Mechanisms Forcing the Diurnal Cycle of Dust in an Arid Closed Basin

Tyler W Barbero[1], Amato Evan[1], and Trinity Robinson[1]

[1]Scripps Institution of Oceanography

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Abstract

The Salton basin is an arid, sub-sea level basin located in southeastern California. Mountain ranges border the basin directly to the west and east, to the north extends a narrow valley that terminates with a transverse mountain range, and to the south spans heavily irrigated, agricultural lands that gradually rise in surface elevation. Within the basin lies the Salton Sea, and surrounding the Sea is diverse terrain that includes dry playa, rocky and vegetated surfaces, and highly emissive alluvial fans and dry washes, among others. Although large dust outbreaks due to orographically forced high wind speed events are frequent in the area, measurements from a new AERONET site stationed within the basin shows that dust is a standard component of the region's atmosphere, even on days with otherwise low wind speeds. We find a diurnal cycle of background dustiness that peaks in the early afternoon. An analysis of boundary layer structure using a Vaisala CL51 suggests that deepening of the boundary layer due to dry convection results in downward mixing of momentum, increased surface wind speeds, and an accumulation of dust in the mixed layer. Further analysis of the CL51 observations at nighttime suggest that high AOD concentrations persist in the shallow nocturnal boundary layer, and can become elevated throughout the night due to westerly katabatic flows. An analysis of surface meteorological station data suggests possible pathways of suspended dust due to mountain and valley flows within the basin.

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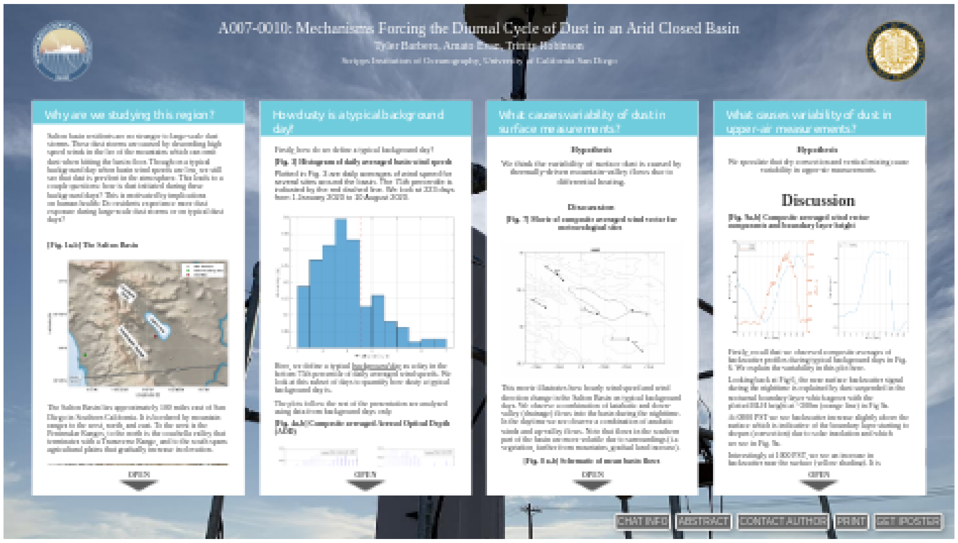

