Processes controlling the evolution of orographic shallow clouds during CACTI

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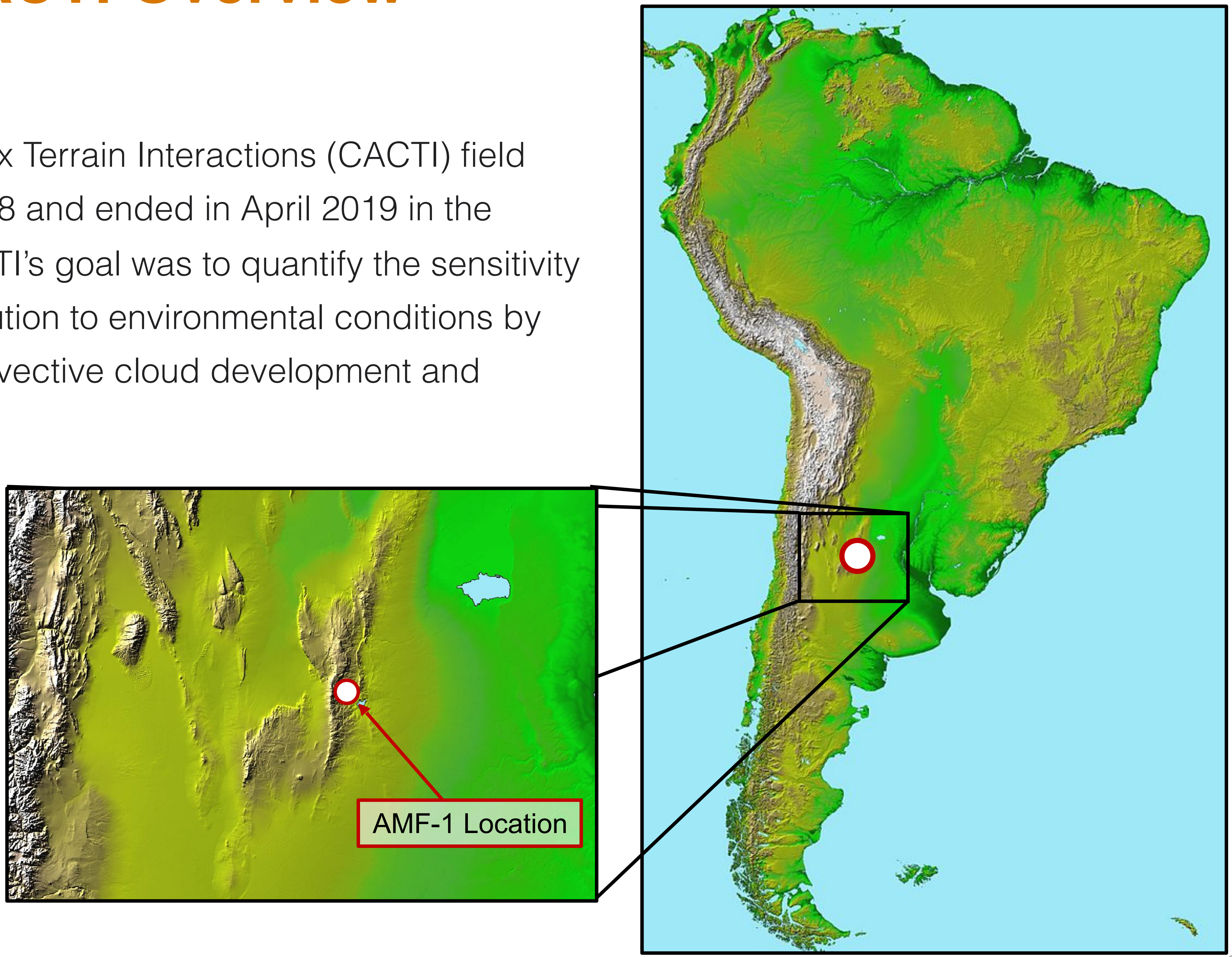
CACTI Overview

The Cloud, Aerosol, and Complex Terrain Interactions (CACTI) field campaign began in October 2018 and ended in April 2019 in the Sierras de Córdoba region. CACTI's goal was to quantify the sensitivity of convective cloud system evolution to environmental conditions by utilizing a natural hotspot for convective cloud development and organization.

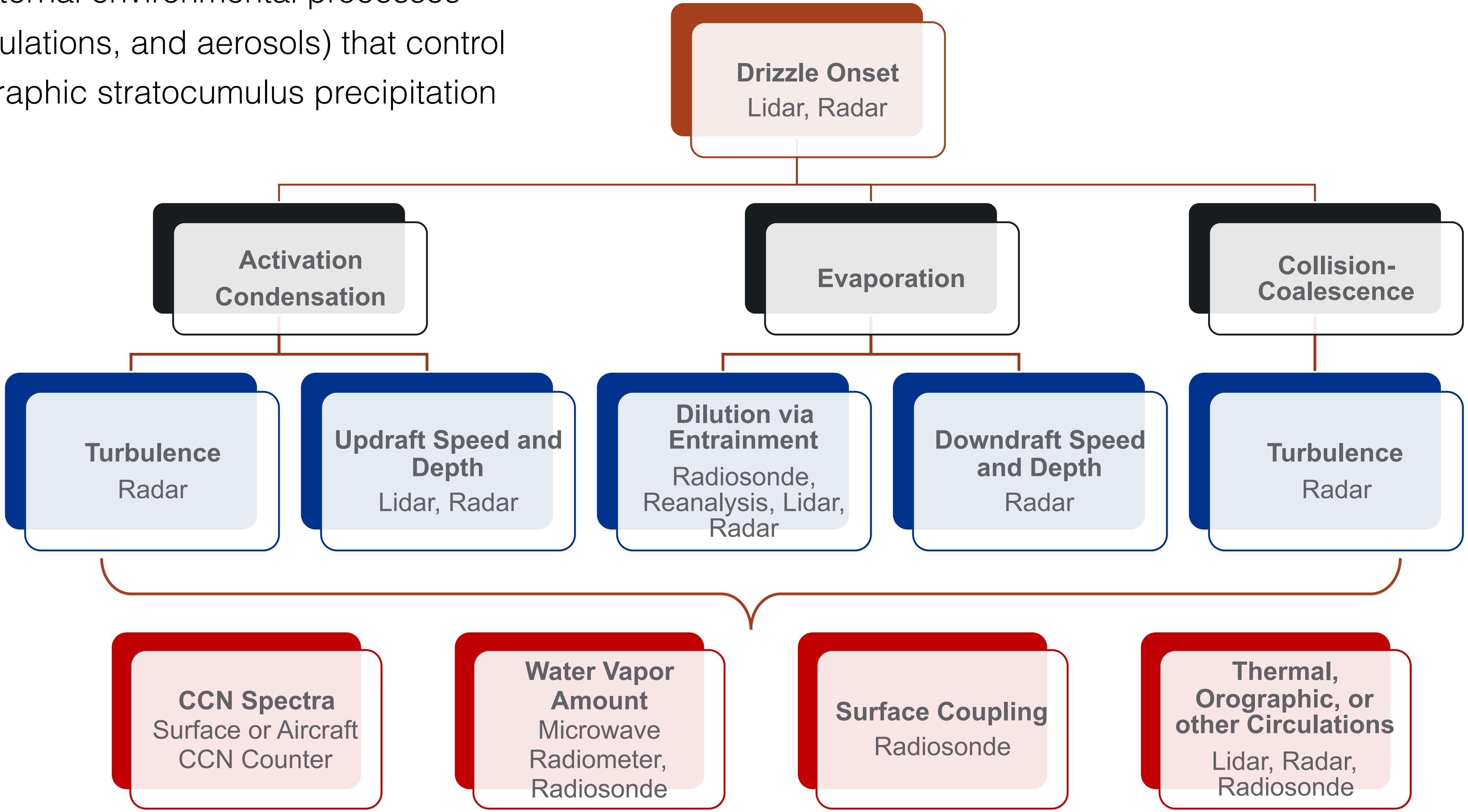
This study is focused on data collected by instrumentation deployed at the DOE ARM Mobile Facility-1 (AMF-1).



