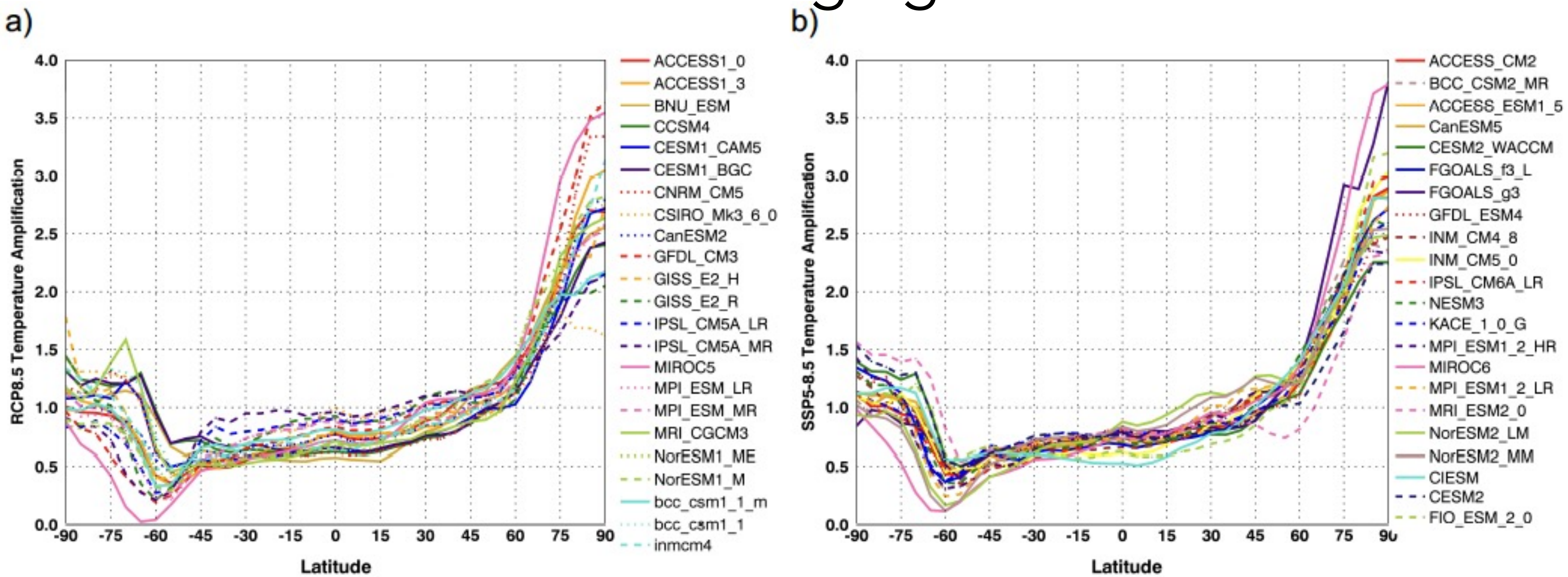
The Influence of Sea Ice on Arctic Cloud Properties: What Can We Learn by Applying an In Situ Observational Strategy to Satellite Data?