Tyler Barbero, Amato Evan, Trinity Robinson

Scripps Institution of Oceanography, University of California San Diego

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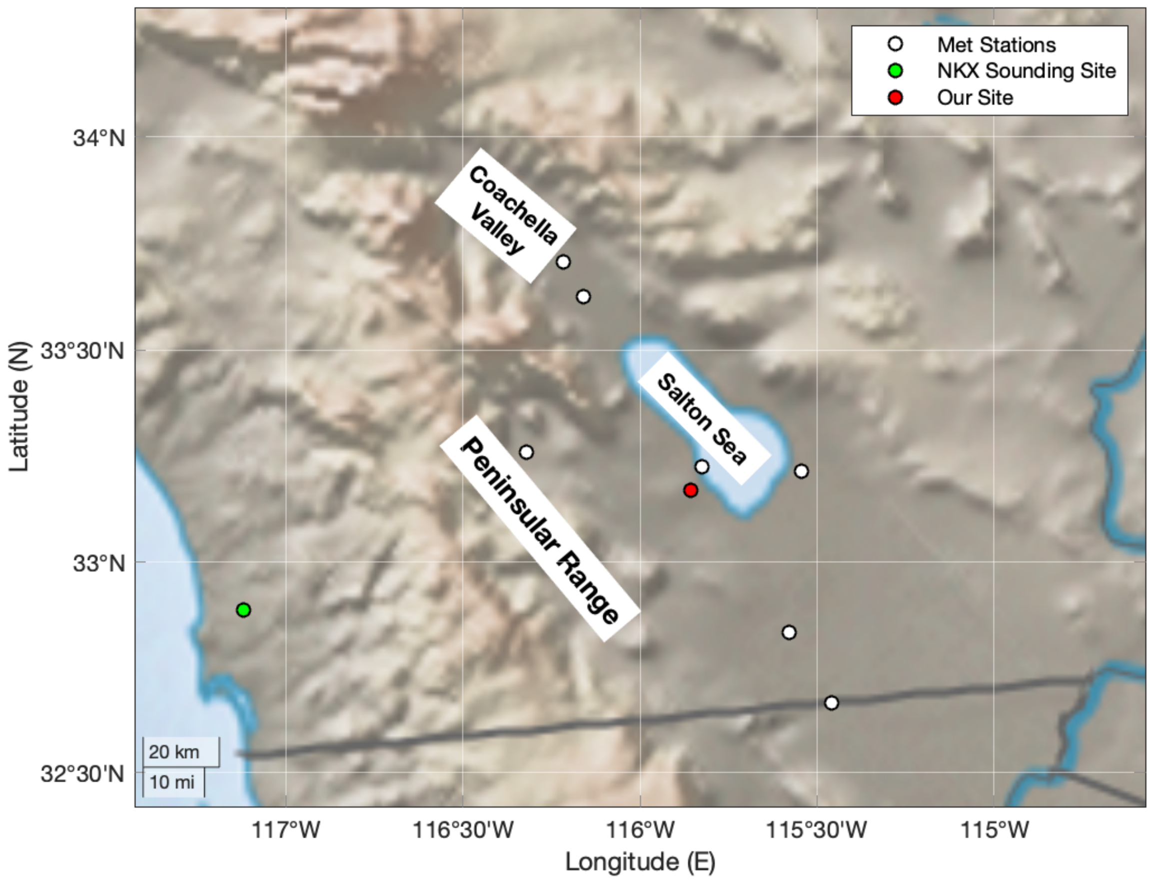
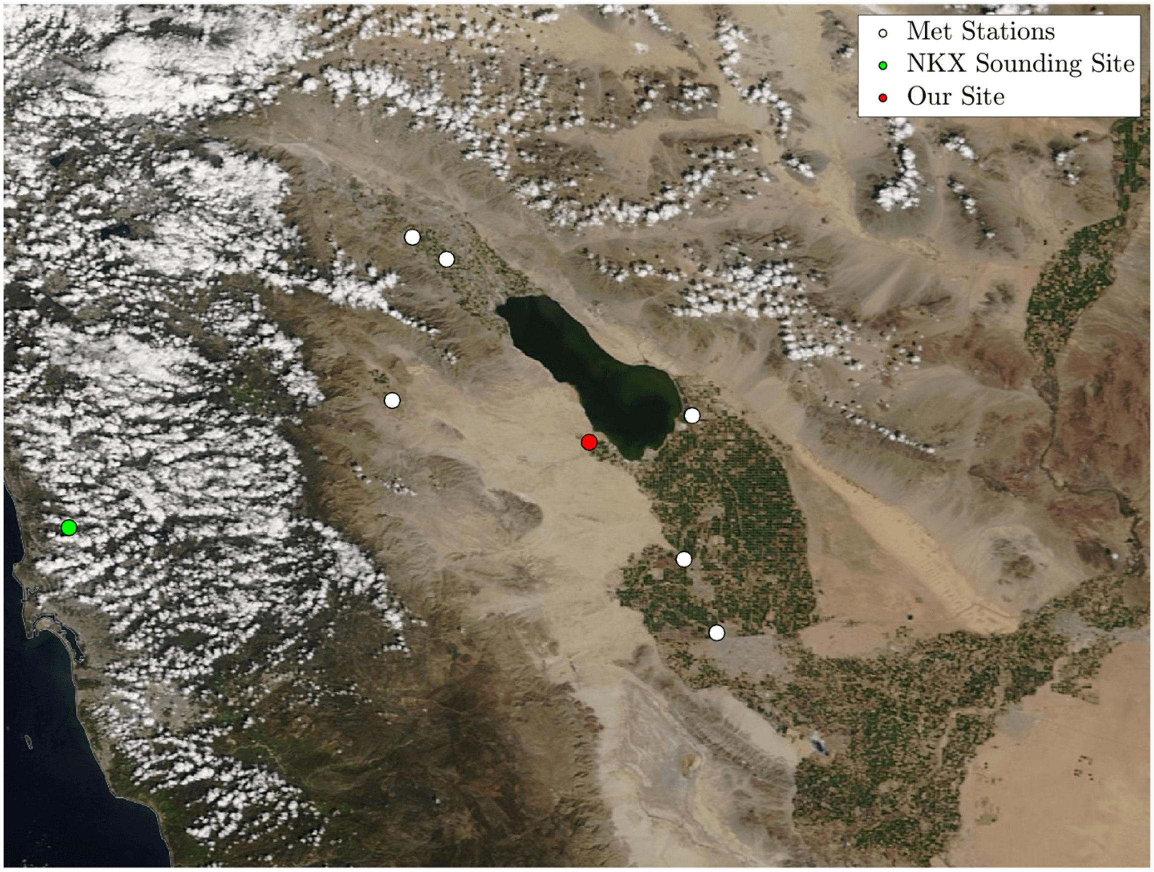
WHY ARE WE STUDYING THIS REGION?

Salton basin residents are no stranger to large-scale dust storms. These dust storms are caused by descending high speed winds in the lee of the mountains which can emit dust when hitting the basin floor. Though on a typical background day when basin wind speeds are low, we still see that dust is prevlent in the atmosphere. This leads to a couple questions: how is dust initiated during these background days? This is motivated by human health: Do residents experience more dust exposure during large-scale dust storms or on typical dust days?

