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Ozone Laminae and Their Entrainment Into a Valley Boundary Layer, as Observed From a Mountaintop Monitoring Station, Ozonesondes, and Aircraft Over California's San Joaquin Valley

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Introduction

The San Joaquin Valley (SJV) of California is wide (~75 km) and long (~400 km), and is situated under strong atmospheric subsidence due, in part, to the proximity of the midlatitude anticyclone of the Pacific High. The capping effect of this subsidence is especially prominent during the warm season when ground level ozone is a serious air quality concern. While relatively clean marine boundary layer air is primarily funneled into the valley below the strong subsidence inversion at significant gaps in the Coast Range mountains, airflow aloft also mixes into the valley from above. Because this trans-mountain flow occurs under the influence of synoptic (and mesoscale) subsidence it tends to present discrete, laminar sheets of differing air composition above the valley boundary layer. Meanwhile, although the atmospheric boundary layers (ABL) tend to remain shallow due to the prevailing subsidence (W), orographic and anabatic venting of valley boundary layer air around the basin whips up a complex admixture of regional air masses into a "buffer layer" just above the boundary layer (z_i) and below the lower free troposphere. This complex airmass is then entrained into the ABL.

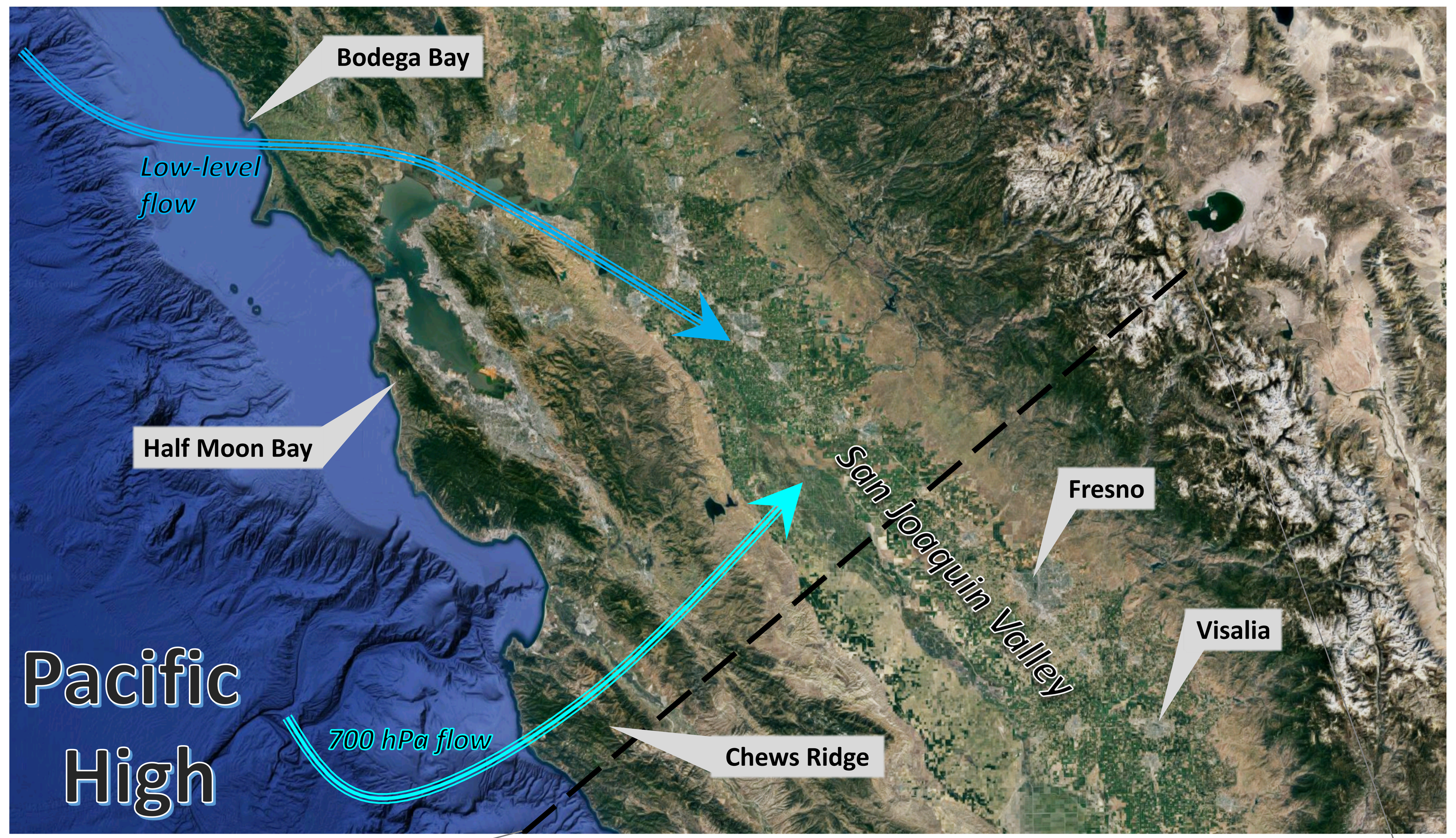

Figure 1. Geography of the study region across Northern California showing the northwesterly low level airflow in through the gaps in the coastal mountains and the southwesterly flow over the mountains atop the valley.

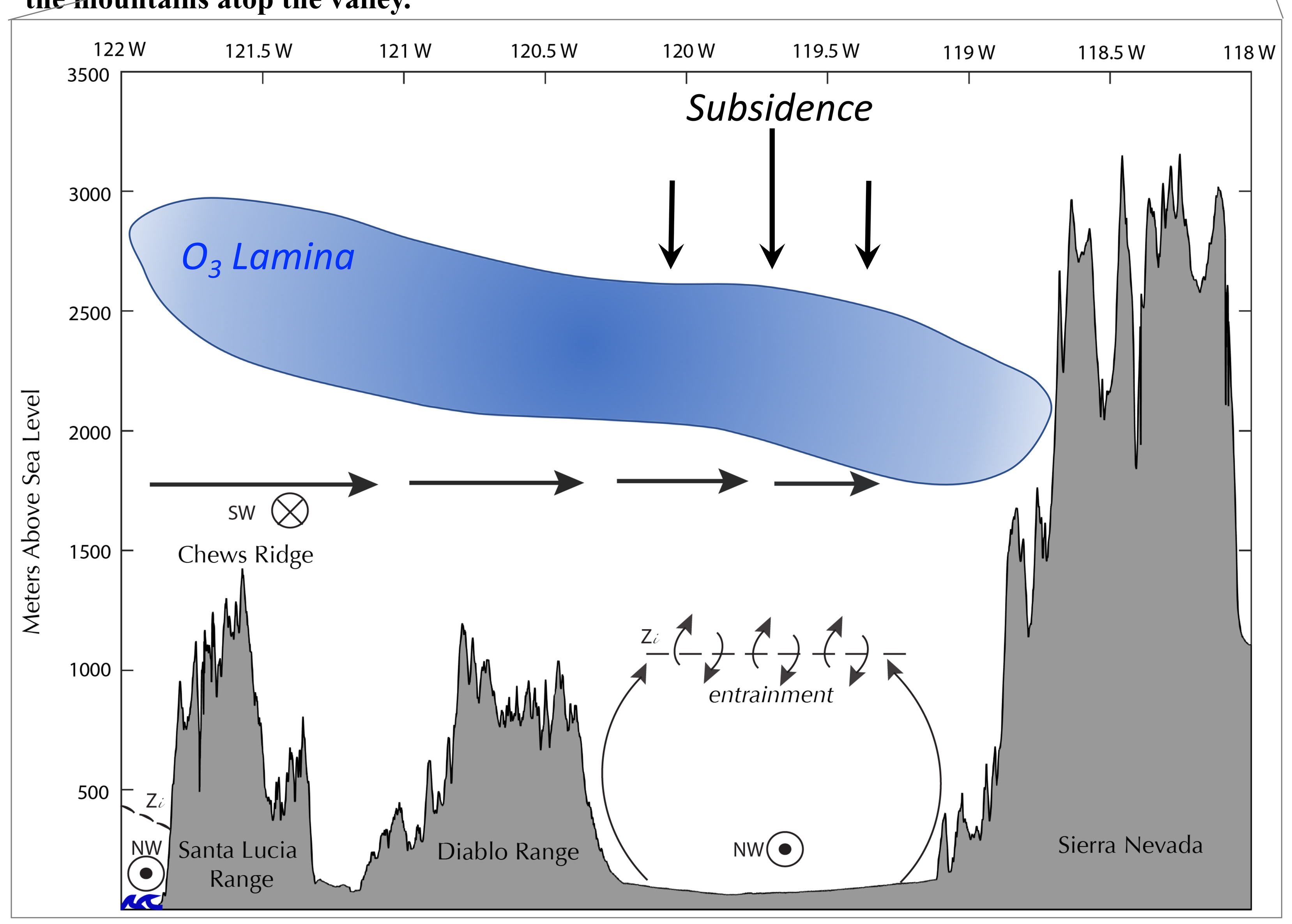

Figure 2. Vertical cross-section across the transverse axis of the San Joaquin Valley.