Patrick C. Taylor and Emily Monroe
NASA Langley Research Center

102nd AMS Annual Meeting
January 26, 2022

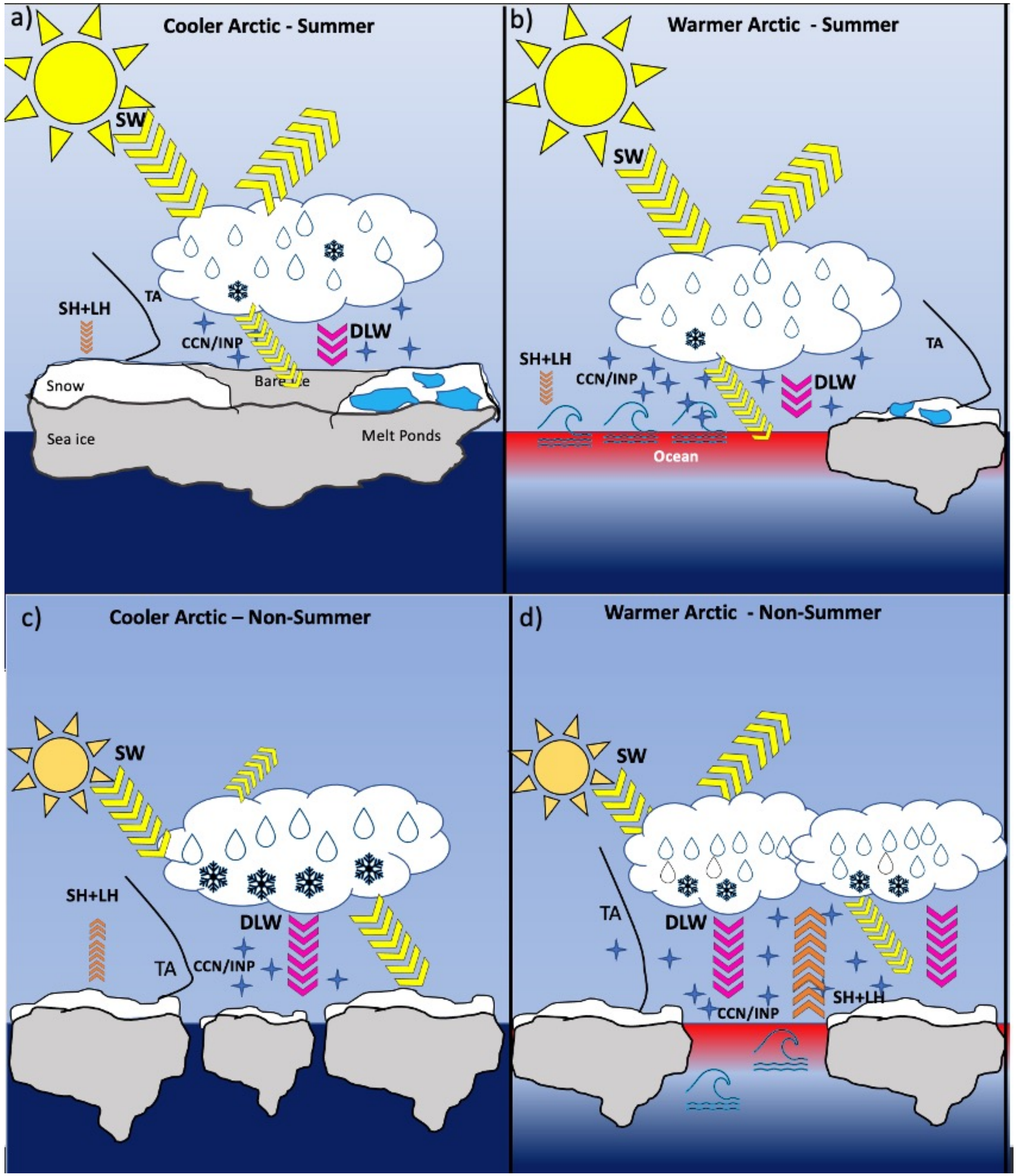
Arctic climate projection uncertainty, larger and unchanging



- Arctic climate projections differ more in the Arctic than anywhere else
- The inter-model spread in projected Arctic Amplification remains unchanged between CMIP5 and CMIP6.

Cloud processes and Arctic climate change: How much do they matter?

- There are many mechanisms through which clouds influence and are influences by the Arctic climate.
- The question remains, how well do models need to represent clouds to produce valuable Arctic climate change projections?