[Fig. 1a,b] The Salton Basin



The Salton Basin lies approximately 100 miles east of San Diego in Southern California. It is bordered by mountain ranges to the west, north, and east. To the west is the Peninsular Ranges, to the north is the coachella valley that terminates with a Transverse Range, and to the south spans agricultural plains that gradually increase in elevation.



Satellite imagery of Salton Basin that shows southern agricultural lands not shown in the elevation map (NASA WorldView Imagery (https://go.nasa.gov/2HUCe8o)).

[Fig. 2] The Shrinking Salton Sea

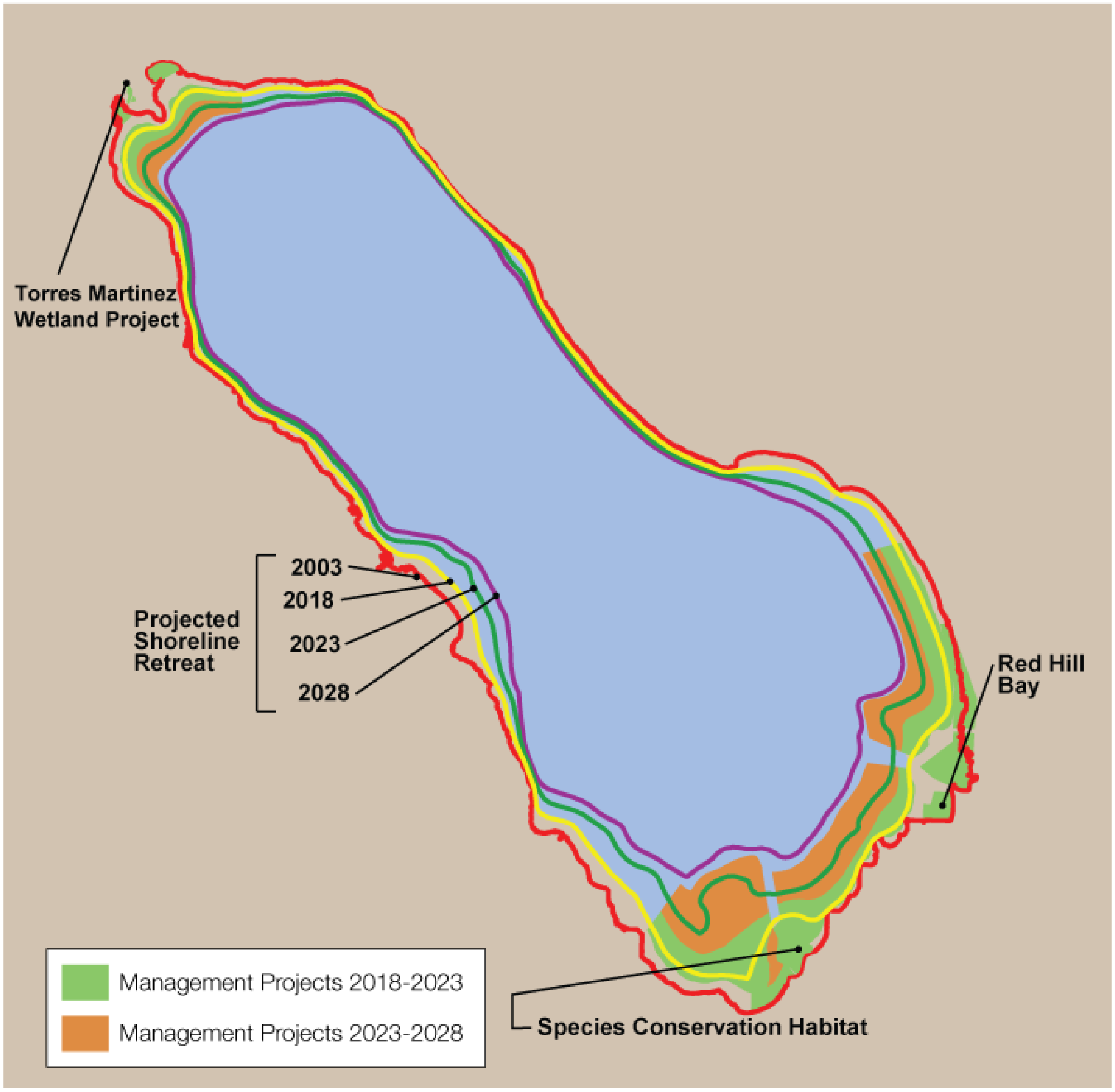


Figure from the California Legislative Analyst's Office: (https://lao.ca.gov/Publications/Report/3879)

Water transfer agreements between Imperial San Diego counties resulted in a decrease in freshwater flows into the Salton Sea. As a result, the Sea is shrinking perhaps at an accelerated rate as projected by the CA analyst's office. Consequently, more playa (dry lakebed) is exposed to the atmosphere which fuel may dust emission events, increasing hazardous air quality levels.

[Fig. 2.5] A Dust Storm Event

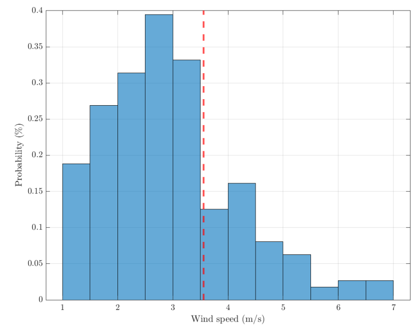
2020-02-22 Dust Storm Event in the Salton Basin. Looking northwest from our Salton Sea site (Credit: Scott Polach (http://art.scottpolach.com/)).

