Ozone in the Lower Free Troposphere and its Impact on Surface Levels in the Northern Sacramento Valley

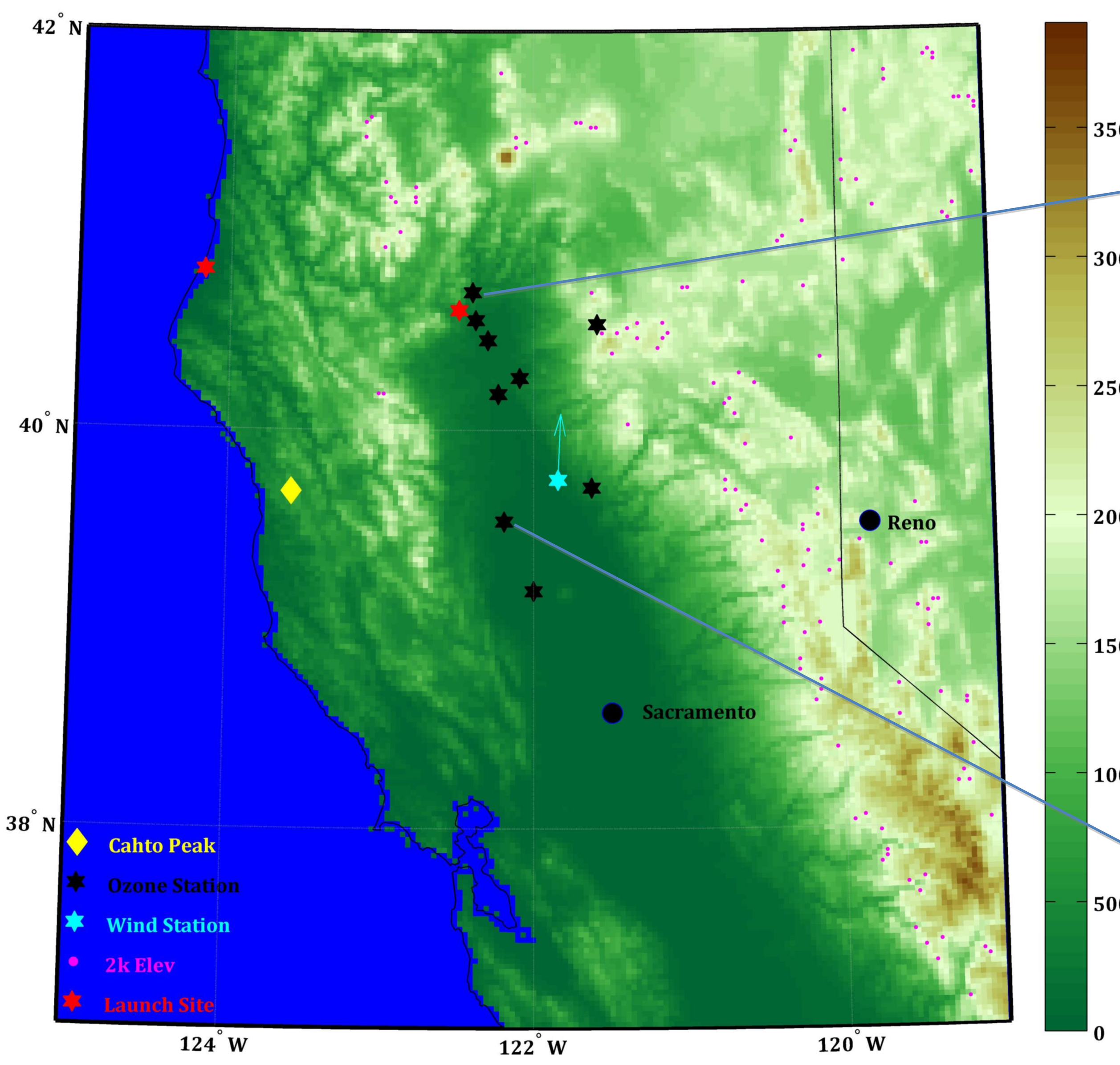
Ian Faloona[1], Stephen Conley[1], Bryan Johnson[2], & Owen Cooper[2]