Lower Free Tropospheric Correlations

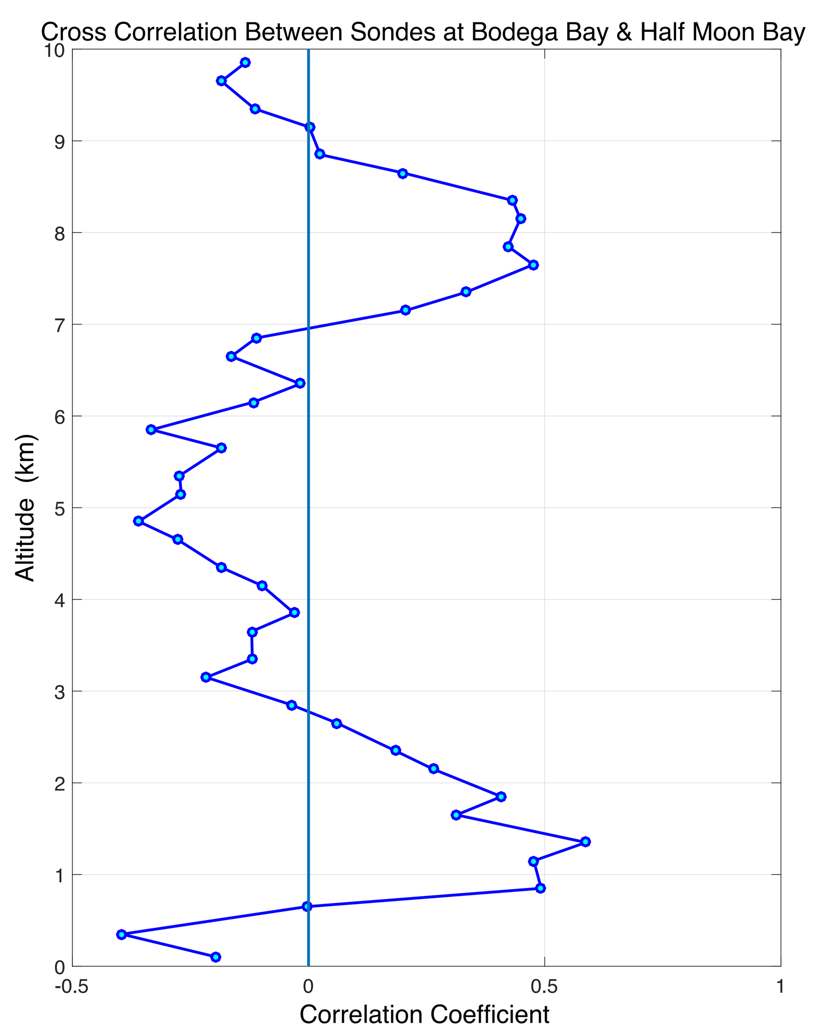

Figure 3. Correlations among simultaneous O_3-Sondes 110 km apart along the California coastline.

