels of O_3 in the eastern side of the range. During such events elevated HNO_3 and NH_3 declined quite rapidly from W due to high deposition velocities of these gases.

4. Despite the large size of the southern California fires, the federal O_3 standard was exceeded only on single days at two air quality monitoring sites in the San Diego area. Therefore it can be expected that spatially limited and less intense prescribed fires, when carefully applied during periods of low photochemical activity (spring, fall or winter), should not cause major problems from a perspective of the O_3 air quality standard. However, the 2007 wildfires caused much more serious violations of the particulate matter standards (PM_{10} and $PM_{2.5}$) (http://www.sdapcd.org/air/reports/smog.pdf) and posed a threat to human health. Consequently, compliance with these standards may be a more serious issue than potential exceedances of the O_3 standard. The issue of compliance with air quality standards during prescribed burning is critical since it could so restrict that practice as to cripple its potential to mitigate subsequent impacts of catastrophic wildfires.

V. Relationship to Other Recent Findings and Ongoing Work

The 2006-2008 air pollution monitoring campaigns in the Sierra Nevada compliments other air pollution monitoring efforts conducted by the US FS Pacific Southwest Research Station in North America. Concentrations of O_3, NO_2, NH_3, HNO_3 and SO_2 have been monitored with passive samplers in southern California, Columbia River Basin, SE Alaska and the Athabasca Oils Sands Region. Information on air pollution distribution in forests and other ecosystems is needed for understanding their potential ecological and health effects. A good understanding of background levels of air pollutants is also needed for evaluation of potential risks related to wildland fires, both wild and prescribed. As an example, with relatively small fires occurring in Alberta, Canada, in the 2008 season, their effect on NH_3 and HNO_3 ambient concentrations was not significant.

Pfister et al., (2008) analyzed increases of O_3 concentrations in areas downwind from the October 2007 southern California wildfires and demonstrated that intense wildfire periods could significantly increase frequency of violations of the U.S. federal air quality standard for O_3 even during the photochemically less active seasons. Our findings provided new perspective on the effects of those fires on air quality – impacts on the remote site located among the fires. For O_3, although we also determined its elevated concentrations caused by fires, exceedances of federal standards were just a few and short-lasting. We also found elevated concentrations of NO_2, NH_3 and HNO_3 during the period of fires, which confirmed that fires may potentially cause increased N deposition with potential effects on ecosystems.

The results of this study highly benefit a key operational program in California and Nevada – The California and Nevada Smoke and Air Committee (CANSAC). The CANSAC forecasting system provides experimental operational forecasts of smoke concentration and transport utilizing the Bluesky framework. Output from this system was used for the analysis discussed in section IV.3 of this report. Bluesky forecasts are used as an operational decision-support tool by fire and air quality agencies in California and Nevada. Thus, the results obtained here provide insight into the skill of the forecasts, and show what components of the Bluesky modeling framework should receive priority for improving predictions through additional scientific analyses.

VI. Future Work Needed

The following suggested future work will enable us to fully utilize data generated during the Joint Fire Science Program project "Tools for Estimating Contributions of Wildland and Prescribed Fires to Air Quality in the Southern Sierra Nevada, California" ending on May 15, 2009:

a. Develop GIS-based maps of exceedances of the O_3 federal and state standards based on the 2008 monitoring campaign. This work will result in a peer reviewed paper.
b. Expand existing local networks of air pollution monitors into a regional network useful for spatial modeling of O_3 and PM concentrations in the southern Sierra Nevada region. For O_3, gradually switch from passive samplers to real-time UV absorption monitors equipped with batteries, solar panels, and meteorological stations that would be capable of satellite data transmission. That would allow for a continuous evaluation of a compliance with the O_3 air pollution standards.
c. Explore a possibility of installing the real-time NO_2 monitors together with the O_3 and PM instruments. Significant progress has already been made in this area and the battery operated NO_2/NOx instruments are available.
d. Implement the new version of the BlueSky dynamic modeling system for the southern Sierra Nevada using local topography, weather conditions and fire history.
e. Develop a statistical model to evaluate the new version of the BlueSky model as a forecasting tool for particulate matter from fires and to estimate the precision of its outcome.
f. Develop a statistical model to forecast next day or next week prescribed fire effects on regional PM.

VIII. Deliverables Cross-Walk Table

No.	Description	Status
1	Establishment of air pollution monitoring networks for the southern Sierra Nevada for 2006-2008 seasons.	Done.
2	Three mobile laboratories for air pollution and weather data collection in vicinity of fires.	Done.
3	A southern Sierra operational protocol for on-demand runs of Blue Sky by the operations center at CANSAC/DRI.	Done.
4	Maps of background O_3 and PM for southern Sierra Nevada for combined three field seasons.	Done for O_3, NH_3 and HNO_3. For PM – work in progress.
5	Statistical models for forecasting ambient PM and ozone ambient concentrations in absence and presence of fires. Task accomplished for ozone.	Two papers by Preisler et al. attached). For PM – work in progress.
6	Guidelines and protocols for instrument sampling and deployment will be developed (field protocol for passive samplers attached)	Done – protocols for passive samplers attached.
7	Migration of all real-time agency air quality monitoring data to the California Air Resources Board AQMIS (Air Quality and Meteorological Information System).	In progress.
8	A Blue Sky model for forecasting smoke and PM dispersion from wildland fires with estimated precision specific for southern Sierra Nevada Data collected BlueSky validation study done. Estimation of precisions still to be done	Done. See references by Fusina et al. and Lu et al.
9	Migration or linkage of the NPS real-time data (via phone modems) to the existing Interagency Smoke Monitoring Website.	In progress.
10	Final report	Done.