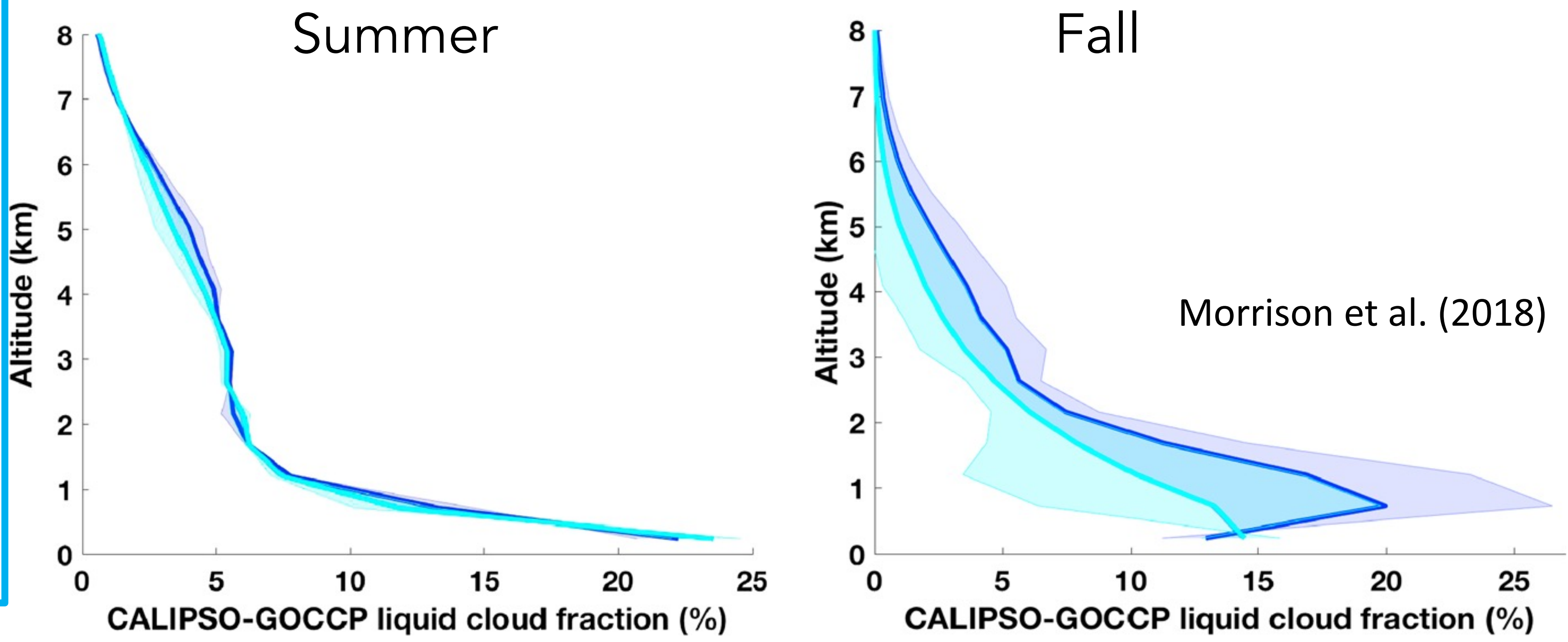


Taylor et al. (2022; Frontiers Earth Science)

Is there consensus of the surface type influence on Arctic cloud properties?

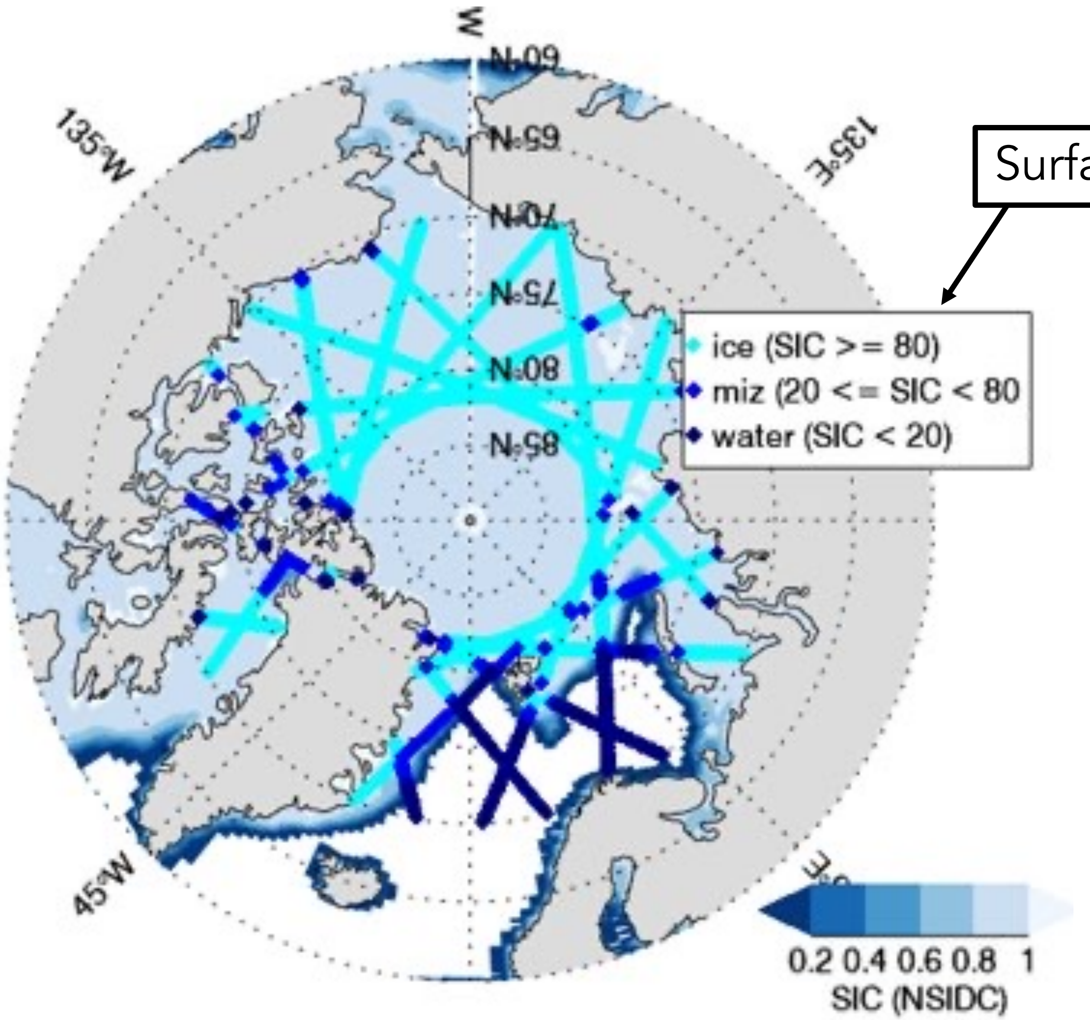
Morrison et al. (2018) illustrates the general consensus in the literature.

