Persistent Cold-Air Pools and Particulate Pollution: Meteorological Processes Modulating Pollution Concentrations in Utah's Salt Lake Valley

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Introduction

The Salt Lake Valley (SLV, **Fig. 1**) and other densely populated topographic basins in northern Utah and throughout the world suffer from prolonged pollution episodes during wintertime that are associated with Persistent Cold Air Pools (PCAPs). PCAPs develop when high-pressure systems and subsidence temperature inversions trap colder air and anthropogenic emissions in topographic basins (**Fig. 2**). This poster addresses the evolution of PCAPs and illustrates feedbacks between meteorological and chemical processes in PCAPs in the SLV.

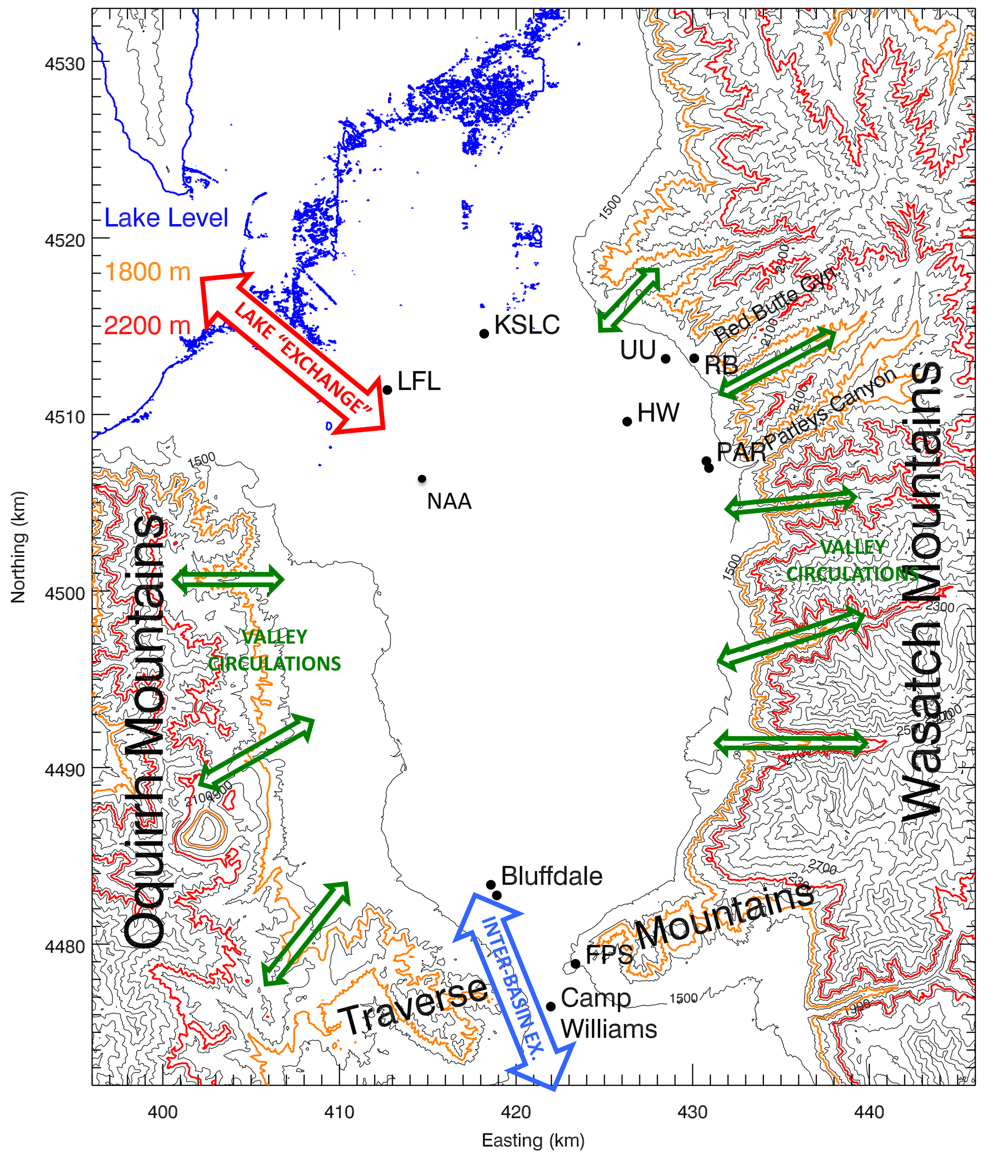

Fig. 1: Topographic map of the Salt Lake Valley and selected observational sites from past field campaigns.

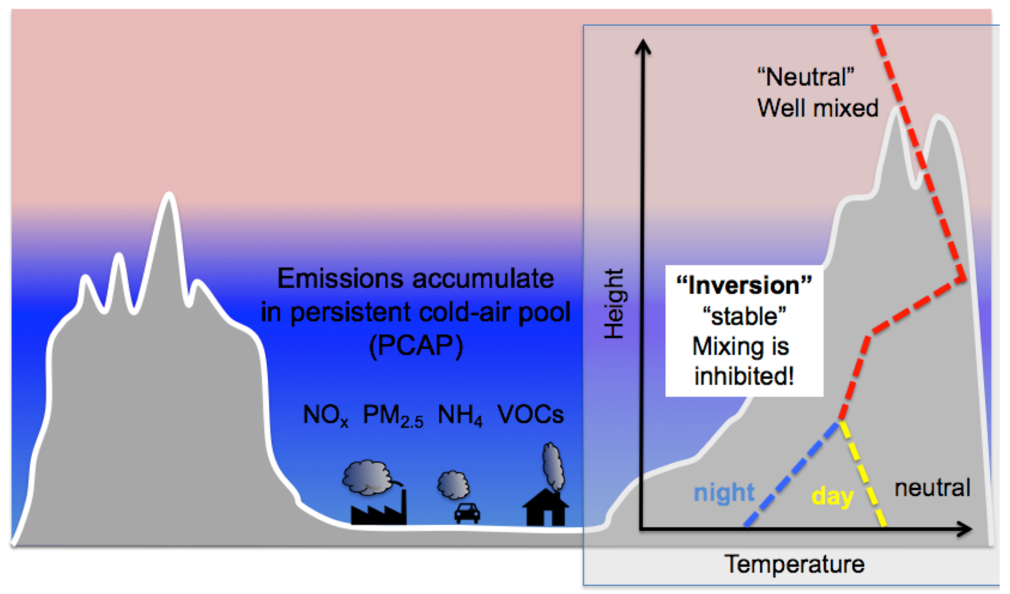

Fig. 2: A simplified schematic of a "clear," i.e. cloud-free Persistent Cold-Air Pool (PCAP).

Cold-Air Pool "Exchange Processes"

While atmospheric mixing and transport processes are generally suppressed under the statically stable atmospheric conditions of PCAPs, some thermally and synoptically driven processes still work to modulate particulate pollutant ($PM_{2.5}$, NH_4NO_3) and pollutant precursor (NH_3, NO_X, etc.) concentrations within and along the edges of the PCAPs.

For the SLV, these processes include (1) **canyon circulations** through tributaries, (2) **lake breeze circulations** from the Great Salt Lake (GSL), (3) **synoptically forced airmass exchanges** with the atmosphere over the GSL, and (4) **inter-basin exchanges** between the Utah Valley and Salt Lake Valley (see accompanying poster).

The Valley Heat Deficit

Under PCAP conditions the diurnal heating is not sufficient to couple the surface boundary layer to the free atmosphere, thus trapping pollution and precursors in a shallow near-surface layer. The Valley Heat Deficit *H* (Whiteman et al. 2014) is a thermo-dynamic measure of the intensity or strength of a cold-air pool, corresponding to the amount of energy that would be needed to bring a valley or basin atmosphere to a neutral stratification. There is a clear correlation between the Valley Heat Deficit and levels of particulate pollution (**Fig. 3**).

$$H_h = c_p \int_{1288\ \mathrm{m}}^{h} \rho(z)[\theta_h - \theta(z)]\mathrm{d}z \quad [\mathrm{J\ m^{-2}}]$$

The Valley Heat Deficit can be calculated from twice-daily radiosonde ascents from the Salt Lake International Airport (KSLC).

