# Atmospheric Radiation Measurement Synergy: Radar, Aerosol, Cloud, and Energy

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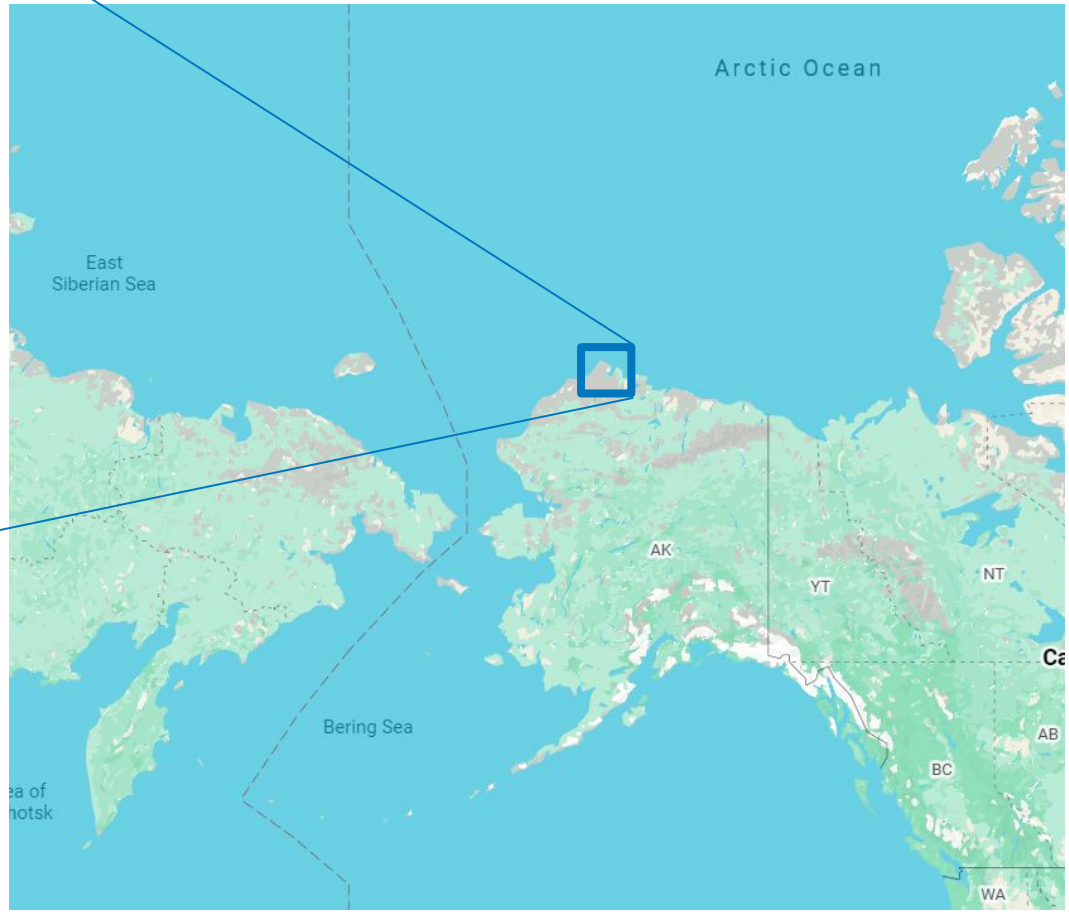
Mentors: Andrew Dzambo and Joe O'Brien


ARM

# Northern Slope of Alaska Site



# The Problem

Clouds are complex…especially mixed-phase clouds

- Lidar and radiosondes provide limited cloud structure coverage due to signal attenuation and infrequent sampling
- Radar reflectivity is often dominated by large ice particles, complicating liquid water retrievals in mixed-phase clouds

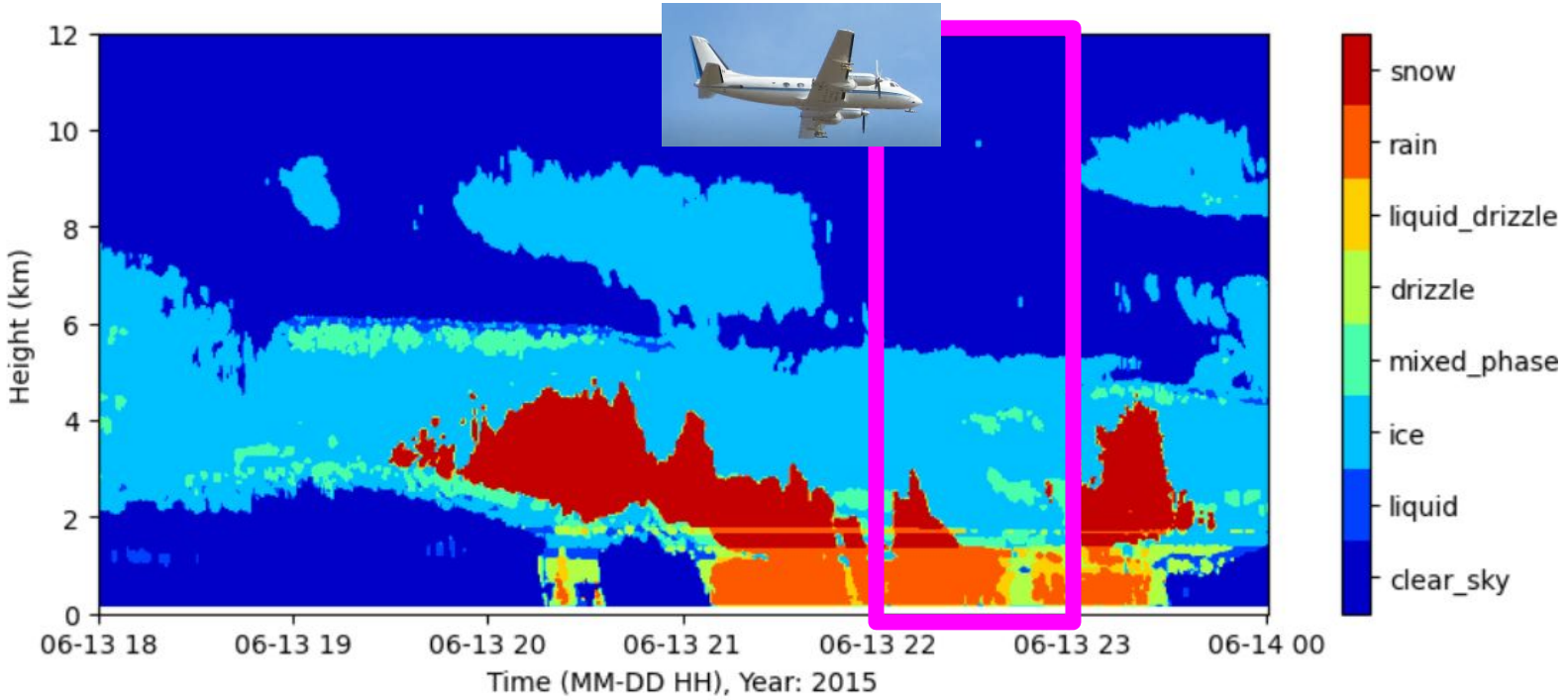
# Our Goal

Use ground-based and aircraft ARM data to study clouds and precipitation in the Arctic