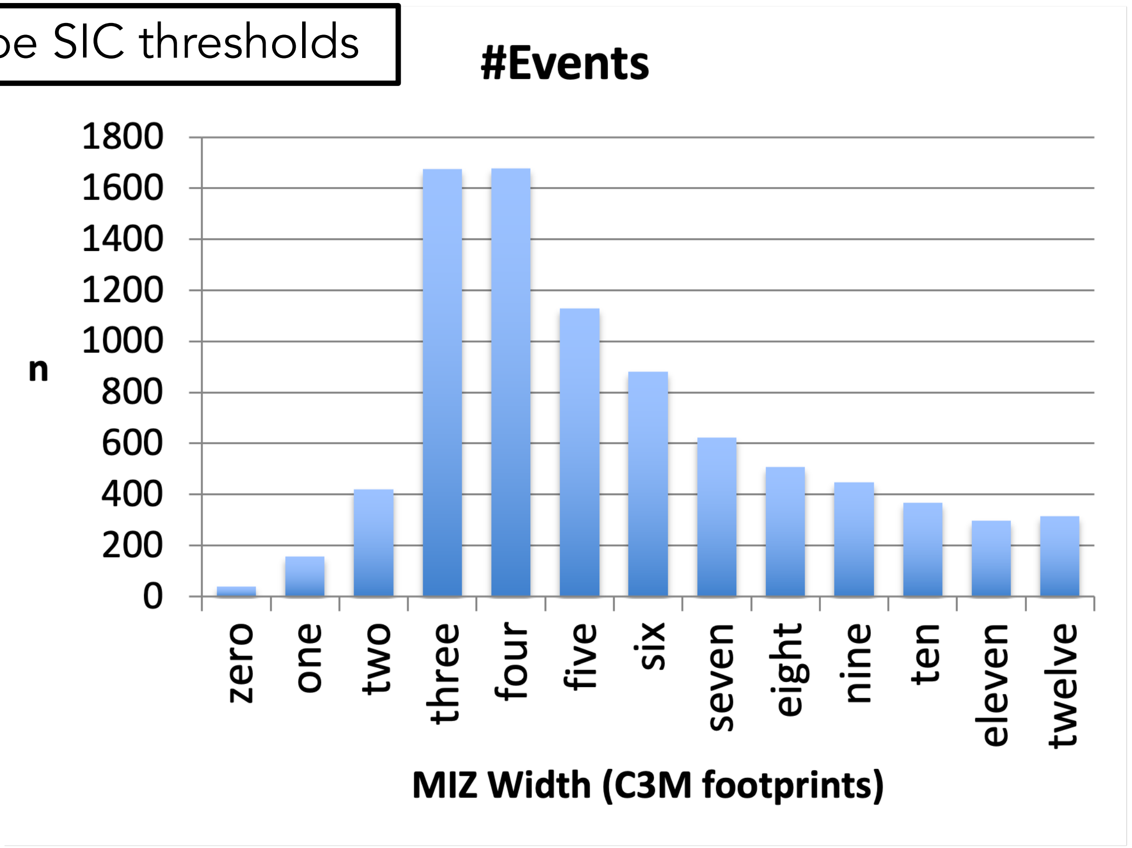
- No impact of surface type on summer clouds.
- Larger low cloud amount over ice-free ocean than sea ice.



