Synoptic to Microscale Meteorological Influences on Atmospheric Chemistry in Complex Terrain

September 26, 2019

Outline:

The Importance of ***Measuring Entrainment Mixing and Horizontal Advection*** (both rarely measured at supersite experiments). This involves highly focused *flight* planning for spending *a lot of time* in the same region upwind of the ground site (for budgeting.)

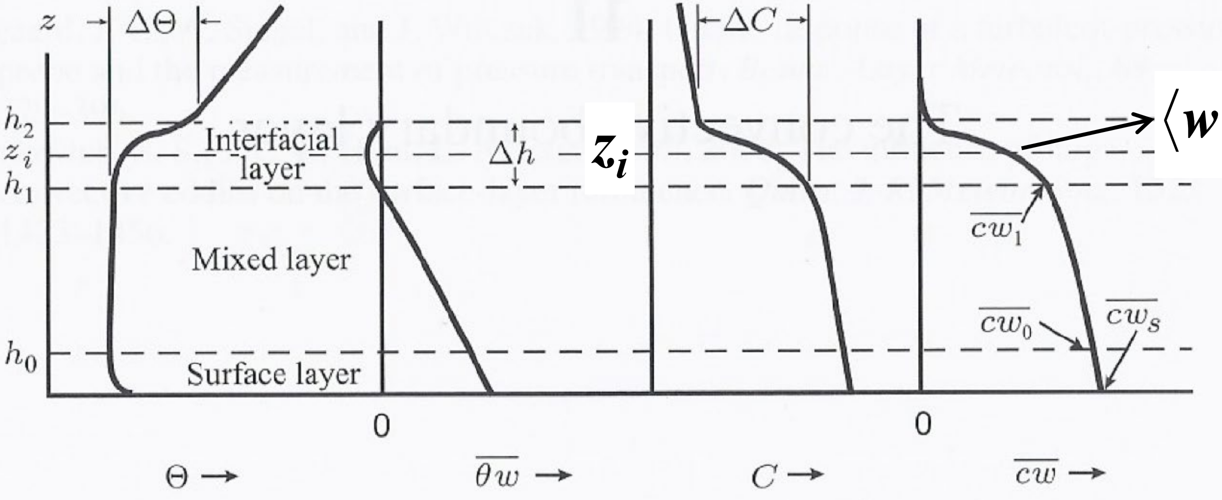
The utility of flight strategies that permit ***scalar budgeting*** (yielding emissions, heat fluxes, drag, entrainment mixing, advection, and subsidence on the "basin" or meso-scale.)

Mixing in complex terrain often involves a larger role of ***mean subsidence***, an atmospheric parameter, despite being a wind (the principal meteorological observable) that is not very often measured. My group is pioneering 2 separate ways to measure this critical parameter by aircraft: 1) budgeting z_i (solving for W), and 2) direct measure via Precise Point Positioning GPS technology and gust probe.

This type of budgeting can also be used to empirically measure the mixing rates, $\boldsymbol{K_z}$, of stable atmospheric layers as was done in the overnight study by Caputi et al. (2019)

The potential importance of agricultural ***soil*** $\boldsymbol{NO_x}$ on wintertime PM2.5 (e.g from M. Kleeman)

Scalar Budgets in a Turbulent Atmospheric Boundary Layer (ABL): A Mixed-Layer Model



$$\langle w'c'\rangle_{z_i} = w_e \Delta C$$

Readily Observable by Aircraft

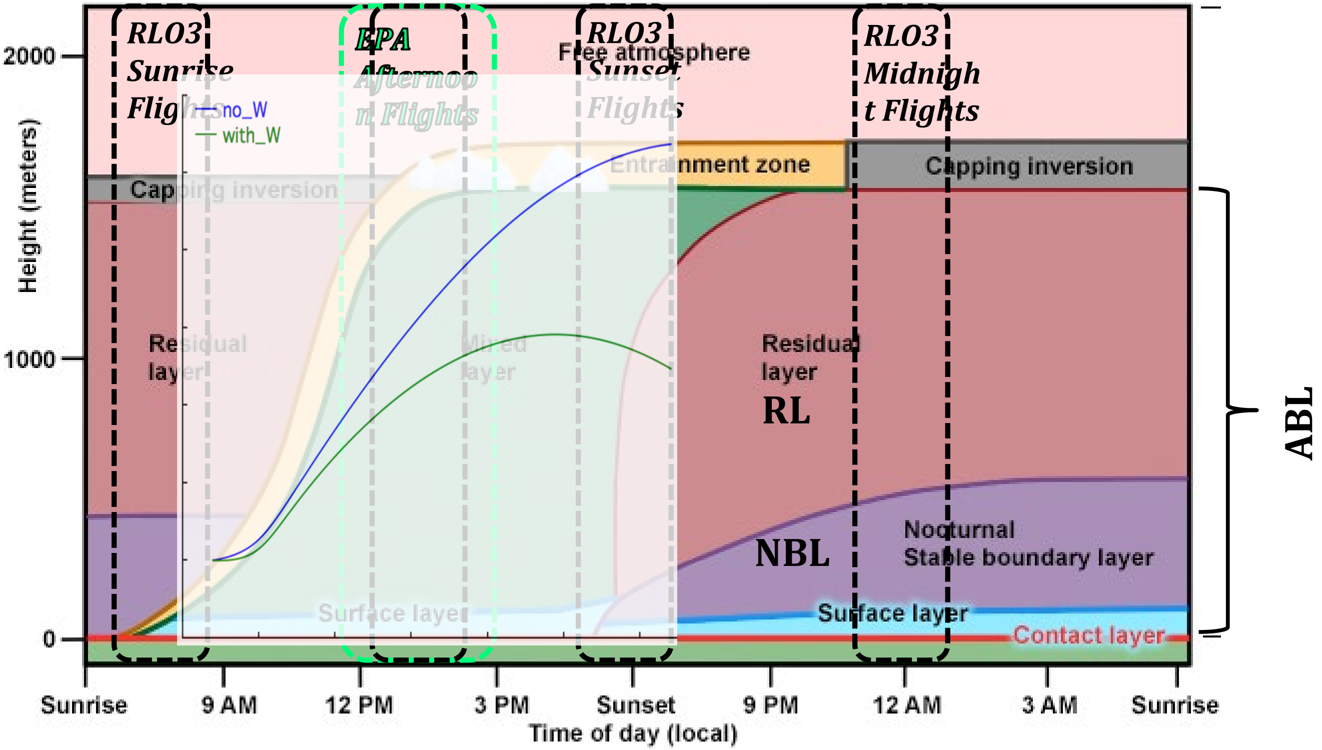
Figure 11.1 Sketches of profiles of mean quantities and their vertical fluxes in the CBL, with its layers, heights, and parameters indicated. Left pair: Virtual potential temperature and its flux. Right pair: A conserved scalar and its flux. From Deardorff (1979). ***source:*** *Wyngaard [2005]*