[1]University of California, Davis [2]NOAA ESRL

ABSTRACT

Ground based studies of atmospheric composition typically suffer from incomplete constraints on the influence of vertical transport on the surface air. While horizontal transport can be explored by multiple surface stations, and chemical processing by the judicious addition of surface measurements, vertical transport is often controlled by the entrainment flux of compounds at the opposite interface: between the atmospheric boundary layer (ABL) and the lower free troposphere (FT.) This entrainment flux is most significantly determined by the difference in concentration between the two layers, a gradient that is nearly always out of reach of traditional measurement techniques, or subject to very sporadic investigation by aircraft.

Here we use ozonesonde data from the Shasta site to study the budget of surface ozone in the Northern Sacramento Valley (NSV) during the CalNex study. Using reasonable approximations of boundary layer entrainment, and dry deposition, in conjunction with the observed horizontal gradients from the surface network, we perform an afternoon O_3 budget for the northern edge of the valley. The analysis yields an approximate quantification of the vertical influx of ozone from aloft. Further, comparison of these entrainment fluxes to estimates of horizontal advection and photochemical production thereby leads to an assessment of the relative importance of exogenous ozone to surface level concentrations in the Northern Sacramento Valley. We work towards combining continuous measurements of ozone from a mountain site in Mendocino County (Cahto Peak) along with periodic sampling of ozone profiles in the valley and offshore by the UC Davis aircraft to build a comprehensive picture of the relative magnitudes of processes contributing to surface ozone levels in the NSV year round.



(🡅) **Figure 1.** The location of the Northern Sacramento Valley ARB sites from which surface O_3 data were compiled (★). Trinidad Head (THD) along the coast and Shasta (RED) in the North end of the valley are sites of the NOAA ozonesonde launches (★). The boundary layer winds, observed with the NOAA radioacoustic sounding system at Chico (★), show a vector average southerly wind at 2.5 m/s. The pink dots represent points where the terrain is 2000 m above sea level - the approximate average boundary layer depth observed at Shasta during CalNex. UC Davis collects continuous ozone measurements from the Calfire lookout station on Cahto Peak (★),