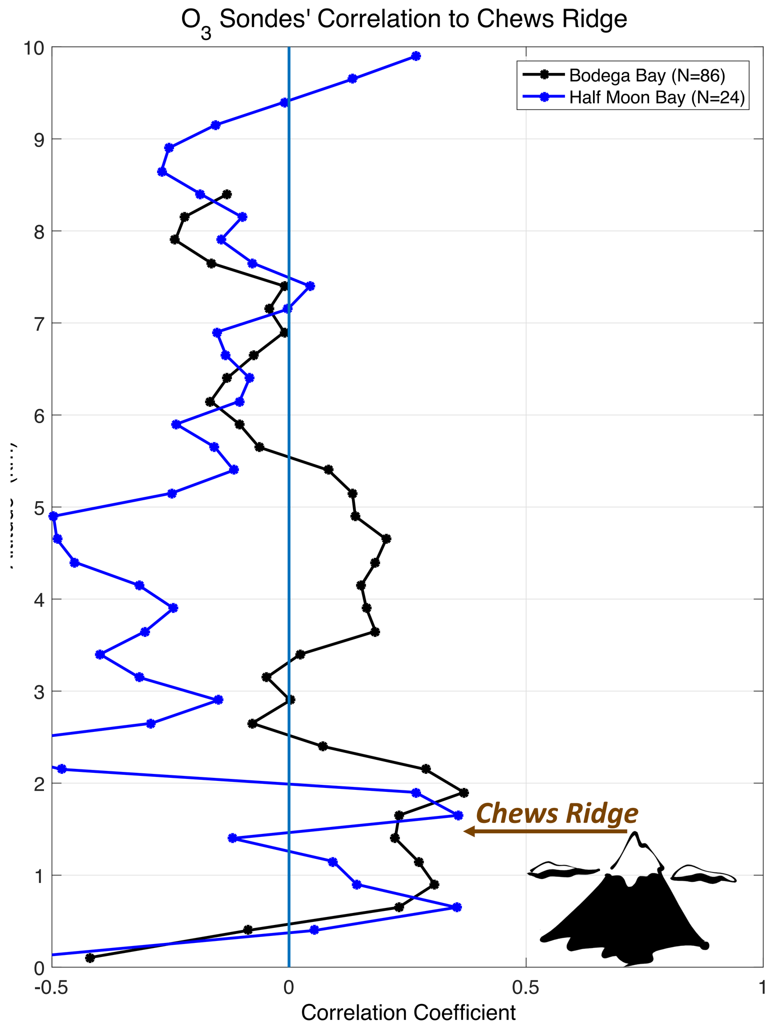

Figure 4. Correlations of O_3-Sondes and Chews Ridge (1550 m asl) 145 km south.

Vertical Structure Within the Valley

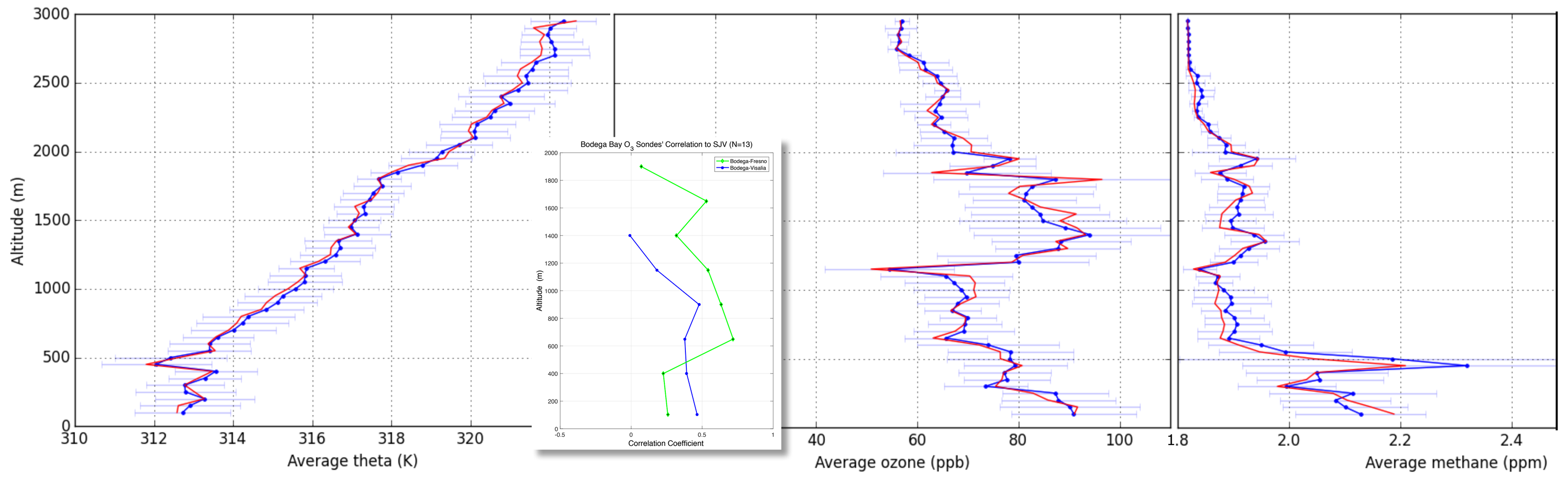

Figure 5. Mean (blue) and median (red) profiles of potential temperature, ozone, and methane for the afternoon (12:00-16:00 PST) of 29-Jul-2016. Inset illustrates the correlations between all flight data collected within 20 km of Fresno & Visalia 6-12 hours after the daily O_3 sonde launch at Bodega Bay.

