Isotopic Signals in Marine Atmospheric Cold Pools

Estefanía Quiñones-Meléndez[1], Simon de Szoeke[1], David Noone[2], Dean Henze[1] and Adriana Bailey[3]
quinones@oregonstate.edu
[1]College of Earth, Ocean and Atmospheric Sciences, Oregon State University, Corvallis, OR, USA [2]Department of Physics, The University of Auckland, New Zealand [3] Earth Observing Laboratory, NCAR, Boulder, CO, USA

CEOAS College of Earth, Ocean, and Atmospheric Sciences

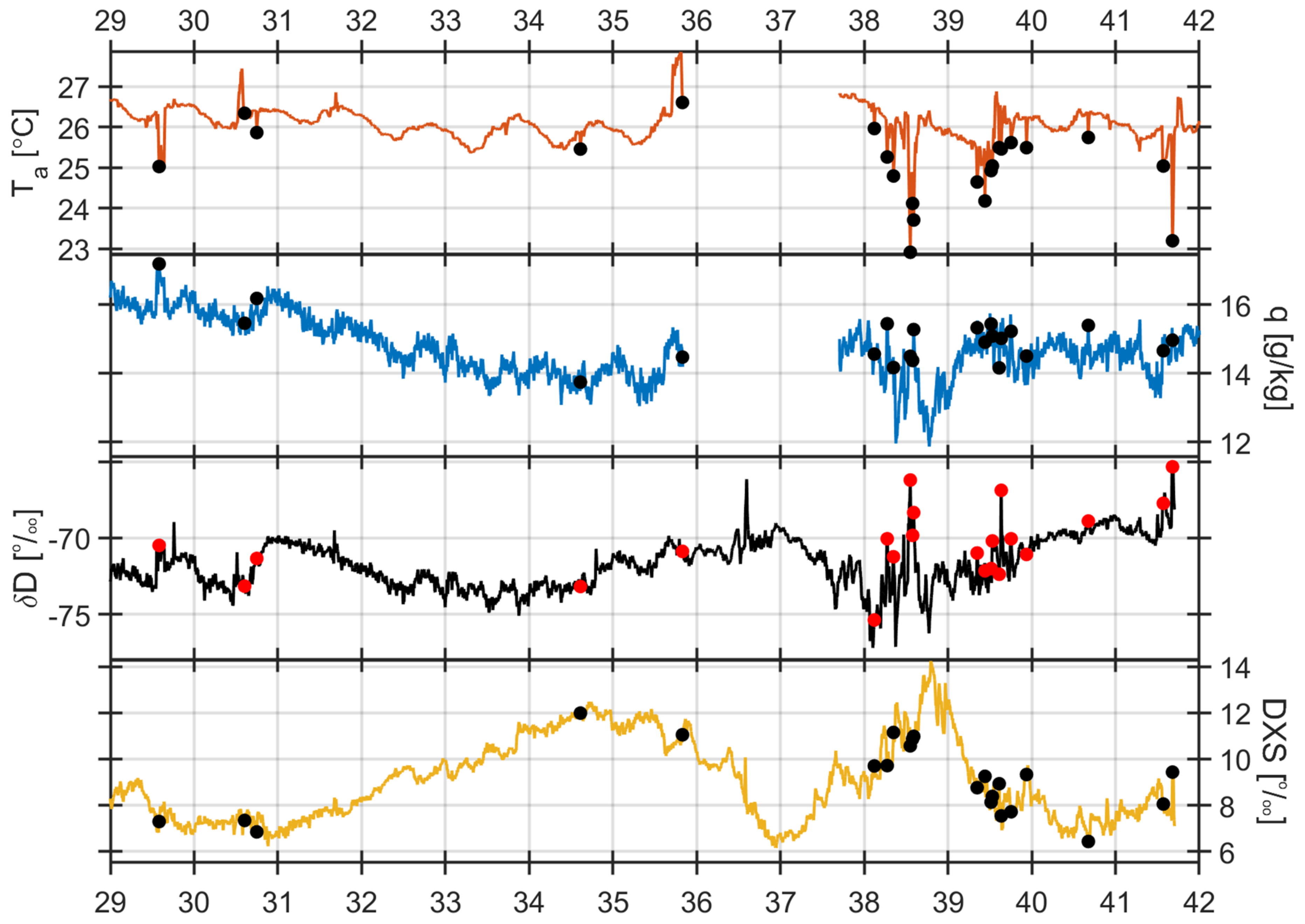
INTRODUCTION

Overview

Behavior of trade cumulus clouds and their role in regional energy balance requires refined understanding of water exchanges in the sub-cloud boundary layer (SBL). One approach focuses on moist cold pools, which are hypothesized to control cloud organization, enhance local evaporation, and intensify the regional boundary layer. Stable water isotopes (HDO and $H_2{}^{18}O$) measured in the SBL could help constrain the influence of moist cold pools in regional energy balances. We analyzed isotopic data from the northern tropical Atlantic (12-16°N to 50-60°W) observed during the ATOMIC/EUREC[4]A campaign in January-February 2020. During the 13-day period, 22 cold pools were identified from air temperature (de Szoeke et al. 2017, Vogel et al. 2021).