Motivation

Use CACTI observations to better understand the factors that control the life cycle of shallow convective clouds

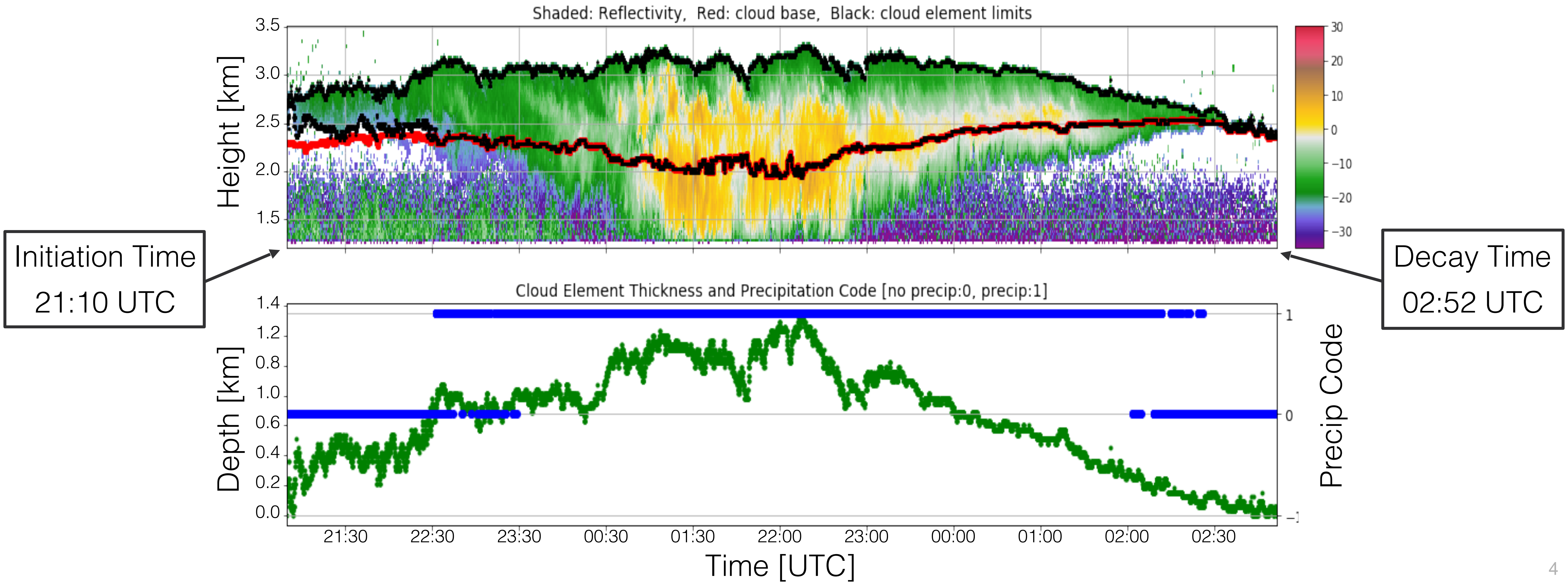
We are interested in identifying internal cloud (microphysics and dynamics) and external environmental processes (thermodynamics, circulations, and aerosols) that control the generation of orographic stratocumulus precipitation



Preliminary shallow cloud statistics

Shallow cloud elements: cloud base > 1.5 km for at least 50% of the time & cloud top < 5 km at all times

Example of 1 case of shallow cloud detected by an objective and automated algorithm that requires only observations from the Ka-Band ARM Zenith Radar (KAZR) and ceilometer (cloud base)

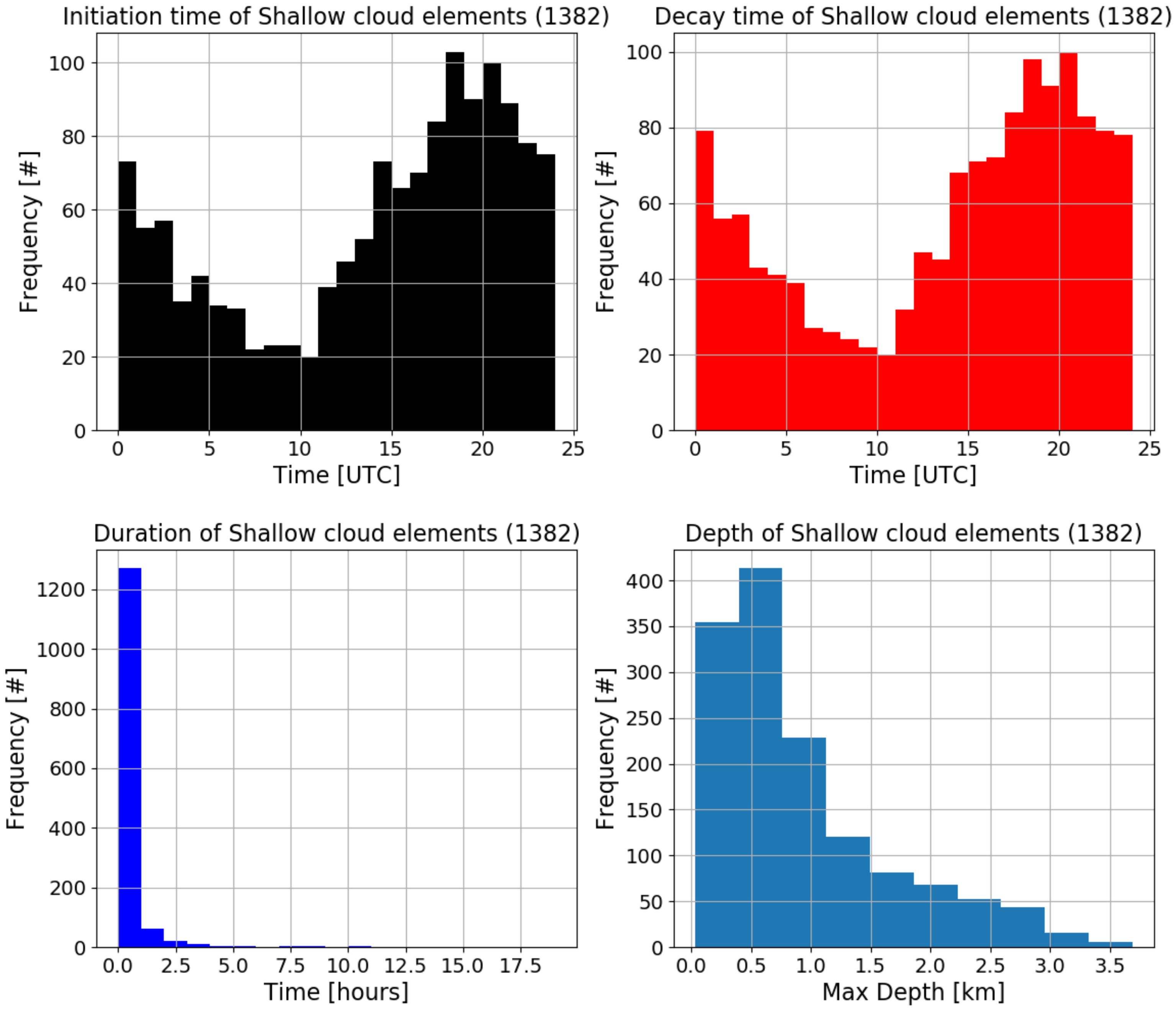


Preliminary shallow cloud statistics

CACTI observations reveal frequent shallow cloud occurrence in Sierras de Córdoba detectable by KAZR