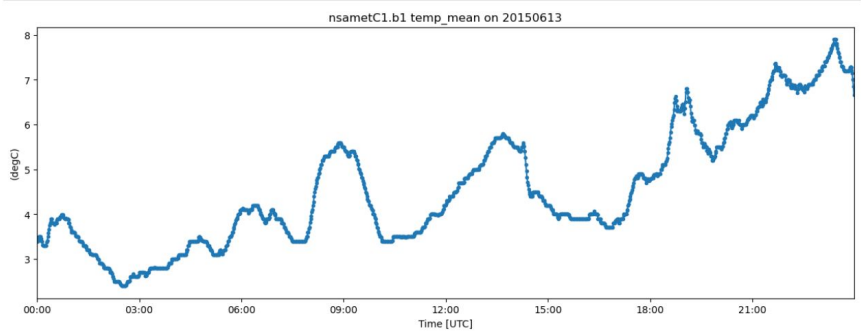
Train and evaluate a machine learning model to **classify cloud phase**

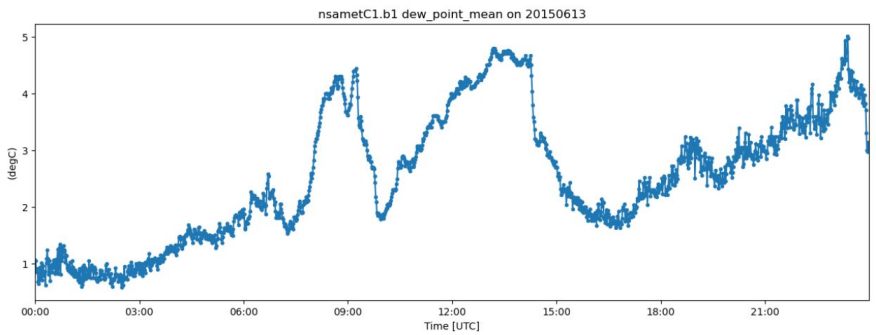
# Case of Interest:
# 13 June 2015
# 22:00 - 23:00 UTC

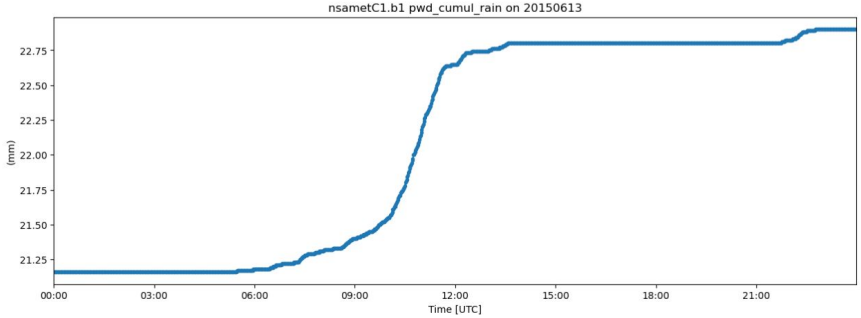
# ARM Thermodynamic Cloud Phase Value Added Product