HOW DUSTY IS A TYPICAL BACKGROUND DAY?

Firstly, how do we define a typical background day?

[Fig. 3] Histogram of daily averaged basin wind speeds

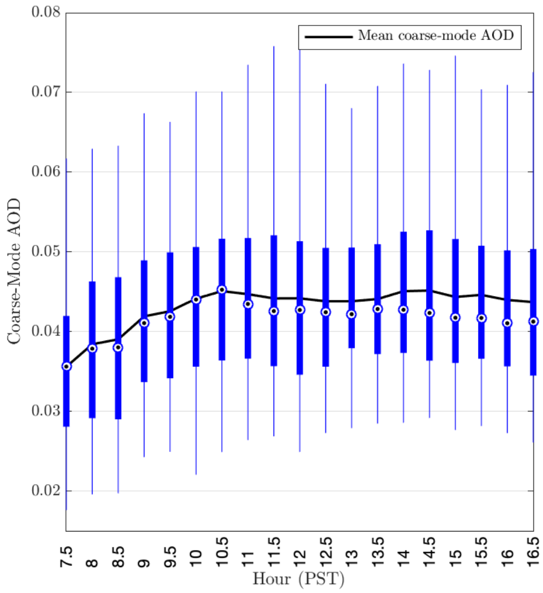
Plotted in Fig. 3 are daily averages of wind speed for several sites around the basin. The 75th percentile is indicated by the red dashed line. We look at 223 days from 1 January 2020 to 10 August 2020.

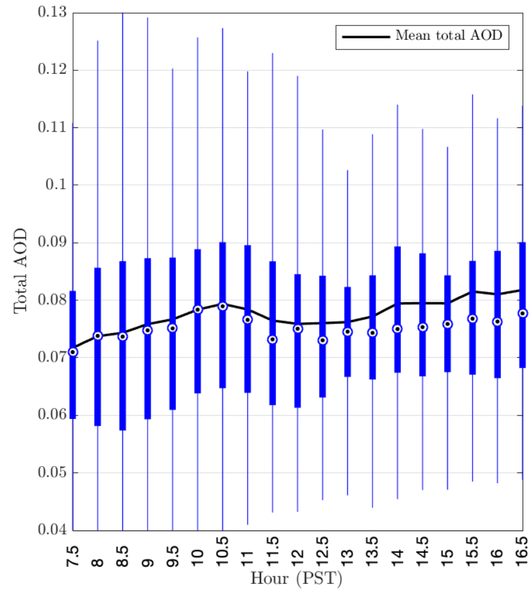


Here, we define a typical ***background day*** as a day in the bottom 75th percentile of daily averaged wind speeds. We look at this subset of days to quantify how dusty a typical background day is.

We use this subset of background days to analyze data, to illustrate what dust is doing on background days.

[Fig. 4a,b] Composite averaged Aerosol Optical Depth (AOD)



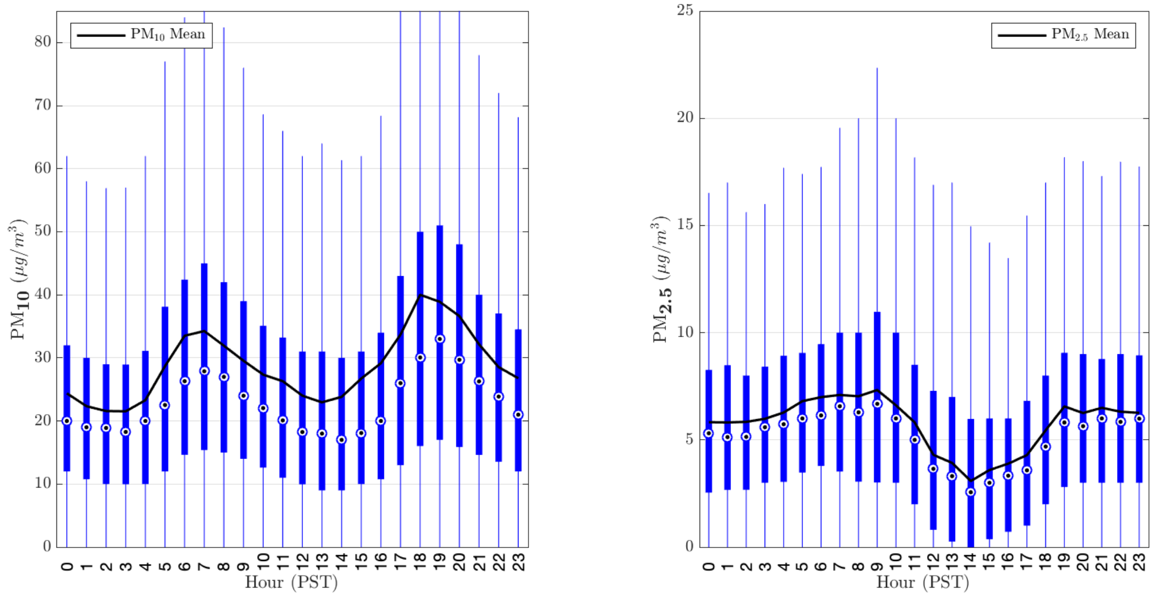


Dust storm day~> 0.1 AOD

In Fig. 4a, the average coarse-mode AOD for the 9-hour period is 0.042 with a maximum of 0.045 at 1030 PST which which remains consistently steady for the remainder of the day (black line, Fig 4a). For reference, in Fig 4a are the hourly median values (blue circles), the inner quartile range (blue bars), and the full range of measured values (thin vertical blue lines).