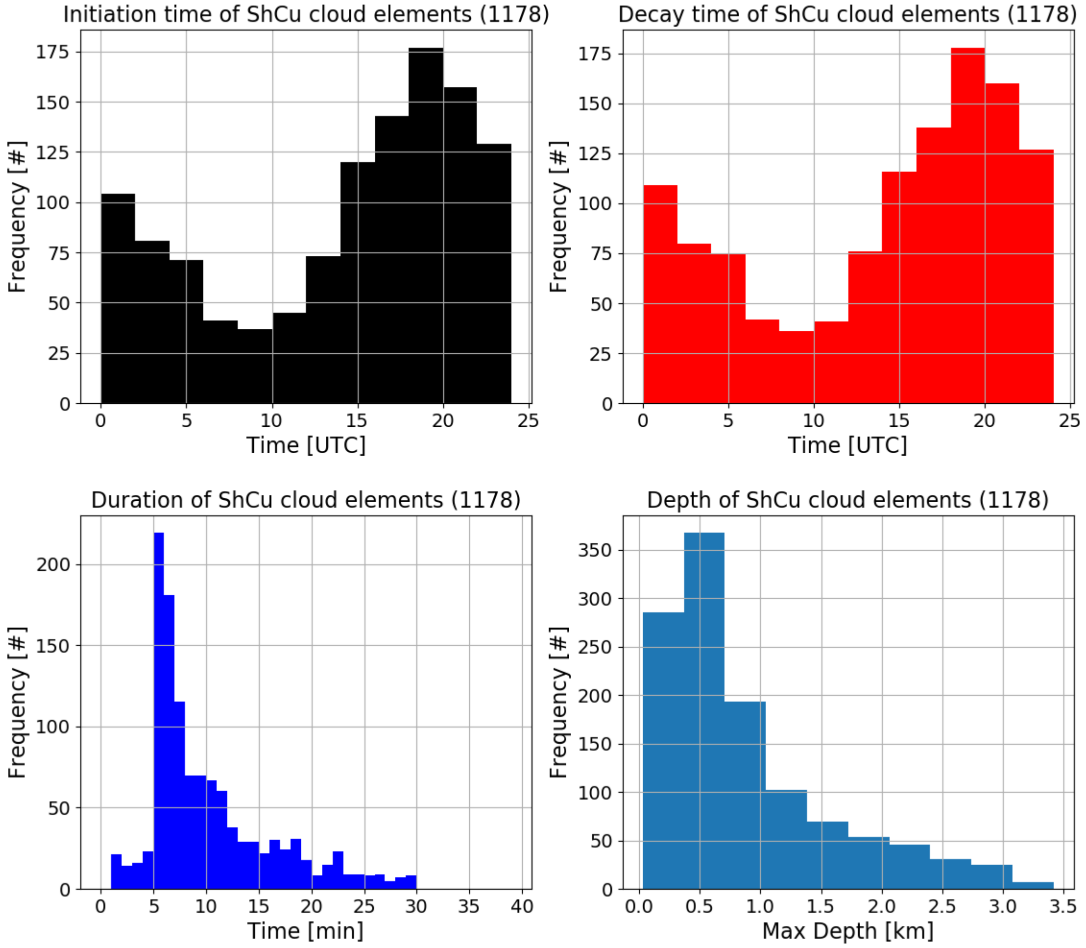
Shallow cloud initiation times occur most frequently in the late afternoon (17-22 UTC, 2-7 PM local), likely in connection with thermal upslope flow forcing and a deepening boundary layer, and a minimum in frequency occurs in the early morning.

Most clouds are relatively short-lived (< 1 hour) and shallow (< 1 km) although lifetimes and depths extend to > 10 hours and > 3 km.



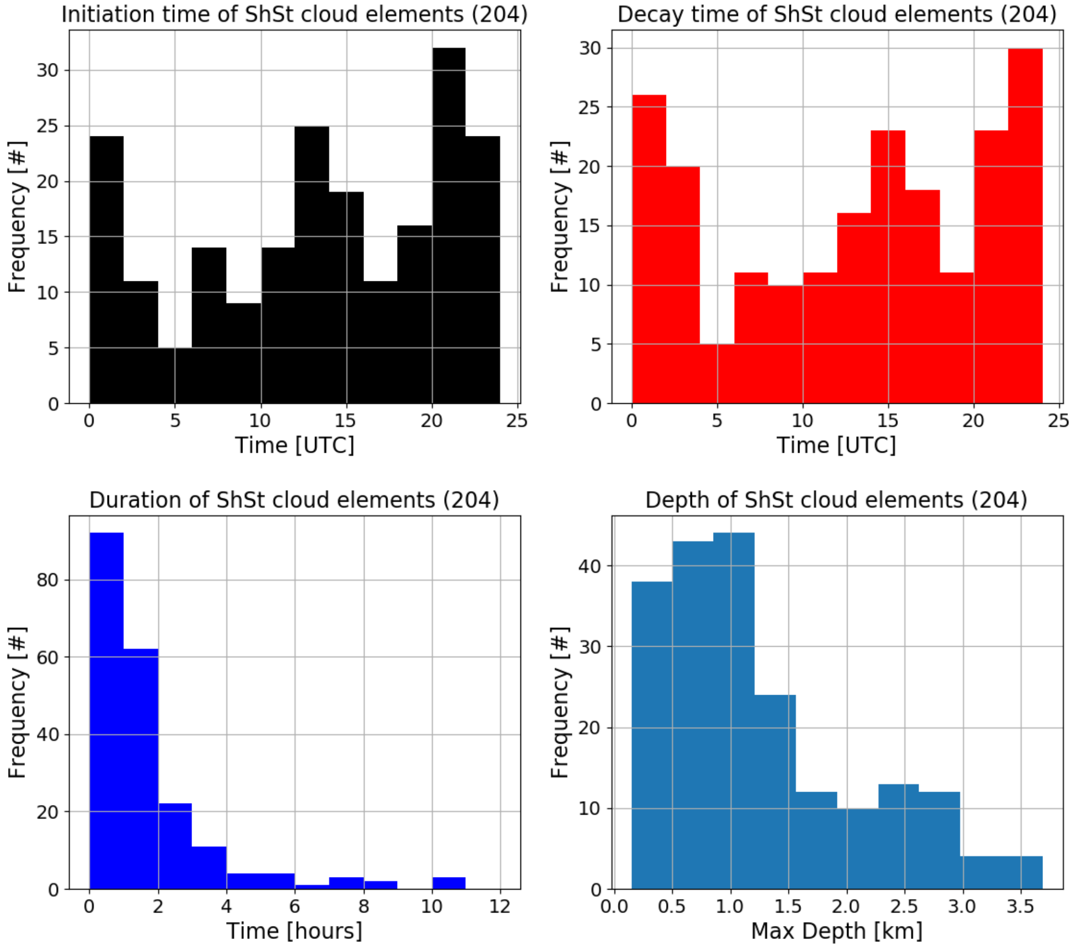
Short-lived and long-lived shallow clouds

Cloud element duration < 30 min



Most clouds are short-lived with a distinct diurnal cycle peaking around 18-20 UTC (3-5 PM)

