Persistent Cold-Air Pools in Mountainous Areas: Distribution, Simulation, and Air Quality

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Motivation

Persistent CAPs occur when the surface heating is not large enough to mix out the stably stratified atmospheric layer, making the stagnant conditions last for more than one day. Due to the stable atmospheric conditions during CAPs, air pollutants accumulate within the valley, which impacts human health. Studies have shown the numerical weather prediction (NWP) and chemical transport models (CTM) do not simulate the poor air quality during CAP events (Sun et al., 2020, Ivey et al., 2019).

Objectives

- Compare existing CAP classification methods: Whiteman et al., (2014), Pierce et al., (2019), & Yu et al., (2017)
- Develop new CAP classification method that can be used throughout the western U.S.
- Evaluate NWP and CTM model performance for CAP events

Approach

- Radiosonde data in western U.S. (12 locations), twice daily
- Surface $PM_{2.5}$ concentrations from EPA air quality network
- Model performance for one month simulation in Salt Lake City
  - Resolution: 4km horizontal, 41 vertical layers

NWP: Weather Research & Forecasting (WRF v3.7)
Planetary boundary layer (PBL) and land surface model (LSM) sensitivity testing to investigate atmospheric turbulence

CTM: Community Multiscale Air Quality Model (CMAQ v5.2)
Emissions: 2011 National Emissions Inventory

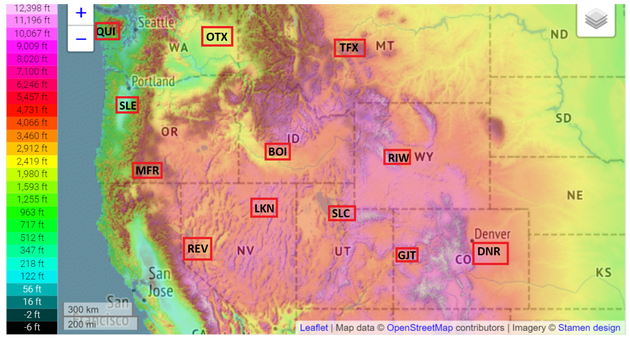


Figure 1. Topographic map of 12 radiosonde locations in the western U.S. *Map From: https://en-gb.topographic-map.com/*

Results

Persistent Cold Air Pool Classification

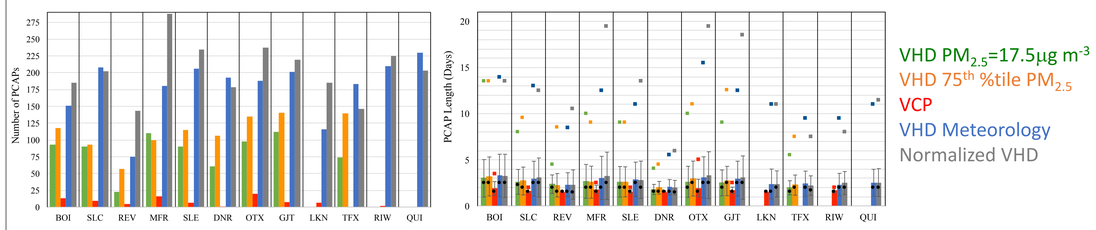


Figure 2. PCAPs for Oct-Mar from 2002-2018. (*left*) Total number of PCAPs based on Whiteman et al., (2014) (green), Pierce et al., (2019) (orange), VCP from Yu et al., (2017) (red), new VHD meteorology method (blue), and new normalized VHD (gray). (*right*) Length of PCAPs in days; mean (bars), standard deviation (whiskers), median (dot), and maximum (square).