Profiles of scalars over the SJV show a complex layering structure similar to a 'buffer' or 'cloud' layer discussed in the literature (Russell et al., 1998). Unlike a traditional buffer layer which is generated by trade wind cumulus convection, the air (up to ~2.5 km) above the valley is lofted there due to the slope (anabatic) venting from diurnal heating in the absence of clouds. This valley buffer layer comes under the influence of the mesoscale valley subsidence, and represents a longer time-scale (~1d), vertical recirculation of the valley air. The layer also appears to be influenced by inflow aloft (Fig. 5 inset).

Proposal for Measuring Subsidence, W

Subsidence is of such critical importance to the dispersion of the ozone laminae and the development of the valley boundary layer, and yet it evades direct measurement (Lenschow et al., 1999). Furthermore, it has a very heterogeneous pattern in the complex terrain of the San Joaquin Valley (SJV). We propose an airborne technique for measuring subsidence at the top of the boundary layer based on a budget equation of z_i:

$$W_{z_i} = \frac{\partial z_i}{\partial t} + U\frac{\partial z_i}{\partial x} - w_e\,, \qquad w_e = \frac{\overline{w'c'}}{\Delta C}$$

With the upcoming installation of a gust probe (Aventech Research Inc., AIMMS-30) on the Scientific Aviation aircraft, we will be able to measure entrainment by the eddy covariance flux-jump method (equation on right) for scalars such as water and methane. In conjunction with simultaneous measurements of the ABL growth rate and advection, subsidence can be determined by the (left) equation above.

Valley Entrainment

Project	Date	Location	ABL Growth Rate $\partial z_i/\partial t$ (cm/s)	Subsidence W (cm/s)	O_3 Photochemical Production (ppb/hr)	Entrainment Velocity w_e (cm/s)
DISCOVER-AQ (Trousdell et al., 2016)	Jan-Feb, 2013	Fresno	1.5 (1.0)	-0.8 (1.1)	2.8 (0.7)	1.5 (0.9)
ArvinO3 (Trousdell et al., 2016)	Jun-Sep, 2013/14	Bakersfield	3.0 (1.2)	1.2 (0.9)	8.2 (3.1)	3.0 (2.1)
CABOTS	Jul-Aug, 2016	Fresno/ Visalia	2.0 (1.2)	-2.3 (0.5)	7.8 (4.7)	4.3 (0.9)
CABERNET (Karl et al., 2013)	May, 2011	SJV & Sierra Foothills	NA	NA	NA	1.4, 5.5, 9.6
Averages			2.2	-1.9	6.3	3.6

Table 1. Entrainment velocities observed over the SJV from 4 separate experiments.

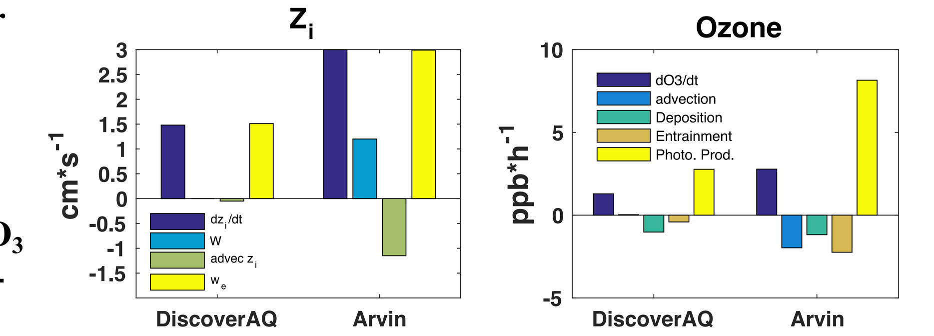

Figure 6. Individual budget terms for z_i and O_3 from the flight mission averages for Discover-AQ and Arvin (Trousdell et al., 2016).