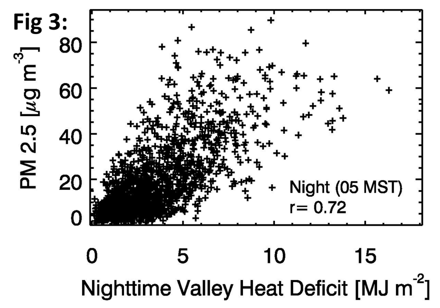

Fig. 4 illustrates the evolution of atmospheric stability, the valley heat deficit $PM_{2.5}$ concentrations at the valley floor (DAQ Hawthorne site, HW), for the 2015-2016 winter season.

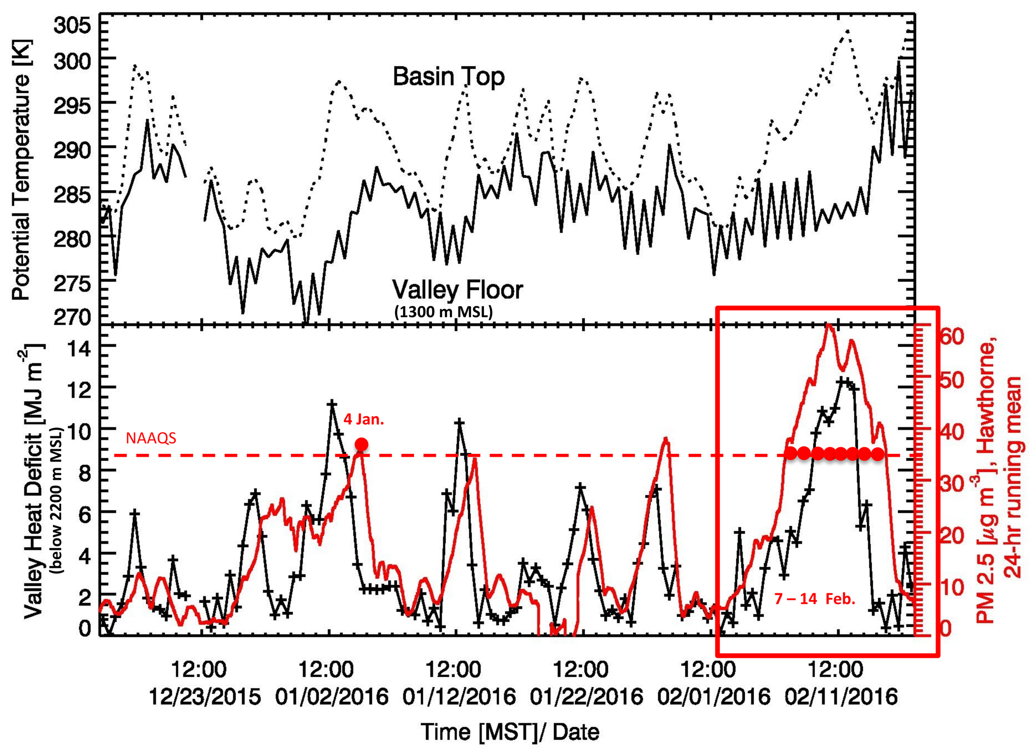

Fig 4: Time series of SLV basin top and base potential temperatures, the valley heat deficit to 2200 m MSL, and a smoothed time series of $PM_{2.5}$ concentrations from the valley floor, for the 2015-2016 winter season, including the intense 2-14 Feb. 2016 episode.

Cold-Air Pool Evolution

Under PCAP conditions, pollutants and pollutant precursors accumulate. Typically, the SLV sees an increase of $PM_{2.5}$ concentrations of 10-15 μg/m³ per day.

