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Surface ozone in the Lake Tahoe Basin

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HIGHLIGHTS

- The Lake Tahoe Basin experiences elevated concentrations of surface O_3.
- Diurnal maxima of ~50–55 ppb occur throughout the Basin for 10:00–17:00 PST.
- At night, there is large site-to-site variability in the observed O_3 concentrations.
- Nocturnal O_3 concentrations depend on elevation, topography, and surface cover.

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ABSTRACT

Surface ozone (O_3) concentrations were measured in and around the Lake Tahoe Basin using both active monitors (2010) and passive samplers (2002, 2010). The 2010 data from active monitors indicate average summertime diurnal maxima of approximately 50–55 ppb. Some site-to-site variability is observed within the Basin during the well-mixed hours of 10:00 to 17:00 PST, but large differences between different sites are observed in the late evening and pre-dawn hours. The observed trends correlate most strongly with elevation, topography, and surface vegetation. High elevation sites with steeply sloped topography and drier ground cover experience elevated O_3 concentrations throughout the night because they maintain good access to downward mixing of O_3-rich air from aloft with smaller losses due to dry deposition. Low elevation sites with flat topography and more dense surface vegetation experience low O_3 concentrations in the pre-dawn hours because of greatly reduced downward mixing coupled with enhanced O_3 removal via efficient dry deposition. Additionally, very high average O_3 concentrations were measured with passive samplers in the middle of the Lake in 2010. This latter result likely reflects diminished dry deposition to the surface of the Lake. High elevation Tahoe Basin sites with exposure to nocturnal O_3-rich air from aloft experience daily maxima of 8-h average O_3 concentrations that are frequently higher than concurrent maxima from the polluted upwind comparison sites of Sacramento, Folsom, and Placerville. Wind rose analyses of archived NAM 12 km meteorological data for the summer of 2010 suggest that some of the sampling sites situated near the shoreline may have experienced on-shore "lake breezes" during daytime hours and/or off-shore "land breezes" during the night. Back-trajectory analysis with the HYSPLIT model suggests that much of the ozone measured at Lake Tahoe results from the transport of "polluted background" air into the Basin from upwind pollution source regions. Calculation of ozone exposure indices indicates that the two most polluted sites sampled by active monitors in 2010 – the highest Genoa Peak site, located on the eastern side of the Lake at an elevation of 2734 m above sea level, and Angora Lookout, located to the south–southwest (SSW) of the Lake at an elevation of 2218 m above sea level – likely experienced some phytotoxic impacts, while the other Tahoe Basin locations received lower ozone exposures.

1. Introduction

Lake Tahoe (elevation 1897 m above sea level) is a large alpine lake that straddles the border between California and Nevada. With

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a maximum depth of 501 m, it is the fourth deepest lake in North America, and it is renowned for the clarity of its water (United States Geological Survey, 2014). Because of its importance as both a unique natural resource and a year-round vacation destination, Lake Tahoe has been extensively studied in terms of issues relating to hydrology and water clarity (Tahoe Environmental Research Center, 2014). The air quality within the Lake Tahoe Basin – especially the deposition of atmospheric pollutants into the lake – has also been investigated (Gertler et al., 2006; Dolislager et al., 2012a; VanCuren et al., 2012). Less attention, however, has been focused upon Lake Tahoe in terms of surface ozone and other air quality issues that are not directly linked to water clarity (Dolislager et al., 2012b).

Historically, the Tahoe Basin had been in compliance with ambient air quality standards for ozone until 2005, when the Air Resources Board of the State of California (CARB) adopted a more stringent 8-h ozone standard (not to exceed 70 ppb). Now some areas within the Basin violate this standard a few times each summer. Given that typically observed in-Basin ozone concentrations have remained low enough so that human health impacts are not a pressing concern (at least in comparison to heavily polluted regions like the western slope of the southern Sierra Nevada), many prior Tahoe Basin ozone studies have instead focused upon the impact of ozone on the health of the extensive pine forests that surround the Lake (Dolislager et al., 2012a; 2012b). Ambient ozone has pronounced adverse effects on forest health in California's mountain regions (Arbaugh et al., 1998). According to large-scale distribution maps of the Sierra Nevada bioregion, the Lake Tahoe Basin's summer-season, 24-h ozone levels are approximately 50–60 ppb (Fraczek et al., 2003). Such ozone levels may be toxic to vegetation (Krupa et al., 1998) and can adversely affect tree health (Arbaugh et al., 1998). Ozone has been observed to cause foliar injury to ponderosa (*Pinus ponderosa*) and Jeffrey (*Pinus jeffreyi*) pines in the central Sierra Nevada (Miller et al., 1996), including the Lake Tahoe Basin (Pedersen et al., 1989).