In Fig. 4b, the average total AOD is 0.075 and follows a similar pattern to coarse-mode AOD though total AOD tends to peak at 1630 PST. The other elements of the 4b are as is described for Fig 4a.

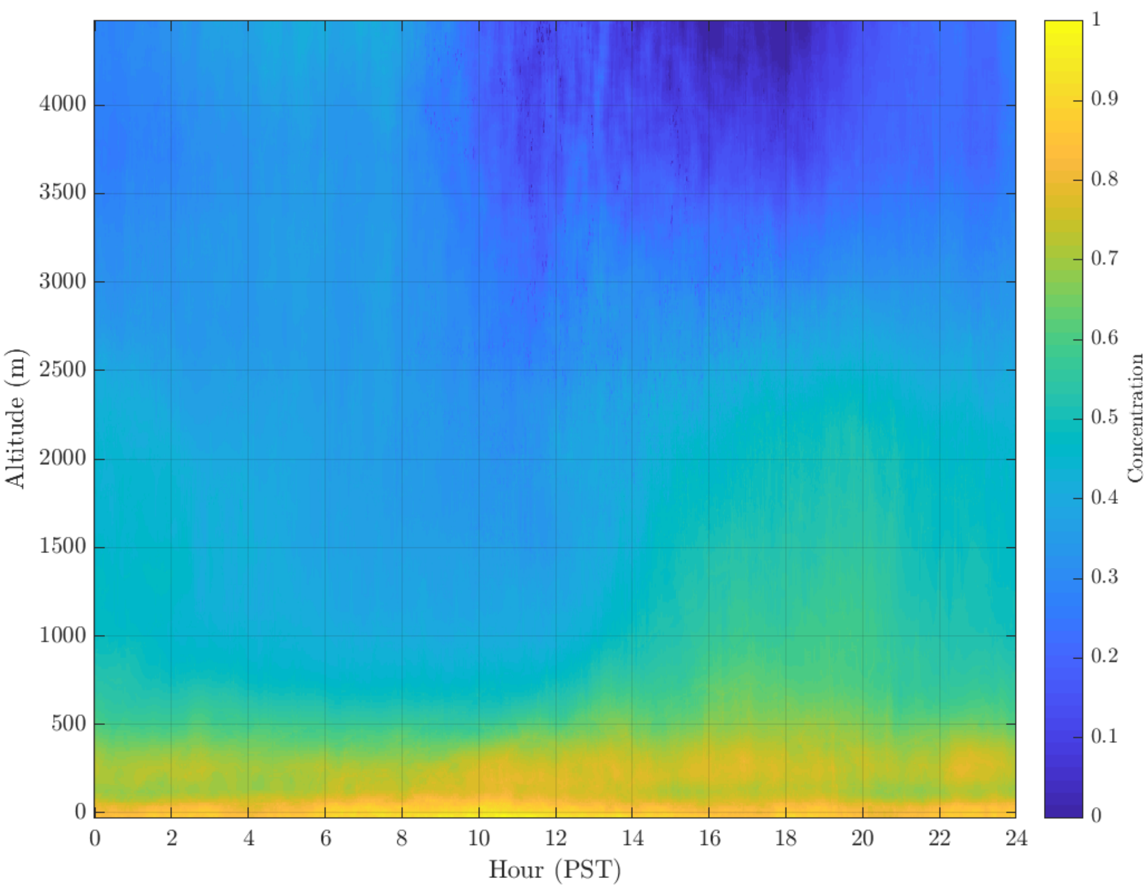
[Fig. 5 a,b] Composite averaged surface Particulate Matter (PM)



The average PM10 for the 24-hour period is 30 mu/m3, with minima at 0200 and 1300 PST of 22 and 23 ug/m3, respectively, and maxima at 0700 and 1800 PST of 34 and 40 ug/m3, respectively (black line, Fig 5a).

The average PM2.5 for 24-hour period is 6 mu/m3 with a minimum of 3 mu/m3 at 14 PST. The other elements of the 5b are as is described for Fig 5a.

[Fig. 6] Composite averaged profiles of Backscatter (BS)



From midnight to around 0800 PST, we observe moderate backscatter near the surface (orange shading). Then at 0800 PST, we start to see backscatter become a little elevated. At around 1000 PST, we see a significant increase in the backscatter at the surface (yellow shading). At 1200 PST, surface backscatter decreases and remains moderate as the backscatter signal increases aloft. From 1400-2000 PST backscatter reaches heights of around 2.5km. After 2000 PST, we see upper-air backscatter values decrease and again a moderate concentration at the surface.