Cloud element duration > 30 min

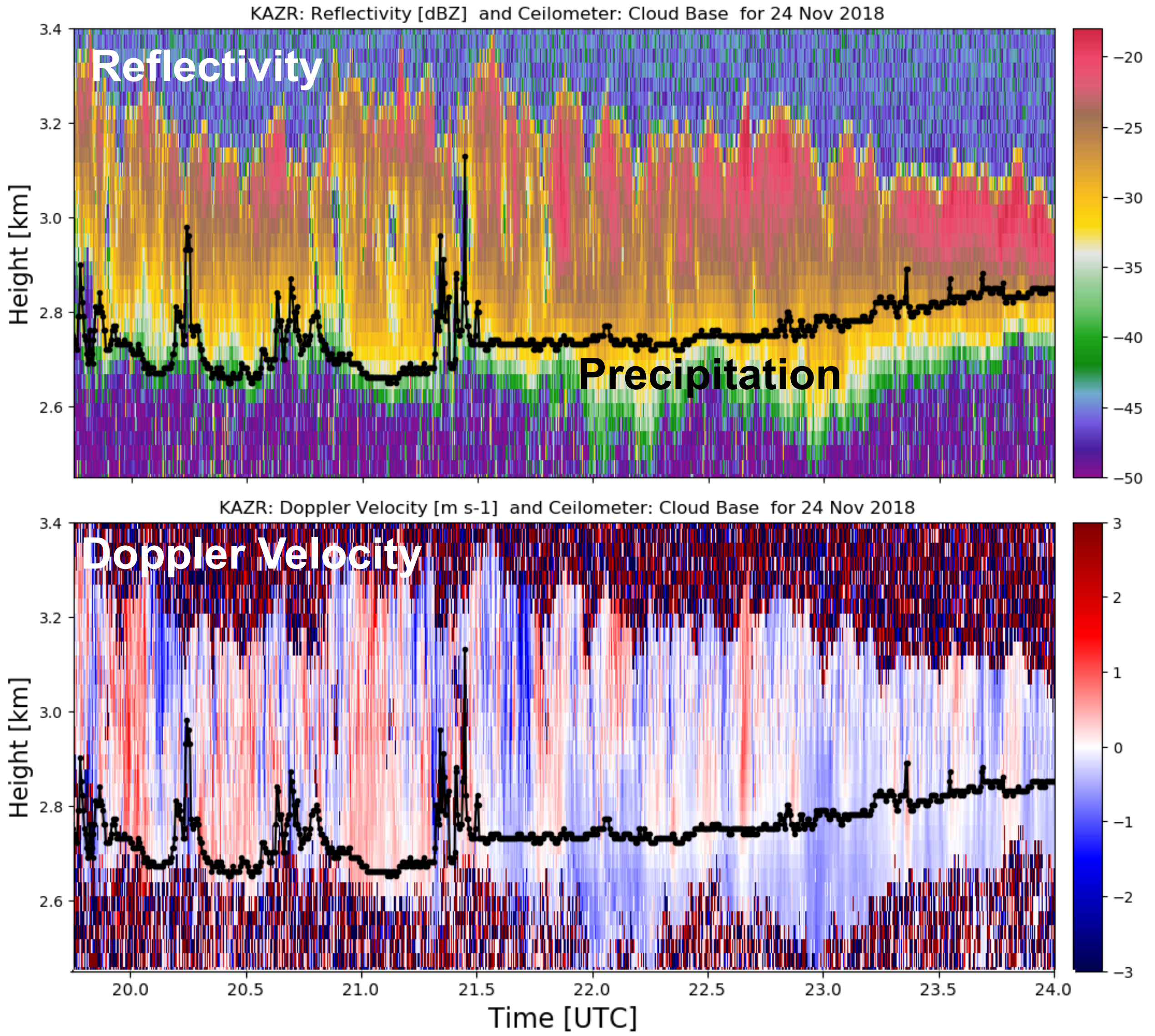


Long-lived shallow clouds are deeper with a bimodal depth distribution. Evening and late morning peaks suggest further controls on occurrence than thermal upslope flow alone.

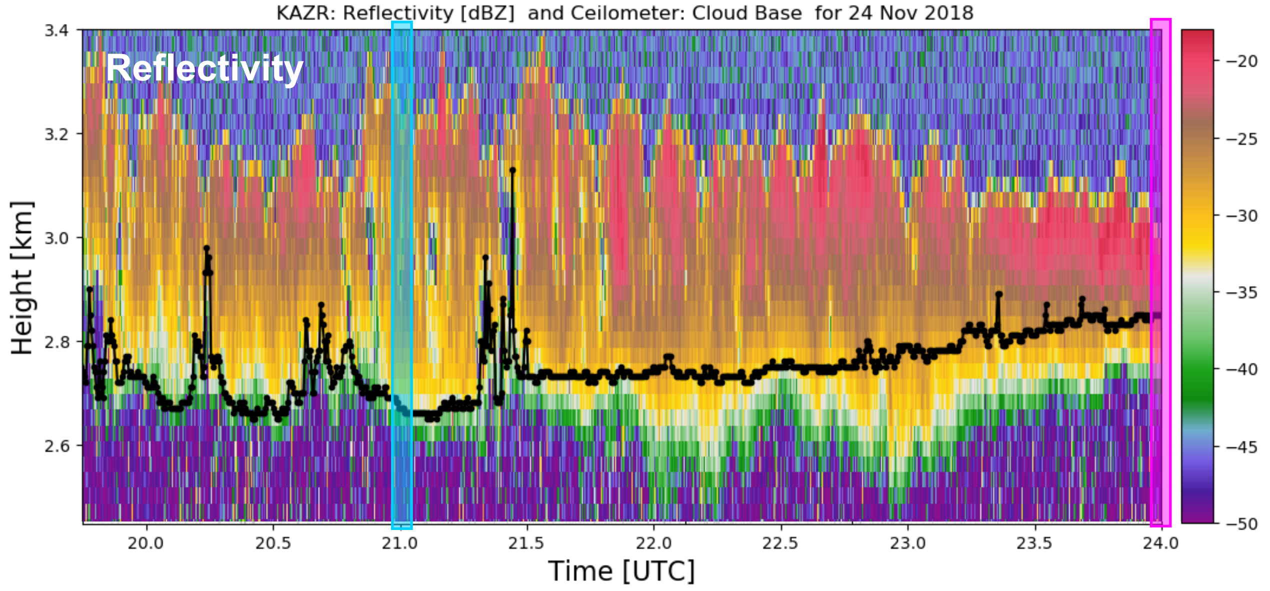
In-depth analysis of a few cases

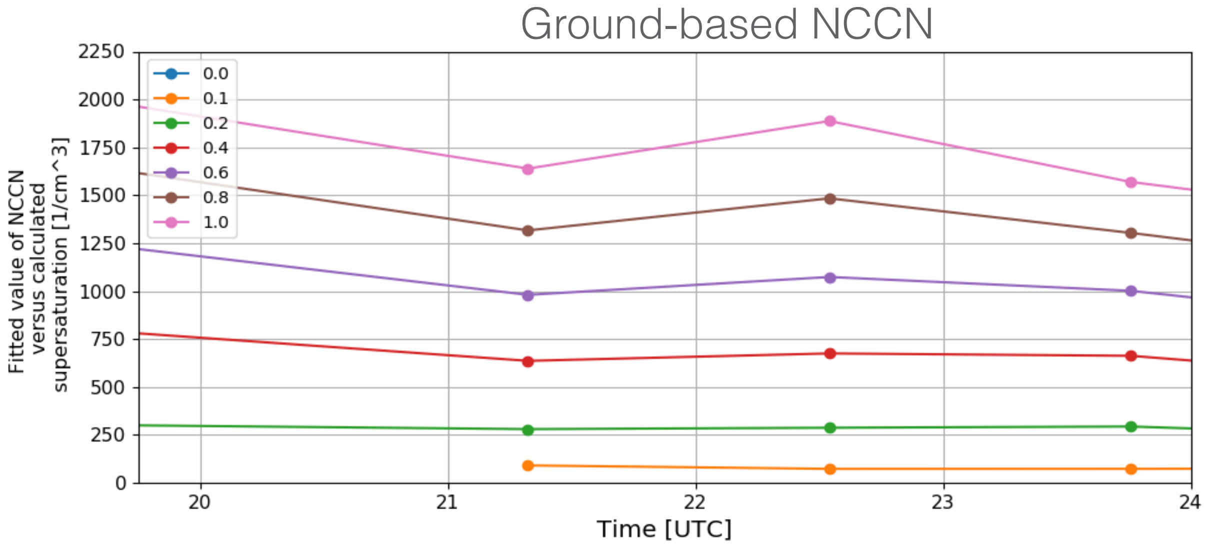
Nov 24th Case

- Very shallow (depth < 600 m) stratocumulus layer with weak reflectivity values (Z_e < -15 dBZ)
- Precipitation particles developed during the evening, after 21:30 UTC (6:30 PM local)
- Convective updrafts present throughout the cloud layer (from cloud base to top)

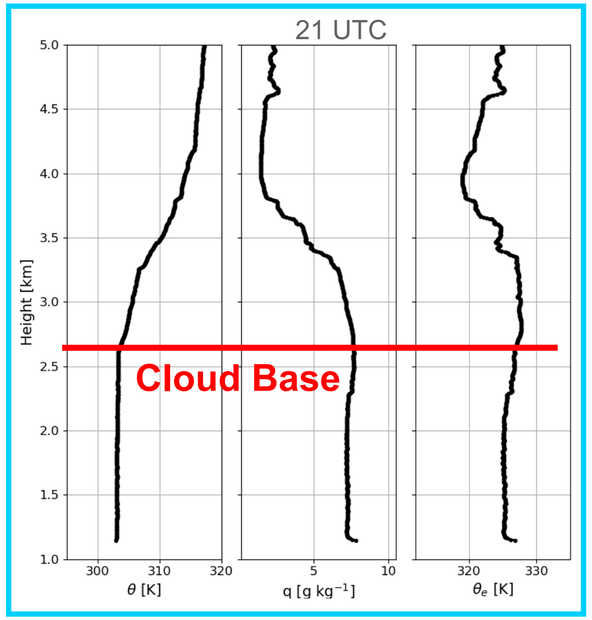


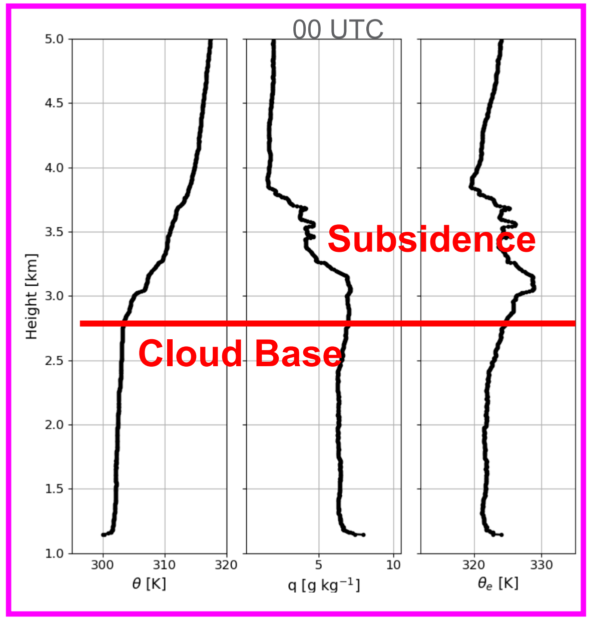
Nov 24th: Surface Coupling and CCN Spectra