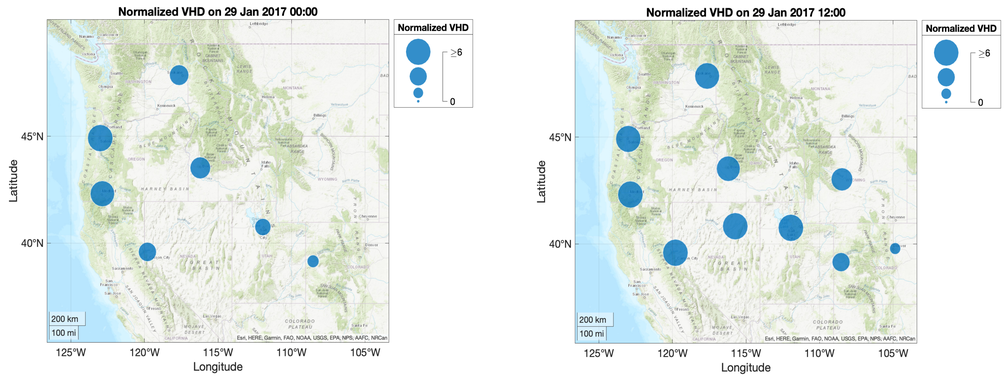
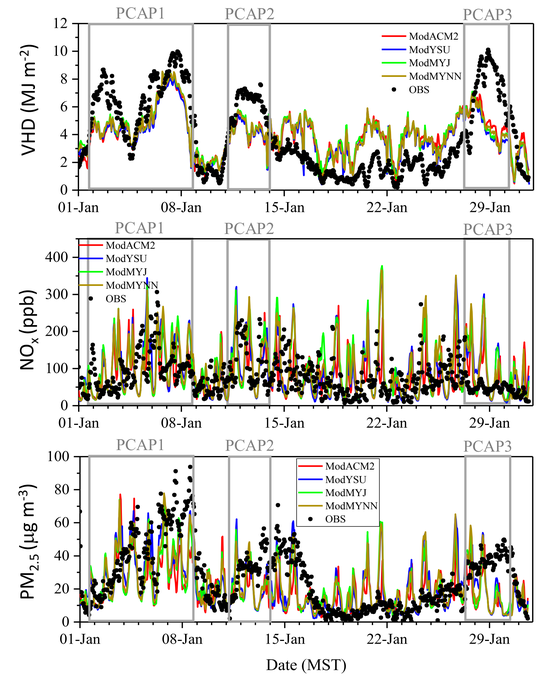


Figure 3. CAP prevalence across the western U.S. Normalized VHD for soundings that met the Normalized VHD CAPs meteorological criteria for 29 January 2017 UTC. (*left*) Afternoon soundings, 00Z. (*right*) Morning soundings, 12Z.

NWP & CTM Model Performance (SLC)



ACM2 *(red)*
PBL: ACM2
LSM: Pleim-Xiu
YSU *(blue)*
PBL: YSU
LSM: Noah
MYJ *(green)*
PBL: MYJ
LSM: Noah
MYNN *(brown)*
PBL: MYNN
LSM: Noah

Figure 4. January 2011 numerical simulations for Salt Lake City: *(top)* valley heat deficit (VHD), *(middle)* NO_x concentrations, and *(bottom)* $PM_{2.5}$ concentrations. Hourly observations (black) compared to CMAQ simulations using four different PBL/LSM sensitivity runs from WRF.

Summary

- VCP underestimates the number of CAP events in the western U.S. because it requires a deep stable layer
- VHD thresholds based on $PM_{2.5}$ concentrations depend on air pollution emissions, not consistent over time or location
- New CAP classification method classifies CAPs using local meteorology (wind speed and surface pressure)
- Normalized VHD provides a method to compare CAP classification and strength across locations
- Air quality model simulated elevated $PM_{2.5}$ concentrations during CAP events but underestimated the magnitude
  - NWP: Underestimated CAP strength in WRF contributes to the underestimated $PM_{2.5}$ concentrations in CMAQ
  - CTM: Underestimated ammonium nitrate formation contributes to the underestimated $PM_{2.5}$ concentrations in CMAQ

References

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