However, not every PCAP develops in the same way. Depending on many factors, such as surface snow cover, mid-level cloudiness, and thermal gradients between the SLV and the Great Salt Lake, different thermal structures can develop, greatly affecting the type and strength, and temporal and spatial extent of mixing processes that can modulate pollution concentrations. **Fig. 5** illustrates the build-up of particulate pollution in the SLV during the 2-14 Feb. 2016 pollution episode in relation to incoming shortwave (solar) and longwave (thermal) radiation.

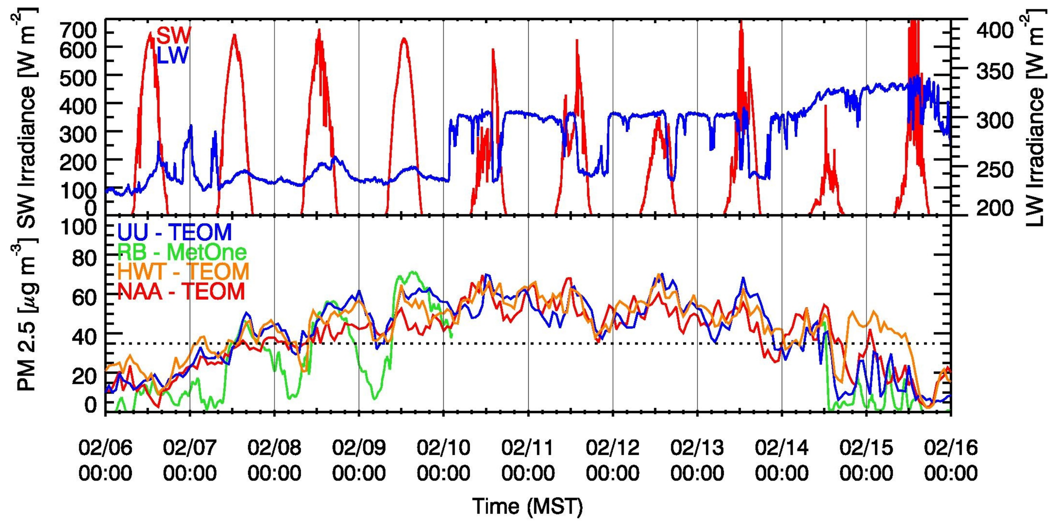

Fig 5: Surface radiative fluxes and pollution buildup during the 2-14 February 2016 pollution episode In the SLV.

Cold-Air Pool Structure

Fig 5. also shows a typical transition often observed in the SLV, where the PCAP becomes saturated and transforms from a "clear" to a "foggy/cloudy" PCAP. This transition has strong implications on the PCAP thermal structure, as illustrated in **Figs. 6 and 7**.

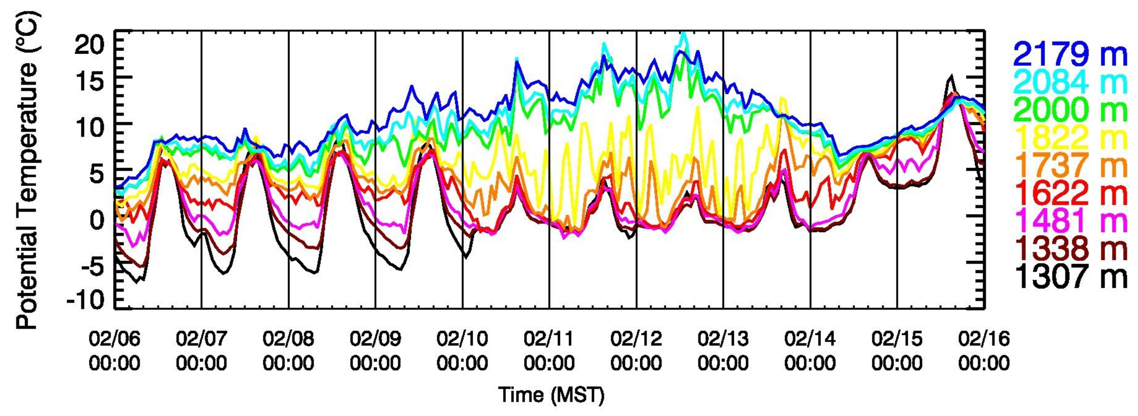

Fig. 6: Time series of potential temperatures along a pseudo-vertical transect in the SLV during the 2-14 February 2016 pollution episode.