In addition to potential impacts on surrounding forests, prior Tahoe Basin ozone investigations have also examined the transport of ozone and ozone precursors from upwind source regions. Carroll and Dixon (2002) performed aircraft measurements of a Sacramento pollution plume and found that maximum ozone concentrations were frequently observed in the afternoon, 40–80 km downwind of the city, but subsequently decreased by about 50% at distances 120 km downwind. Zhang et al. (2002) used aircraft measurements to study nitrogen and phosphorus in and around the Lake Tahoe Basin. Bytnerowicz et al. (2004) studied spatial and temporal ozone distributions as two-week integrated averages measured by passive samplers during the 2002 summer season for the entire Lake Tahoe Basin and for upwind areas on the western slopes of the Sierra Nevada. They concluded that the Sierra Nevada crest west of the Lake Tahoe Basin acts as a barrier that restricts polluted air masses and high ozone concentrations from the Sacramento Valley and Sierra Nevada foothills from entering the Basin. Dolislager et al. (2012b) assessed the relative impacts of transport versus local photochemical production by making continuous measurements during the summer of 2003 along the axis of predominant airflow (i.e., roughly southwest to northeast). They utilized two transport assessment sites at Big Hill and Echo Summit, along with other monitoring sites at various locations on the western slope of the Sierra Nevada, plus four in-Basin monitoring sites. Also incorporating aircraft data, they concluded that pollutants from upwind regions act to raise background concentrations entering the Tahoe Basin to the extent that local contributions do not need to be large to cause exceedances of air quality standards.

While the prior Tahoe Basin studies noted above are most

Table 1
Sampling locations equipped with both active monitors and passive samplers.

Location	Code	Latitude (degrees)	Longitude (degrees)	Elevation (masl)	Site description
Angora Lookout	AGL	38.8817	−120.0548	2218	Steep hillside near top of ridge; extensive fire damage
Echo Summit (CARB site)	ECHO	38.8116	−120.0331	2250	Flat clearing/parking lot along U.S. Hwy. 50
Folsom[a] (CARB site)	FOL	38.6833	−121.1644	108	Suburban location near green open space
Genoa Peak 7000	GP7	39.0789	−119.9091	2232	Small clearing on mild slope; thick grass
Genoa Peak 8000	GP8	39.0504	−119.9072	2449	Open clearing on moderate slope; heavy fire damage
Genoa Peak 9000	GP9	39.0438	−119.8834	2734	Rocky outcropping near summit; excellent exposure
Incline Village[a] (SLAMS site)	IVL	39.2504	−119.9567	1957	Rooftop in residential/commercial neighborhood
Lower Blackwood Creek	LBC	39.1098	−120.1901	1948	Flat open meadow with wet grass
Placerville[a] (CARB site)	PLA	38.7253	−120.8219	612	Semi-rural location in Sierra foothills
Sacramento[a] (CARB site)	SAC	38.5684	−121.4931	15	Rooftop near downtown Sacramento
Sugar Pine Point State Park	SPP	39.0419	−120.1448	1951	Flat open meadow; a few nearby trees
Thunderbird Lodge	THB	39.1739	−119.9316	1915	On the roof of a shed at the base of a steep incline
Upper Incline	ICN	39.2856	−119.9241	2523	Wide, open, steep slope with lots of green plants
Valhalla	VAL	38.9360	−120.0448	1906	Flat sandy terrain with low scrub; near CA Hwy. 89
Watson Creek	WC	39.2294	−120.1251	2293	Flat open meadow with leafy green plants

[a] These four long-term monitoring sites did not collect any passive sampler data.