Ultimately, we observe abundant concentrations of aerosols (dust, pollution) at the surface and aloft on background days. Interestingly, we see observe temporal and spatial varibility of dust in the AOD, PM and backscatter plots. The next two columns explain the variability in these measurements during a typical background day.

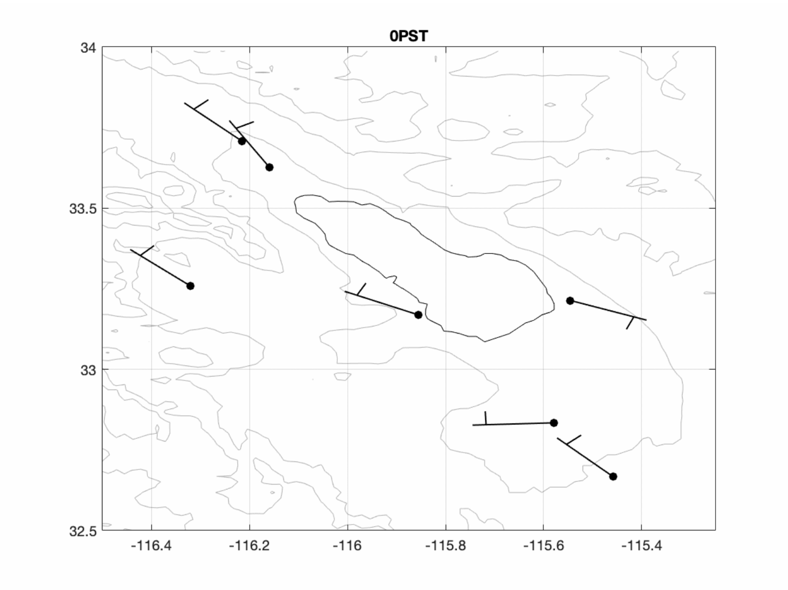
WHAT CAUSES VARIABILITY OF DUST IN SURFACE MEASUREMENTS?

Hypothesis

We think the variability of surface dust is caused by thermally-driven mountain-valley flows due to differential heating.

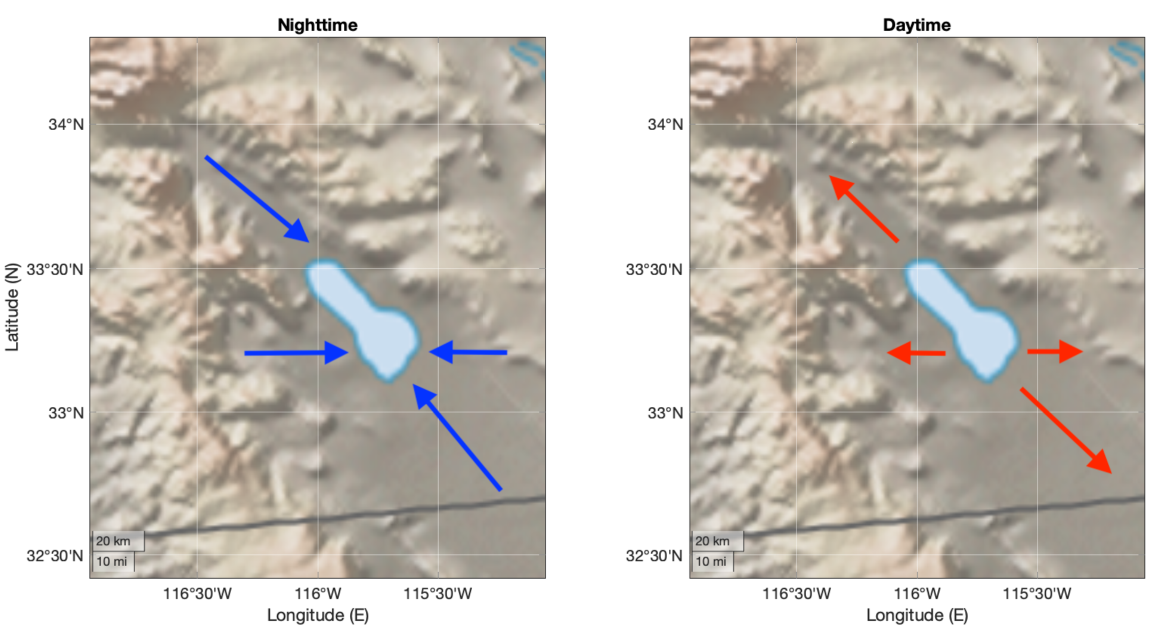
Discussion

[Fig. 7] Movie of composite averaged wind vector for meteorological sites



This movie illustrates how hourly wind speed and wind direction change in the Salton Basin on typical background days. We observe a combination of katabatic and down-valley (drainage) flows into the basin during the nighttime. In the daytime we see observe a combination of anabatic winds and up-valley flows. Note that flows in the southern part of the basin are more volatile due to surroundings (i.e. vegetation, farther from mountains, gradual land increase).

[Fig. 8 a,b] Schematic of mean basin flows



Indicated by the blue lines in Fig. 8a, we observe mean northwesterly(NW) and southeasterly(SE) down-valley flows from the Coachella Valley and the southern plains, respectively, that spills into the lower elevation Salton Sea. Concurrently, we see coupled westerly and easterly katabatic winds from the west and east.

