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2.4 HIGH-ALTITUDE OZONE CONCENTRATIONS IN YOSEMITE NATIONAL PARK, SIERRA NEVADA

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1. INTRODUCTION

Degrading air quality has become a major concern for many national parks in North America. Currently, Yosemite National Park exceeds the state and federal 8-hour ozone standard (120 ppb) approximately 5 times per summer (http://www.nps.gov/yose/nature/air_ozone.htm). This paper discusses preliminary results from a pilot study that was conducted in Yosemite National Park during the period of 9-20 August 2003 to better understand the structure of thermally-driven circulations and ozone transport at high elevations in the park and in the Sierra Nevada.

Although mountain-valley winds have been studied in many regions throughout the world (Whiteman 1990), there has been little research on local scale circulations in the Sierra Nevada (Clements 1999) and to our knowledge this is the first study that examines the vertical and spatial structure of thermally-driven circulations in Yosemite National Park.

Pollutants from California's Sacramento and San Joaquin Valleys are transported to the western slope of the Sierra Nevada by daytime, local-scale flows (Ewell et al. 1989; Van Ooy and Carroll 1995; Zhong et al. 2002). During the night, down-valley winds are typically cleaner and thus, may represent either clean air from aloft that is mixed downward, or air that has been scavenged due to dry deposition (Broder and Gygax 1985; Loffler-Mang et al. 1997). However, Van Ooy and Carroll (1995) found higher ozone concentrations at many locations on the western slope of the Sierra Nevada during nighttime periods. They attributed these higher concentrations to elevated pollutant layers that remain aloft after the decay of the daytime convective boundary layer.

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2. FIELD EXPERIMENT

To investigate the structure of thermally-driven circulations and the role of such circulations on ozone concentrations in Yosemite National Park, a small field experiment was conducted in cooperation with the National Park Service. Yosemite National Park (YNP) is located in the central Sierra Nevada in eastern California. Although ozone and standard meteorological variables are continuously measured at lower elevations of the park (Turtleback Dome and Yosemite Valley floor), this short, intensive study was intended to resolve transport mechanisms in higher, more alpine regions and the general flow structure at a mid-elevation site in the Sierra Nevada. During this period two additional ozone monitors were installed, one at Tuolumne Meadows (2612 m MSL) and one at Tioga Pass (3033 m MSL). Four portable meteorological towers were installed along an east-west transect of the Sierra Nevada, with one collocated with each ozone monitor. At Tuolumne Meadows, a Scintec, Inc., MFAS-64 Doppler Sodar ran continuously during the sampling period providing vertical wind profiles up to 600 m AGL. In addition, a 3-D sonic anemometer was installed on an existing tower at turtleback Dome, located just outside the entrance to Yosemite Valley, along the southern rim. Further detail regarding the field experiment can be found in Clements *et al*. (2004).

3. PRELIMINARY RESULTS

The synoptic-scale weather during the measurement period was dominated by a ridge of high pressure centered over the western U.S that led to very weak upper-level winds and very dry conditions with no afternoon convection. These conditions allowed for the development of local-scale circulations to persist throughout the period.

3.1 *Thermally-Driven Circulations at Tuolumne Meadows*

Diurnal surface winds at Tuolumne Meadows showed the typical up-valley daytime winds and down-valley nighttime winds with velocities of 4-6 m s^{-1} for up valley winds and much weaker winds (0-2 m s^{-1}) at night (Fig. 1).

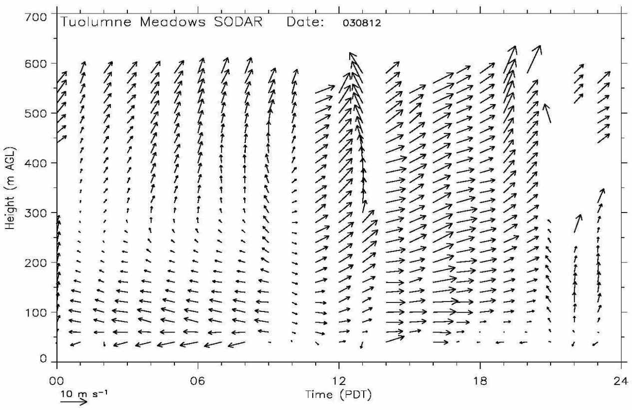

Figure 1. Time-height wind vector plot from SODAR at Tuolumne Meadows for 12 August 2003.