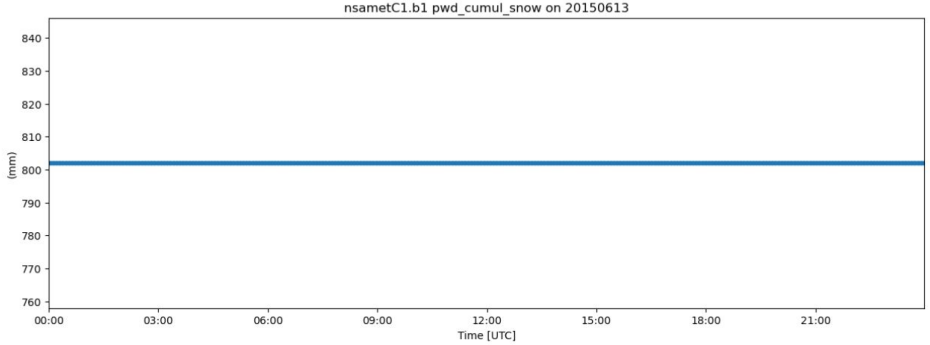


# MET Data on 13 June 2015

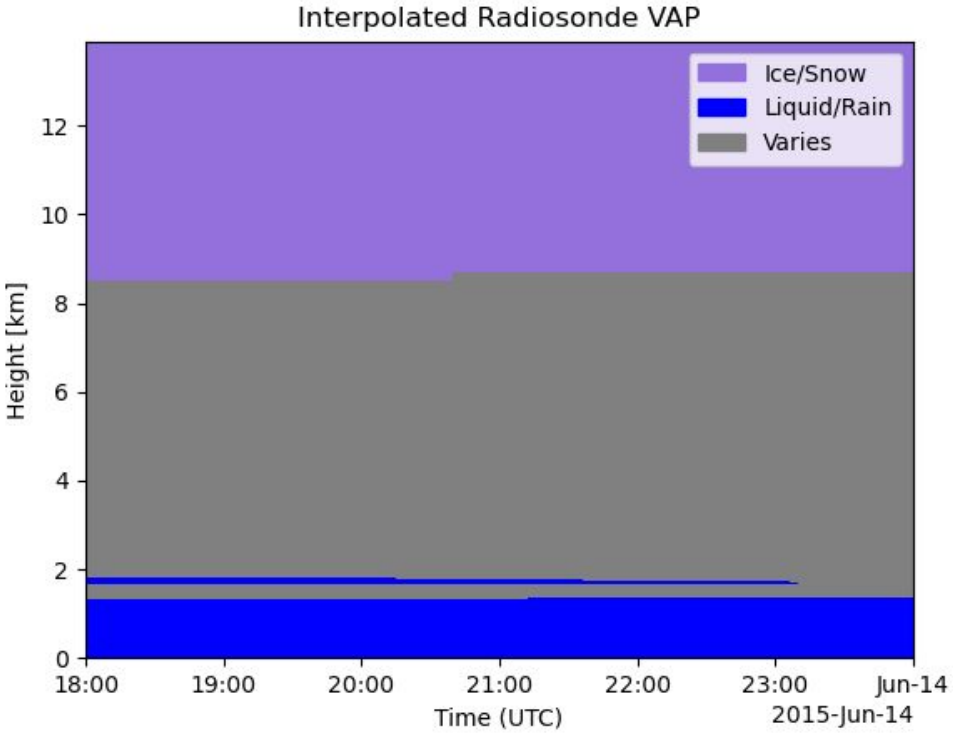


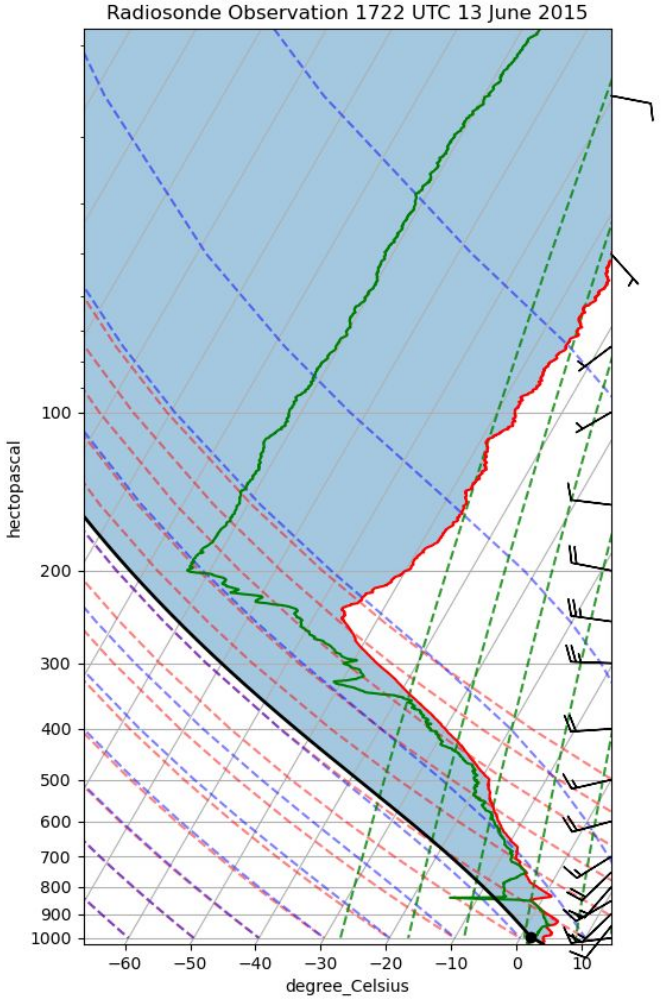



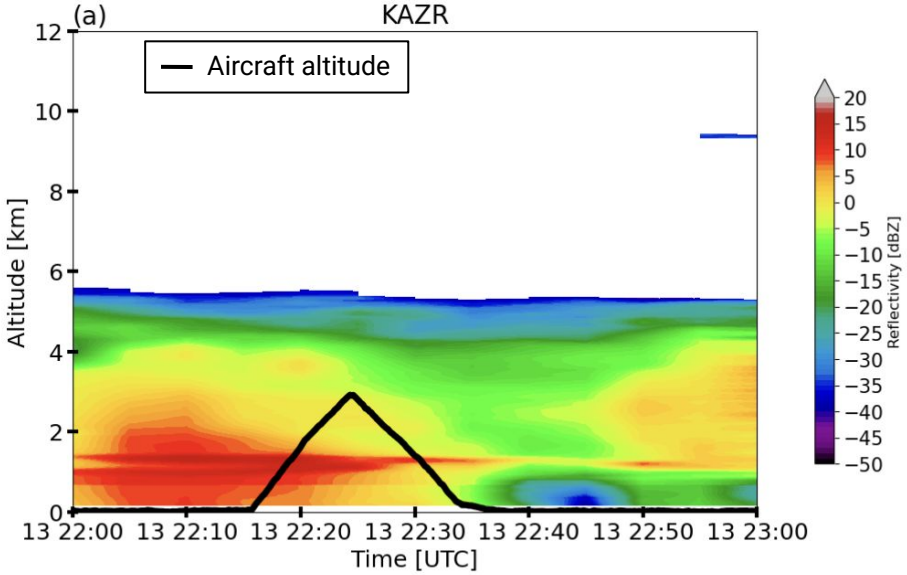



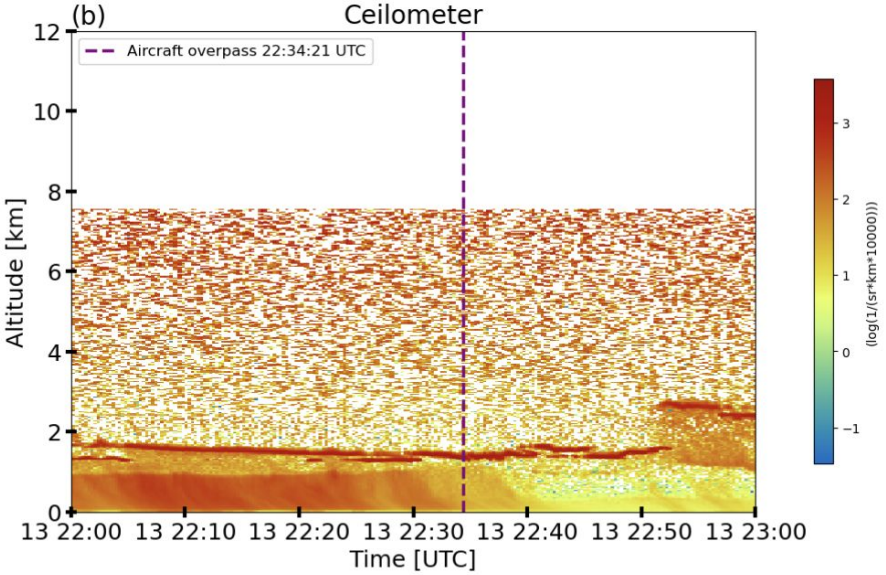
# Radiosonde Measured and Interpolated Temperature