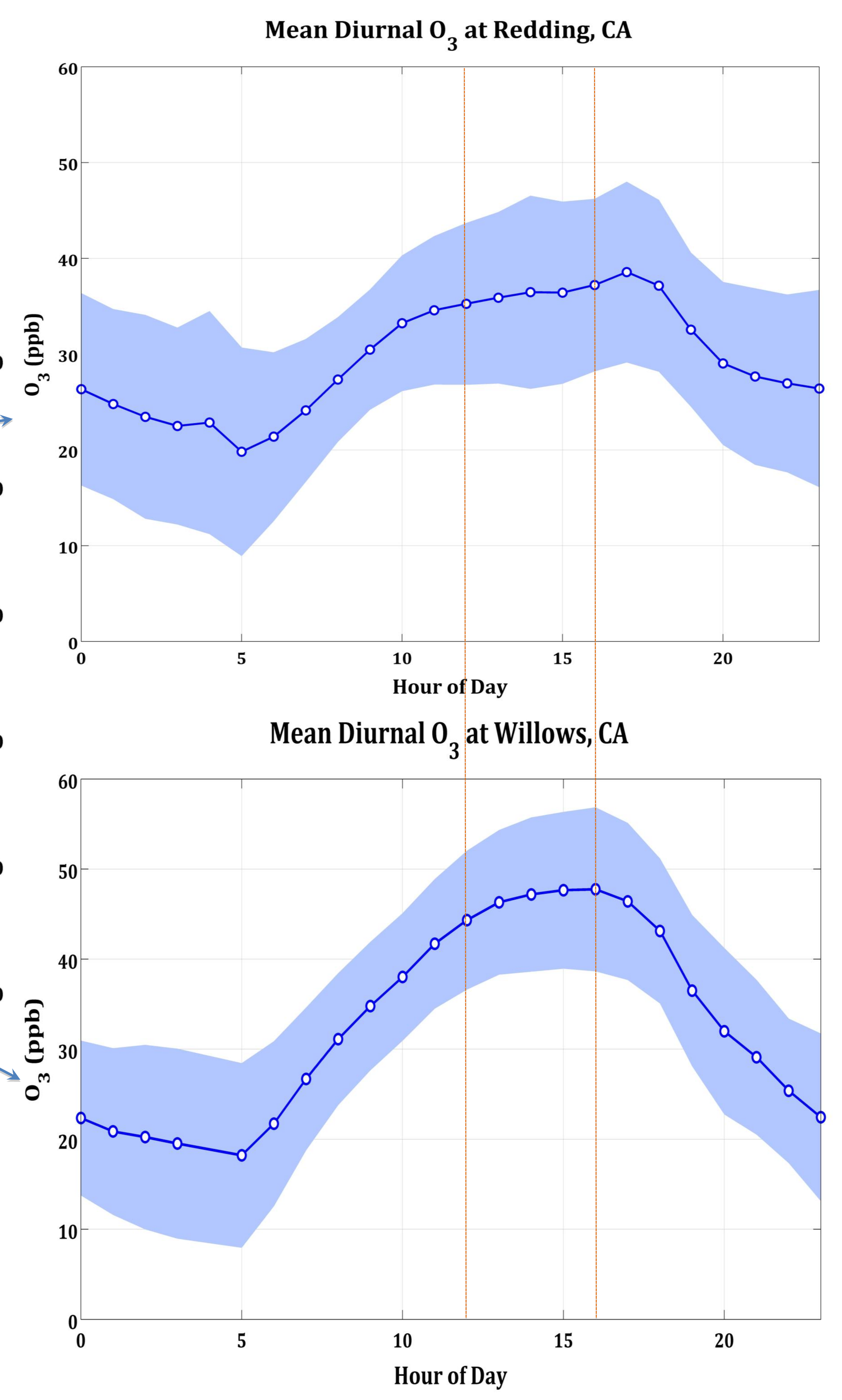
METHODOLOGY

We use the ARB surface air quality sites to track the diurnal ozone changes in the NSV in conjunction with the ozonesonde data to map the vertical structure, thereby deriving a scalar budget of O_3 for the atmospheric boundary layer:

$$\frac{\partial O_3}{\partial t} = -\overset{\vee}{U} \bullet \nabla O_3 + \frac{w_e \Delta O_3 - v_d O_3}{z_i} + P_{net}$$