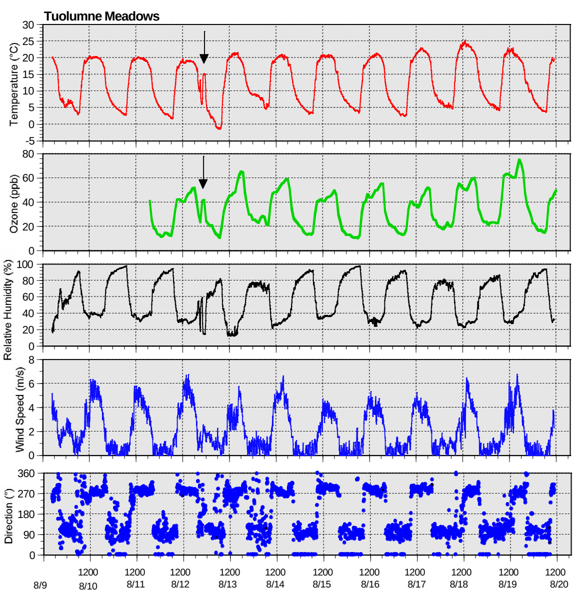

Figure 2. Time series of surface meteorology and ozone concentrations at Tuolumne Meadows.

3.2 *Nocturnal Mixing Event*

On the evening of 12 August 2003, a mixing event occurred at Tuolumne Meadows that is indicated in Fig. 2 by the arrows. This event increased the surface ozone concentration from approximately 25 ppb to 40 ppb in a relatively short period and included an increase in temperature of 10°C. During the two-hour period when the mixing occurred, the surface winds increased slightly, but had a southerly direction rather than an easterly direction as in other nights

This mixing event indicates that either an elevated layer of higher ozone concentrations was mixed vertically downwards to the surface or that higher concentrations were advected horizontally by the southerly winds. The SODAR time-height plot for this time period (Fig. 1) indicates that winds above the surface-based inversion layer at approximately 2100-2200 PDT were from the south and may be responsible for the observed mixing event at the surface. Further discussion will be presented in section 4.

3.3 *Ozone Concentrations in Yosemite National Park*

Measurements of ozone concentration at three locations in YNP are shown in Fig. 3. The spike found at Tuolumne Meadows on 12 August is also found at Tioga Pass and Turtleback Dome, where it occurred approximately 3-4 later than at Tuolumne Meadows.

Another striking feature found in the time series is the double peak in concentration--one in the morning and one late in the afternoon. The morning spike is likely associated with the break up of the nocturnal stable boundary layer when higher concentrations are mixed downwards. The peak in the afternoon is associated with either locally generated photochemical production or horizontal transport from the up-valley westerly winds. Since the area is fairly remote the regional transport is the more likely cause for these diurnal variations.

Another feature in the time series is the very high concentrations observed on 19

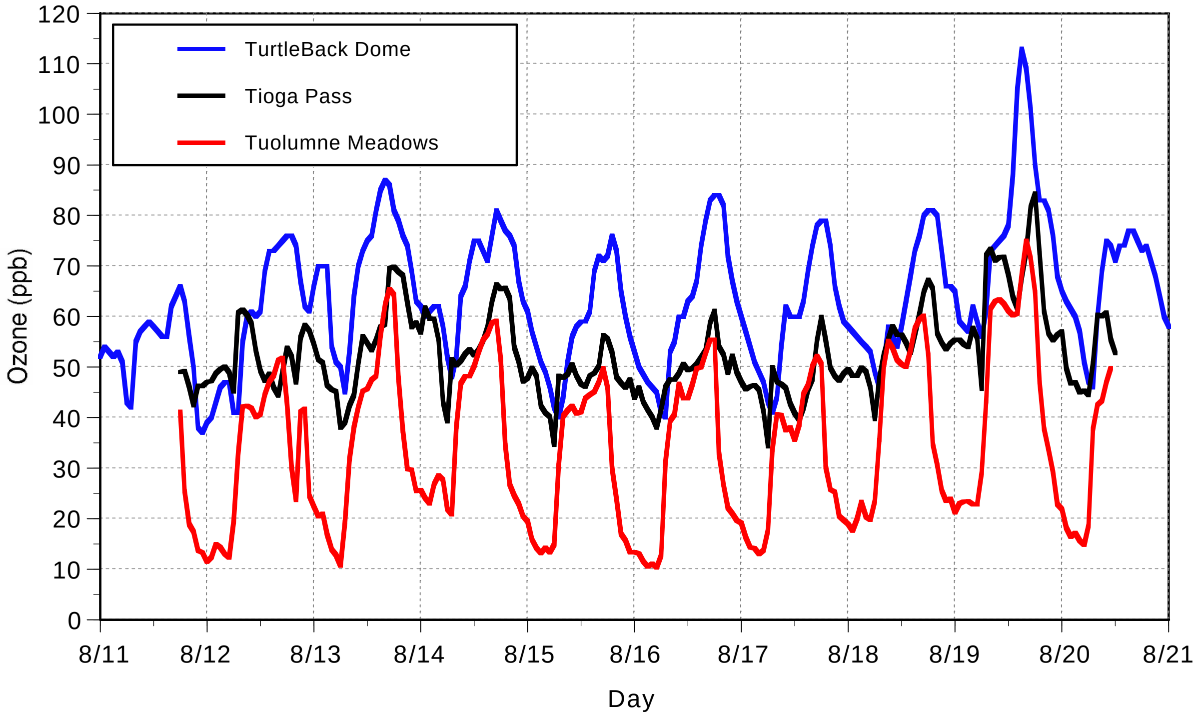

Figure 3. Time series of ozone concentrations from three locations in Yosemite National Park.