$$\frac{\partial C}{\partial t} = \frac{\langle w'c'\rangle_0 - \langle w'c'\rangle_{z_i}}{z_i} - U\frac{\partial C}{\partial x} + P_{net}$$

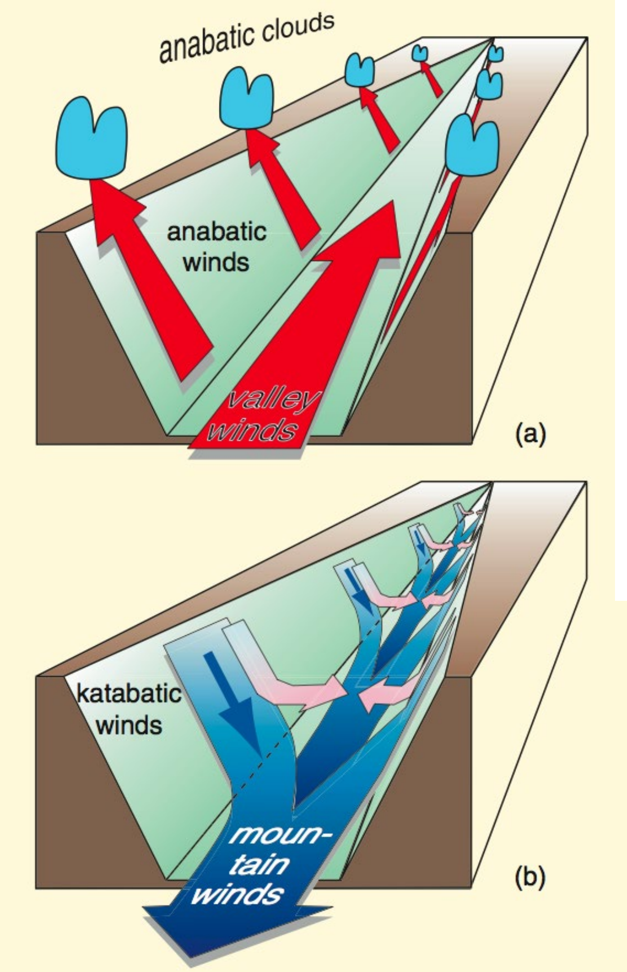
Entrainment velocities are estimated during the midday flights by measuring the growth rate and advection of z_i, but require a (WRF) model estimate of mean vertical wind, W, which can be a leading term in complex terrain.

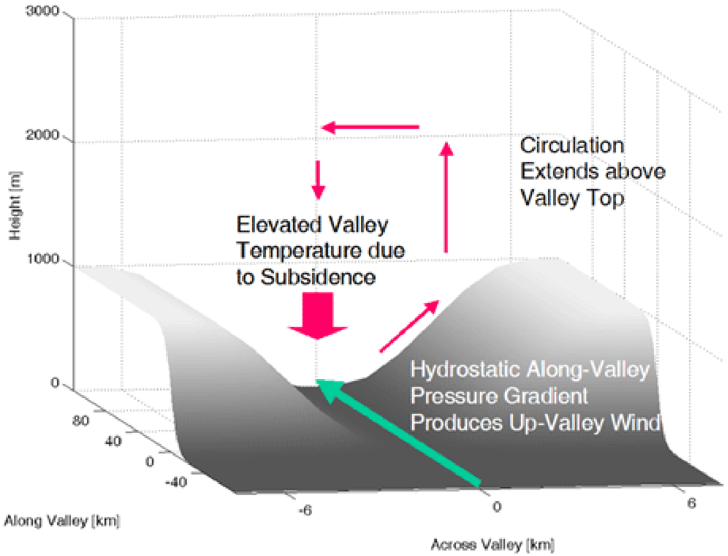
$$\frac{\partial z_i}{\partial t} = -U\frac{\partial z_i}{\partial x} + W + w_e$$

Average Obs (cm/s): 1.3 -0.3 -1.4 3.0, Avg. z_i = 550 m



Classical *daytime* valley-mountain circulation creates horizontal divergence inducing subsidence over the valley