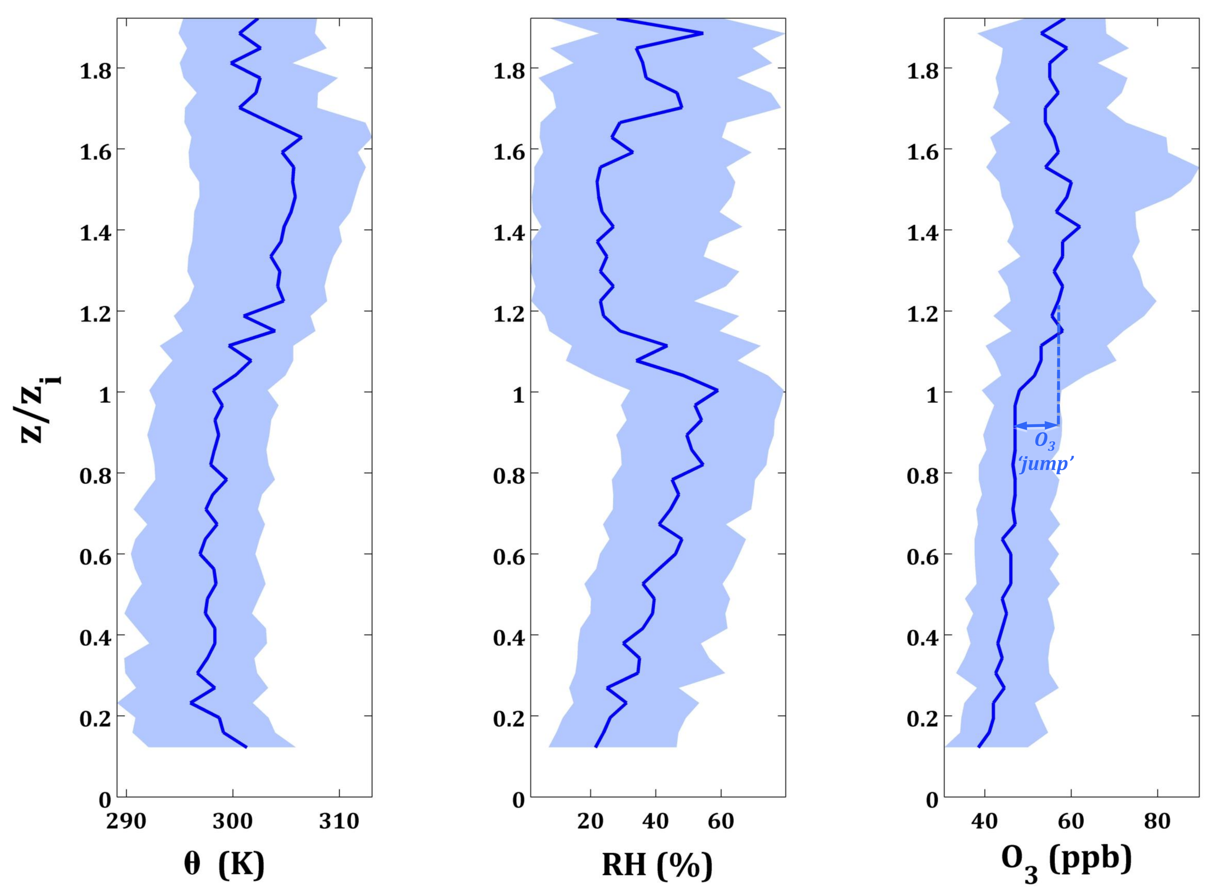
$\vec{U}$ – horizontal ABL wind
w_e – entrainment velocity (est. 5 cm/s)
ΔO_3 – jump across entrainment zone above z_i
v_d – dry deposition velocity (est. 0.5 cm/s)
z_i – ABL depth (2200 ± 900 m, from sondes)
P_{net} – net in-situ photochemical production

Measurements of the time rate of change of O_3, and horizontal gradients along with estimates of entrainment velocity and dry deposition provide the opportunity to solve for the in-situ photochemical production rate of ozone during the afternoon (average of 0.9 ppb/hr between 12:00-16:00 during CalNex.)



(🡅) **Figure 2.** The average (±1σ) diurnal profiles of ozone at two sites in the NSV. The vertical dashed lines represent two hours before and after each ozonesonde launch. From the time series a daily temporal O_3 trend is calculated at Redding (Table 1), and the network of ARB surface sites is used to generate a regional gradient which when combined with the ABL winds (Figure 4) yields the contribution of advection to the local O_3 budget.