Cold pool detection

Cold pools form as low temperature density currents resulting from rain evaporation. They are identified by an onset and a trailing wake. Temperature at the onset is T_{max}; at its coldest is T_{min}. End of cold pools: when T_a first exceeds $T_{max} - (T_{max} - T_{min})(e^{-1})$.



Air temperature (top), specific humidity (second), deuterium ratio (third), and deuterium excess (bottom) time series. Cold pools identified by time of T_{min} (black and red dots). Horizontal axis in day of the year 2020. Data assembled into 1-min averages and filtered with an 11-min running average.

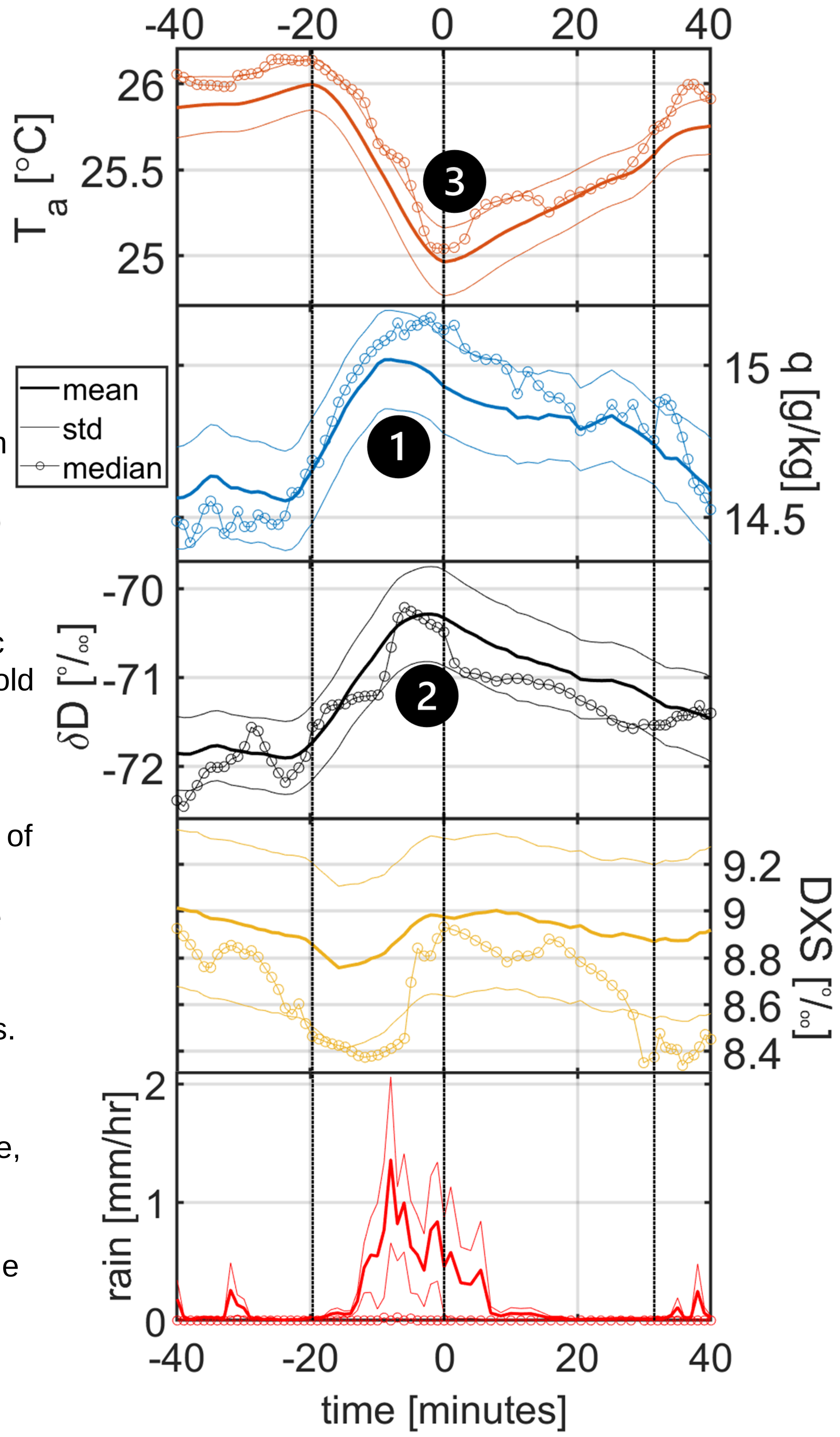
Observed cold pools are slightly moist, on average. Water vapor can come from two sources: (1) convergence of surface water vapor at the cold pool front, or (2) evaporation of hydrometeors. Higher enrichment in downdrafts may be visible if hydrometeors, enriched by cloud condensation distillation, evaporate mostly in downdrafts. *If cold pools are found to be enriched relative to surface water vapor, then we can infer that they have a hydrometeor source.*