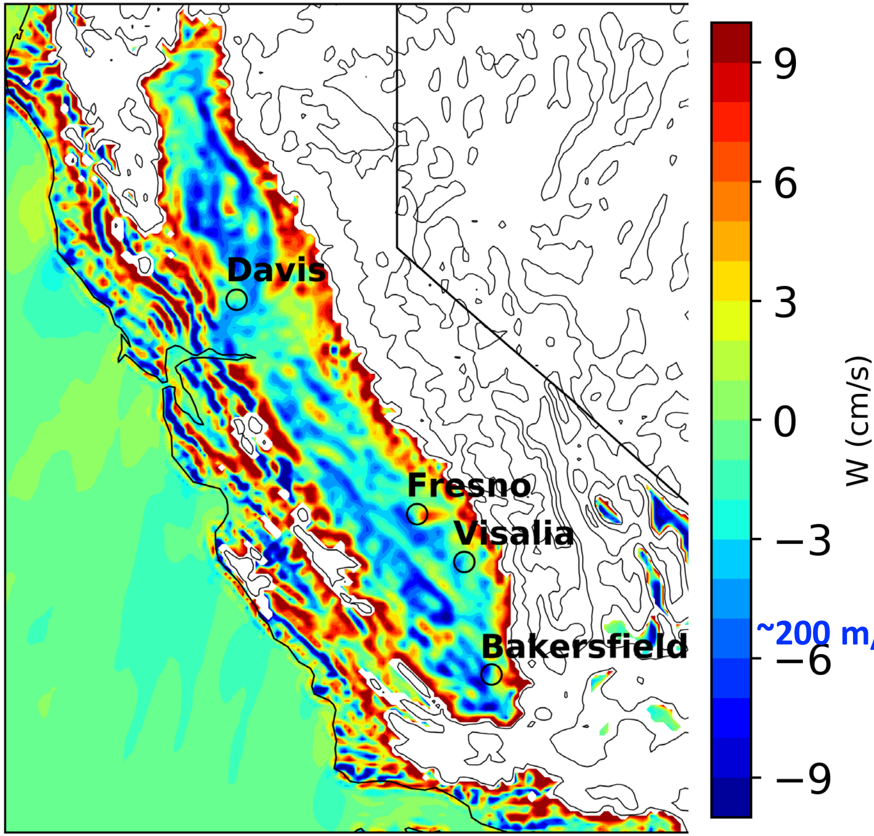


↑ from Schmidli & Rotunno [2010]

← from Wallace & Hobbs [2005]

(Mean) Vertical Motion at ABL top in the SJV: winter values are likely an order of magnitude smaller

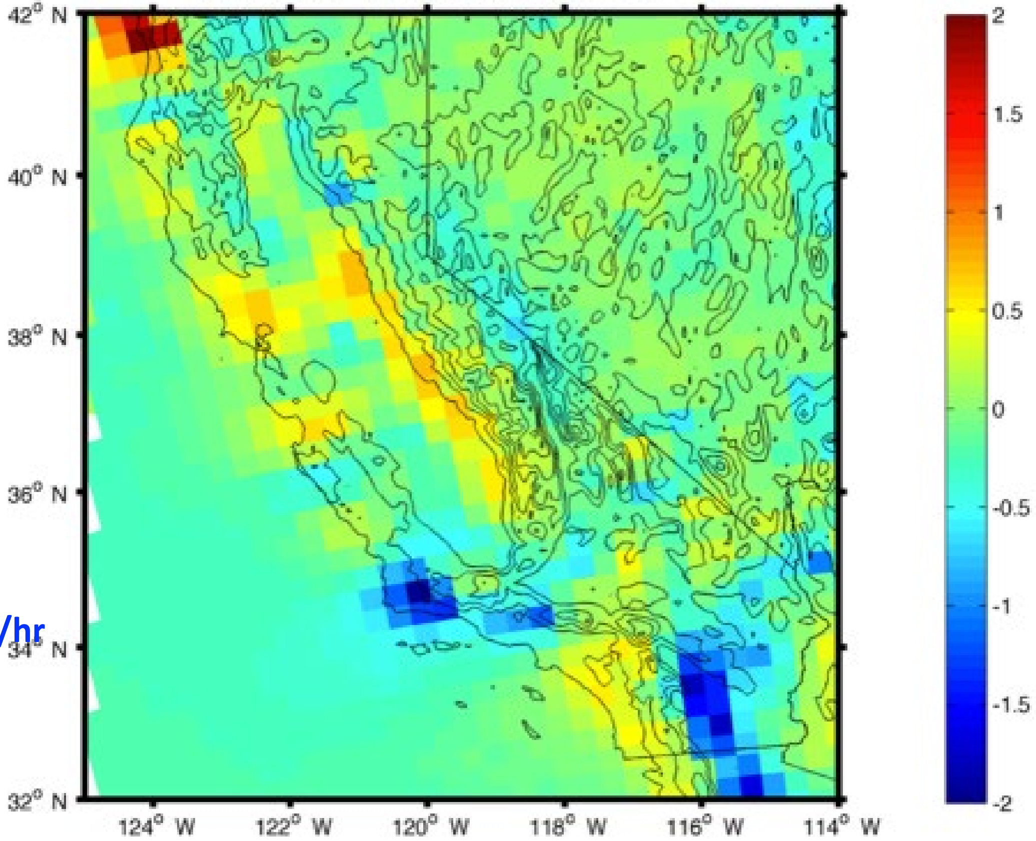
WRF 12:00-16:00 over 6 days Jul/Aug 2016