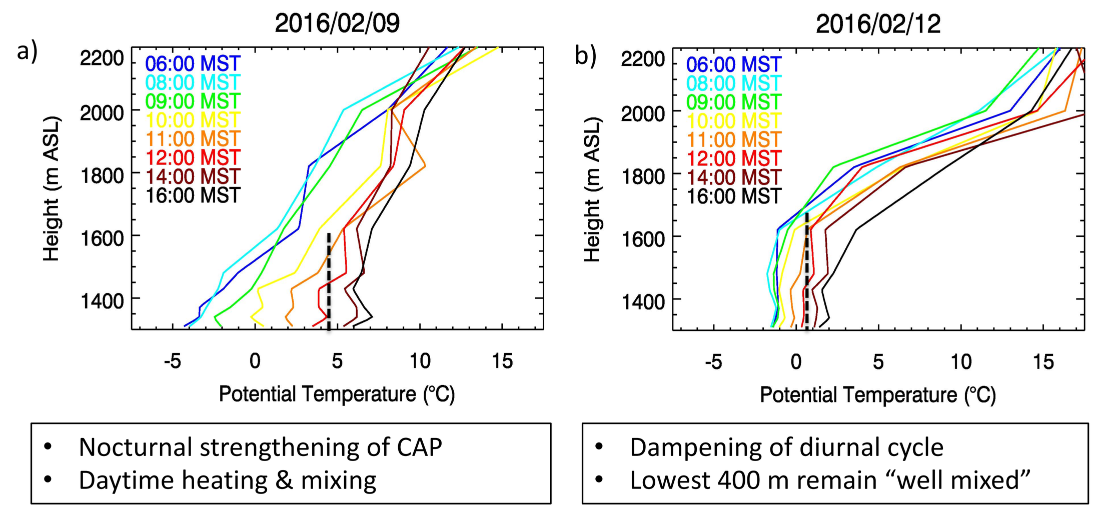

Fig. 7: Pseudo-vertical potential temperature profiles in the SLV during a "clear" and "cloudy/foggy" day during the 2-14 February 2016 pollution episode.

Such transitions are likely to affect chemical processes in the PCAP, as the thermal structure directly affects vertical mixing and can either couple or decouple different reservoirs in the PCAP, and may allow for different reactive pathways to dominate over others.

Lake Breezes from the Great Salt Lake

The SLV is unique due its vicinity to the Great Salt Lake (GSL). The lake boundary layer can act as a reservoir of both a "clean" or "polluted" air mass, depending of thermal gradients and the duration of a pollution episode. **Figs. 10** and **11** show the effect of the lake breeze on $PM_{2.5}$ and ozone O_3 concentrations during the 30 Jan. 2017 lake breeze event.