RESULTS

Signals during cold pools

Composites for temperature, specific humidity, isotopic ratios and precipitation were generated by averaging all (22) cold pool events together. Normalized time units referenced to when T_{min} was recorded, so that t_{min} = 0 minutes. Partly due to the 20-minute cut off prior to t_{min}, t_{max} occurs 19.7 minutes before t_{min}. Based on means, t_{end} occurs 31.5 minutes after t_{min}. t_{end} also referred to as t_{rec}, since air temperature recovers during the wake. These key times represented by vertical black dashed lines on the composite plots. During an event, T_a decreases while specific humidity, δD and rainfall amounts increase.

All quantities recover during the wake. Note that the phasing is different for each of the first three panels. Numbered circles indicate the order in which extreme values occur during the cold pool.

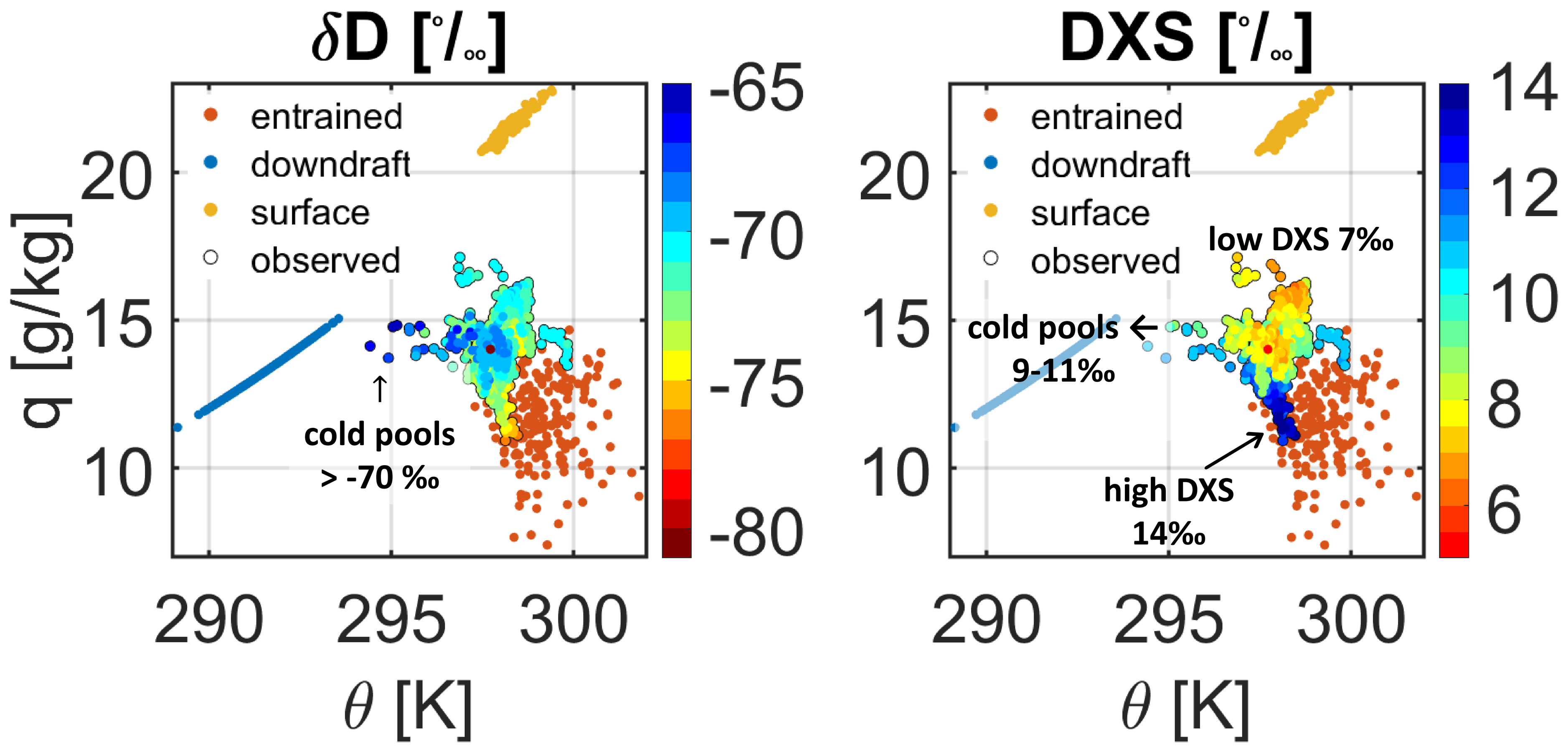


Key points:

- δD enrichment present in 59% of cold pools.
- Specific humidity and δD lead the colder temperatures.
- There is not a systematic variation of DXS in the cold pools.
- Rain accumulations (>1mm) observed on the ship only during half (11) of the cold pool events.
- Cases with no rain at the surface had high δD, suggesting hydrometeor evaporation contributions.
- Higher peaks of δD correspond to larger decreases in temperature, and higher amounts of rainfall [not shown].
- Cold pools manifest at the surface as periods of abrupt low temperature, and distinctive humidity changes.

DISCUSSION

Conserved thermodynamic properties



Conserved properties diagrams for deuterium ratio (left) and deuterium excess (right). Representative values (end members) of different air masses in the SBL identified from radiosondes [dry entrained air (θ, q @ 1 km); cool downdraft air (mean θ_w, q from trade cumulus layer brought to surface)] and in situ observations (moist surface air @ 1 m). Observed air (from in situ observations height adjusted to 400 m) color coded with isotope ratios. Reverse color scale for better contrast in entrainment space: reds => low; blues => high.