~200 m/hr

↑ from Caputi et al., in prep

NARR *W* (cm s^{-1}) Jan–Feb 2004–2013

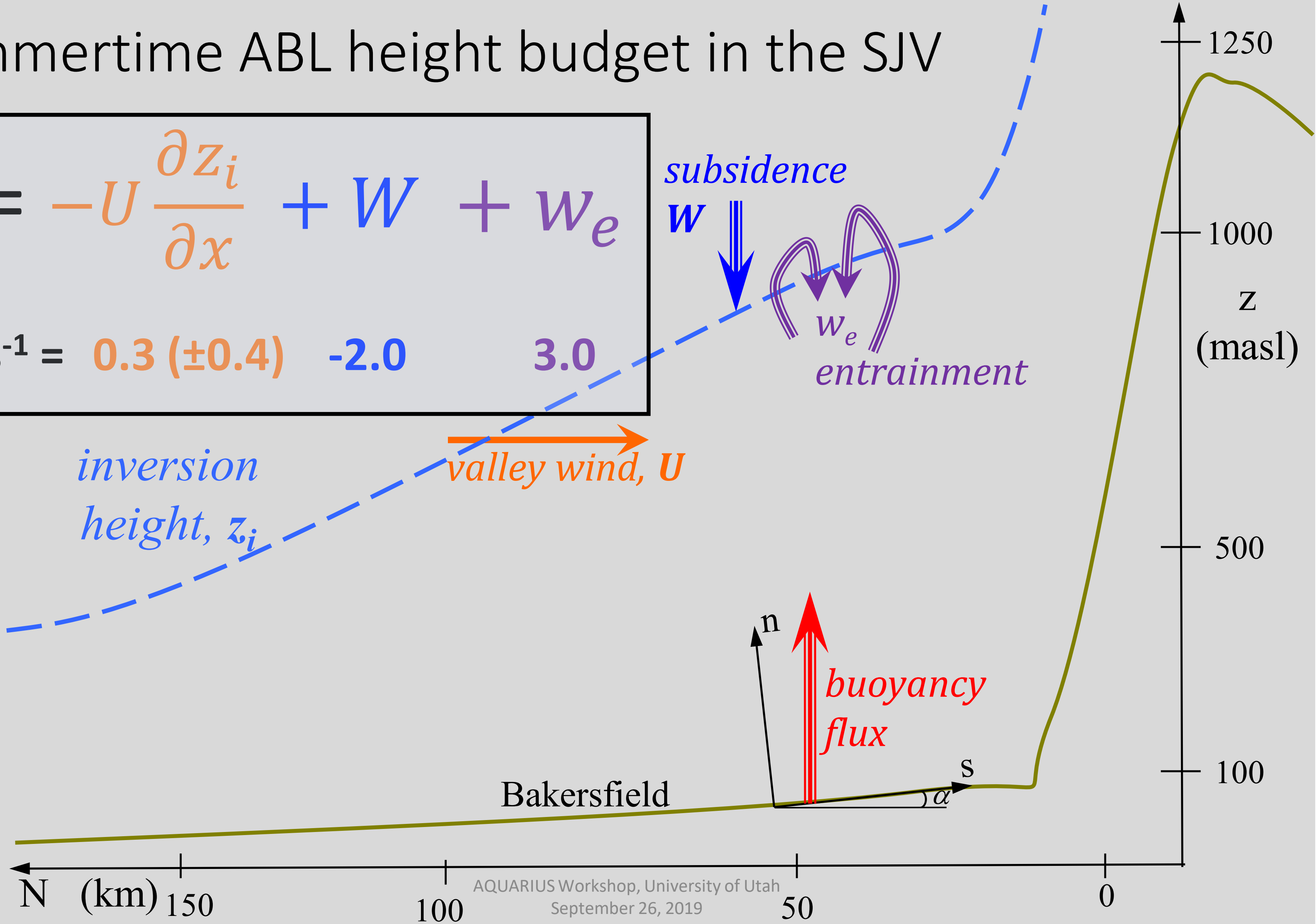


↑ from Trousdell et al., ACP, 2016

Summertime ABL height budget in the SJV

$$\frac{\partial z_i}{\partial t} = -U\frac{\partial z_i}{\partial x} + W + w_e$$

1.3 cms^{-1} = 0.3 (±0.4) -2.0 3.0



Relative importance of afternoon entrainment to dominant term of each scalar budget

$$\frac{\partial C}{\partial t} = \frac{w_e \Delta C - F_0}{z_i} - U\frac{\partial C}{\partial x} \pm P_{chem}$$

'storage'

emission/
dry deposition

(net) chemical
loss/production

entrainment

(horiz.) advection

Scalar, *C*	Ent. Fraction	Leading Budget Term (avg. value)
Ozone, O_3	-0.10	Photochemical Production (6.7 ppb/h summer; 2.8 ppb/h winter))
NO_x	-0.15	Surface Emissions (220 tons/day)
Methane, CH_4	-0.90	Surface Emissions (440 Gg/yr)
Water, q	-0.75	Surface evapotranspiration (125 Wm^{-2})
Potential Temp, θ	0.20 (±0.13)	Surface sensible heat flux (190 Wm^{-2})

***source**: Trousdell et al., ACP, 2019*

Aircraft budgeting used to quantify mixing rates, K_z, in stable nighttime conditions