During the daytime in Fig. 8b, we observe a reversal of winds corresponding to those in Fig. 8a.

Due to differential heating between the mountains-valleys and mountains-plains at different times of day, we see changes in direction and magnitude of surface flows. These thermally-driven flows force variability in surface dust measurements.

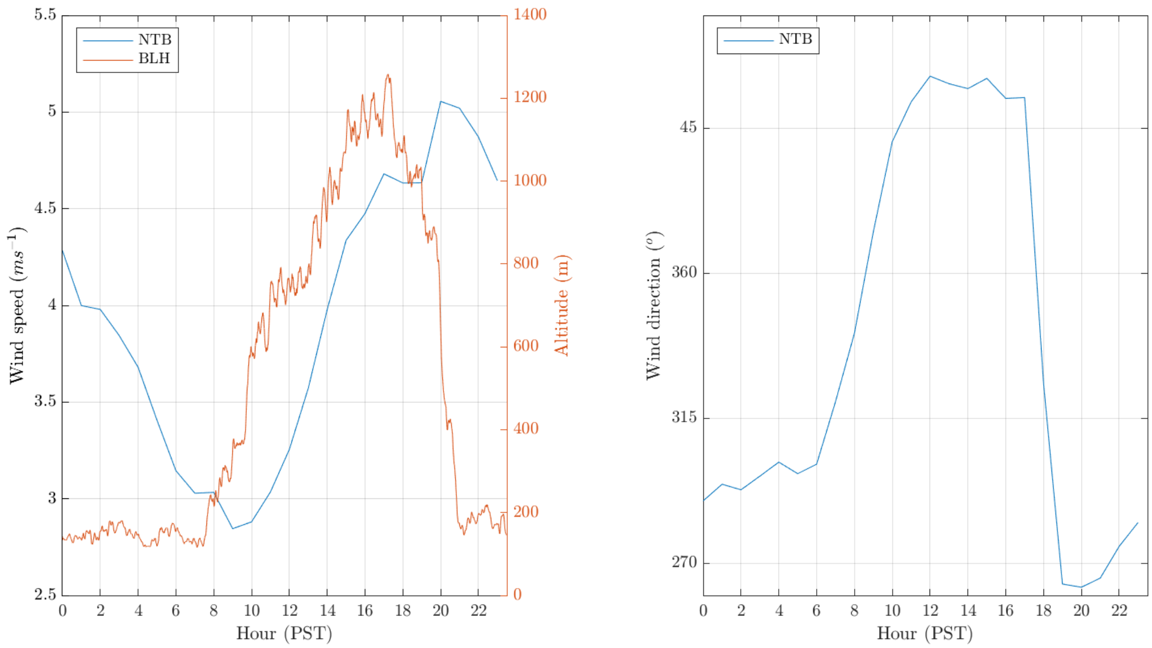
WHAT CAUSES VARIABILITY OF DUST IN UPPER-AIR MEASUREMENTS?

Hypothesis

We speculate that dry convection and vertical mixing cause variability in upper-air measurements.

Discussion

[Fig. 9a,b] Composite averaged wind vector components and boundary layer height



Firstly, recall that we observed composite averages of backscatter profiles during typical background days in Fig. 6. We explain the variability in this plot here.

Looking back at Fig 6, the near surface backscatter signal during the nighttime is explained by dust suspended in the nocturnal boundary layer which agrees with the plotted BLH height at ~200m (orange line) in Fig 9a.

At 0800 PST we see backscatter increase slightly above the surface which is indicative of the boundary layer starting to deepen (convection) due to solar insolation and which we see in Fig. 9a.

Interestingly at 1000 PST, we see an increase in backscatter near the surface (yellow shading). It is important to note that the CL51 is biased by water vapor. This increase corresponds to moist air coming from the Salton Sea when winds shift NE, Fig. 9b.