Conserved properties (specific humidity and potential temperature) diagrams enable insight into constraining processes by including the entire 13-day time series. Recall that composites looked at temperature and specific humidity during the cold pool events and no more than 40 min before or after t_{min}. Highest δD values occur at lowest temperatures during cold pool events. Cold pools lie the closest to the θ-q space for downdrafts. Deuterium excess (DXS = δD – 8δ^{18}O) was moderate for cold pools (9 to 11 ‰), but for the rest of the timeseries, it is anticorrelated with humidity. Observed air lies in the θ-q space attributed to the mixing of the different air masses, and it mainly varies between dry entrained air and moist surface evaporation.

Conclusions

- δD signal is as consistent as the specific humidity signal in cold pools.
- Enrichment in downdrafts is visible (high δD precedes coldest temperatures).
- δD enrichment in 59% of cold pools suggests the source of water vapor, for those events, could be hydrometeor evaporation.
- Though DXS does not vary systematically with cold pools, as shown by the composites, it is consistently anticorrelated with specific humidity outside of the cold pool events, as shown by the conserved thermodynamics properties.
- θ and q in the SBL can tell the relative contribution of surface flux, downdraft, and turbulent entrainment end members to the SBL.
- Stable water isotopes (HDO and $H_2{}^{18}O$) measurements help constrain the influence of moist cold pools in regional energy balances.

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