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Chapter 6

Introduction to a regional passive ozone sampler network in the Sierra Nevada

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Abstract

An extensive survey of ambient ozone (O_3) patterns and ozone injury to crowns was conducted for the Sierra Nevada between May and October in 1999. The study area included the Sierra Nevada subregion, and extended from the Sequoia National Forest in the south through the Lassen National Forest in the north. Both Westside and Eastside forests were included in the ambient ozone survey. This survey included passive O_3 sampler data at 89 locations across the Sierra Nevada, of which nine were collocated with active ozone monitors. In addition, digital elevation maps, and spatial maps of temperatures and precipitation were developed as part of the analysis.

1. Introduction

Real-time electronic ozone (O_3) monitors are useful for understanding local seasonal and diurnal patterns in mountain areas. In the Sierra Nevada the first program to characterize ambient ozone in mountainous areas was the Sierra Cooperative Ozone Impact Assessment Study (SCOIAS). This program monitored ambient O_3 and meteorological variables at six Sierra Nevada sites (Van Ooy and Carroll, 1995) between 1990 and 1994. Yosemite, Sequoia–Kings Canyon and Lassen Volcanic National Parks, joined SCOIAS by contributing ambient O_3 data at three locations within each Park, and the US Forest Service, Pacific Southwest Research Station, provided four years (1992–1995) of ambient O_3 data from a site in the San Bernardino Mountains.

Due to their cost and technical limitations, such as a need for electric power and micro-environmental requirements (Krupa and Legge, 2000), using only real time electronic monitors is not practical for understanding spatial patterns at large scales. Even with the extensive cooperative effort of SCOIAS only

10 sites were established with active continuous monitors, far too diffuse a network to characterize the extensive mountainous area of the Sierra Nevada. Recent developments in O_3 sampler technology, however, have resulted in low-cost samplers that are useful for large regional surveys. The most widely used passive O_3 sampler (Ogawa & Company, USA, Inc., Pompano Beach, FL) was designed for ambient (Koutrakis et al., 1993) and indoor (Liu et al., 1994) monitoring. The principal component of the coating on the filter medium is the nitrite anion, which in the presence of O_3 is oxidized to nitrate. After sample collection, the filters are extracted with ultrapure water, and analyzed by ion chromatography. It has been shown that fluctuations in relative humidity (from 10–80 percent) and temperature (from 0 °C to 40 °C) do not influence sampler performance at typical ambient O_3 levels (40–100 ppb) (Koutrakis et al., 1993).

In 1993, measurements made with Ogawa passive O_3 samplers were compared with those from UV-photometric O_3 analyzers at five sites in two National Parks by the National Park Service (Ray and Flores, 1994). Passive sampler measurements agreed well for each site and were within ± 10 percent accuracy for each measurement period. Excellent agreement between an active O_3 monitor (Dasibi Model 1003) and Ogawa passive O_3 samplers has also been reported for sites in Mount Rainier National Park ($R^2 = 0.997$, Brace and Peterson, 1994. In Europe, Ogawa samplers have been used successfully in the Krakow Region in southern Poland (Godzik, 1997), in the Carpathian Mountains and Kiev Region in the Ukraine (Blum et al., 1997), and at Praha Peak in the Czech Republic ($R^2 = 0.911$, Bytnerowicz et al., 1995. Recently, Ogawa samplers were used to measure O_3 levels throughout the entire range of the Carpathian Mountains in Central Europe (Bytnerowicz et al., 2002).

In 1990–1991 the Forest Ozone REsponse STudy (FOREST) was established as a companion program to SCOIAS (Arbaugh et al., 1998). The two parallel projects were conducted at the same locations in the Sierra Nevada from 1991–1994. Forest vegetation plots were established near SCOIAS monitoring stations for the purpose of annual assessments of O_3 injury to ponderosa and Jeffrey pine populations. Since 1992, Project FOREST has monitored the condition of pines and O_3 air quality at ten locations in the Sierra Nevada from Lassen Volcanic National Park in the north to Sequoia National Forest in the south and one site located in the San Bernardino Mountains in southern California. Injury amounts in the Sierra Nevada range from almost no crown injury in the north to moderate crown injury in the south.