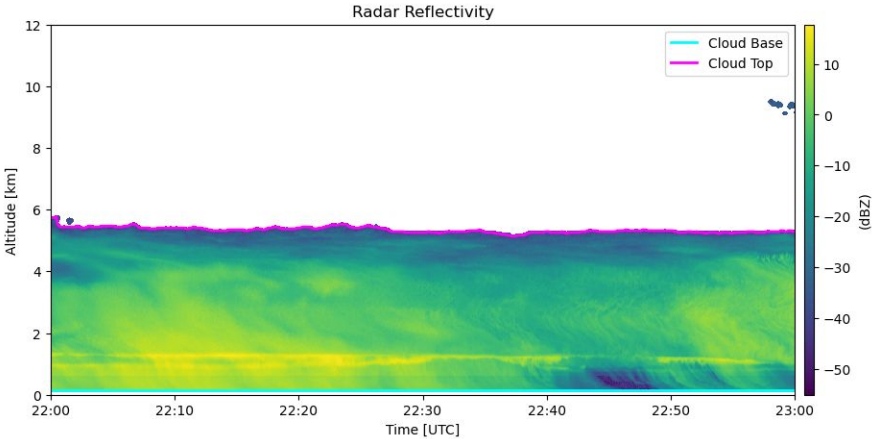



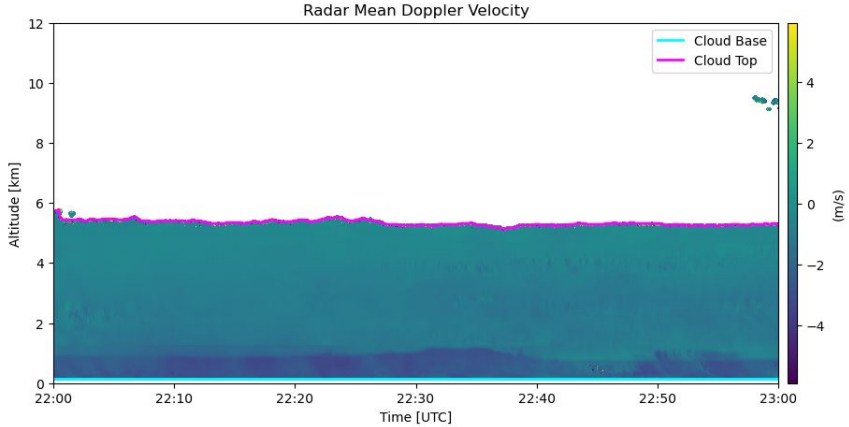
# Radar and Ceilometer Comparison

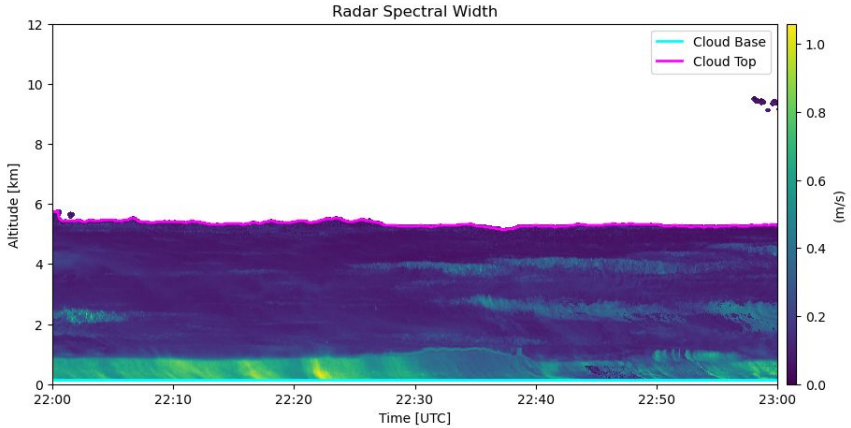


# Radar Data

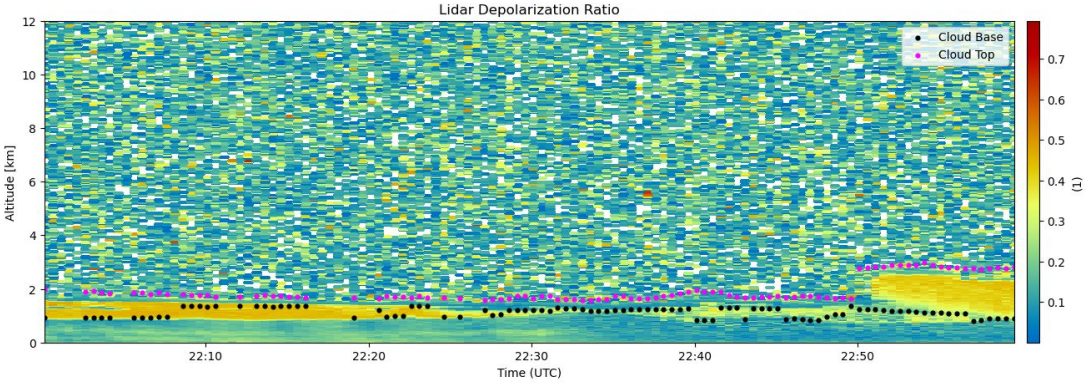

Radar Reflectivity
Cloud Base
Cloud Top
Altitude [km]
Time [UTC]
(dBZ)


Radar Mean Doppler Velocity
Cloud Base
Cloud Top
Altitude [km]
Time [UTC]
(m/s)

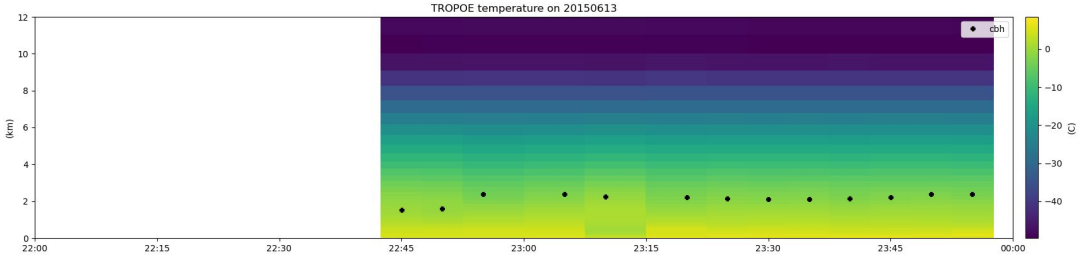

Radar Spectral Width
Cloud Base
Cloud Top
Altitude [km]
Time [UTC]
(m/s)

# Micropulse Lidar and AERI Measurements

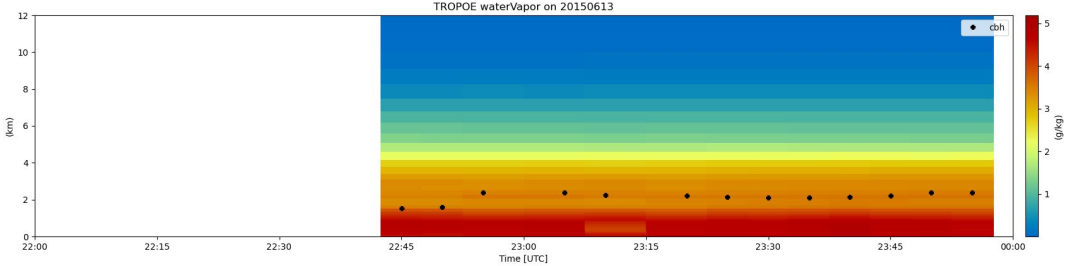
Lidar Depolarization Ratio




Temperature
(TROPoe VAP, AERI-retrieved)




Water Vapor
(TROPoe VAP, AERI-retrieved)



