The influence of inland atmospheric rivers on cold season precipitation

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PMM STM 2020 Session II

Atmospheric Rivers and Ground- and Space-based Observations

Atmospheric Rivers – Mattingly

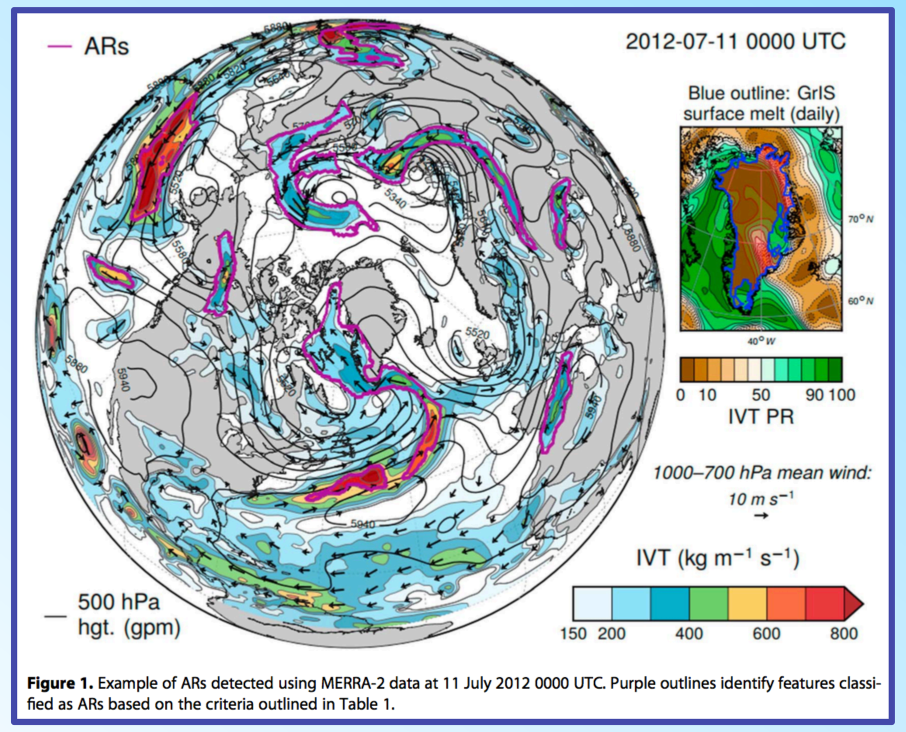


Figure 1. Example of ARs detected using MERRA-2 data at 11 July 2012 0000 UTC. Purple outlines identify features classified as ARs based on the criteria outlined in Table 1.

Atmospheric River (AR) identification database for Northern Hemisphere high-latitudes:

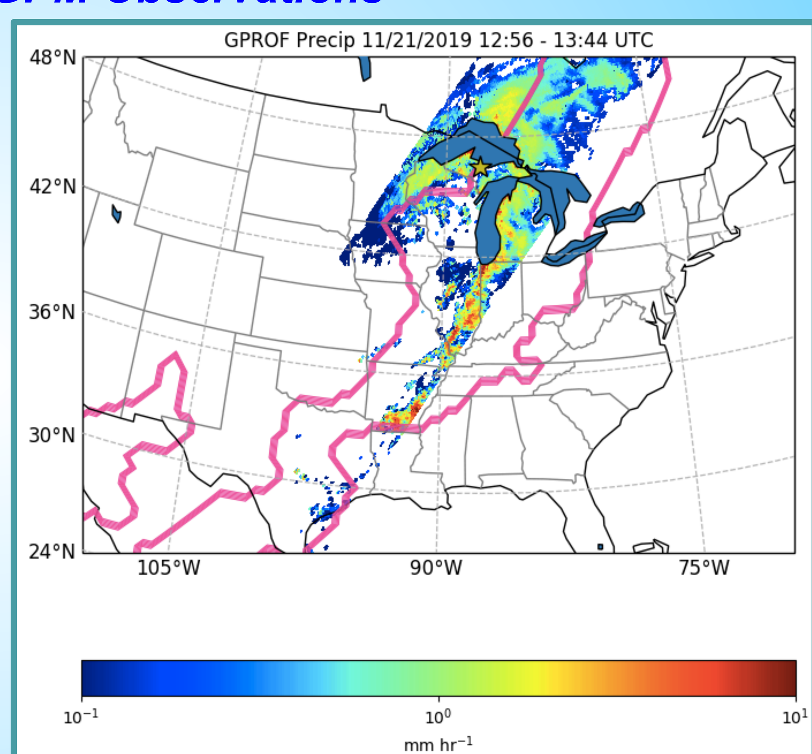
- IVT from MERRA-2
- Re-gridded to 0.5° by 0.5°
- 6-hourly resolution
- 1979 – 2019
- Details in Mattingly et al. (2018)