The 1999 Sierra Nevada study was designed as an extension of SCOIAS and FOREST. The original SCOIAS network of sites was limited to the west side of the Sierra Nevada, and the analyses were limited to north-to-south changes in O_3 and its effects. With the development of inexpensive passive samplers, regional assessments of air pollution patterns became possible, by including a network extending west-to-east as well as the original north-to-south network.

Thus, in this study a dense network of passive monitors in the Sierra Nevada was used for estimating seasonal spatial patterns of ambient O_3. Data from 89 passive and 9 active monitor sites were gathered between May 15 and October 1 in 1999.

Few studies have examined spatial O_3 patterns in remote areas. Similar studies (Phillips et al., 1997) have indicated that geospatial analysis (kriging), or modern regression techniques such as locally weighted regression (Cleveland et al., 1992) may have value for this type of data. As part of this study several analysts independently modeled the data, thereby providing a comparison of different analytical approaches. The USDA Forest Service Statistician, Haiganoush Preisler (PSW), Witold Frączek of the Environmental Systems Research Institute (ESRI), and E. Henry Lee of the US Environmental Protection Agency (EPA) independently analyzed the data set created in this project. W. Frączek used an analysis approach that incorporated a spatial analysis program that applied ordinary cokriging with elevation and temperature as collateral variables. In contrast, H. Preisler and E.H. Lee used locally weighted non-parametric regression, and kriging as a residual analysis technique. Each analysis approach and results are presented in detail separately in later chapters of this volume.

A similar approach was taken to compliment the Project FOREST portion of this study as was done for SCOIAS. It was hypothesized that mapped estimates of ponderosa and Jeffrey pine crown injury could be estimated using combination of low cost foliar evaluation and a detailed map of seasonal ambient O_3 based on projected summer season ambient ozone exposure. Accordingly, crown injury was measured at 25 sites to examine the ability of spatial exposure maps to estimate O_3 injury for sensitive pines of the Sierra Nevada. Relationships between the foliar injury and ambient O_3 were then examined to determine if reliable relationships exist that are useful for estimating spatial patterns of foliar injury from ambient O_3 data.

In this chapter the design and implementation of this project will be discussed as a general introduction to succeeding chapters reporting results of individual analyses, and synthesis of the results. The study design and supplemental data used in the individual analyses will be discussed in detail. Impacts of natural and human disturbances on passive samplers will also be detailed, so that future studies can estimate the losses that can be expected from this type of study.

2. Study design

Initial sites for passive monitors were selected at three general elevations along the north to south gradient of air pollution on the western side of the Sierra

Nevada. It was important for spatial extrapolation that sample sites extend below and above the mixed conifer forest zone for which O_3 exposures and their effects were to be estimated. Accordingly, low elevation monitor sites were located mostly in oak-chaparral areas below the mixed conifer zone at 1000–1400 m elevation. Upper elevation sites were located in the upper montane and subalpine forest zones above the expected upper boundary of urban transported O_3.

The Sierra Nevada Framework (SNF) (USDA, 2001) entered into the project, and site selection was expanded to include some central and eastern locations to assist with the establishment of a Sierra Nevada wide monitoring network. Because the SNF was interested in bioregional level information, it became important to include all areas of the Sierra Nevada, rather than just the western Sierra Nevada.