Shasta Site Ozonesondes

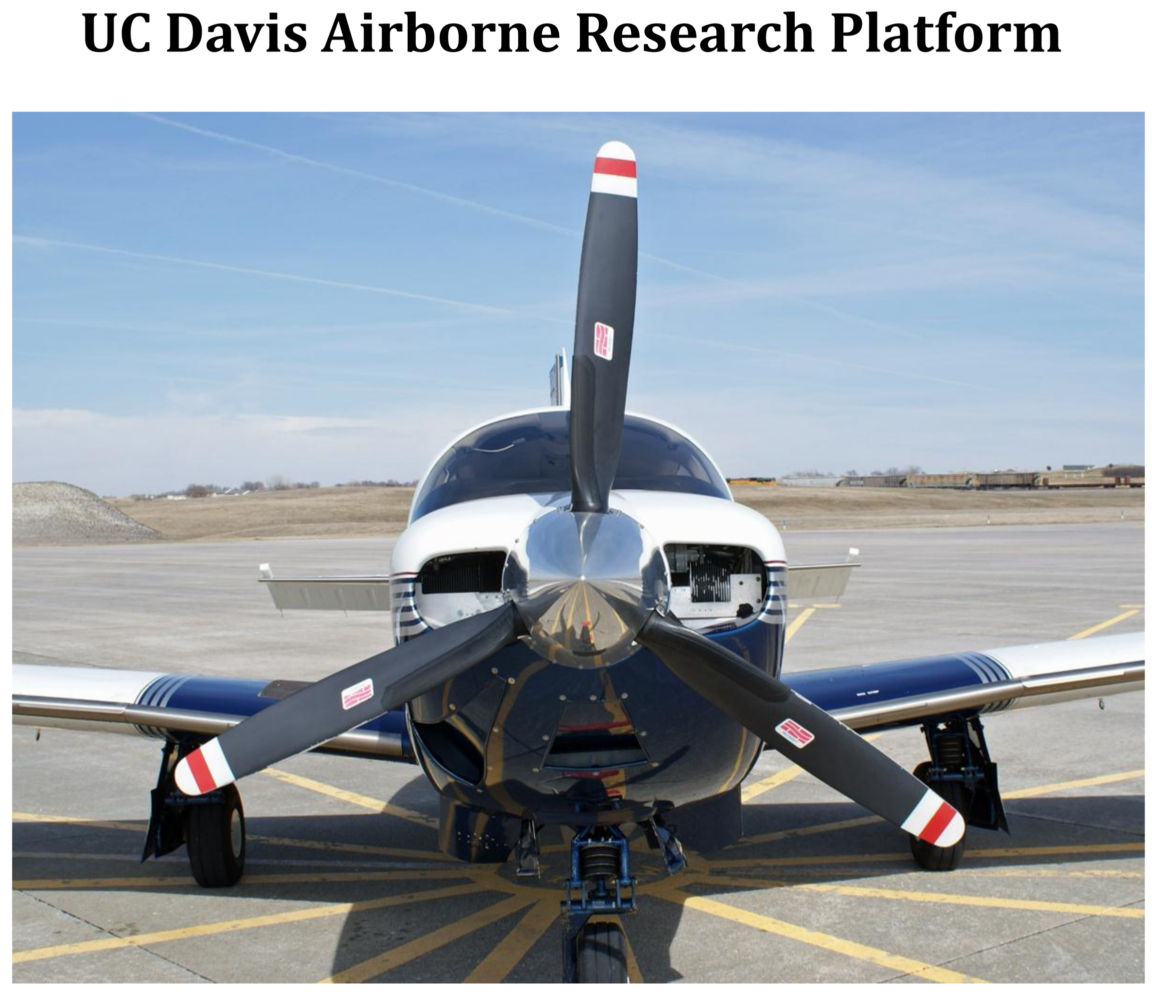


(🡅) **Figure 3.** Mean potential temperature (θ), relative humidity (RH), and O_3 from the CalNex ozonesondes at the Shasta site as a function of altitude scaled by the ABL depth (z_i). The thick blue line is the median of each bin and the blue swatches are ±1σ around the mean. The average O_3 jump across the top of the ABL is 5.3±6.6 ppb.

(🡇) **Table 1.** Summary of the O_3 budget estimates at Redding for each CalNex ozonesonde launch. The O_3 jump across the top of the ABL is calculated as the difference between average ozone 400 m on either side of the inversion. Fixed 5 cm/s entrainment velocity and 0.5 cm/s dry deposition velocity are assumed.