Raw IVT	IVT PR	Minimum Size	Location	Length	Length-to-Width Ratio	Zonal Transport	Meridional Transport
>150 kg m^{-1} s^{-1}	>85th %-ile	> 150 grid points (0.5° × 0.5°)	Poleward of 10°N	>1500 km	>1.5	u wind > 2 m s^{-1}	v wind > 0 m s^{-1}

Mattingly ARs and GPM Observations

Merge AR detection with GPM observations:

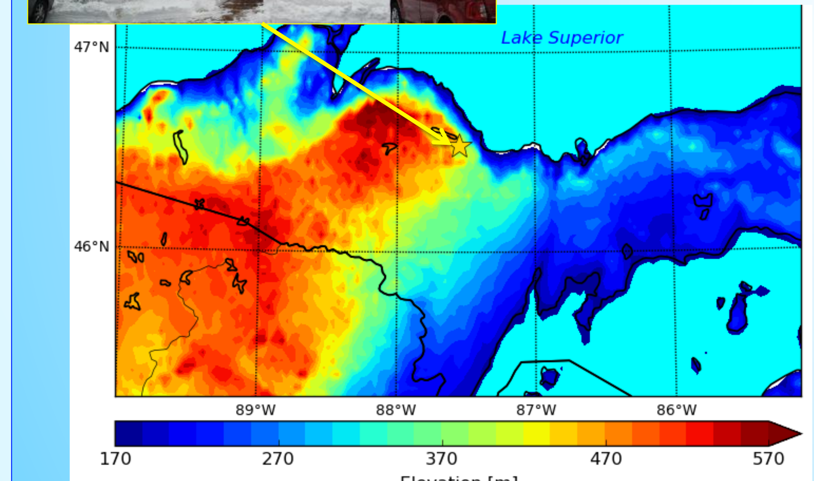
- Use ARs identified with the Mattingly et al. (2018) methodology and merge with timed GPM overpasses
- Currently, we have created NetCDFs of GPROF observations with an added flag indicating the presence/absence of an AR
- An example is shown in the figure with an AR (outlined in pink) traversing the central US. GPROF precipitation rates are shown as well.



Ground-based Observations – Marquette, Michigan (MQT)

Why Marquette, Michigan?

- High snowfall totals
- Abundance of LES
- Great facilities: NWS MQT
- Continuous data since 2014
- See Pettersen et al. (2020)



Instrumentation:

- MicroRain Radar (MRR)
  - Vertically profiling
  - 3000 m height range
- Precip. Imaging Package (PIP)
  - In situ images of snow
  - Rain/Snow rates
- Surface Meteorological Data
- NEXRAD

References:

- Mattingly et al., "Atmospheric River Impacts on Greenland Ice Sheet Surface Mass Balance", JGR: Atmospheres, 2018, doi: 10.1029/2018JD028714.
- Pettersen et al., "A composite analysis of snowfall modes in Marquette, Michigan", JAMC, 2020, doi: 10.1175/JAMC-D-19-0099.1

Data Analysis – Cold Season Precipitation Events from 2014 – 2019

Precipitation Events with and without an AR Present

Precipitation Event Selection:

- Examine ground-based observations adjacent to 0000, 0600, 1200, and 1800 UTC
  - This is to time match the MERRA reanalysis products used in the Mattingly AR detection method
  - Example: 0600 UTC AR would correspond to ground-based observations from 0530 to 0630 UTC
- Only use precipitation events where the surface temperature is < 2.0 °C for the entire hour
- At least 15 minutes of the one hour time window needs to have precipitation (non-consecutive) as observed by the NEXRAD and MRR
- Use the MRR observations to categorize cold season as "deep" or "shallow" (see Pettersen et al., 2020)

Identified a total of 1,162 individual time windows with cold season precipitation

