Biosphere and Atmosphere Interactions in Sierra Nevada Forests[1]

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In the Sierra Nevada, studies are being conducted to assess the impacts of both anthropogenic and biogenic hydrocarbon emissions on regional tropospheric ozone and fine aerosol production. Impacts of ozone deposition and management practices on ecosystem health are also being studied. Human-induced changes in regional air quality have consequences for Sierra Nevada ecosystems and human health. To explore these consequences, research has been conducted at a site in the central Sierra Nevada since June 1997. The research site is located in a ponderosa pine plantation which is downwind of the significant anthropogenic pollution sources of Sacramento and the agricultural Central Valley (Goldstein and others 2000). To illustrate the complex links between air pollution, biogenic gas emissions, and forest management, three specific results from this research are briefly summarized below.

Anthropogenic emissions of nitrogen oxides contribute to ozone pollution in the Sierra Nevada.

Ozone causes significant problems when it occurs at high concentrations in the troposphere (lower atmosphere). A byproduct of human pollution, tropospheric ozone can damage lungs and trees and is a serious problem in the Sierra Nevada where summer levels regularly exceed State and Federal standards. Damage to ponderosa and Jeffrey pines is routinely observed.

The formation of ozone occurs when nitrogen oxides (NOx) and volatile organic compounds (VOCs) react in the presence of sunlight. These chemicals are produced both by humans (anthropogenic) and through natural (biogenic) processes. For example, VOCs are typically produced by trees. To effectively manage air quality, it is critical to understand the contributions from these various sources so as to appropriately target pollution-reduction measures.

During the summers of 1998 and 1999 continuous, hourly measurements of hydrocarbons were made at the Blodgett Forest Research Station using instrumentation based on a gas chromatograph with dual flame ionization detector (GC-FID). Combining these measurements with knowledge about local meteorology, researchers were able to determine the contributions of anthropogenic and biogenic VOCs to local ozone production.

Researchers found that biogenic, or forest-produced VOCs, contributed to between 40 and 70 percent of total ozone production. Furthermore, they suggested that the amount of ozone produced in this manner was controlled by the NOx concentrations being delivered from the Sacramento Valley rather than by the biogenic VOC production itself (Bauer and others 2000, Kurpius and others 2002).

Regulations to reduce ozone production can target either human-produced NOx or human-produced VOCs. Given that trees contribute a large portion of the VOCs and that NOx

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seems to control overall ozone production, regulatory efforts can be focused on further controlling anthropogenic NOx emissions.

Ozone deposition research may improve models for predicting damage to trees.

High levels of ozone due to air pollution in the troposphere can cause significant damage not only to human health but also to forests. In California, ponderosa pines, a dominant tree of Sierra Nevada forests, are particularly susceptible to injury from the uptake of ozone.

Most metrics of ozone damage to date have assumed that maximum injury occurs when ozone is at its highest concentration. A combination of climatic factors and tree physiology, however, refutes this assumption in many cases. To assess the potential impact of ozone on California forests, it is important to better understand the circumstances under which ozone damage occurs (Panek and others 2002).

Since 1997, a number of experiments at the Blodgett Forest Research Station and at sites throughout the Sierra Nevada have been performed to study the environmental and physiological factors that control ozone uptake by trees. Researchers have examined the effect of ozone concentration, drought, and tree phenology (when buds break) on ozone uptake and have also looked at different pathways of ozone deposition in forests (Bauer and others 2000, Panek and Goldstein 2001).

The work has shown that climatic variability from year to year and season to season can have a large impact on the amount of ozone taken up by trees. Drought can greatly reduce uptake owing to the closing of stomata (pores through which ozone uptake occurs and which close in response to lack of water), and only about a third of total annual ozone uptake occurs during the summer when ozone concentrations are highest (Kurpius and others 2002). One of the most surprising findings is that, during the summer months, about half of the ozone deposited is actually lost through gas-phase chemical reactions in the canopy rather than through uptake by trees (Kurpius and Goldstein 2003). All of these results provide a more complete picture of the conditions that influence ozone injury to forests. Contrary to previous assumptions, the greatest damage may occur when ozone concentrations are not at their highest (Goldstein and others 2003).