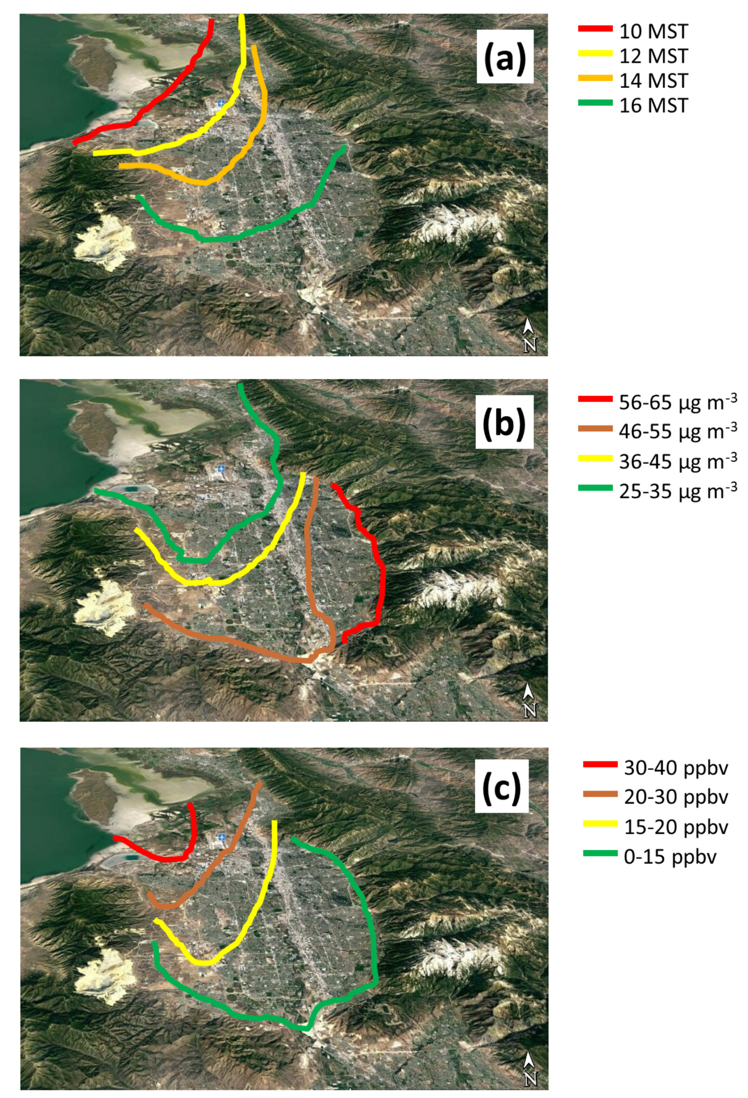

Fig. 10: a) Isochrones of lake breeze frontal location, and spatial distribution of b) $PM_{2.5}$ and c) ozone (O_3) at 1700 MST during the 30 Jan. 2017 lake breeze event in the SLV.

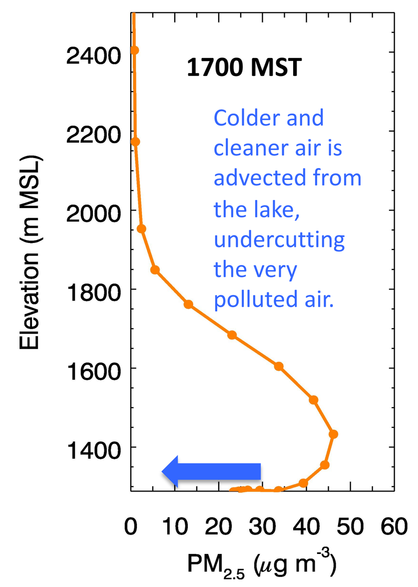

Fig. 11: Vertical profile of $PM_{2.5}$ concentrations from ~1700 MST observed by a local news helicopter.

Canyon Circulations

During the January 2017 Utah Winter Fine Particulate Study (UWFPS), thermally-driven canyon circulations in two tributary canyons, the smaller Red Butte Canyon (RB) and larger Parleys Canyon (PAR), were investigated for their role in modulating pollutant concentrations.

