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7.5 THERMALLY-DRIVEN WIND SYSTEMS AND HIGH-ALTITUDE OZONE CONCENTRATIONS IN YOSEMITE NATIONAL PARK

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1. INTRODUCTION

Degrading air quality has become a major concern for many national parks in North America. A new report released by the EPA has listed Yosemite National Park as one of eight national parks that now fail the federal smog standard. This has major implications for park management. 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 in general (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. Clements (1999) found a complex wind regime in the eastern Sierra Nevada that includes daytime down-canyon winds that could lead to pollutant transport over the Sierra Nevada crest.

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.

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 (Fig. 1). Although, ozone and standard meteorological measurements are continuously measured at lower elevations of the park (Turtleback Dome and Yosemite Valley floor), this study focused on a short intensive observation period that was aimed at determining 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 at each ozone monitor. At Tuolumne Meadows, a Scintec, Inc., MFAS-64 Doppler Sodar ran continuously during the 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 on the south rim of Yosemite Valley.

3. PRELIMINARY RESULTS

The synoptic-scale weather during the measurement period was associated with 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

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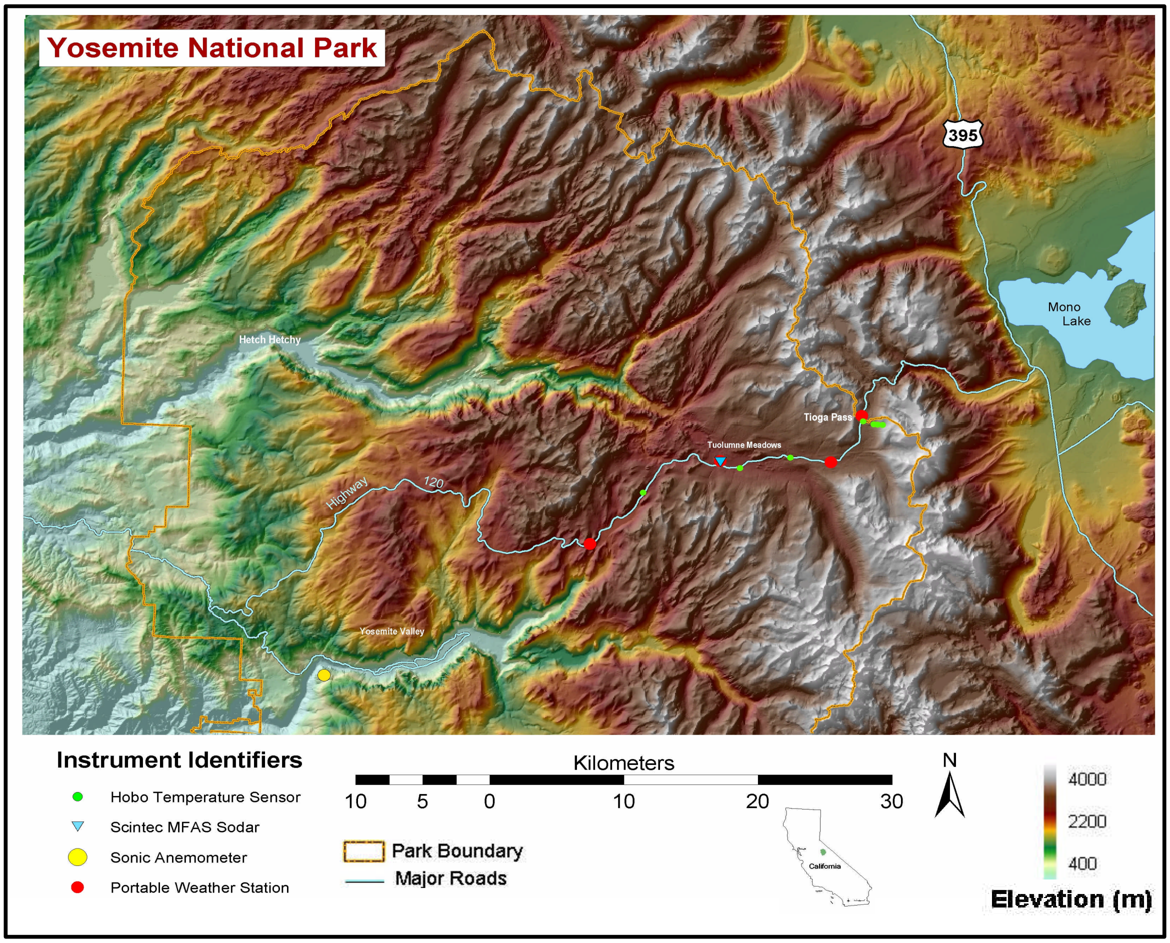

Figure 1. Map of Yosemite National Park, terrain, and instrument locations. Ozone concentrations were measured at Yosemite Valley floor (not indicated), Turtleback Dome (yellow dot), Tuolumne Meadows, and Tioga Pass.

afternoon convection. These conditions allowed for the development of local-scale circulations to persist.