The research on ozone deposition has resulted in a far more comprehensive understanding of when trees take up ozone through their stomata and how ozone is actually deposited in ecosystems. This information will be critical in developing models to predict and assess pollution damage to California’s forests and will put managers in a better position to protect them in the years ahead (Panek and others 2003).

Precommercial forest thinning may affect regional air quality.

Biogenic hydrocarbon emissions contribute to tropospheric ozone and aerosol production. One important class of such compounds, monoterpenes, is emitted by many forest ecosystems. Monoterpenes produce the familiar “pine” smell associated with softwood cutting. Models of monoterpene emission rates from forests typically presume emissions to be driven by temperature and sometimes by ambient light. However, several studies have shown that mechanical disturbances, such as touching, rain, or herbivory, can enhance emissions. It seemed reasonable to expect that forest operations might also affect monoterpene emissions.

In this study, monoterpene flux from a ponderosa pine plantation (Blodgett Forest Research Station) was measured before, during, and after a precommercial thinning operation. The thinning was conducted in spring 2000. Approximately one-half of the plantation biomass was thinned and left onsite.

Measurements indicated that monoterpene output increased tenfold during the thinning. Most of the increase was due to higher basal emission rates. However, a small change in temperature dependence was detected. The thinning increased subsequent yearly emissions by a factor of five.

Given the magnitude of this increase, it is conceivable that regional atmospheric chemistry could be affected by forest operations such as precommercial thinning. If the responses observed here were extrapolated to all the documented timber removal in the pine forests of the United States, national estimates of monoterpene emissions could be underestimated by several percent (Schade and Goldstein 2003).

References

Bauer, M.R.; Hultman, N.E.; Panek, J.A.; Goldstein, A.H. 2000. **Ozone deposition to a ponderosa pine plantation in the Sierra Nevada Mountains (CA): A comparison of two different climatic years**. Journal of Geophysical Research 105: 22123-22136.

Goldstein, A.H.; Hultman, N.E.; Fracheboud, J.M.; Bauer, M.R.; Panek, J.A.; Xu, M.; Qi, Y.; Guenther, A.B.; Baugh, W. 2000. **Effects of climate variability on the carbon dioxide, water, and sensible heat fluxes above a ponderosa pine plantation in the Sierra Nevada (CA)**. Agricultural and Forest Meteorology 101: 113-129.

Goldstein, A.H.; Panek, J.A.; Kurpius, M.R. 2003. **Ozone uptake by ponderosa pine in the Sierra Nevada—a measurement perspective.** In: Bytnerowicz, Andrzej; Arbaugh, Michael; Alonso, Rocio, editors. Ozone air pollution in the Sierra Nevada: Distribution and effects on forests. Elsevier Science.

Kurpius, M.R.; Goldstein, A.H. 2003. **Gas-phase chemistry dominates O_3 loss to a forest, implying a source of aerosols and hydroxyl radicals to the atmosphere**. Geophysical Research Letters. 30: 1371.

Kurpius, M.R.; McKay, M.; Goldstein, A.H. 2002. **Annual ozone deposition to a Sierra Nevada ponderosa pine plantation.** Atmospheric Environment 36: 4503-4515.

Panek, J.A.; Baldocchi, D.D.; Goldstein, A.H. 2003. **The need for spatially and functionally integrated models of ozone deposition to Sierra Nevada forests.** In: Bytnerowicz, Andrzej; Arbaugh, Michael; Alonso, Rocio, editors. Ozone air pollution in the Sierra Nevada: Distribution and effects on forests. Elsevier Science.

Panek, J.A.; Goldstein, A.H. 2001. **Response of stomatal conductance to drought in ponderosa pine: Implications for carbon and ozone uptake.** Tree Physiology 21: 337-344.

Panek, J.A.; Kurpius, M.R.; Goldstein, A.H. 2002. **An evaluation of ozone exposure metrics for a ponderosa pine ecosystem.** Environmental Pollution 117: 93-100.

Schade, G.W.; Goldstein, A.H. 2003. **Increase of monoterpene emissions from a pine plantation as a result of mechanical disturbances.** Geophysical Research Letters 30: 1380.