Broad surface CCN spectra (supersaturation of 0.6% produces 4 times the CCN as 0.2%) indicating supersaturation in updrafts may have a strong control on droplet growth

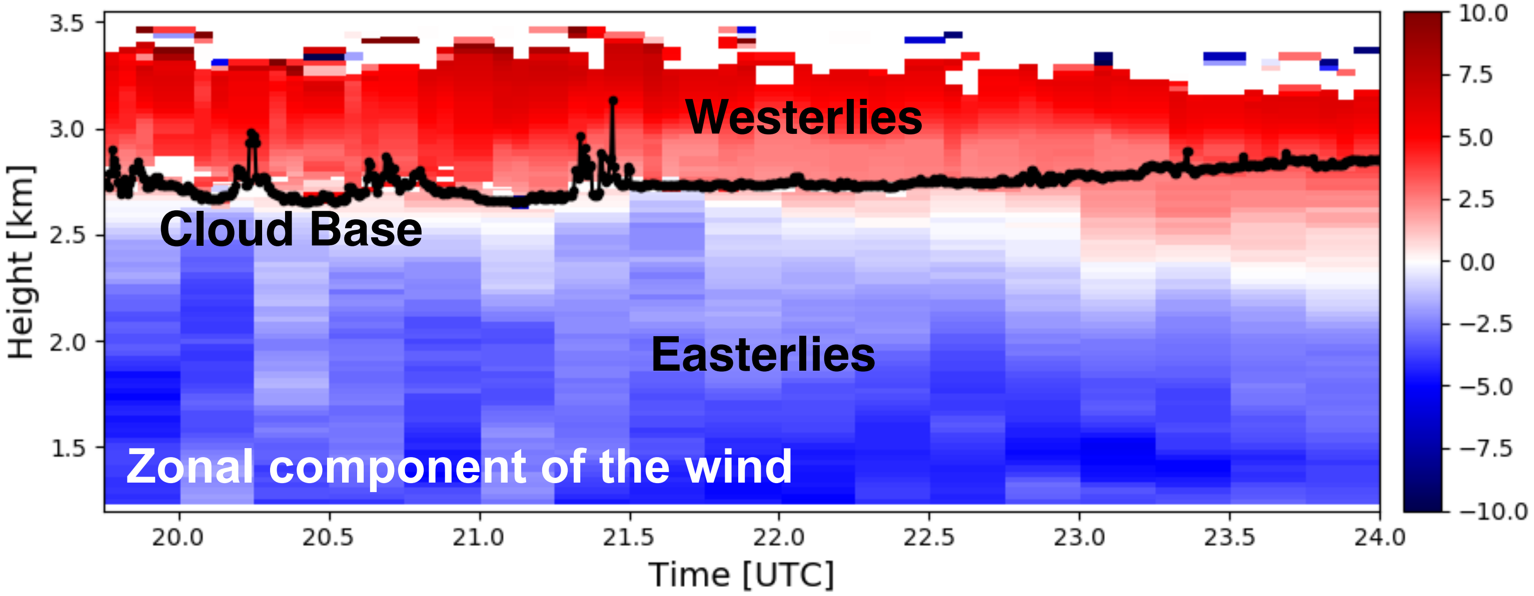




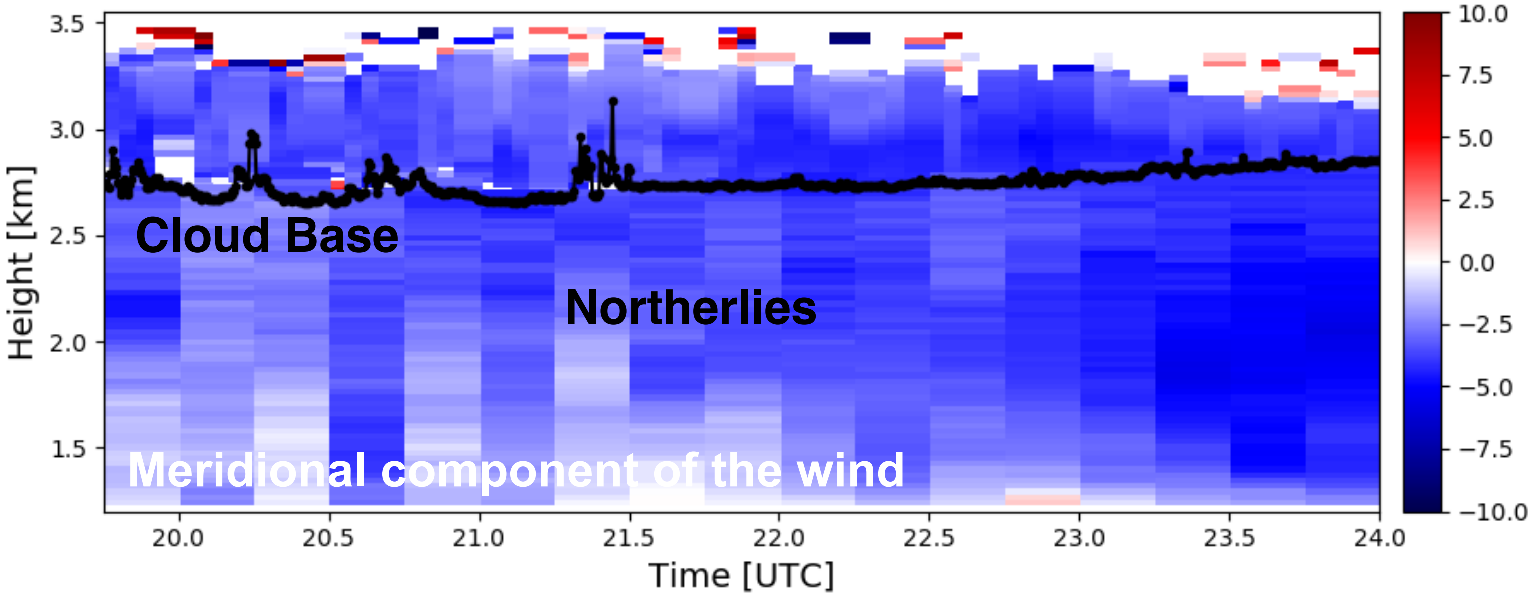
Decoupling of the cloud from the boundary layer indicated by greater cloud theta-e than boundary layer theta-e

Nov 24th: Environmental Circulations

In-cloud and below cloud base VAD horizontal wind retrievals from Scanning ARM Cloud Radar (SACR) and Doppler Lidar observations



Easterly flow below cloud base that rapidly shifts to westerly in the cloud layer, with the directional change descending in time consistent with subsidence observed in soundings