At the time this study was initiated no information existed on extrapolation error associated with passive O_3 monitors in the Sierra Nevada, or other large mountainous areas. A similar study was underway in the Carpathian Mountains

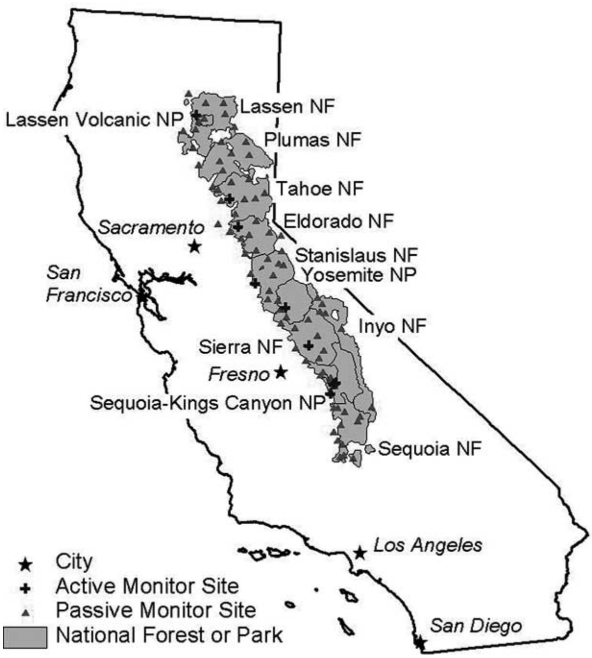

Figure 1. Locations of passive and collocated active monitoring stations located throughout the national forests and parks of the Sierra Nevada. There are 3 active/passive monitor sites located along an elevation gradient in Sequoia–Kings Canyon National Parks.

of central Europe (Bytnerowicz et al., 2002), but information on the required density of monitoring sites was not available at that time. Lacking such information to do formal estimation of sample size requirements, the maximum affordable number of samplers was used for the study. This resulted in 89 locations monitored with passive samplers over the Sierra Nevada between the Lassen National Forest to the Sequoia National Forest (Fig. 1).

All sites were located at least 200 m from frequently used roads, in open areas with vertical mixing of air. Nine passive monitor sites were collocated with active monitors that were operated continuously over the summer season. Seventeen mid-elevation passive monitor sites were located near stands of ponderosa or Jeffrey pines that were used for FPM surveys. A single Ogawa passive O_3 sampler, containing two cellulose filters saturated with nitrite was installed at each site (Koutrakis et al., 1993). The samplers were located at about 1.5–2.5 m above ground level in forest clearings (about 20 m or more from the dense forest). At eight to ten monitoring sites in each collection period, two blank filters were also tested. Blank unexposed filters were kept at room temperature in tightly closed plastic vials. In the field, the filters were changed every two weeks during the summer growing season. After the exposures, the filters were placed in plastic vials, and refrigerated until analyzed. Ozone concentrations were continuously monitored by UV absorption (Thermo Environmental Model 49, Cambridge, MA, or an equivalent instrument), at nine active monitoring stations for comparison with the passive samplers.

3. Supplemental data used in the analyses

Digital elevation data (DEM) was used as a collateral data to enhance the quality of the geostatistical estimation of the primary variable O_3. The relevant, fine resolution elevation data for many topoquads was downloaded from the United States Geological Survey (USGS) web site http://edcwww.cr.usgs.gov/webglis/, resampled to a coarser resolution and merged into a single map. An effort was made to determine the optimal resolution of the DEM by W. Frączek (Frączek et al., Chapter 9, this volume). Depending on the purpose of the analysis, the capacity of a computer disk, and the speed of its processing unit, the resolutions from 30 meters to 1 km were found to be valuable for spatial surface estimation.