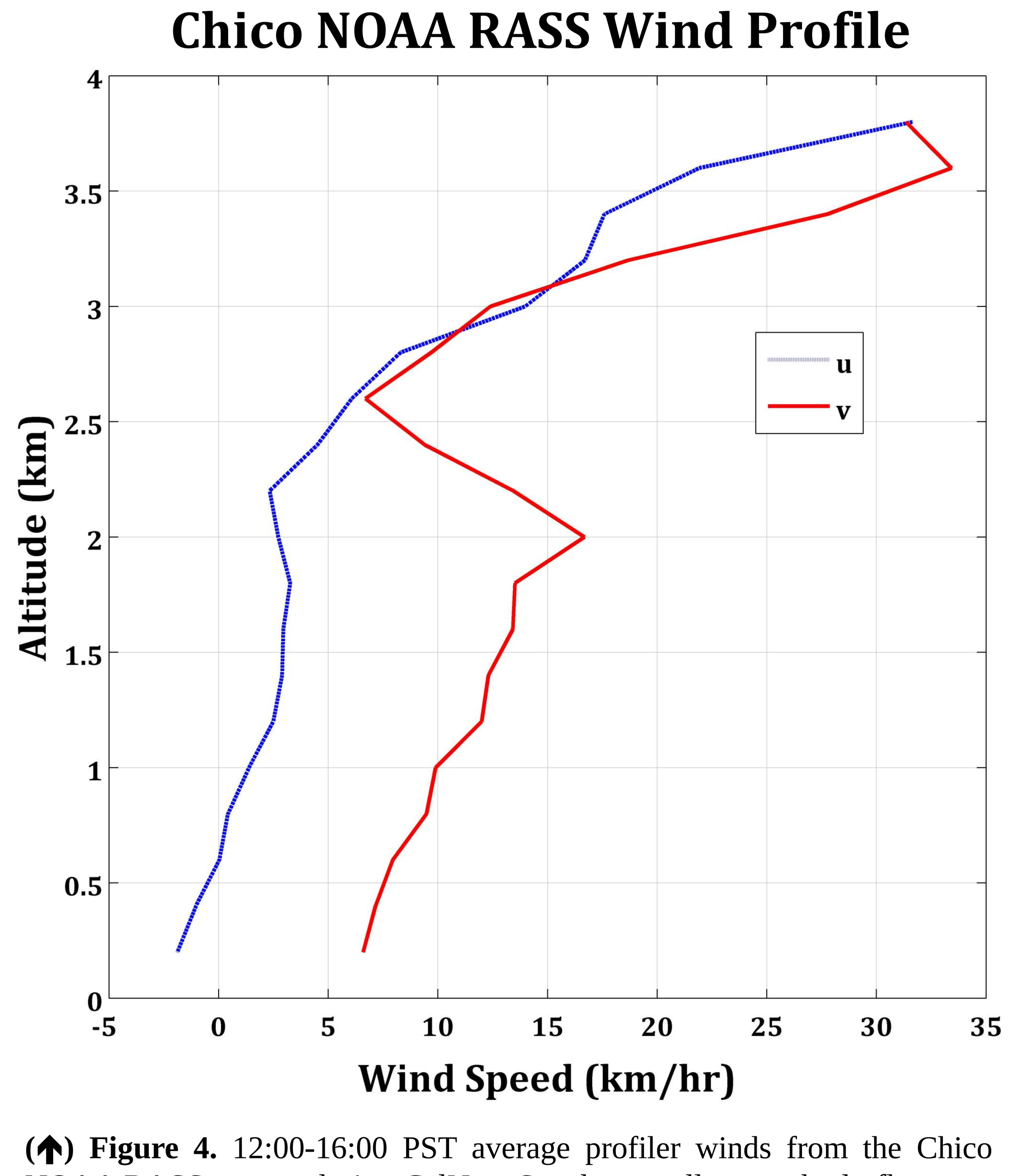
Date	dC/dt (ppb/hr)	Advection (ppb/hr)	O_3 Jump (ppb)	Entrainment (ppb/hr)	Dry Deposition (ppb/hr)	Net Production (ppb/hr)	z_i (km)	ABL O_3 (ppb)
5/8	-0.15	-1.19	1.50	0.11	-0.37	1.30	2.5	51.3
5/9	0.87	0.14	6.42	0.43	-0.33	0.63	2.7	49.3
5/10	2.89	-1.93	16.58	0.90	-0.34	4.25	3.3	61.8
5/11	1.45	1.14	18.75	0.99	-0.34	-0.34	3.4	64.8
5/12	0.85	0.15	3.75	0.19	-0.32	0.83	3.5	62.5
5/13	1.15	-0.21	-1.50	-0.18	-0.81	2.34	1.5	67.3
5/15	-1.33	-0.67	13.50	1.28	-0.37	-1.57	1.9	39.0
5/16	1.00	-0.68	1.25	0.15	-0.57	2.10	1.5	47.5
5/17	-5.25	0.04	15.50	0.93	-0.26	-5.95	3.0	43.8
5/19	1.55	-0.10	0.00	0.00	-0.47	2.12	1.8	47.0
5/20	1.70	-0.37	-0.75	-0.05	-0.34	2.46	2.5	47.0
5/22	-1.10	0.66	8.83	0.50	-0.30	-1.95	3.2	53.7
5/23	0.75	0.47	13.50	1.22	-0.40	-0.54	2.0	44.0
5/24	-0.15	2.21	-0.50	-0.05	-0.50	-1.82	2.0	55.0
5/25	4.40	1.88	1.25	0.13	-0.55	2.94	1.7	51.8
5/26	-1.40	-0.21	1.92	0.22	-0.42	-0.98	1.6	37.3