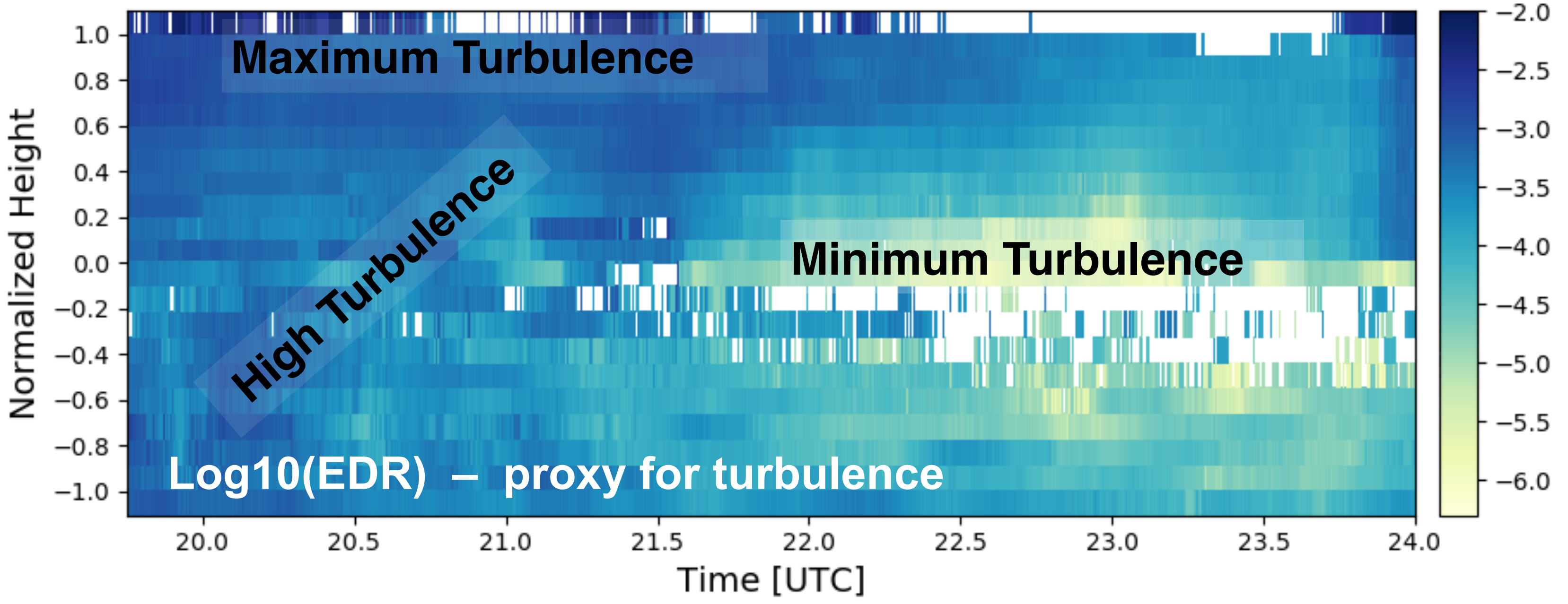


Northerly flow throughout, that slightly intensifies in the evening at cloud base during the period of drizzle onset and in the residual boundary layer in time

Nov 24th: In-cloud and below cloud Turbulence

In-cloud and below cloud base EDR retrievals from KAZR and Doppler Lidar observations

Normalized cloud height (cloud top =1, cloud base = 0, lowest observable height = -1)



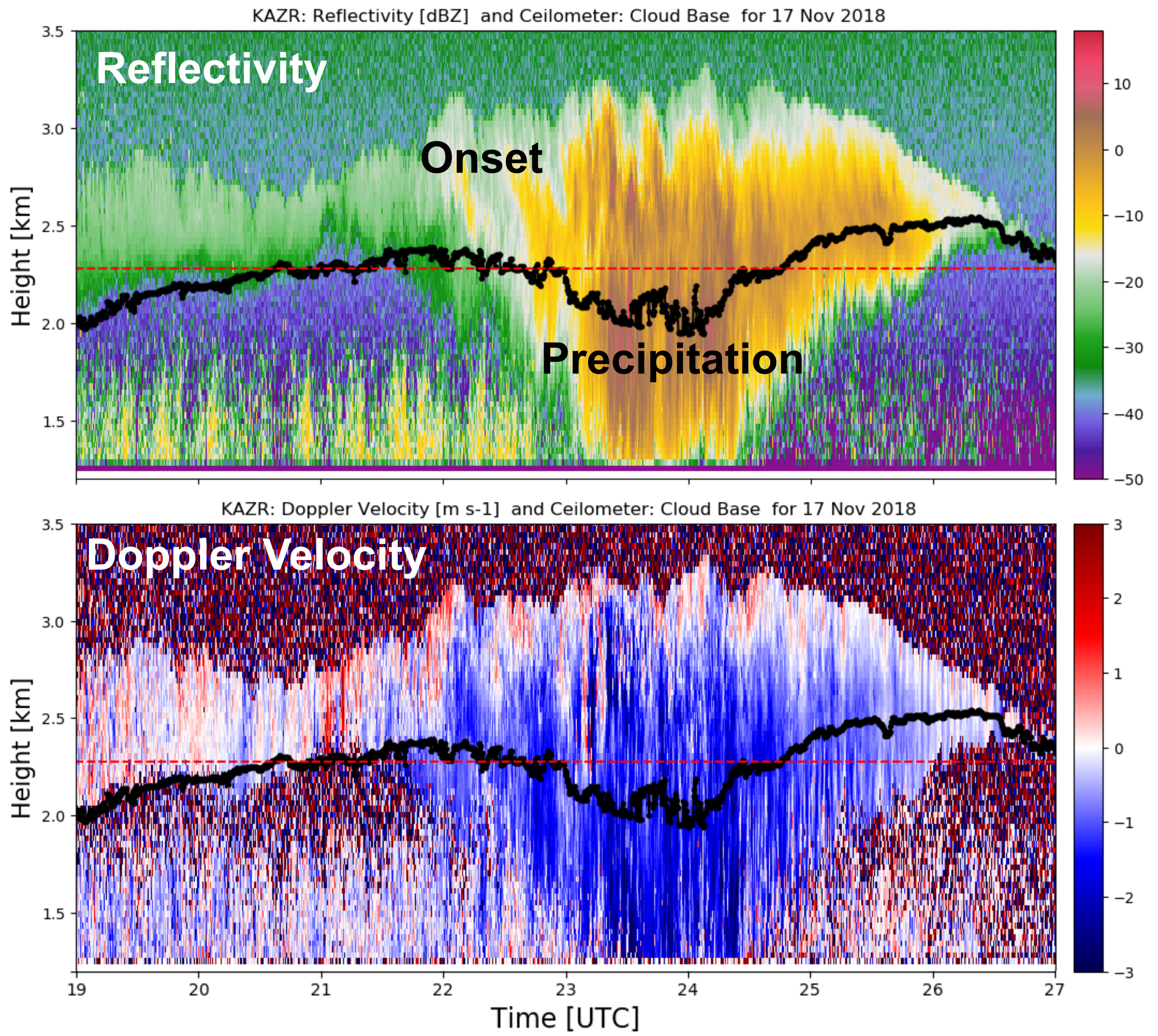
Cloud top is the most turbulent region (where precipitation is expected to be forming)

Before 21:30 UTC, ~homogeneous EDR vertical structure from the boundary layer to cloud top, indicates boundary layer thermals dominating the turbulence

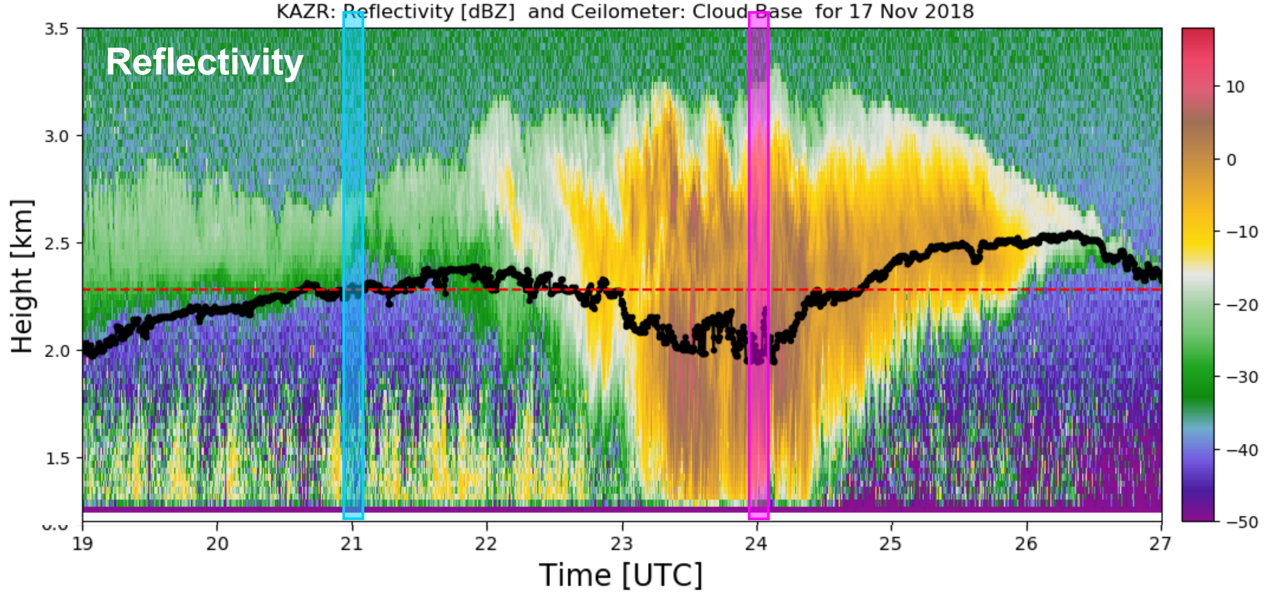
After 21:30 UTC, when precip-size particles are present in the cloud, there is a sharp decrease in turbulence, especially from mid-cloud to cloud base and extending into the boundary layer, indicating decoupling from the boundary layer