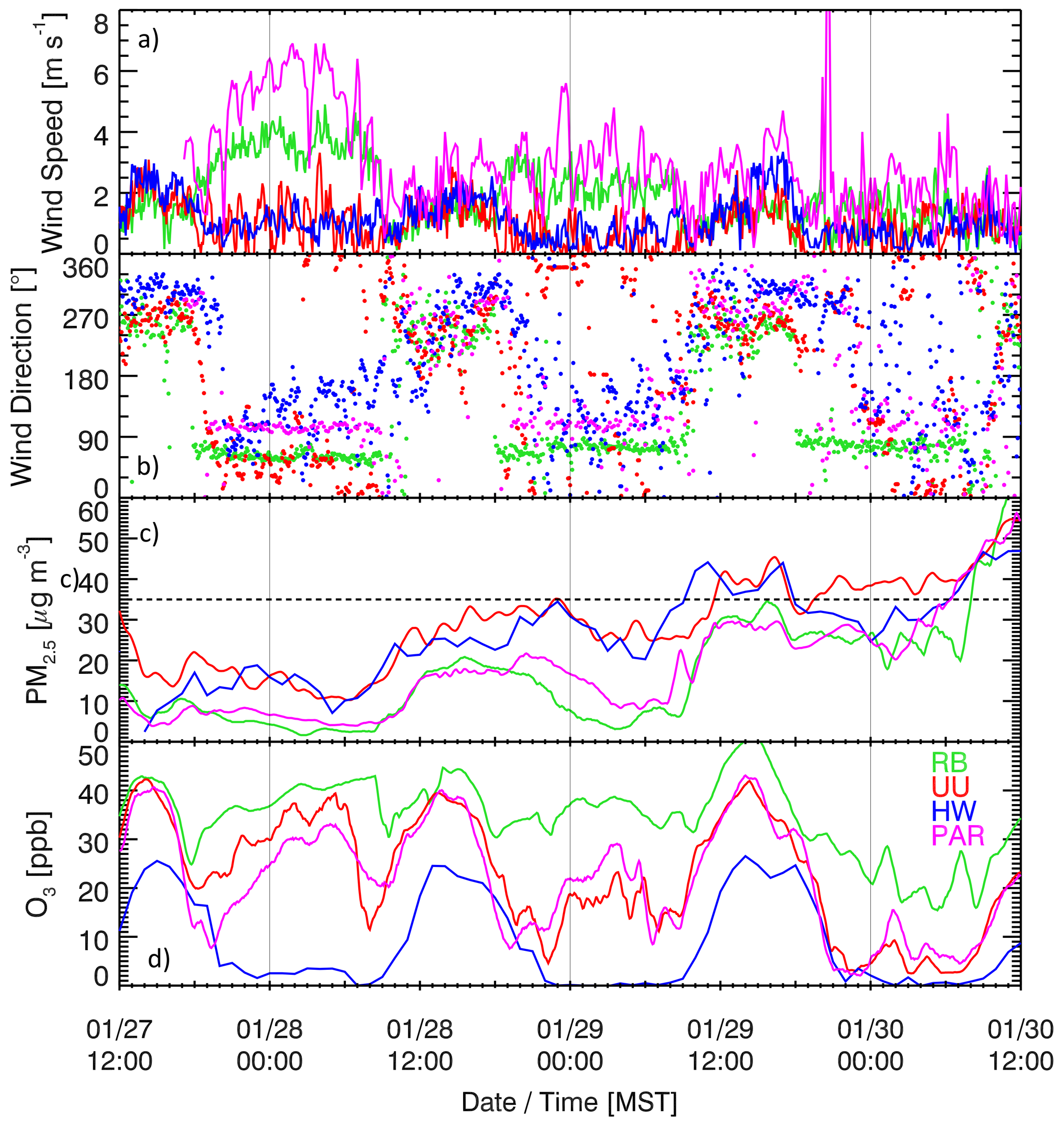

Fig. 8: Time series of a) wind speeds, b) wind direction, c) $PM_{2.5}$, and d) ozone (O_3) concentrations collected at four selected sites near the mouths of tributary canyons (PAR, RB), on the valley sidewall (UU), and the basin floor (HW) during the onset of the 26 Jan. - 3 Feb. 2017 pollution episode.

Fig. 9: The University of Utah mini-SoDAR deployed at the mouth of Parleys Canyon during UWFPS.