5/27	-2.05	-1.11	4.00	0.48	-0.59	-0.84	1.5	49.0
5/30	1.35	0.04	-0.25	-0.03	-0.39	1.73	1.6	35.0
6/2	-1.85	0.45	0.58	0.11	-0.44	-1.97	1.0	24.7
6/3	-1.40	1.48	7.33	1.47	-0.73	-3.61	0.9	36.7
6/5	1.67	-0.35	12.75	1.21	-0.54	1.35	1.9	56.8
6/6	2.35	0.55	-11.25	-1.07	-0.54	3.41	1.9	57.0
6/7	1.62	-0.98	10.25	0.62	-0.28	2.27	3.0	47.0
6/8	1.90	-0.84	12.75	0.62	-0.21	2.34	3.7	44.0
6/9	2.00	-0.38	12.00	0.90	-0.30	1.79	2.4	40.3
6/10	-0.85	-1.09	7.25	0.44	-0.29	0.10	3.0	48.5
6/12	1.50	-0.46	-1.50	-0.09	-0.25	2.30	3.0	42.0
6/13	2.50	-0.06	1.00	0.06	-0.30	2.79	2.8	46.0
6/14	2.95	-1.95	3.25	0.28	-0.35	4.98	2.1	41.0
6/15	0.25	0.71	5.25	0.38	-0.31	-0.53	2.5	42.5
6/16	1.65	0.02	3.75	0.23	-0.28	1.68	3.0	46.5
6/17	4.90	0.28	2.25	0.24	-0.46	4.85	1.7	43.8
Mean	**0.80**	**-0.07**	**5.29**	**0.39**	**-0.40**	**0.89**	**2.3**	**47.6**
Std Dev	**2.02**	**0.95**	**6.63**	**0.52**	**0.14**	**2.43**	**0.8**	**9.2**