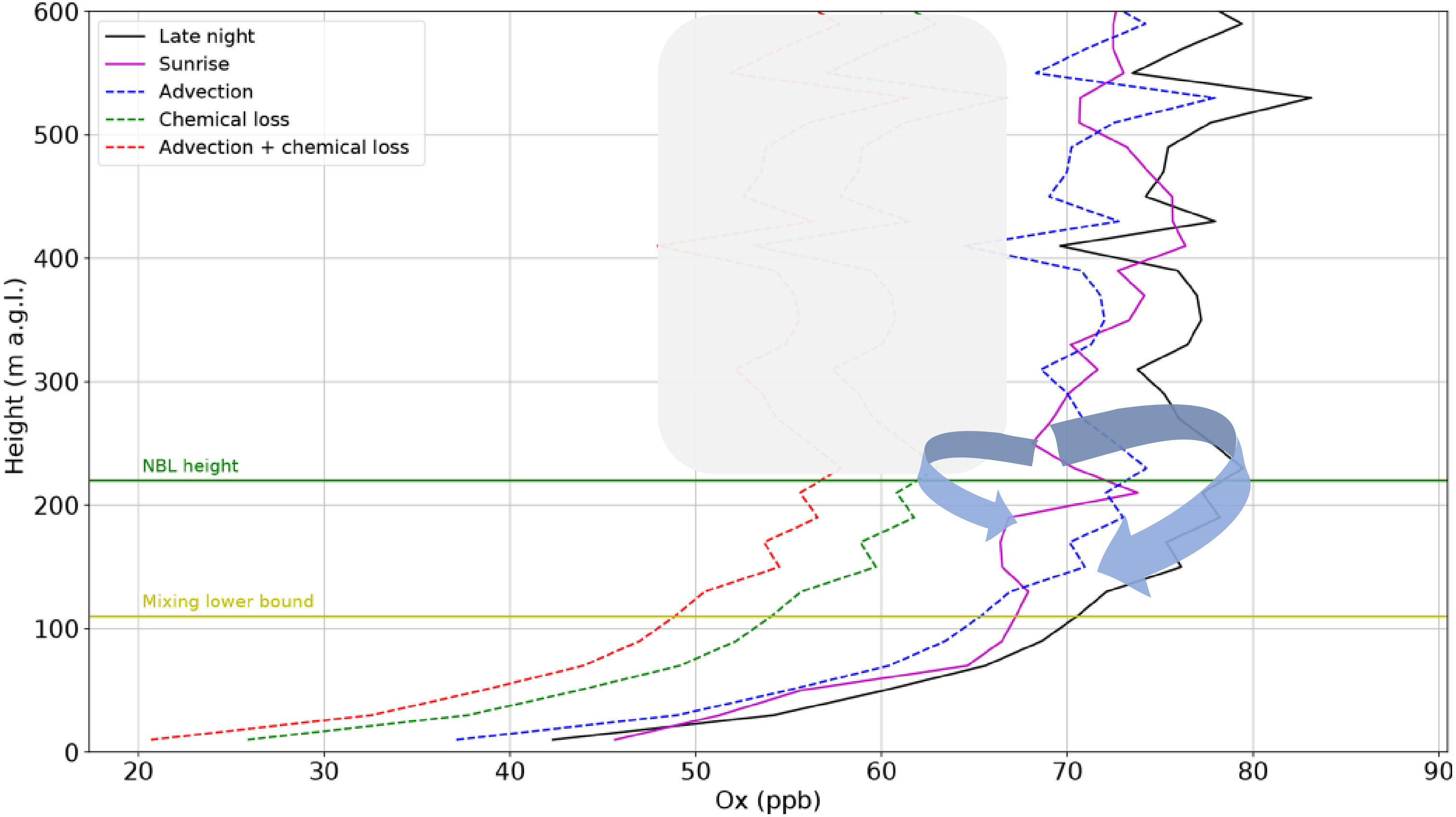


Figure 6. O_x profiles from 4 June 2016 overnight analysis, NBL height (green line), and lower bound to vertical mixing gradient (yellow line). The solid lines are observations and the dashed lines are calculated based on expected changes due to horizontal advection (blue), chemical loss (green), and the sum of the two (red).

source: Caputi et al., ACP, 2019

Focusing on our work in more stable conditions we have experience from DISCOVER-AQ and nocturnal boundary layers in the summertime