3.1 *Valley Wind Structure at Tuolumne Meadows*

A typical example of the down-valley vertical wind profiles at Tuolumne Meadows is shown in Fig. 2. The vertical wind structure had typical features including a pronounced down-valley jet located at approximately 90 – 100 m AGL with velocity maxima of 4-6 m s^{-1}. A minimum in the down-valley jet occurs at approximately 300 m AGL, but decreases in height by midmorning. Winds above the down-valley jet are from the south in this example.

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. 3).

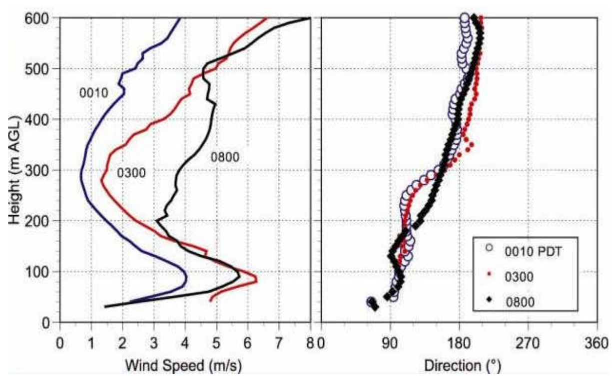

Figure 2. Vertical wind profiles from SODAR measurements at Tuolumne Meadows for 12 August 2003.

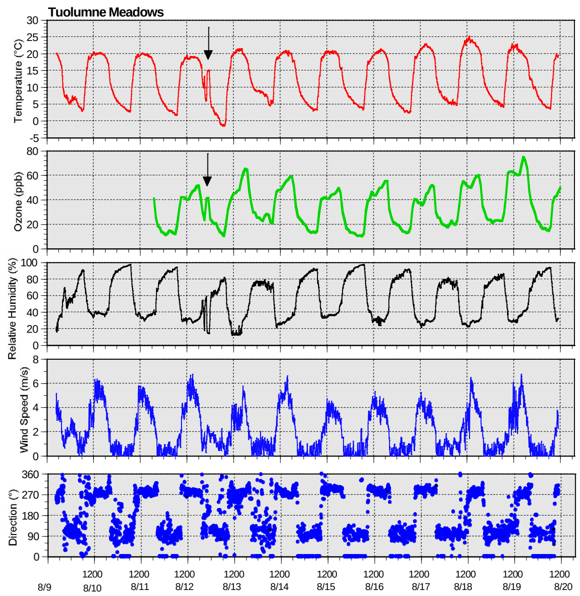

Figure 3. Time series of surface meteorology and ozone concentrations at Tuolumne Meadows.

3.2 *Nocturnal Mixing Event*

On the evening of 12 August 2003, a mixing event occurred at Tuolumne Meadows that is indicated in Fig. 3 by the arrows. This event increased the surface ozone concentration from approximately 20 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.

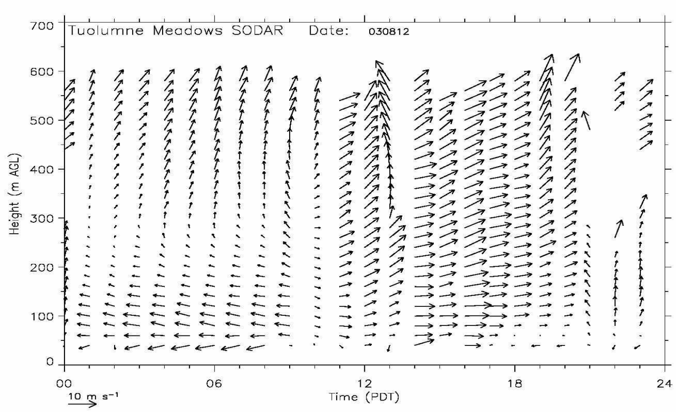

Figure 4. Time-height wind vector plot from SODAR at Tuolumne Meadows for 12 August 2003.