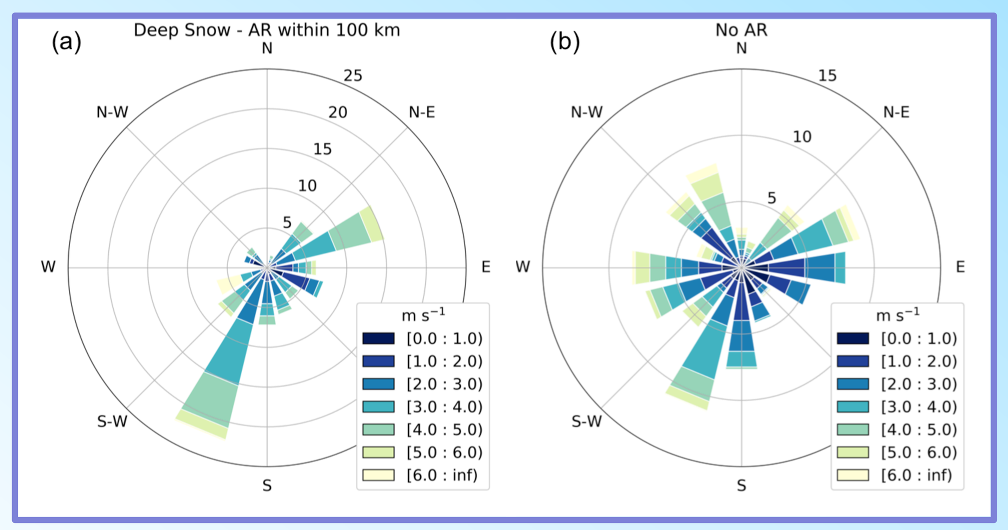
Influence of ARs on Cold Season Precipitation at MQT:

- We define a "coincident AR" as occurring within <100 km of the MQT instrument site
- Coincident ARs occur 6.4% of the time, regardless of precipitation
- Coincident ARs occur 9.4% of the time during ground-based observed precipitation
  - Shallow precipitation 3.9%
  - **Deep precipitation 28%** (58 events with AR, 148 no AR)

***Cold season deep precipitation** is **three times** more likely to be connected to an AR when compared to all cold season precipitation, and **seven times** more likely when compared to cold season shallow precipitation*

***Cold season deep precipitation** is **four times** more likely to occur as **rain phase** at the surface when coinciding with an AR versus not (AR within 100 km of MQT: rain occurrence 19.8%; no AR: 5.7%)*

Surface Observations of Deep Precipitation: With and Without AR Present



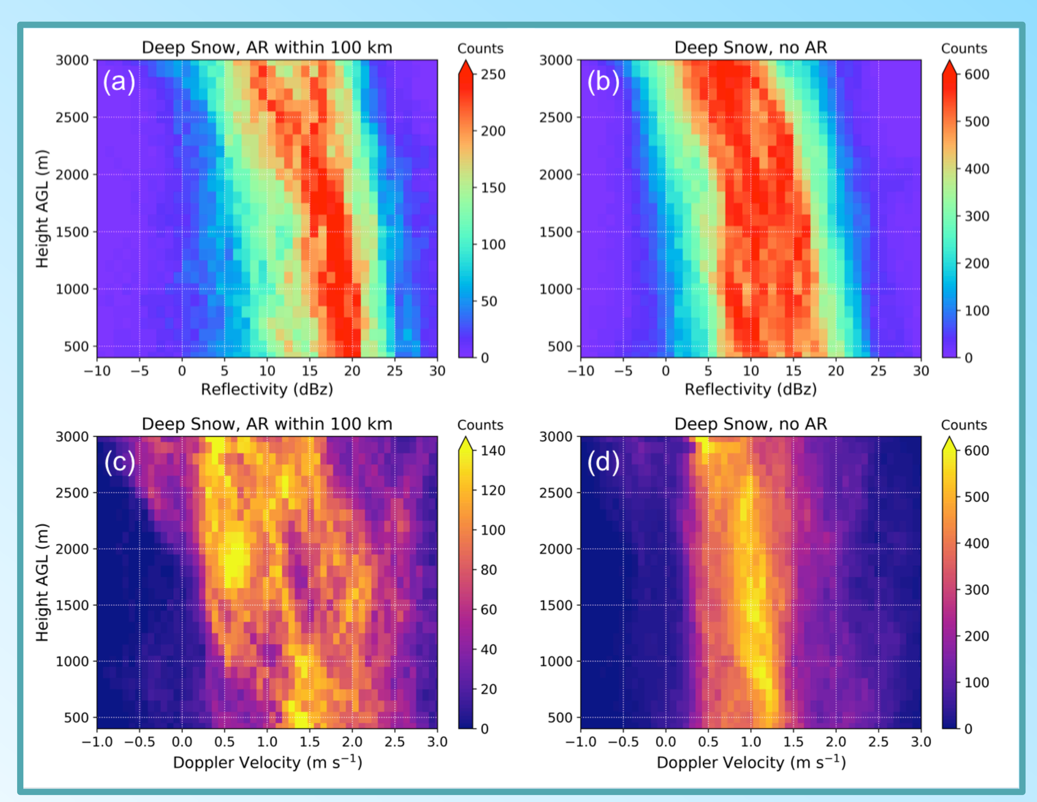
The left panel (a) illustrates the distributions of winds during cold season deep precipitation events associated with an AR and the right panel (b) those events without an AR. The winds are preferentially out of the SSW (20%+) when there is an AR present and broadly diffuse when no AR (note different axes).