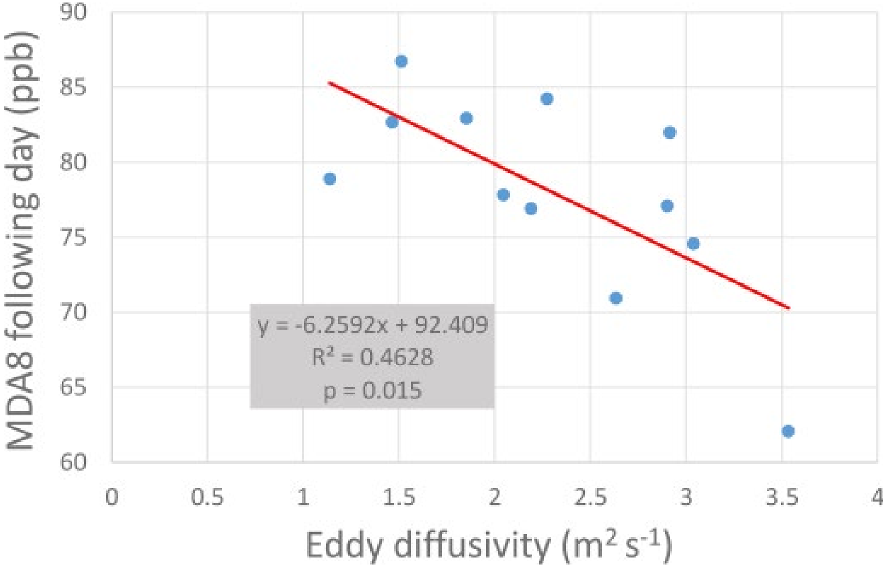
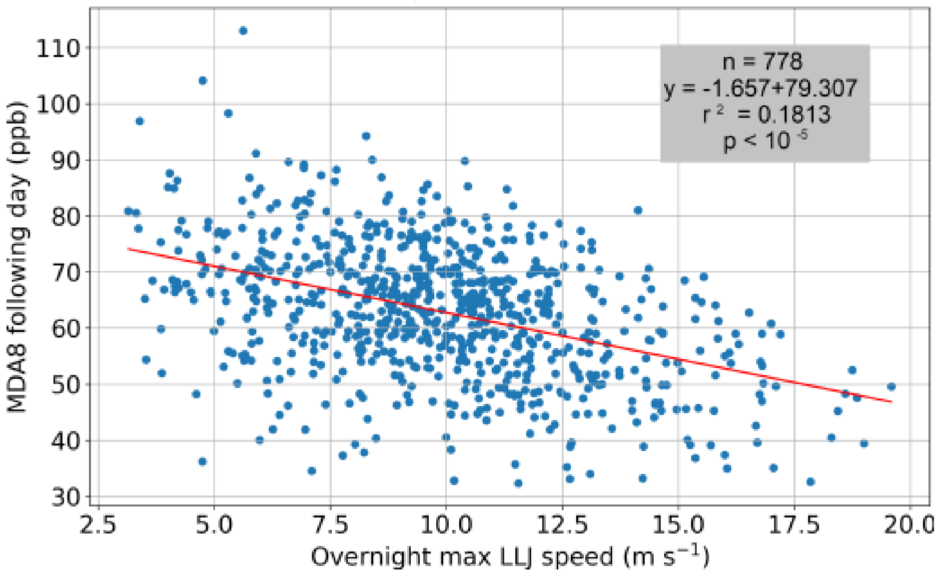


Figure 10. Correlation between overnight eddy diffusivity and maximum daily 8 h average ozone (MDA8) the following day. All values are averages of 11 CARB surface network stations that are within the flight region.