# Model Results

# ML Model: Random Forest

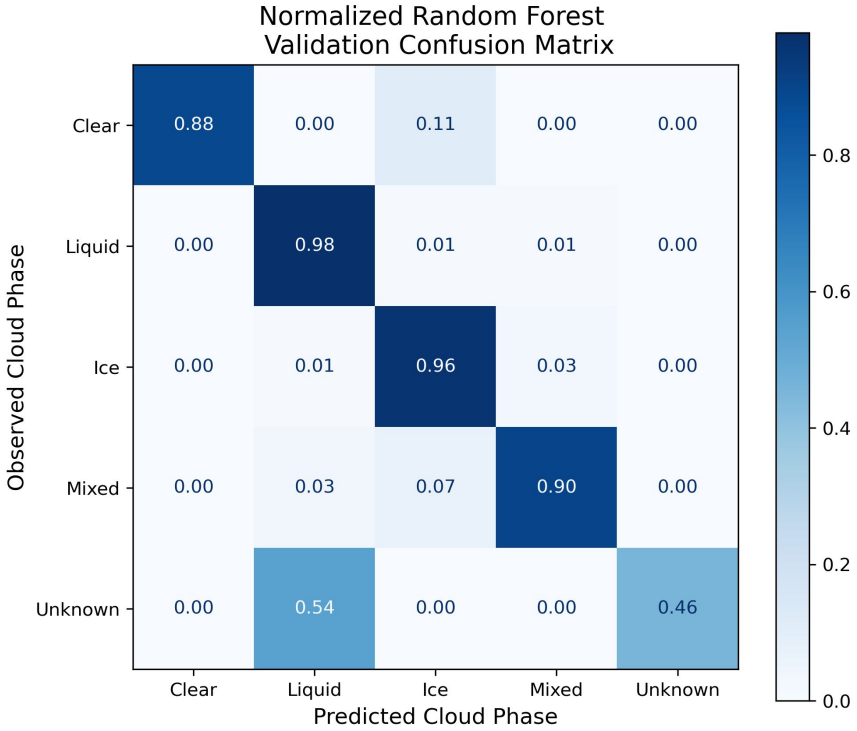
**Dataset from 10th June 2015**

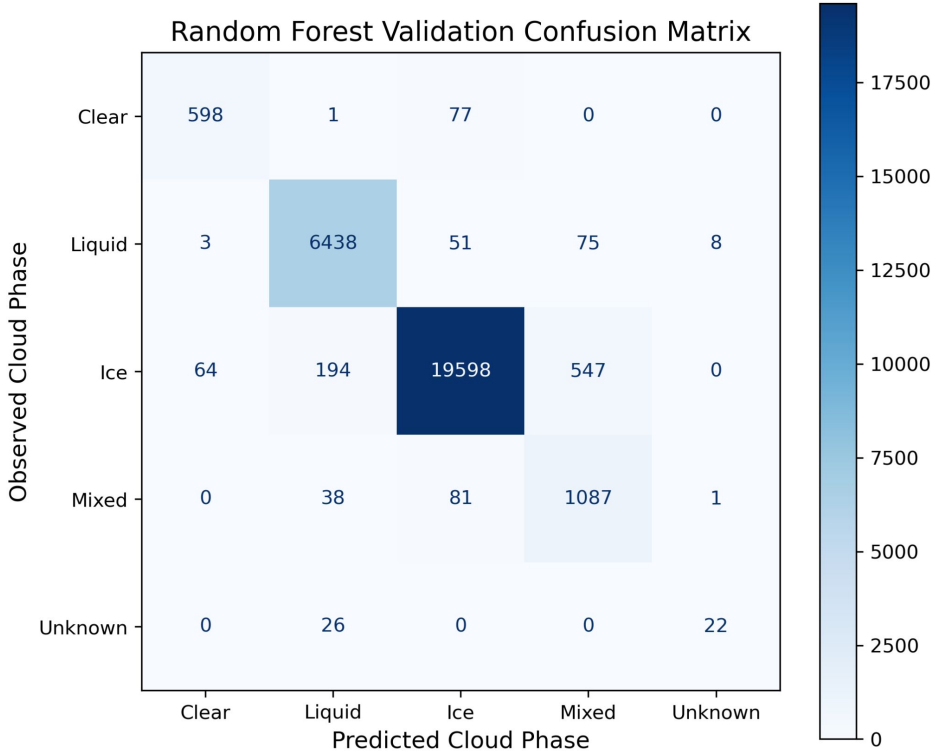
## Input:

Reflectivity (Ka-Band ARM Zenith Radar)
Mean doppler velocity (Ka-Band ARM Zenith Radar)
Spectral width (Ka-Band ARM Zenith Radar)
Backscatter (Ceilometer)
Liquid water path (Microwave Radiometer)

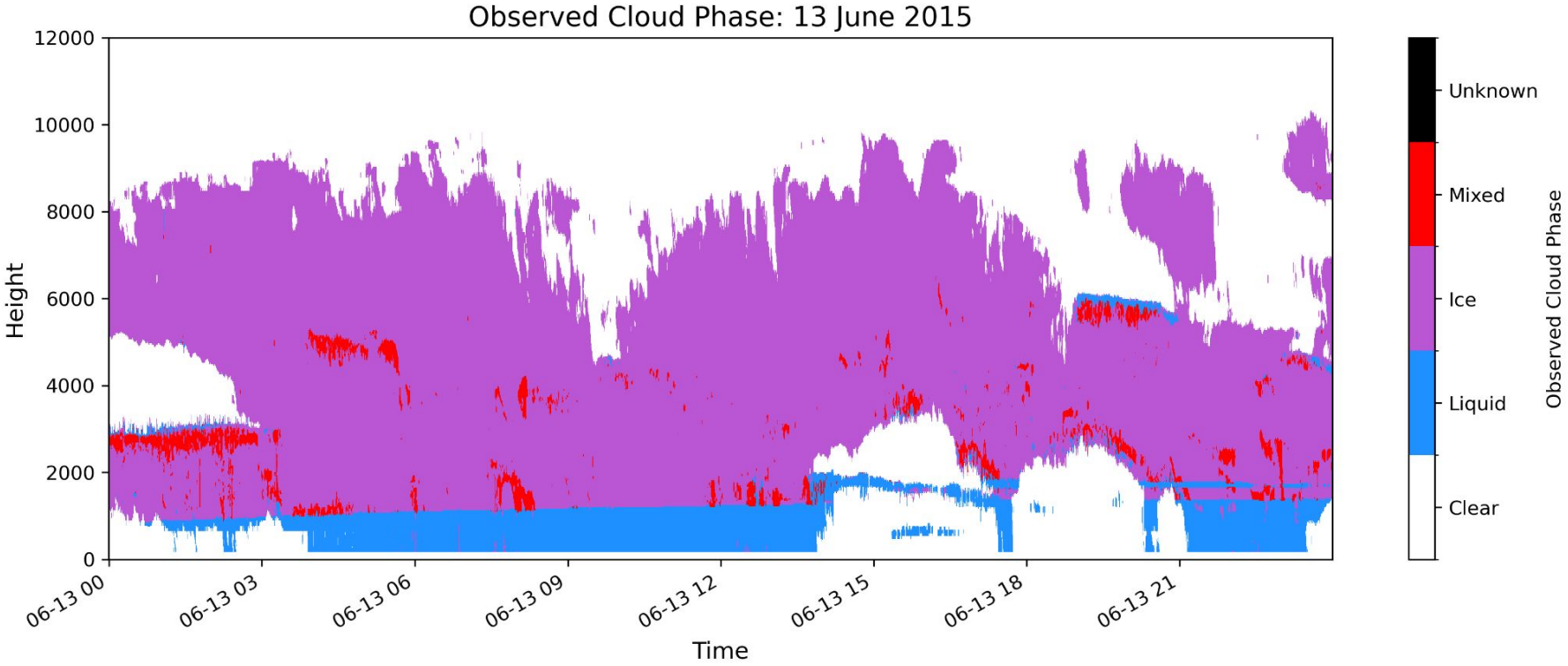
**Truth:** Thermodynamic Cloud Phase (multi-instrument Value -Added Product)