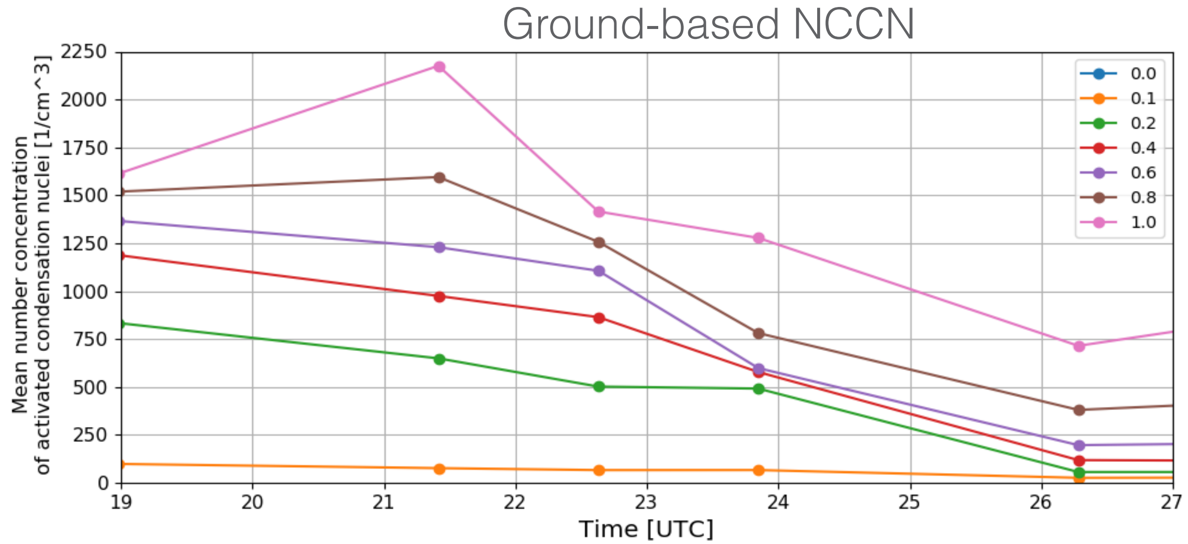
Nov 17th Case

- Thicker cloud (depth ~ 1 km) with greater reflectivity (Z_e > 0 dBZ) than for Nov 24.
- More spatially homogeneous cloud coverage than Nov 24 case
- After 22 UTC downward motion from the precipitating particles overcome the air motion and overpowers the velocity observed by KAZR although updrafts are seen near cloud top throughout

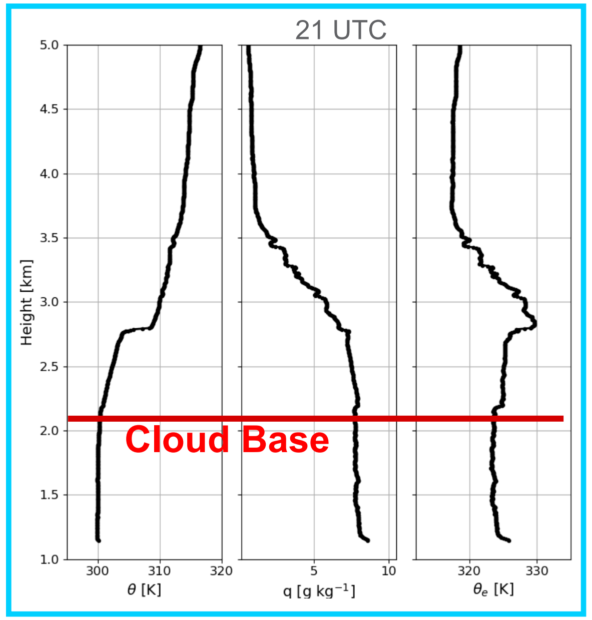


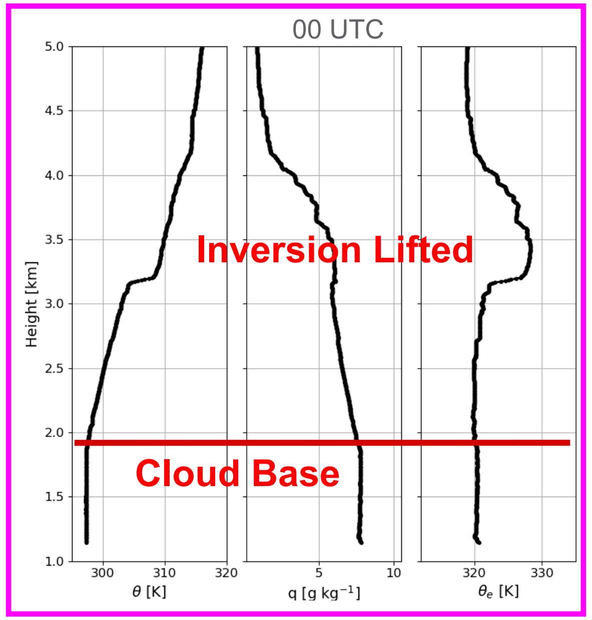
Nov 17th: Surface Coupling and CCN Spectra





Similar CCN spectra as Nov 24th before precipitation onset in the upper cloud at 22 UTC where the supersaturation experienced in updrafts will strongly impact cloud droplet growth