⇦ 15 paired flights of this overnight study

D. J. Caputi et al.: Residual Layer Ozone Mixing

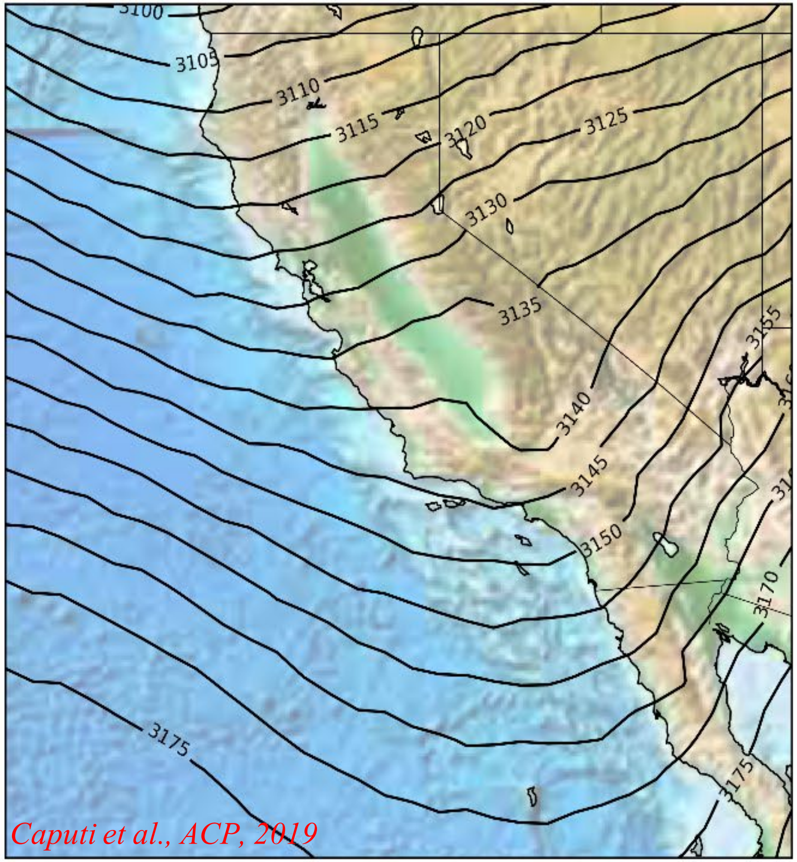


7-year climatology of LLJ & [O_3] ⇨

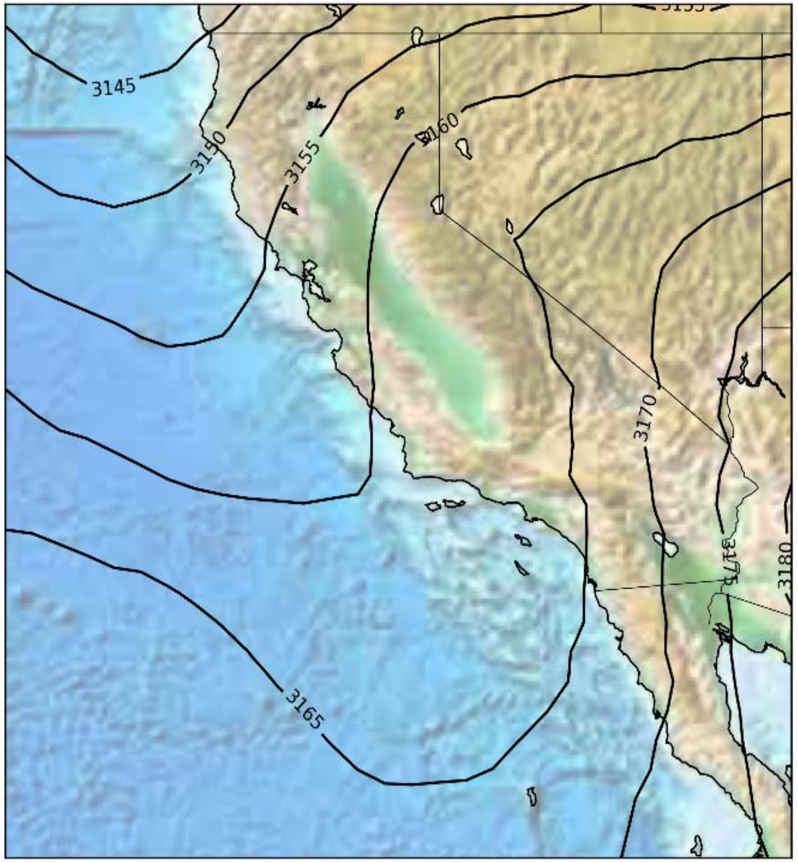
Figure 11. Correlation between nocturnal low-level jet speed and the following day's MDA8 in Visalia, CA, for calendar days 152–273 from 2010 to 2016.

Looking for synoptic conditions that promote the LLJ and thus enhance overnight removal of O_3

Strong LLJ (U>12 m/s)

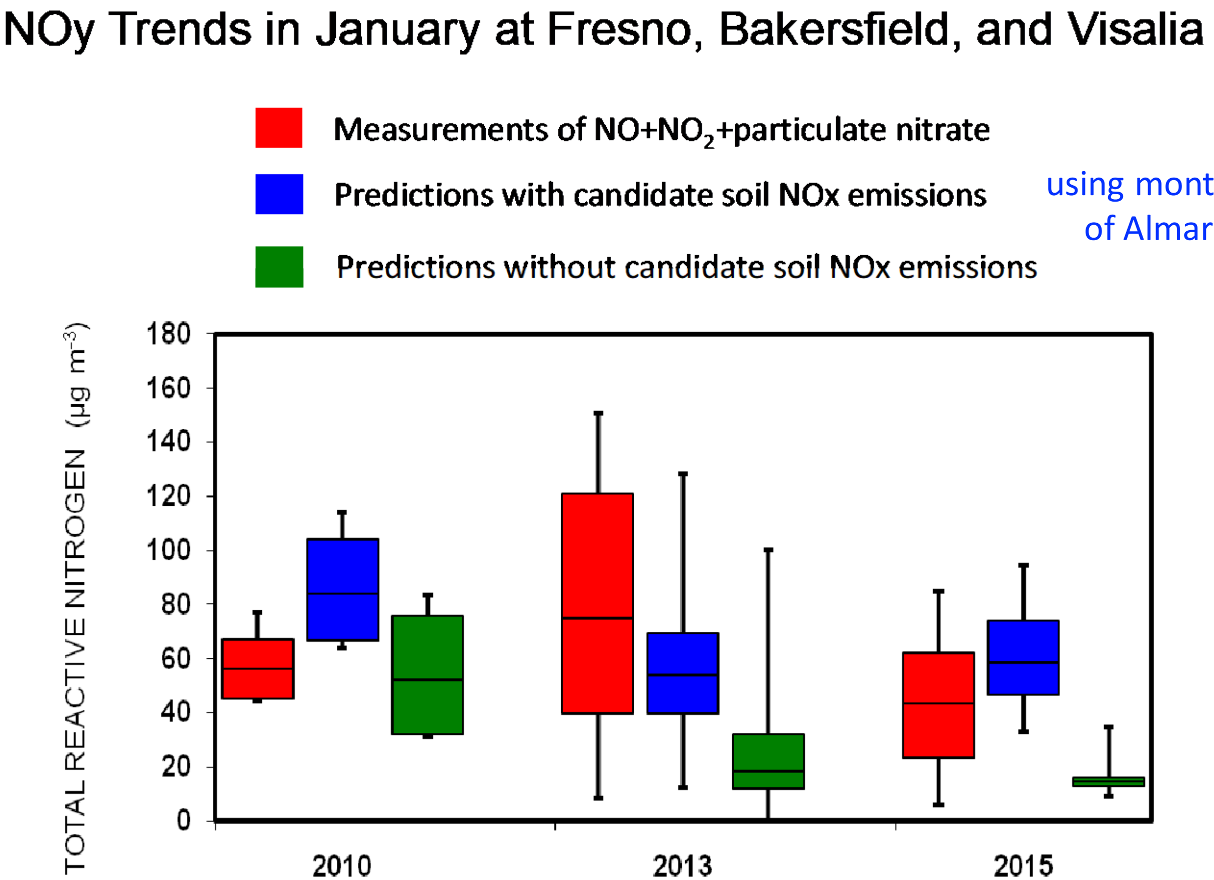


Weak LLJ (U<7 m/s)



source: *Caputi et al., ACP, 2019*

Results of wintertime PM modeling by M. Kleeman



using monthly model results of Almaraz et al. (2018)