# Confusion Matrices for Validation Data (20%)

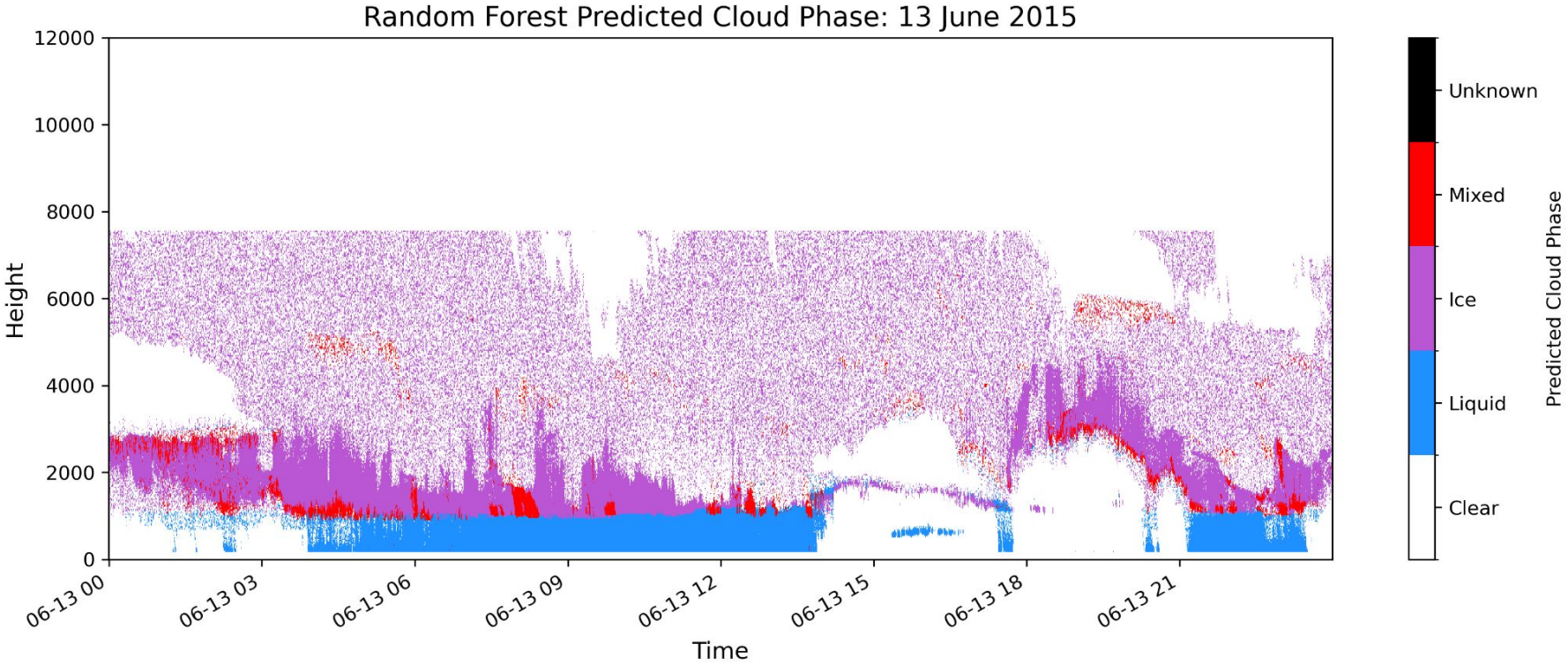


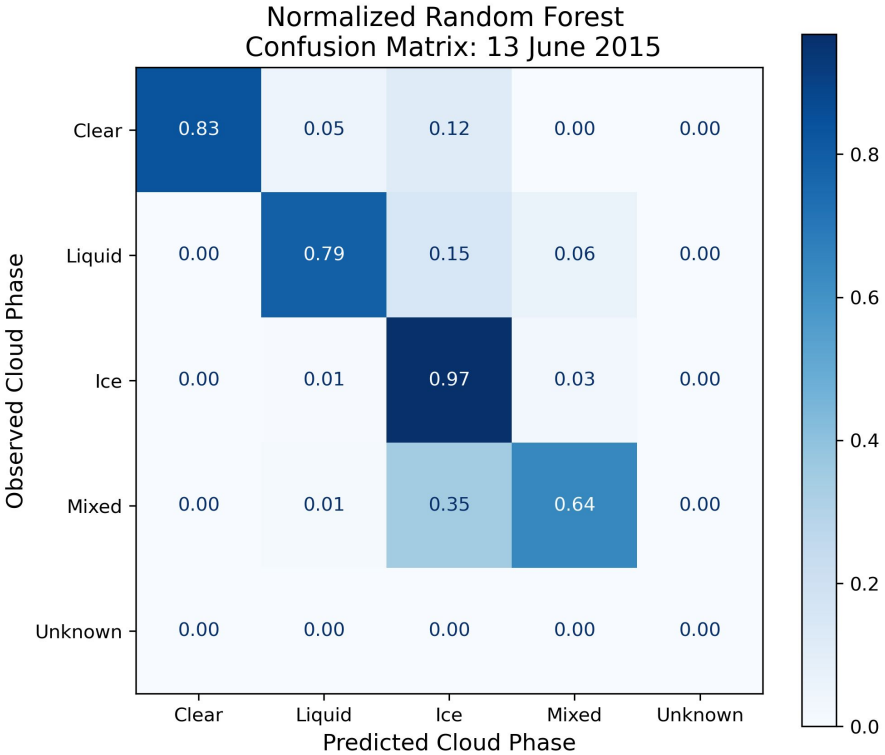
# Truth/Observed Case of Interest (13 June 2015)



# Predicted Case of Interest (13 June 2015)



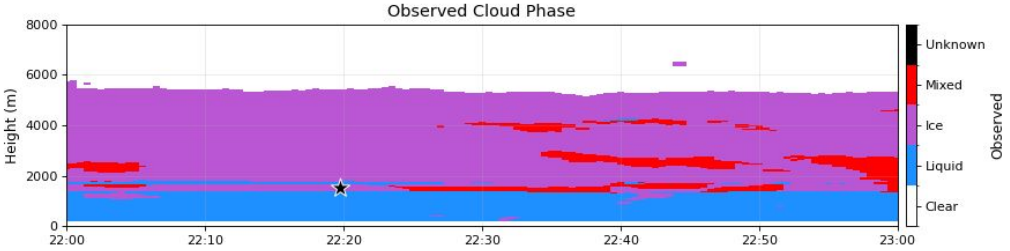
# Confusion Matrices for Predicted Case of Interest

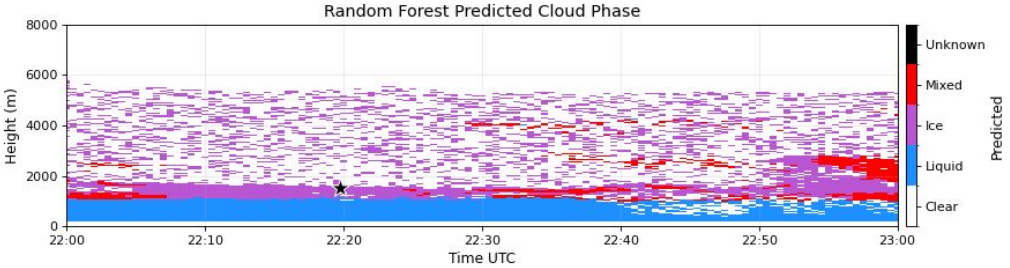


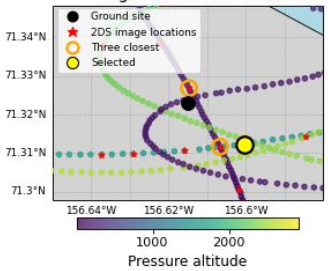

June 13 classification report:

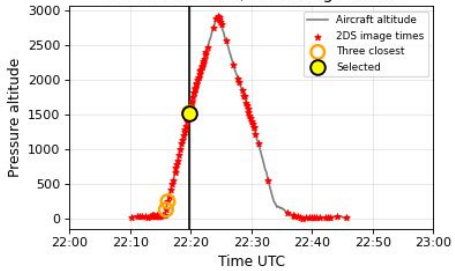
| | precision | recall | f1-score | support |
|---|---|---|---|---|
| Clear | 0.83 | 0.83 | 0.83 | 1931 |
| Liquid | 0.97 | 0.79 | 0.87 | 56916 |
| Ice | 0.93 | 0.97 | 0.95 | 191744 |
| Mixed | 0.49 | 0.64 | 0.56 | 12829 |
| accuracy | | | 0.91 | 263420 |
| macro avg | 0.81 | 0.81 | 0.80 | 263420 |
| weighted avg | 0.92 | 0.91 | 0.91 | 263420 |

# Cloud Phase Curtains and 2DS Imagery Near the Field Site
13 June 2015, 22:00-23:00 UTC

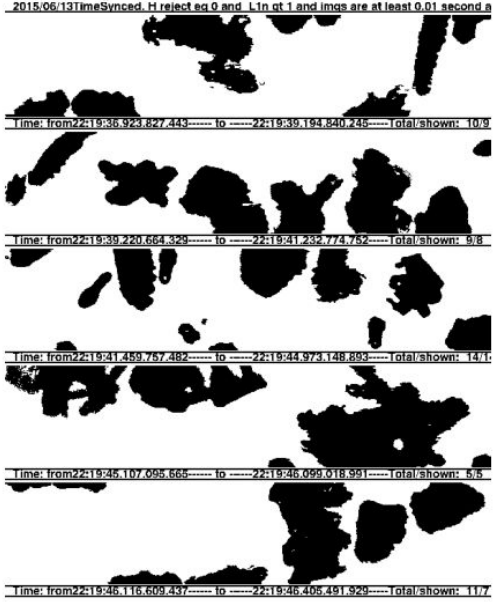



2DS Image: Closest Point 3 of 3
2DS_H_ACMEV_G1_images.20150613a_221946_405491_RA.png
Image time: 2015-06-13 22:19:46 UTC
Aircraft time: 2015-06-13 22:19:46 UTC
Distance to site: 1.30 km | Pressure altitude: 1529



# Future Work

# Future work

- Training on longer temporal range of data
- Generalizing model to more sites
- Different/More features
- Different models (Convolutional Neural Network)
- Denoise the Ceilometer data before training a ML/AI model

# References (Literature)

Goldberger, L., Levin, M., Harris, C., Geiss, A., Shupe, M. D., & Zhang, D. (2025). Classifying thermodynamic cloud phase using machine learning models. Atmospheric Measurement Techniques, 18(20), 5393–5414. https://doi.org/10.5194/amt-18-5393-2025

Morrison, H., de Boer, G., Feingold, G. et al. Resilience of persistent Arctic mixed-phase clouds. Nature Geosci 5, 11–17 (2012). https://doi.org/10.1038/ngeo1332

Shupe, M. D., and Coauthors, 2008: A Focus On Mixed-Phase Clouds. Bull. Amer. Meteor. Soc., 89, 1549–1562, https://doi.org/10.1175/2008BAMS2378.1

# References (Data)


Zhang, D., Ermold, B., & Morris, V. Ceilometer (CEIL), 2015-06-10 to 2015-06-13, North Slope Alaska (NSA), Central Facility, Barrow AK (C1). Atmospheric Radiation Measurement (ARM) User Facility. https://doi.org/10.5439/1181954

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Turner, D. Tropospheric Optimal Estimation Retrieval (TROPOE), 2015-06-10 to 2015-06-13, North Slope Alaska (NSA), Central Facility, Barrow AK (C1). Atmospheric Radiation Measurement (ARM) User Facility. https://doi.org/10.5439/1996977

Kyrouac, J., Shi, Y., & Tuftedal, M. Surface Meteorological Instrumentation (MET), 2015-06-13 to 2015-06-13, North Slope Alaska (NSA), Central Facility, Barrow AK (C1). Atmospheric Radiation Measurement (ARM) User Facility. https://doi.org/10.5439/1786358