August that are associated with regional scale transport. Transport is indicated by the time lag between peak concentrations found at Turtleback Dome, Tuolumne Meadows, and Tioga Pass; each maxima occurring ~1-2 hr later. Also, concentrations of over 80 ppb at Tioga Pass appear to be extreme for a high-elevation site in the Sierra Nevada (3029 m MSL). The high ozone concentrations observed on this day are associated with southerly winds aloft (not shown) suggesting that these higher concentrations of ozone are due to transport from the southern San Joaquin Valley which typically has higher ozone concentrations than the central part of the Central Valley of California.

4. MM5 / HYSPLIT SIMULATIONS

To better understand the mixing event that was observed on 12-13 August, high-resolution simulations were conducted with the MM5 mesoscale meteorological model using three (36, 9, 3, km) two-way nesting grids and a finer, one-way nesting domain with a resolution of 1-km centered over Yosemite National Park.

Simulations are able to capture the diurnal structure of the local circulations within the 1-km domain fairly well. In order to determine the mechanisms that may have led to the observed mixing event on 12 August, backward trajectories were calculated with the Hybrid Single Particle Lagrangian Integrated Trajectories (HY-SPLIT) model (Draxler and Rolph, 2003) initialized using the 3-km domain MM5 simulations conducted for the period. Back trajectories from Tioga Pass, Tuolumne Meadows, and Turtleback Dome were calculated for 12 hours back in time (Fig. 4).

Results from HYSPLIT show that there was indeed strong downward motion over the higher elevations of YNP during 22 PDT, indicating that the surface air originated from well above the surface (lower plot of Fig. 4). While strong downward motion was shown to occur at Tioga Pass and Tuolumne Meadows, this vertical motion did not occur at Turtleback Dome during the period. However, backward trajectories show that air at Turtleback Dome was associated with easterly surface winds. These winds are the down-valley mountain winds that were observed regularly during the field study.

This suggests that downward mixing brings background concentration air from aloft to the surface at higher elevation regions and is then entrained into the surface layer where the air is finally transported to lower elevations of Yosemite National Park by the nocturnal down-valley flows. Downward mixing events, such as in this case, most likely represent background ozone concentrations from above the mixed layer and thus, are not high in concentration. However, these downward mixing episodes represent a mechanism that can account for the linking of regional transport to local-scale transport in regions of complex terrain.

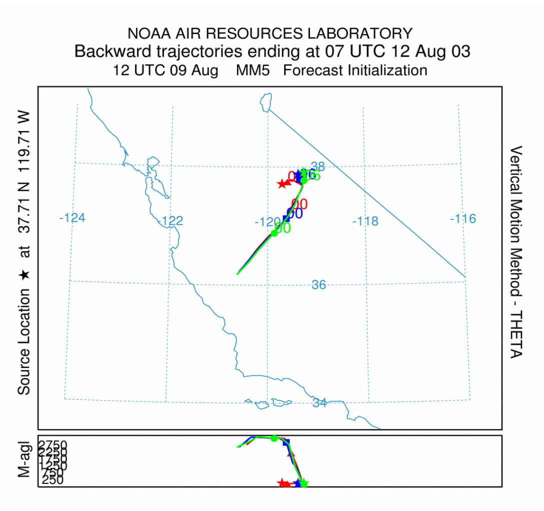

Figure 4. HYSPLIT 12 hour backward trajectory isentropic analysis initialized from 3-km domain MM5 simulations. Green is Tioga Pass, blue is Tuolumne Meadows, and red is Turtleback Dome.

5. CONCLUSIONS

A nocturnal mixing event observed at Tuolumne Meadows was associated with strong downward motion that occurred at both Tuolumne Meadows and Tioga Pass. Background concentration air was mixed downwards from aloft to the surface layer where it was then transported horizontally to lower elevation sites in the park by down-valley winds. This phenomenon appears to be a mechanism that links regional transport to local-scale transport.

Further simulations, with finer horizontal resolution, are planned with the WRF model coupled to the CMAQ air chemistry model.

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