IX. Papers, Talks and Presentations

- Preisler, H.K. (2006) Estimating Contribution of Smoke from Wildland Fires on Hourly Ozone Levels. Presented at 22nd International Meeting for Specialists in Air Pollution Effects on Forest Ecosystem IUFRO Research group 7.01 Sept 10-15 2006, Riverside, CA.
- Fusina, L., S. Zhong, J. Koracin, T. Brown, A. Esperanza, L. Tarney, H. Preisler (2007) Validation of BlueSky Smoke Prediction System using surface and satellite observations during major wildland fire events in Northern California. In *Proceedings, 2nd Fire Behavior and Fuels Conference*, 26-30, March, Destin, FL.
- Bytnerowicz, A., H. Preisler, M. Arbaugh, J. Auman, T. Brown, R. Cisneros, A. Esperanza, L. Fusina, C. Hunsaker, J. Koracin, T. Procter, L. Tarnay, S. Zhong (2007) Joint Fire Science Meeting, Destin, FL, March 22, 2007. 'Tools for Estimating Contributions of Wildland and Prescribed Fires to Air Quality in the Southern Sierra Nevada, California – Progress of Work. Poster. IV.D.1, 79, 82.
- Fusina, L., S. Zhong, R. Solomon, X. Bian, and J. Charney (2008) BlueSky Smoke Modeling Frameworks predictive ability in simulating smoke impacts from the October 2007 Southern California wildfires. In *Proceedings, The '88 Fires: Yellowstone and Beyond*. Jacksonhole, WY, 22-27, Sept. 2008.
- Fusina, L. A. (2008) Investigation into the ability of the BlueSky Smoke Modeling Framework in simulating smoke impact from wildland fires. M.S. Thesis, Department of Geography, Michigan State University.
- Lu, W., J. Charney, S**.** Zhong, and X. Bian (2008) A 28-year Haines Index Climatology for North America. *Internal Journal of Wildland Fire* (in review).
- Jovan, S., H. Preisler, R. Cisneros, A. Bytnerowicz (2008) 23rd IUFRO Conference for Specialists in Air Pollution and Climate Change Effects on Forest Ecosystems, Murten, Switzerland; 7-12 September 2008. "Effects of elevated nitrogen deposition on lichen communities of mixed conifer forests in SE Sierra Nevada, California", Poster.
- Bytnerowicz et al. (2008) Air quality in the Sierra Nevada in the absence and presence of wildland fires. Pacific Coast Fire Conference: Changing Fire Regimes, Goals & Ecosystems, San Diego, December 1-4, 2008, oral presentation and abstract.
- Bytnerowicz, A. et al. (2008) Effects of the 2007 San Diego wildland fires on ambient ozone concentrations. Pacific Coast Fire Conference: Changing Fire Regimes, Goals & Ecosystems, San Diego, December 1-4, 2008, oral presentation and abstract.
- Preisler, H. K., S. Zhong, A. Esperanza, L. Tarney, and J. Koracine (2009) A statistical model for forecasting hourly ozone levels during fire season. *Developments in Environmental Science 8:* (S. V. Krupa Ed.): *Wildland Fires and Air Pollution* (Bytnerowicz, A., Arbaugh, M., Riebau, A., Andersen, C., Editors). Elsevier, 551-565.
- Bytnerowicz, A., M. J. Arbaugh, C. Andersen, and A. R. Riebau. (2009) Integrating research on wildland fires and air quality: needs and recommendations. *Developments in Environmental Science 8:* (S. V. Krupa Ed.): *Wildland Fires and Air Pollution* (Bytnerowicz, A., Arbaugh, M., Riebau, A., Andersen, C., Editors). Elsevier, 585-602.
- Cisneros, R. et al. (2009) Air pollution transport across Sierra Nevada through the San Joaquin River drainage (journal article) – *paper to be submitted to Environmental Pollution*
- Preisler, H.K., S. Zhong, A. Esperanza, T.J. Brown. (2009) A statistical approach to ozone forecasting during fire season in the National Parks, Sierra Nevada, California. *Submitted to Environmental Pollution*.

X. Photographs and Figures uploaded

- **Power Point I: Bytnerowicz et al., Air quality in the Sierra Nevada in the absence and presence of wildland fires.** Pacific Coast Fire Conference: Changing Fire Regimes, Goals & Ecosystems, San Diego, December 1-4, 2008, oral presentation.