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. 4) indicates that winds above the building inversion layer at approximately 2100-2200 PDT were from the south and may be responsible for the observed mixing event at the surface.

3.3 *Ozone Concentrations in YNP*

Measurements of ozone concentration at four locations in YNP are shown in Fig. 5. The spike found at Tuolumne Meadows on 12 August is also found at Turtleback Dome and it occurs here approximately an hour later than at Tuolumne Meadows. This most likely occurs because of the lower elevation of Turtleback Dome (1605 m MSL) relative to Tuolumne Meadows (2612 m MSL) suggesting that this event is due to downward mixing from aloft and over the western region of YNP since it does not occur at Tioga Pass further to the east.

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 SBL when higher concentrations are mixed downwards. The peak in the afternoon is associated with horizontal transport from the up-valley westerly winds.

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

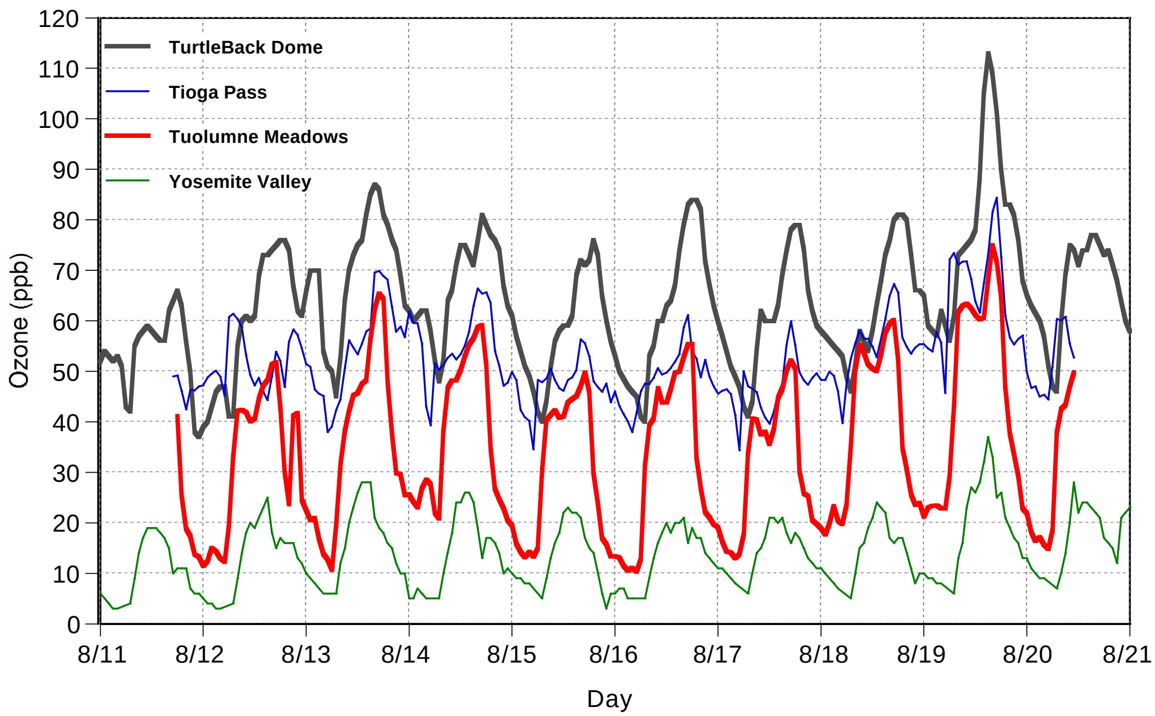

Figure 5. Time series of ozone concentrations from four locations in Yosemite National Park.

Another feature in the time series of Fig. 5 is the relatively low ozone concentrations found at the floor of Yosemite Valley. Titration of ozone may be responsible for the observed low ozone concentrations in the valley since nearly 6000 cars and 63 buses visit the valley daily during peak tourist season (NPS, 2002, Pers. Com.).

4. ON GOING AND FUTURE WORK

Numerical simulations have been conducted for this study period using the MM5 mesoscale model with an inner domain of 1-km horizontal resolution. Further finer horizontal resolution simulations are planned using the WRF model with coupled simulations using the CMAQ air chemistry model.

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