UC Davis Airborne Research Platform



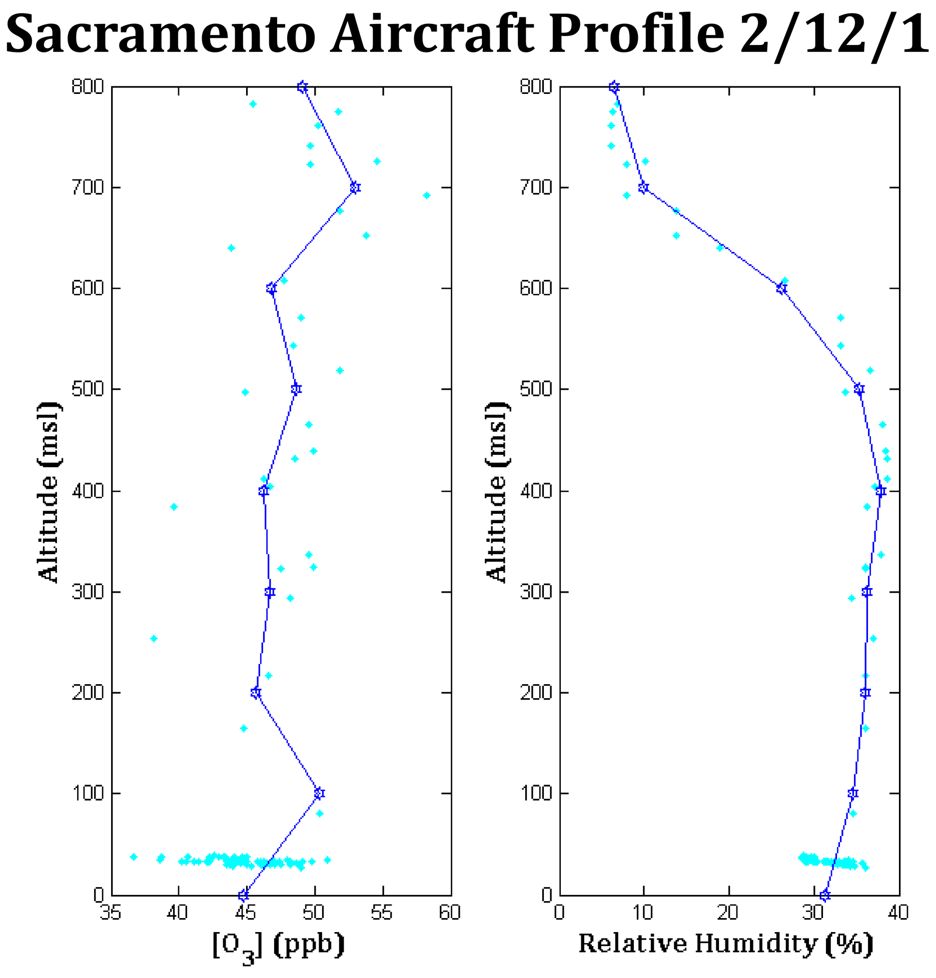
(🡅) **Figure 6.** UCD's airborne research group conducts regular flights using the instrumented Mooney TLS above. Equipped with three sample inlets and capable of measuring temperature, humidity, horizontal wind, ozone (O_3), carbon monoxide (CO), carbon dioxide (CO_2), this airplane has a range of nearly 1,000 nautical miles while delivering nearly 15 mpg and can remain airborne more than 5 hours. Burning 14 GPH, the Mooney consumes roughly 1/50th the fuel of a C-130.

Chico NOAA RASS Wind Profile



(🡅) **Figure 4.** 12:00-16:00 PST average profiler winds from the Chico NOAA RASS system during CalNex. Steady up-valley, southerly flow was observed in the atmospheric boundary layer (average depth ~2.2 km). The winds genlty veer with height until strongly veering to the geostrophic southwesterlies aloft. Strong shear at the top of the ABL most likely promotes entrainment over the Northern valley.

Sacramento Aircraft Profile 2/12/11



(🡅) **Figure 5.** Profile of the Sacramento boundary layer from UCD's airborne research platform (shown in figure 6). Flight conducted as part of the NOAA/ESRL Carbon Cycle Greenhouse Gasses Group (CCGG) aircraft monitoring program. These operations are performed monthly and include long transits and deep profiles from the Sacramento valley to the coast (THD). In addition to collecting whole air samples, the flights include continuous measurements of O_3, temperature, and humidity.

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FUTURE RESEARCH

- Refine the estimate of entrainment velocity using measurements of ABL growth rates with hourly profile flights during the afternoon.
- Once airborne, in-situ winds can be measured and flight tracks designed to measure upwind ozone gradients at multiple levels.
- Improve applicability of budget by carefully selecting flight days when ozone levels exceed relevant standards.