Meteorological data from 62 weather stations (Fig. 2) also provided information for the analyses (National Climatic Data Center, WIMS). The meteorological monitoring stations were located across a wide variety of elevations (52 to 2551 meters). Maximum temperature and the probability of precipitation were utilized as secondary variables for the analyses. Surfaces were generated

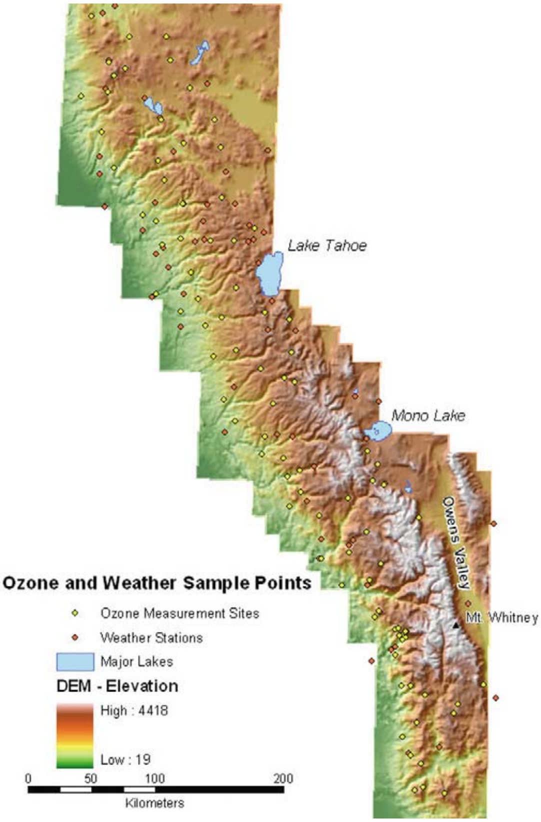

Figure 2. Ozone measurement sites and weather stations form two independent networks of sampling points over the Digital Elevation Model of the Sierra Nevada.

by each analyst separately using techniques consistent with their analysis approach. Hence, ESRI used cokriging, while the PSW used a smoothed scatter plot approach, and EPA used a quadratic loess fit. Sample maps of estimated maximum temperatures differed slightly for the studies, but all indicated that low elevation areas had higher temperatures, while high elevation, interior locations were generally cooler.

In addition to SCOIAS network of continuous monitors, portions of the EPA AIRS database were used by all studies, as well as several monitors established in Sequoia as part of a multi-year research study conducted by USFS Research (Grulke et al., 2002). The PSW and ESRI studies used information from nine monitoring stations where passive and continuous monitors were co-located in the Sierra Nevada. The EPA study used 61 stations located in both the Sierra Nevada and adjacent San Joaquin Valley.

4. Crown injury evaluation

Twenty-five sites, near selected passive O_3 samplers, were surveyed using the Forest Pest Management (FPM) method. The FPM method is less costly to perform than the OII evaluation used for Project FOREST, and the results of both survey types can be related to each other with a high degree of accuracy at the plot level (Arbaugh et al., 1998). The FPM method quantifies O_3 injury by noting the youngest whorl of needles that shows chlorotic mottle. The index has a range from 0 to 4 for each tree. If there is injury on current year needles, the FPM score is 0. If there is no injury on the current year needles but injury on the 1-year old needles, the FPM score is 1. If there is no injury on either the current year or 1-year old needles, but there is injury on the 2-year old needles, the FPM score is 2. This evaluation is applied through the 4-year old needles, where if no injury has occurred, the FPM score is 4, and the tree is considered to be uninjured by ozone. Thirty trees per site were used to provide a representative sample in the FPM method. All tree observations were made between August 15 and September 15 when injury development was the most apparent.

5. Summary

The development of low cost robust passive ozone monitors has enabled, for the first time, affordable landscape studies of air pollution distribution in remote areas. The design of this study was among the first to combine the new technology with existing continuous monitors, and foliar surveys to build spatial and temporal relationships of ambient ozone patterns, risk and foliar injury to trees. An important aspect of this work is the development of new analysis approaches that can be used with the extended database developed through landscape studies. In the following chapters several approaches will be explored that utilize this data to develop bi-weekly and seasonal patterns of ozone distribution, examine the adequacy of the design described in the section, and describe important climate variables that need to be included in future surveys using passive and active ozone measures in remote areas.

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