We found clear evidence that nocturnal down-canyon flows advected air with lower $PM_{2.5}$ and higher O_3 concentrations to the mouths of the two tributary canyons. Meteorological factors such as cloud cover, surface albedo, and static stratification impacted the strength, depth, and duration of both the nighttime down-valley and daytime up-valley circulations. Future work will aim at quantifying total mass budget contributions.

"Dirty" Lake Breezes or "Lake Recharge"

A mini-SoDAR deployed near the shore of the Great Salt Lake (LFL) during UWFPS captured thermally driven lake breezes as well as synoptically forced air mass exchanges. A typical "lake recharge" event was captured on 3 February 2017 and led to large spatial pollution gradients in the SLV, as illustrated below.

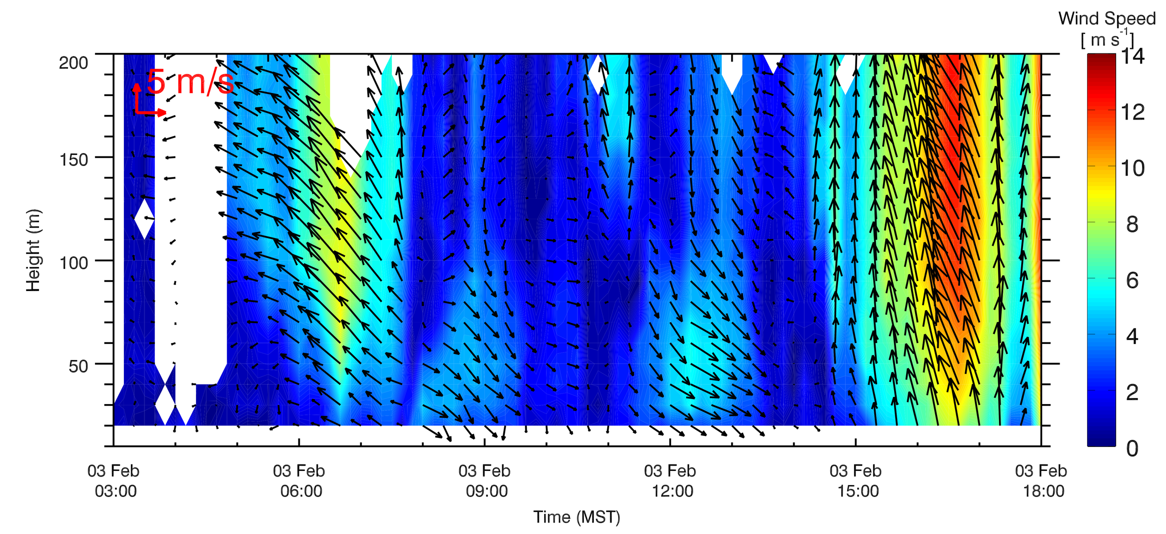

Fig. 12: Time-height cross section of SoDAR wind retrievals during the 3 Feb. 2017 lake recharge event.

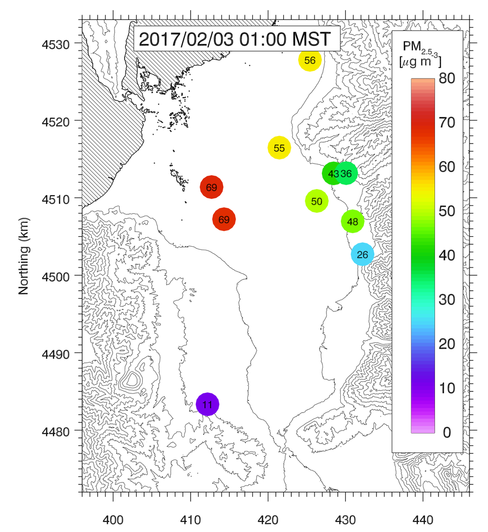

Fig. 13: Spatial distribution of $PM_{2.5}$ concentrations at 0100 MST, 3 Feb. 2017

Fig. 14: Picture showing the lake recharge event, ~ 1200 MST, 3 Feb. 2017.

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