Valley Subsidence

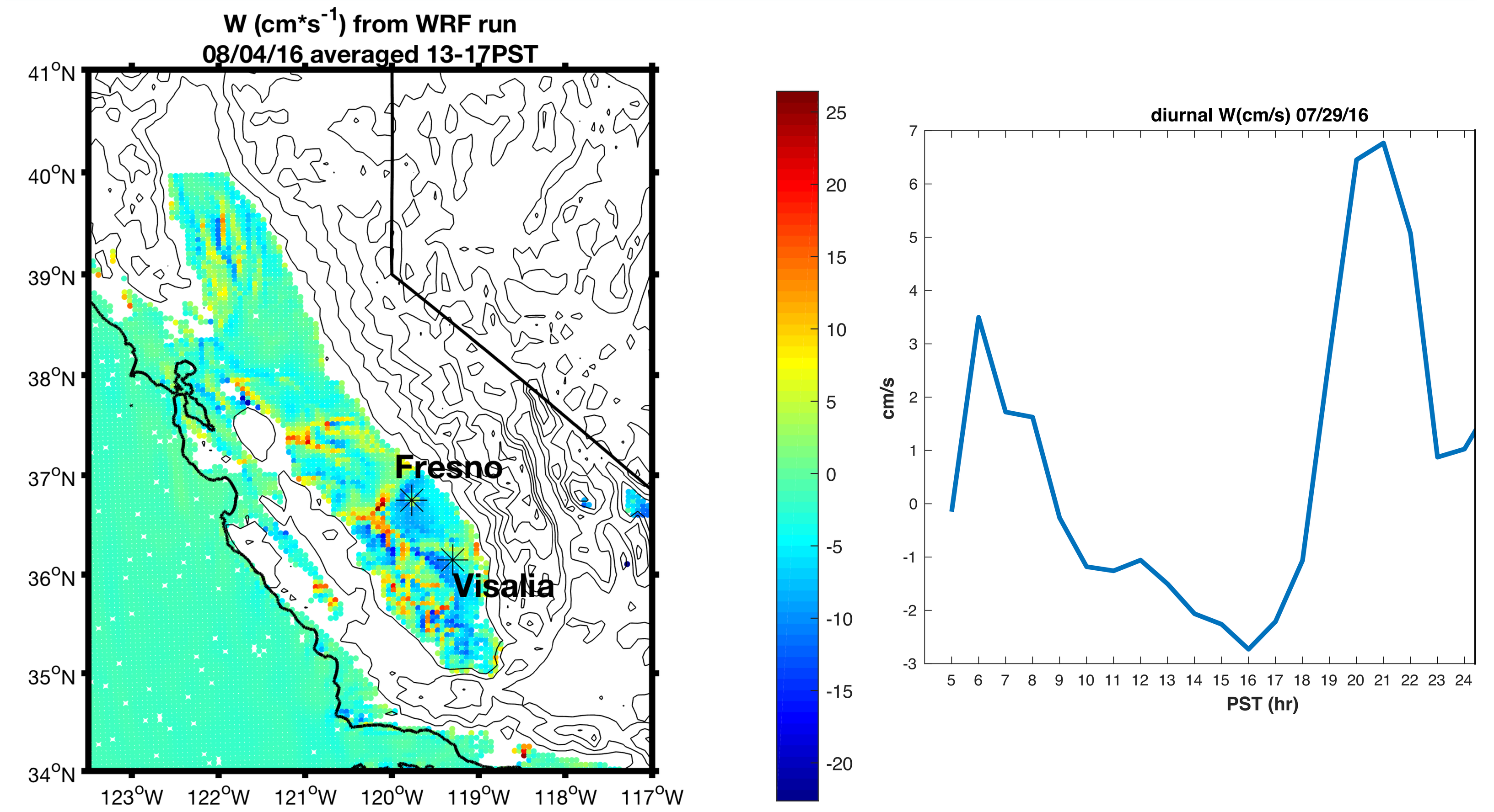

Figure 7. WRF modeled afternoon subsidence rates across California from 4-Aug-2016 (left), and the diurnal average for the region between Fresno & Visalia from 29-Jul-2016 (right) during the California Baseline Ozone Transport Study (CABOTS). (Courtesy S.-H. Chen)

Conclusions

- **Daily O_3-sondes along the coast show broad (~100s km), but layered correlations among themselves and at levels just above the valley ABL in the SJV.**
- **The inflow over the mountains mixes with air that is lofted along the valley sidewalls during the daytime to create a 'buffer layer' above the valley.**
- **The buffer layer is pushed downward during the daytime due to mesoscale subsidence, and is then entrained into the ABL. Several measurements of the entrainment velocity in the SJV are all concordant between 1.5 to 9.5 cm/s.**

References

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