Surface Variable	AR	No AR
Temp (°C)	-4.54	-5.49
Wind Speed* (m s^{-1})	2.83	2.54
MRR Near-Surface Doppler Velocity (m s^{-1})	1.79	1.20
MRR Near-Surface Reflectivity (dBZ)	15.2	12.0
PIP Precipitation Rate (mm hr^{-1})	1.25	0.815

This table illustrates the differences in surface (and near-surface) observations. Generally, there are warmer temperatures and higher reflectivities, Doppler velocities, and precipitation rates when an AR is present. These differences are significant to the 95% (except wind speed).

Profile Observations of Wintertime Precipitation: With and Without AR Present

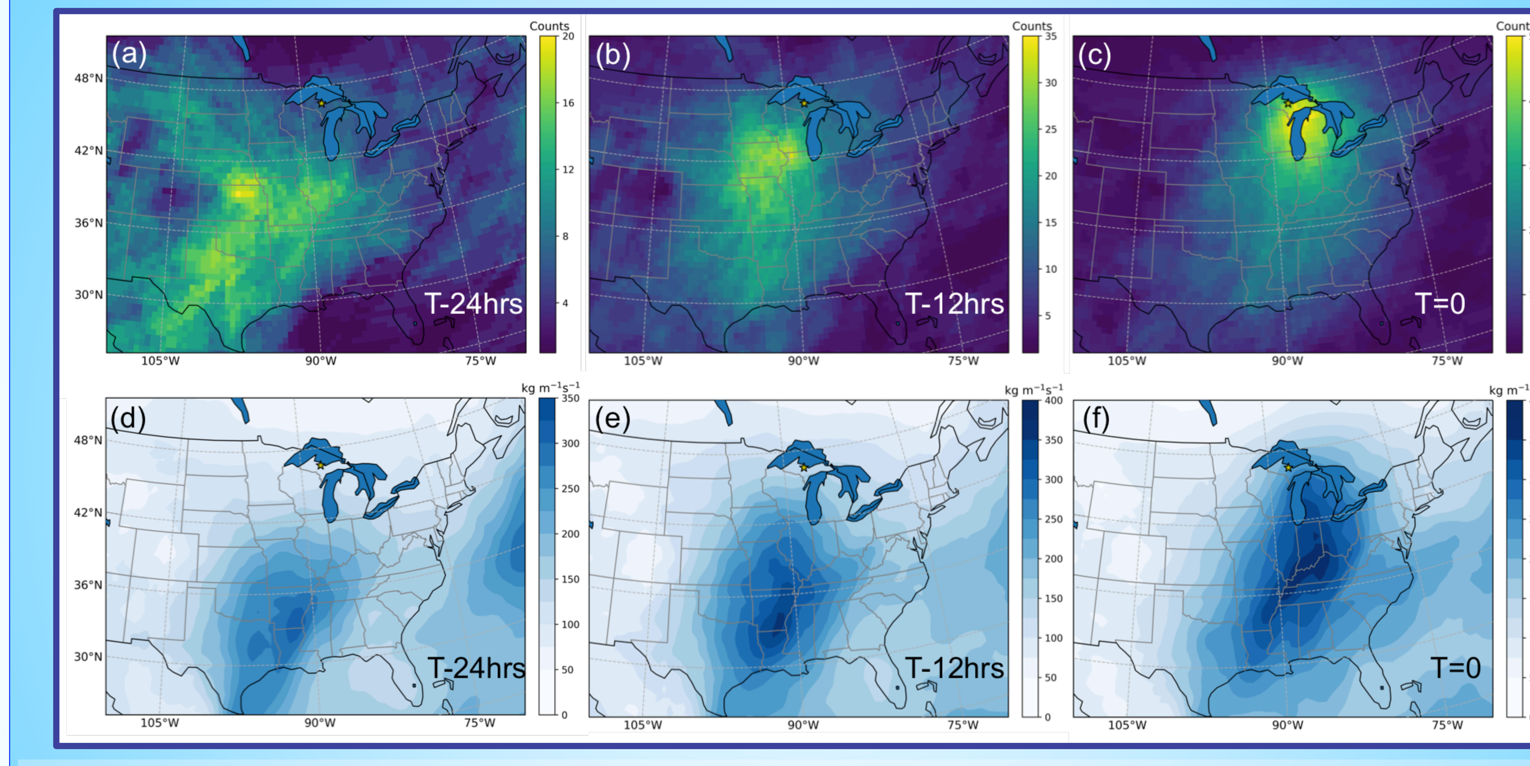
MRR composite 2D histograms of the cold season deep precipitation events coincident with an AR are shown for reflectivity (a) and Doppler velocity (c). The reflectivity range is narrower and higher compared to the no AR events, implying increased precipitation. The broad Doppler velocity values may indicate turbulence throughout the column.