# Thank you for listening!

# Extra Slides

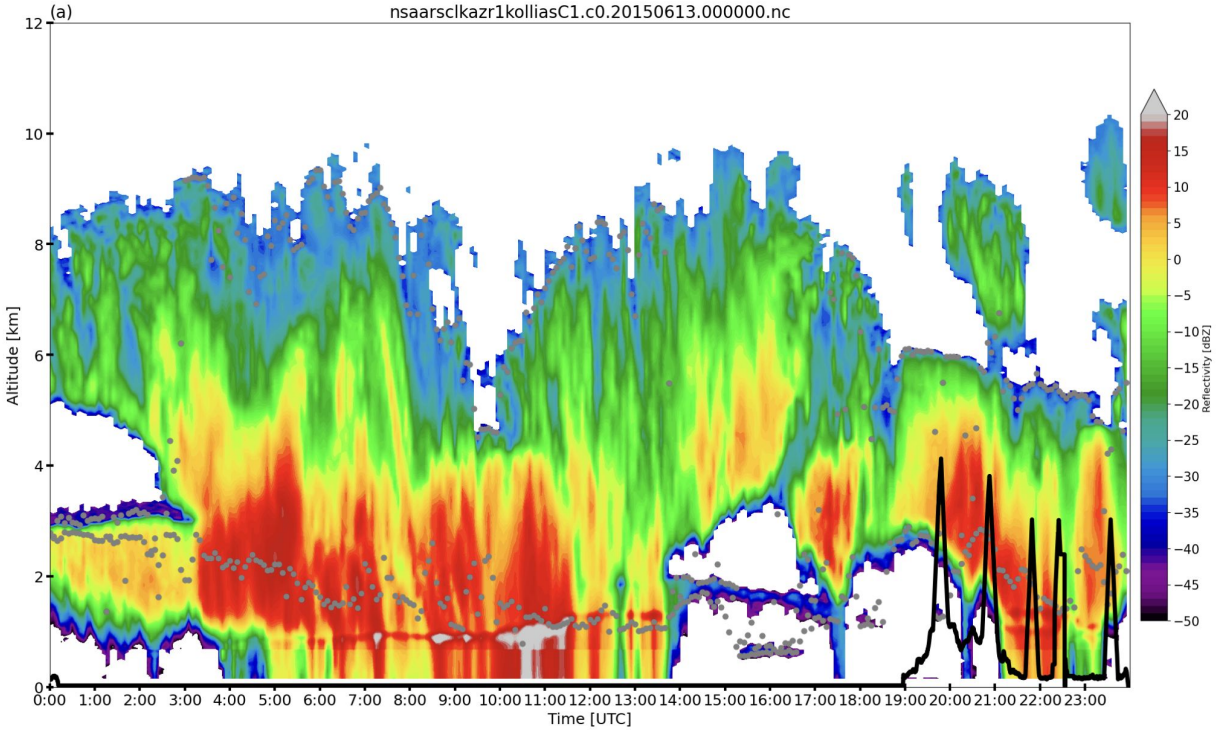
# Background

**ARM site**: North Slope of Alaska (NSA)

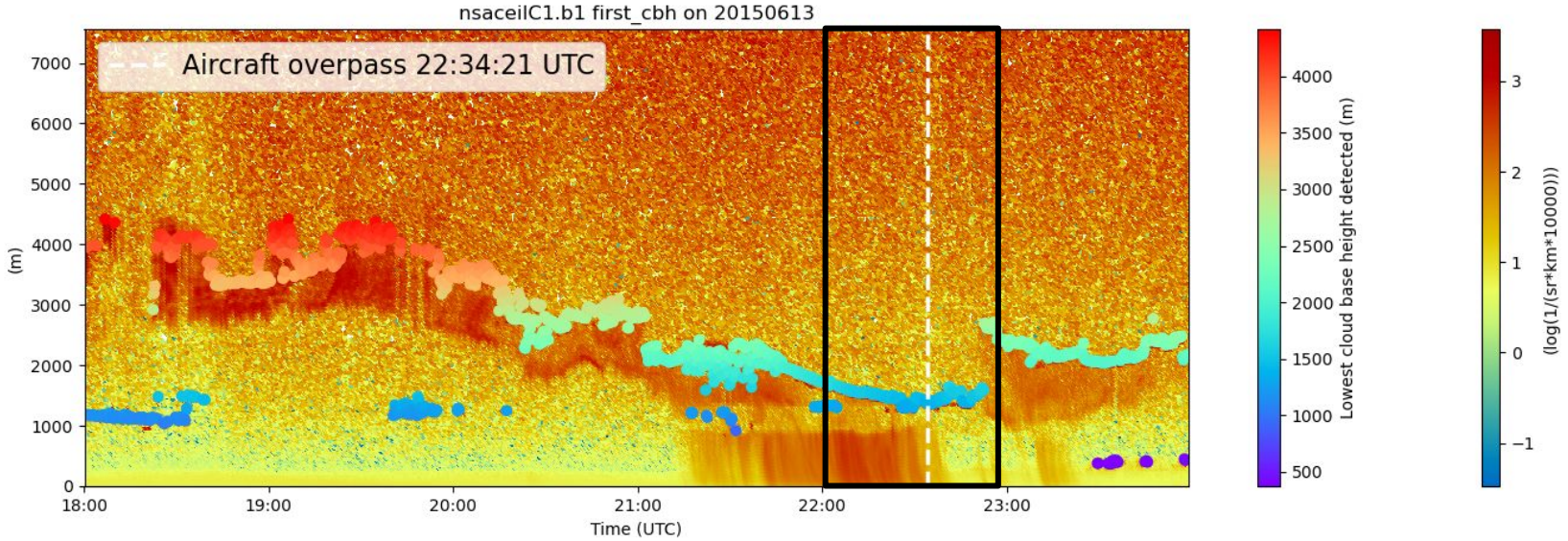
**Regional context:** The Arctic is a region facing atmospheric and environmental changes in recent decades.

**Science topic:** Mixed-phase clouds have an impact on the radiative fluxes in the Arctic, making it pertinent to study in the context of climate change.

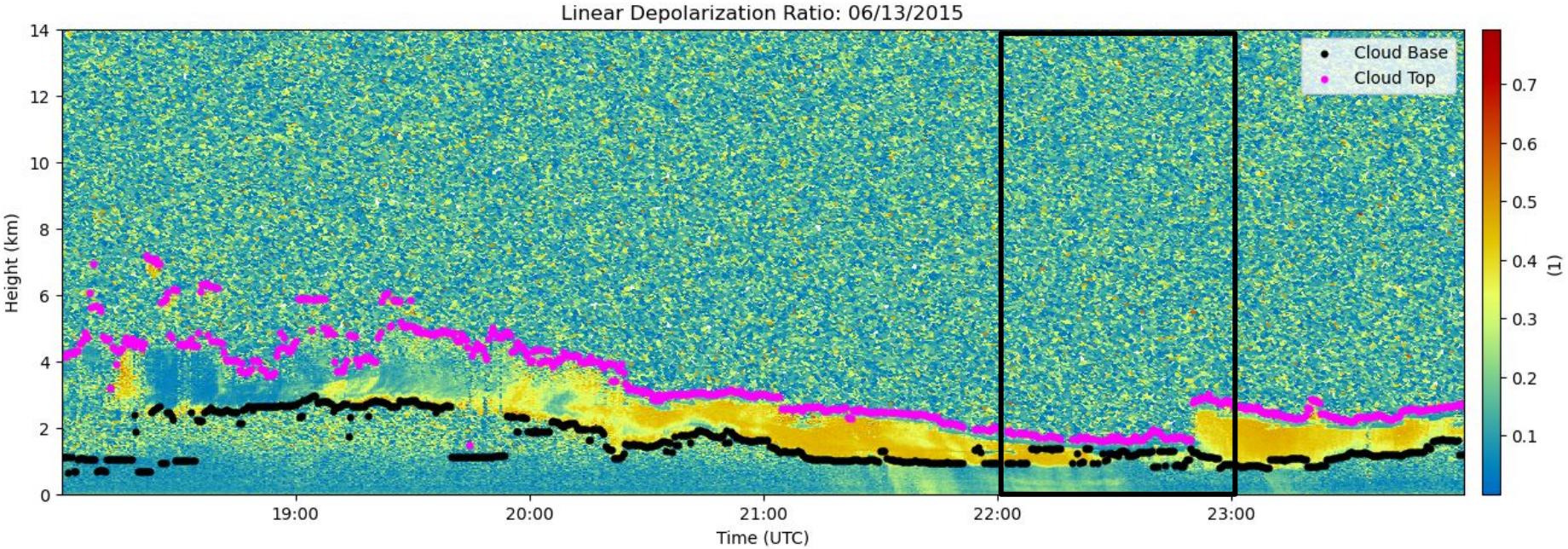
# Radar reflectivity (13 June 2015, entire day)



# Ceilometer backscatter and lowest cloud base height (13 June 2015, 18:00 to 24:00 UTC)



# Micropulse lidar depolarization ratio and cloud bounds (13 June 2015, 18:00 to 24:00 UTC)



# Random Forest Params

```
rf = RandomForestClassifier(
    n_estimators=500,
    max_depth=None,
    min_samples_leaf=10,
    max_features="sqrt",
    class_weight="balanced",

random_state=RANDOM_STATE,
```

# Cloud hydrometeor phase type classes

| Class | Description |
|---|---|
| Ice | Only cloud ice particles |
| Snow | Only snow particles (defined based on a reflectivity threshold which is related to particle size) |
| Mixed-phase | Cloud liquid droplets and cloud ice particles in the same volume |
| Liquid | Only cloud liquid droplets |
| Liquid+drizzle | Cloud liquid droplets and drizzle drops in the same volume |
| Drizzle | Only drizzle drops (defined based on a reflectivity threshold which is related to drop size) |
| Rain | Only rain drops (defined based on a Doppler velocity threshold which is related to drop size) |