Source:
https://ww3.arb.ca.gov/research/seminars/seminars.htm

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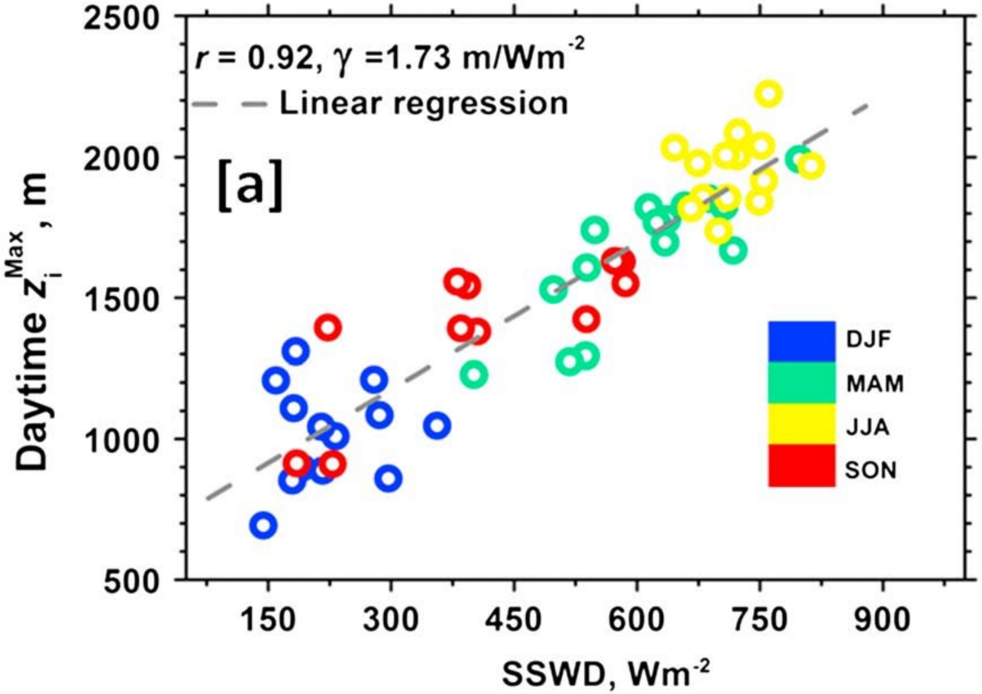
Charge from steering committee: *critical needs for future aircraft/ground study focused on wintertime air quality in Western mountain basins*

Critical Observations:

- Careful measurement of (mesoscale **horizontal) advection**. Perfect for small aircraft.
- Measurement of **boundary layer height budget** (including **entrainment** and **subsidence** and **growth rates**). Also perfect for small aircraft.
- Measurements of regional fluxes to connect point precision of a tower to regional averages (key to forcing of regional models)
- **Mixing rates in stable layers** (can be done with careful budgeting techniques in large or small aircraft, but low altitudes of interest may favor small aircraft.)
- **Soil NO_x** emissions (maximum likely in midday high T, but still possibly significant in winter)

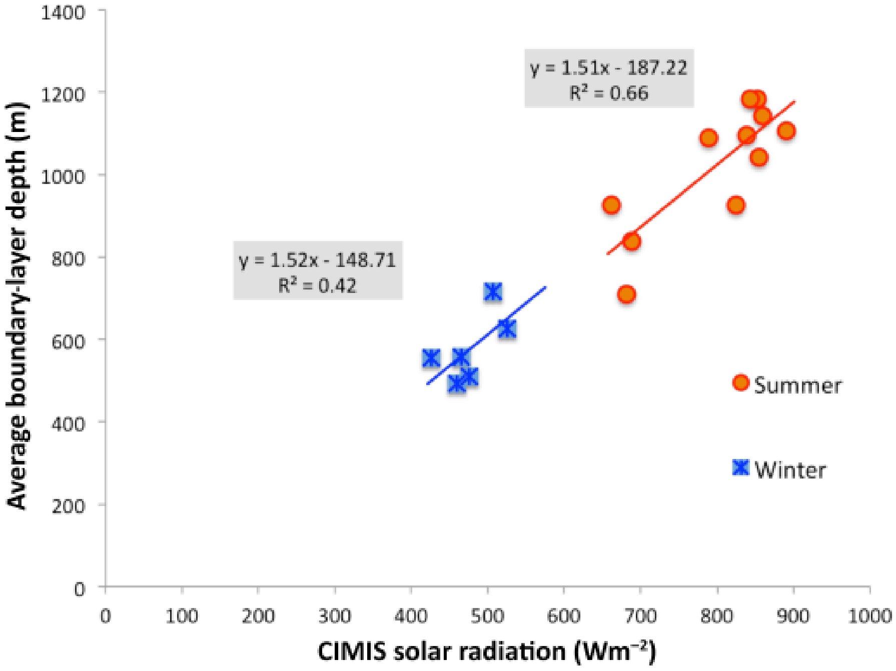
Surface Shortwave Downwelling Radiation & ABL Heights

SIRTA Observatory near Paris



source: Pal & Haeffelin, JGR, 2015

Airborne Observations in SJV



source: Trousdell et al., ACP, 2019