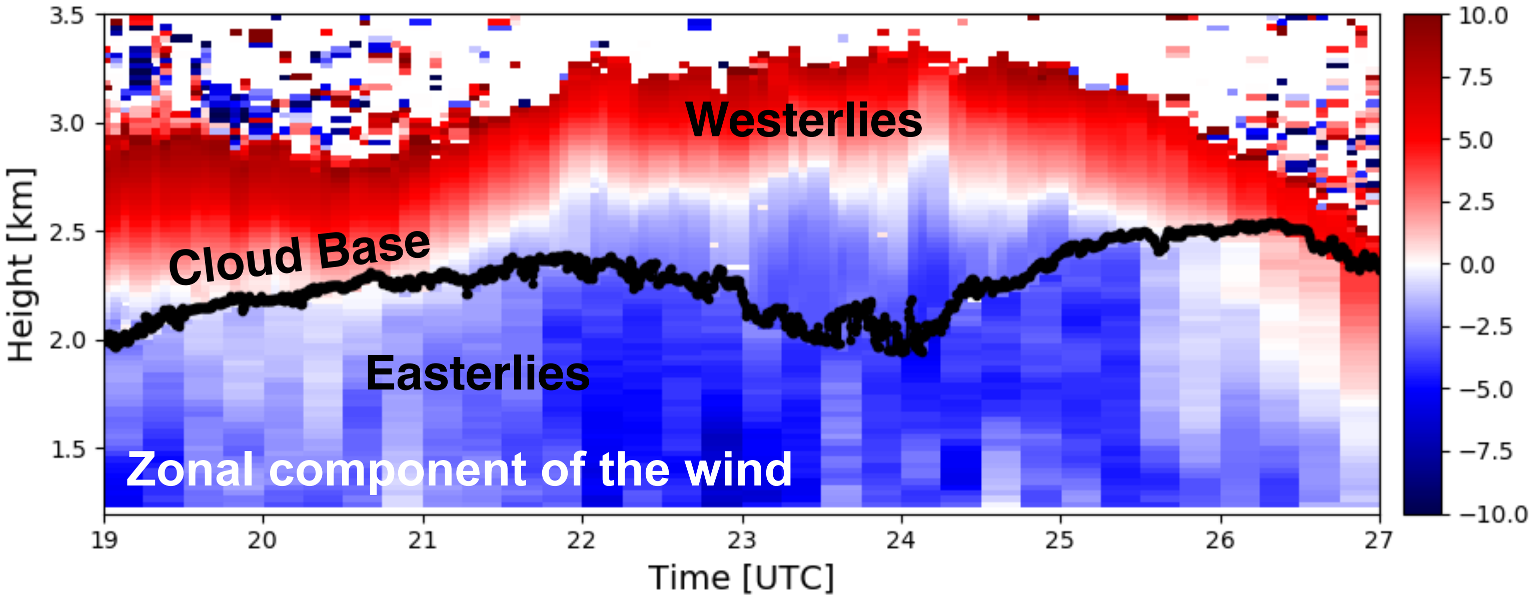




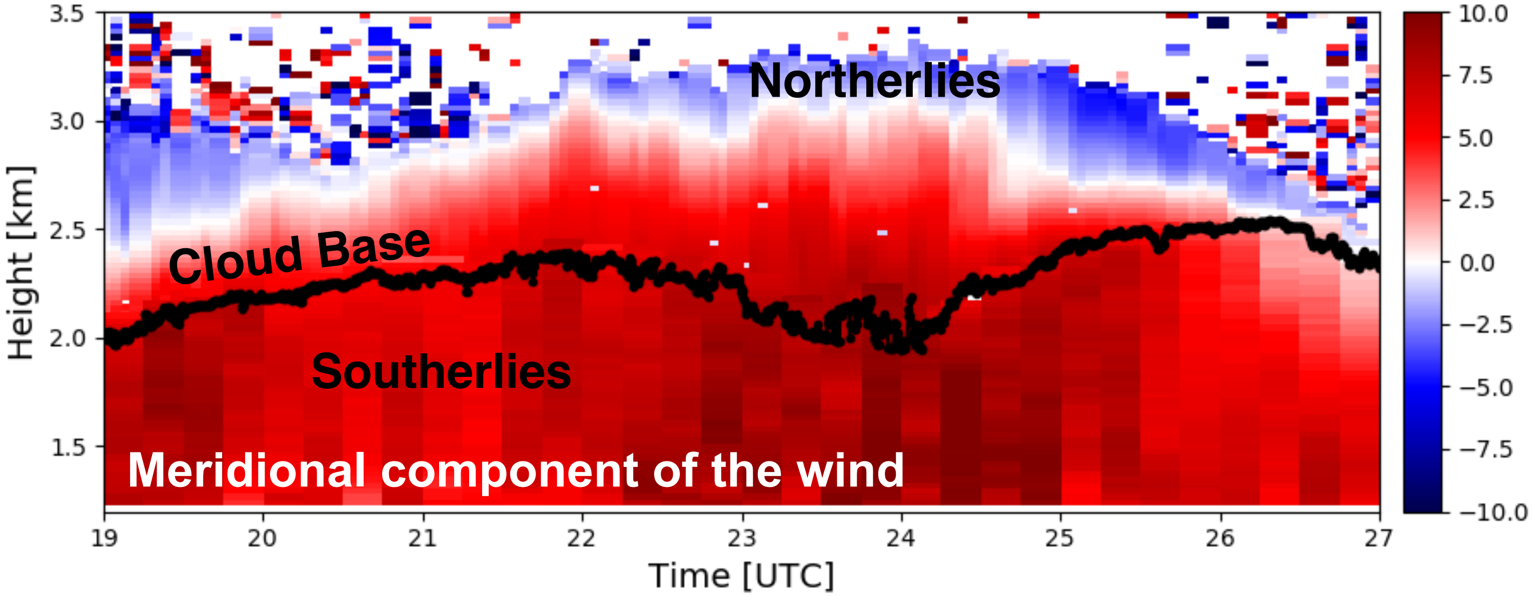
Not a clear decoupling of the cloud from the boundary layer indicated by similar theta-e values from the surface through the cloud layer

Nov 17th: Environmental Circulations

In-cloud and below cloud base VAD horizontal wind retrievals from Scanning ARM Cloud Radar (SACR) and Doppler Lidar observations



There's a shift in wind direction from easterly to westerly in cloud that rises in altitude in association with drizzle onset and subsides with cloud dissipation. Boundary layer easterlies maximize at time of drizzle onset. These, coupled with the sondes, indicate lift that could be associated with an orographically induced wave.

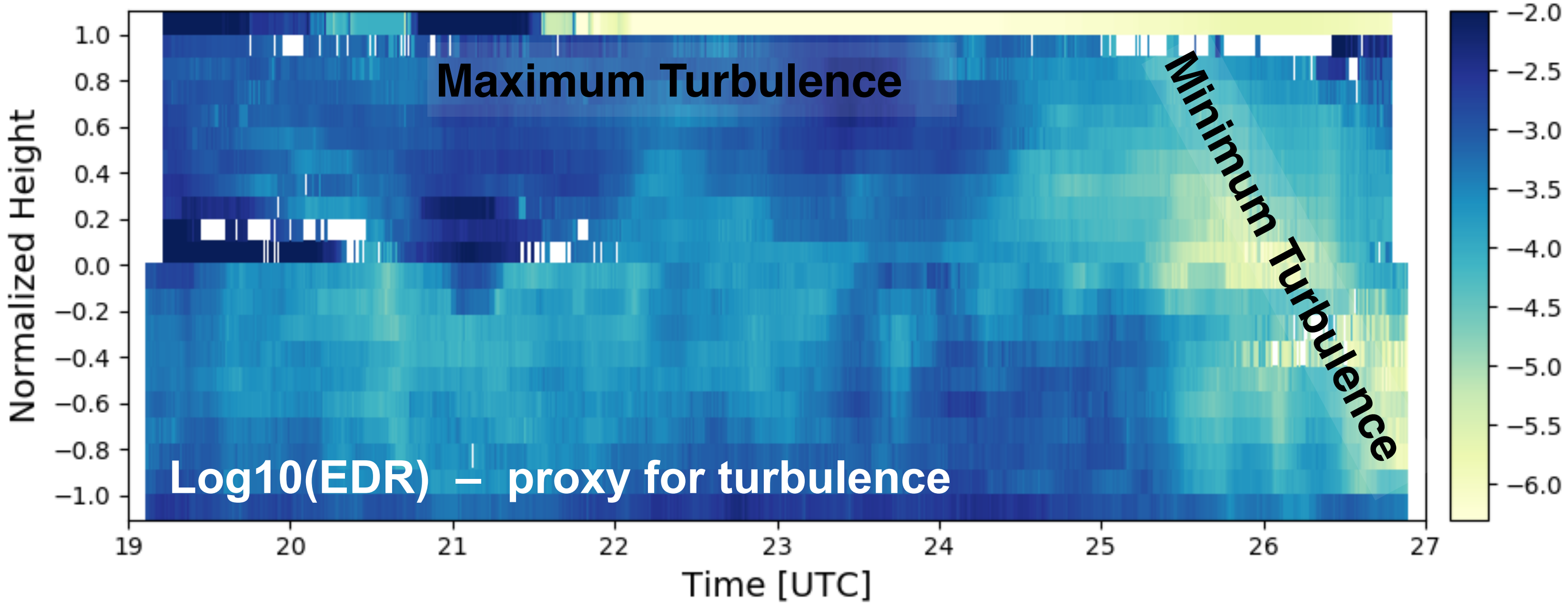


Cloud top is the only region affected by northerly winds. As for the zonal wind, the shift in meridional component of the wind rises in time during drizzle onset and subsides during cloud decay.

Nov 17th: In-cloud and below cloud Turbulence

In-cloud and below cloud base EDR retrievals from KAZR and Doppler Lidar observations

Normalized cloud height (cloud top =1, cloud base = 0, lowest observable height = -1)



This is a more turbulent case than Nov 24th with no clear boundary layer decoupling signal in turbulence.

A turbulence maximum near cloud top around 21 UTC and between 23-24 UTC could be associated with precipitating particles formation

Turbulence sharply decreases once the cloud starts to decay and precipitation no longer reaches the ground

Summary and Preliminary Findings

- We developed an objective and automated algorithm to categorize cloud and precipitation elements as they evolve over the Ka-Band ARM Zenith Radar (KAZR) for the entire duration of CACTI in the Sierras de Córdoba region in central Argentina.
- We have utilized a combination of radiosonde, Doppler lidar, Scanning ARM Cloud Radar (SACR), KAZR, CCN, and microwave radiometer observations to explored a few cases of drizzle formation during the evening transition.
- One case decouples from the boundary layer with subsidence at cloud top, perhaps indicating key roles for CCN concentration and turbulence for precipitation onset. A second case remains coupled with the boundary layer but experiences mesoscale lift, which may be the dominant control on precipitation onset in that case.
- Next, we will further explore retrieval of cloud updrafts using Doppler spectra and investigate the roles of orographic circulations as lifting mechanisms in the cloud layer. We will also extend this analysis framework to the many more shallow cases identified.

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Thank you