Other studies: Kay and Gettelman (2009) Barton et al. (2012), Taylor et al. (2015) Yu et al 2019)

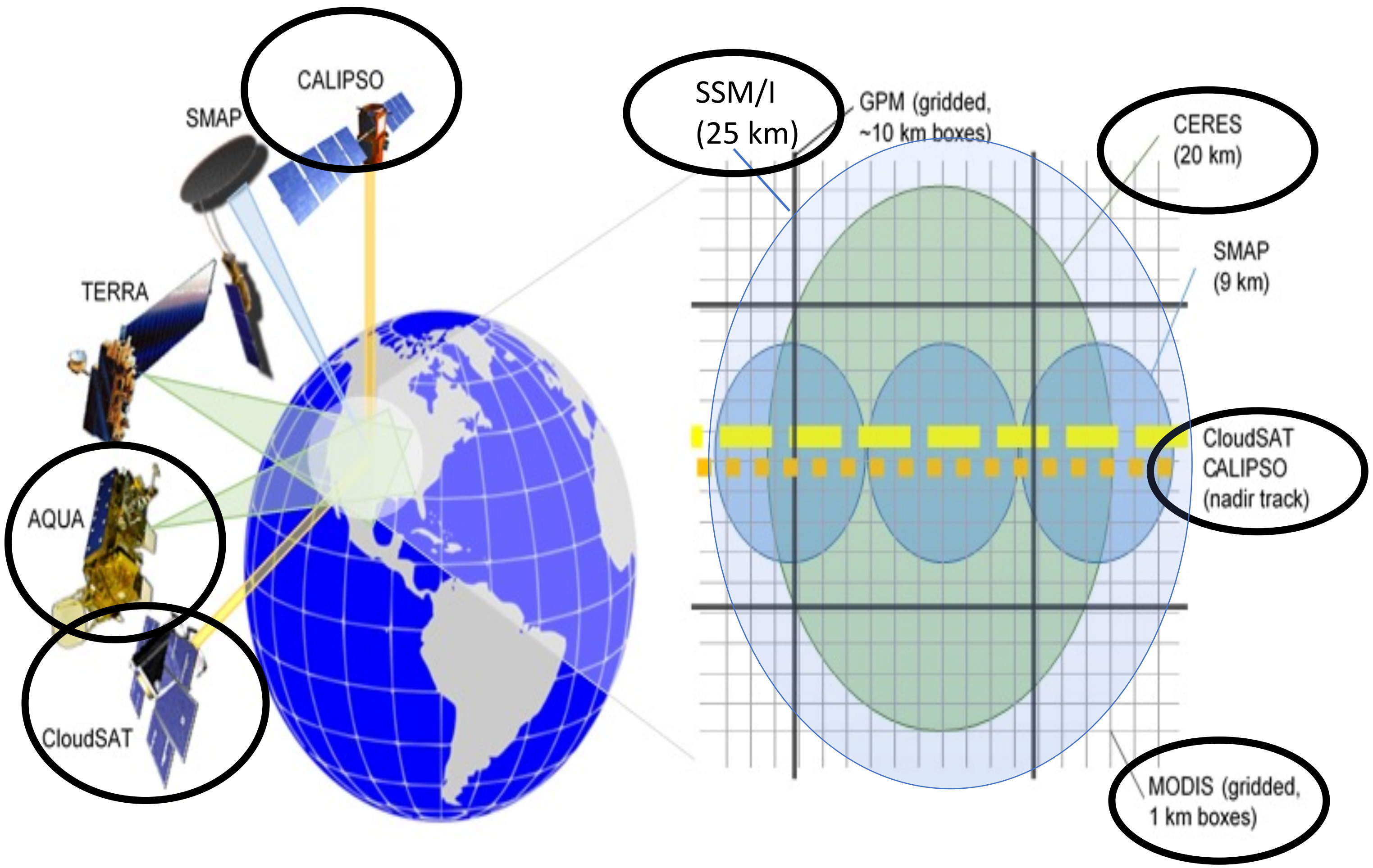
Methodology: >5000 Marginal Ice Zone Crossing Events





An **event** is found when the there are at least 6 consecutive water and 6 consecutive sea ice footprints on either side of the Marginal Ice Zone (MIZ).