MRR composite 2D histograms of the cold season deep precipitation events without an AR are shown for reflectivity (b) and Doppler velocity (d). The reflectivity range is broader with lower values compared to coincident AR events. The Doppler velocity values are narrower than the AR events and generally invariant as a function of height.

Data Analysis – Cold Season Deep Precipitation AR Events 2014 – 2019

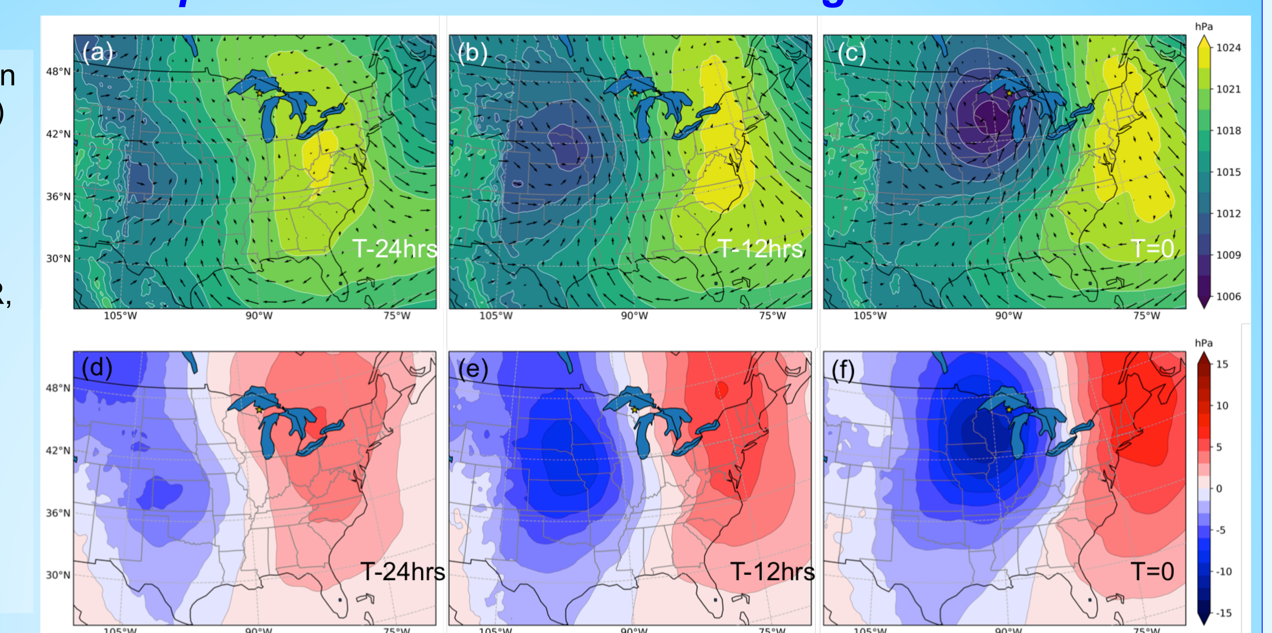
Atmospheric River Locations Prior to and During Storms