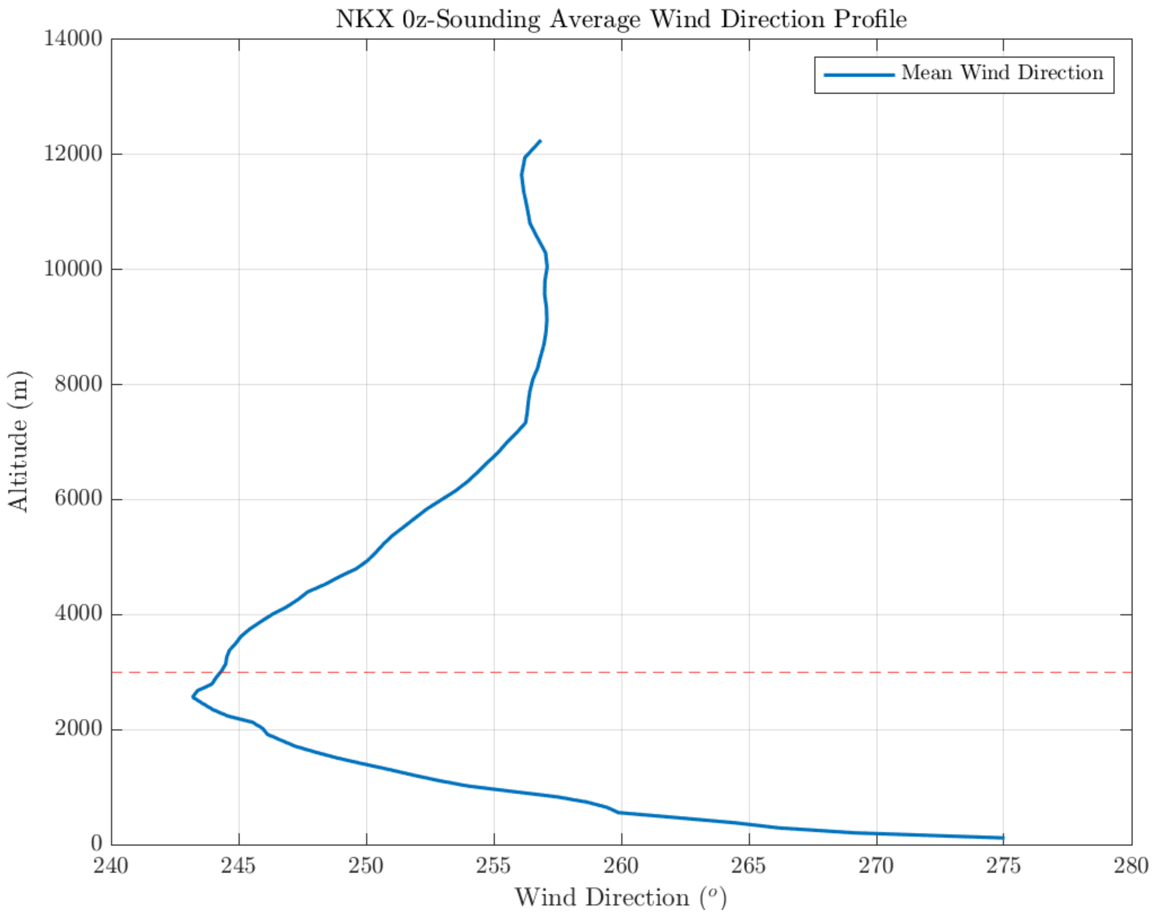
At around 1200 PST, near surface backscatter decreases and we see backscatter slightly increase aloft. Coincidently, BLH is increasing as well, Fig 9a. At this point, dust is lifted slightly upwards by convection.

Two hours later at 1400 PST, backscatter is seen at heights of 2.5km in Fig 6, indicative of rapid BL deepening and vertical mixing of surface dust as the residual layer is burned off.

Since dust is being mixed vertically, we should see a decrease in dust at the surface which we do from morning to 1300 PST. However, PM10 starts to increase again at 1400 PST (Fig. 5a). We see a new influx of surface dust at 1400 when winds are easterly and increasing at ~4m/s (Fig. 8a,b). This suggests wind speeds have increased high enough to emit dust off the playa to the east. At 1700PST, winds shift back to westerly and are still increasing. This is due to SW-westerly jet (Fig. 10) at height above Mt. Laguna (3km) mixing its momentum downward resulting in an increase in wind speeds and shift in wind direction to westerly.

Note that time of boundary layer growth in Fig 6 and Fig 9a align however the magnitues are off. More exploration in understanding how BLH is measured is needed.

[Fig. 10] Composite averaged sounding wind direction profiles



Red dashed line indicates height of the Mt. Laguna.

Soundings from NKX in San Diego California. We assume upper air flow here is representative of flow above the Salton Basin.

Next Steps

- Identify a small set (1-3 days) of typical background days to simulate in WRF numerical model
- Validate our hypotheses using model output

Data

Surface meteorological data are taken from the MESOWEST Network (https://mesowest.utah.edu/), air quality data is retreived from the California Air Resources Board (https://www.arb.ca.gov/aqmis2/aqdselect.php), AOD observations were used from NASA's AERONET (https://aeronet.gsfc.nasa.gov/cgi-bin/data_display_aod_v3?site=Salton_Sea&nachal=2&level=1&place_code=10), satellite imagery retrieved from NASAs WorldView (https://worldview.earthdata.nasa.gov/), sounding data taken from the University of Wyoming (http://weather.uwyo.edu/upperair/sounding.html).

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The Salton basin is an arid, sub-sea level basin located in southeastern California. Mountain ranges border the basin directly to the west and east, to the north extends a narrow valley that terminates with a transverse mountain range, and to the south spans heavily irrigated, agricultural lands that gradually rise in surface elevation. Within the basin lies the Salton Sea, and surrounding the Sea is diverse terrain that includes dry playa, rocky and vegetated surfaces, and highly emissive alluvial fans and dry washes, among others. Although large dust outbreaks due to orographically forced high wind speed events are frequent in the area, measurements from a new AERONET site stationed within the basin shows that dust is a standard component of the region's atmosphere, even on days with otherwise low wind speeds. We find a diurnal cycle of background dustiness that peaks in the early afternoon. An analysis of boundary layer structure using a Vaisala CL51 suggests that deepening of the boundary layer due to dry convection results in downward mixing of momentum, increased surface wind speeds, and an accumulation of dust in the mixed layer. Further analysis of the CL51 observations at nighttime suggest that high AOD concentrations persist in the shallow nocturnal boundary layer, and can become elevated throughout the night due to westerly katabatic flows. An analysis of surface meteorological station data suggests possible pathways of suspended dust due to mountain and valley flows within the basin.