From our powers combined…

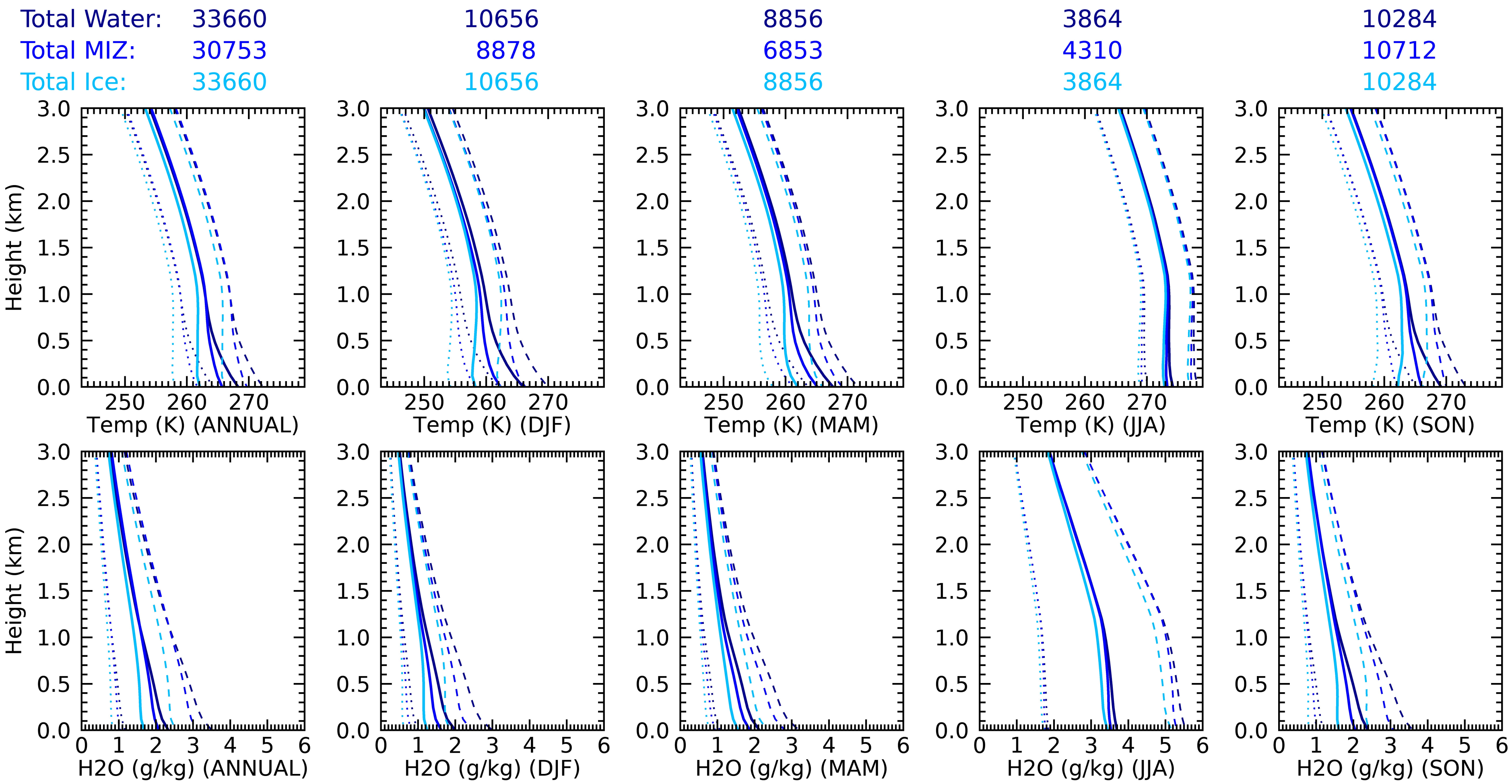


- CALIPSO-CloudSat-CERES-MODIS (C3M; Kato et al. 2010;2011)
  - July 2006-June 2010
  - Cloud Fraction
  - Cloud Liquid/Ice Water Content profiles
  - Radiative Fluxes
- MERRA-2 and ERA5
  - Thermodynamic Profiles
  - Winds
  - Surface Turbulent Fluxes

We leverage data fusion to advance cloud-sea ice interactions research.