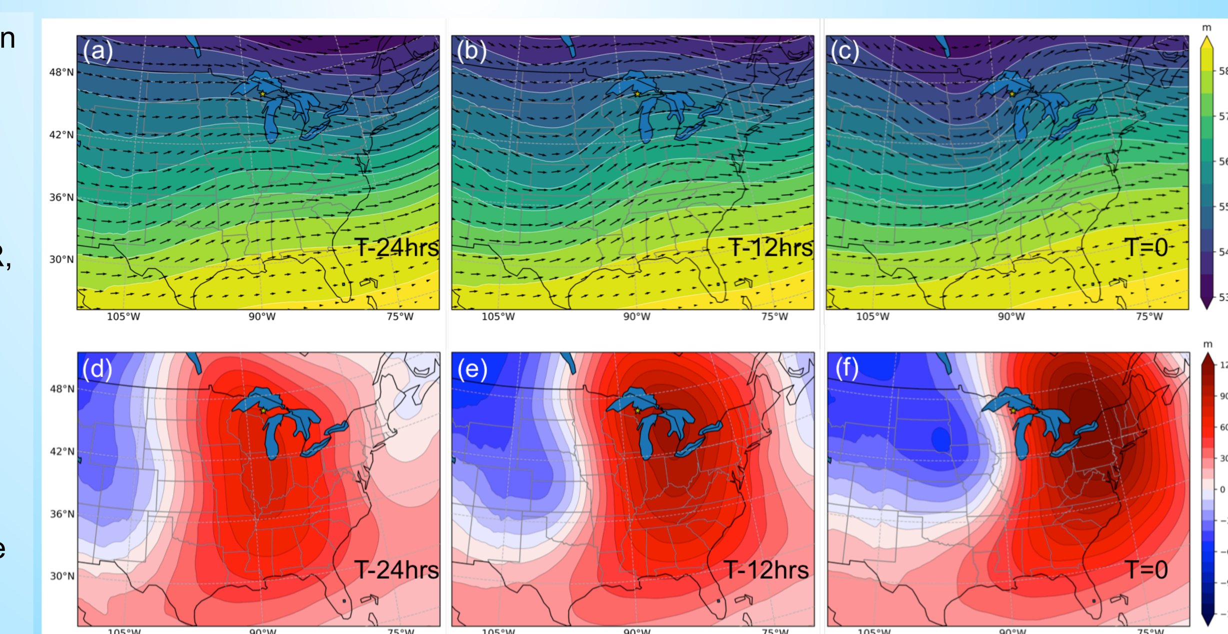
The top panels illustrate the composite detected ARs 24 hours prior (a), 12 hours prior (b), and during (c) the cold season deep precipitation events with an AR within 100 km of MQT. The bottom panels are the integrated water vapor transport values, respectively (IVT; d-f). The AR and IVT patterns indicate enhanced moisture originating primarily from the Gulf of Mexico and secondarily from the west coast transported north of the Rocky Mountains and converging through the Midwest to the Great Lakes region.

Mean Atmospheric State Prior to and During Storms

Composites of the mean sea level pressure (a-c) and associated anomalies (d-f) from ERA5 for the cold season deep precipitation with an AR, prior to and during the event. In general, there is a statistically significant anomalous low centered over Wisconsin with surface winds from the south and southwest of MQT.



Composites of the mean 500 mbar geopotential heights (a-c) and associated anomalies (d-f) from ERA5 for the cold season deep precipitation with an AR, prior to and during the event. There is a statistically significant anomalous ridge in the northeastern CONUS. This pattern is significantly correlated with the negative phase of the Pacific Decadal Oscillation (PDO).



Key Takeaways

Inland ARs impact cold season deep precipitation at MQT in the following ways:

- Precipitation is four times more likely to **occur as rain** at the surface
- PIP surface observations of precipitation rates are **significantly higher**
- MRR near-surface reflectivity and Doppler velocity values are **significantly higher**
- Warm, moist air is transported mainly from the **Gulf of Mexico**
- These events are significantly correlated to the **negative phase of the PDO**

Future Work

Further examine the impacts of ARs on cold season precipitation at high-latitude:

- Examine the merged GPROF and AR product between 50°N and 70°N
- Explore similar ground-based observations from Haukeliseter, Norway