Controlling for large-scale meteorology…

- Annual and seasonal mean temperature and water vapor profiles above ~1km are similar for surface types.
- Largest differences are near the surface and attributed to the surface type differences.



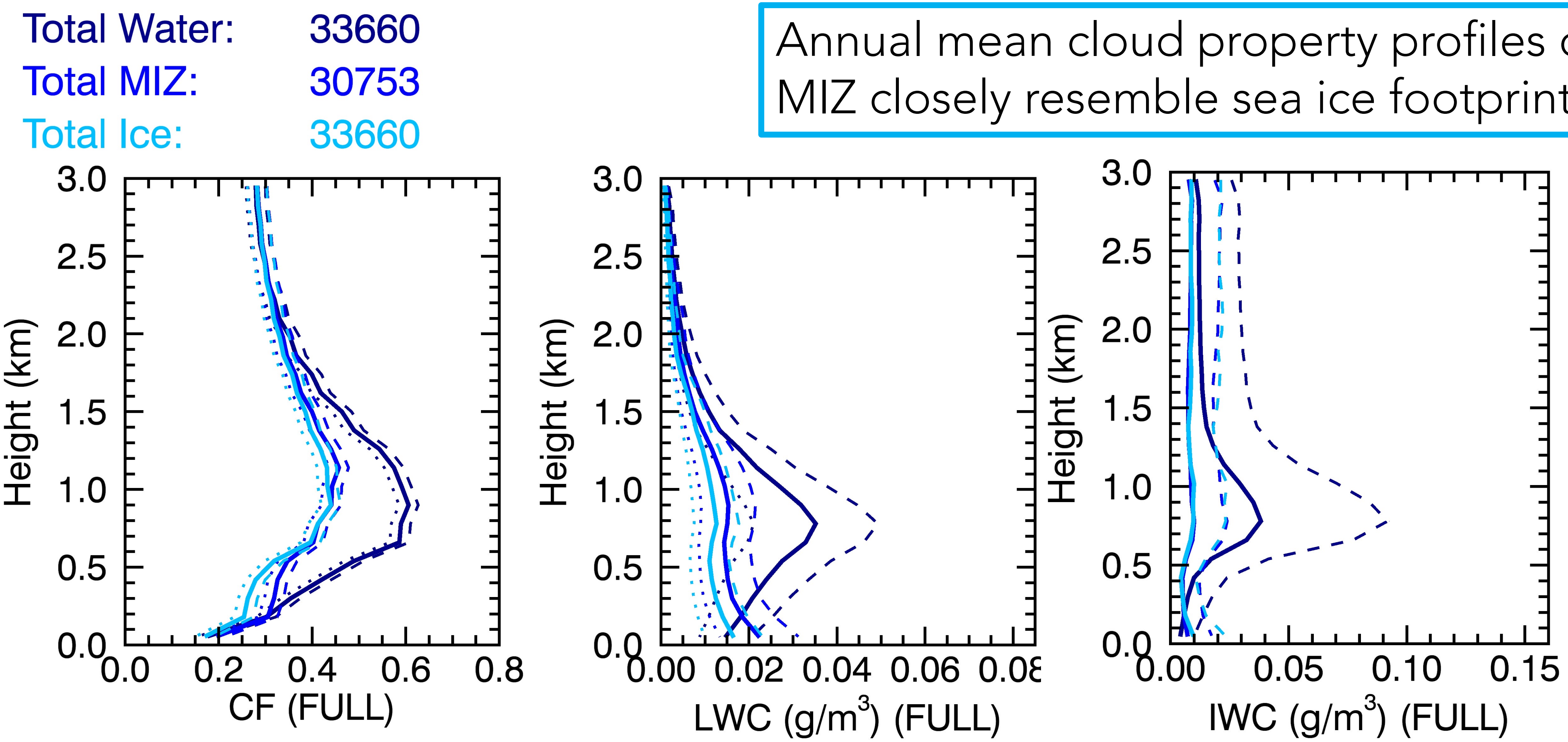
Indicators of large-scale dynamic and thermodynamic atmospheric state are statistically indistinguishable between water and sea ice footprints.

Results:

Comparing cloud properties over ice-free ocean and sea ice during MIZ crossing events

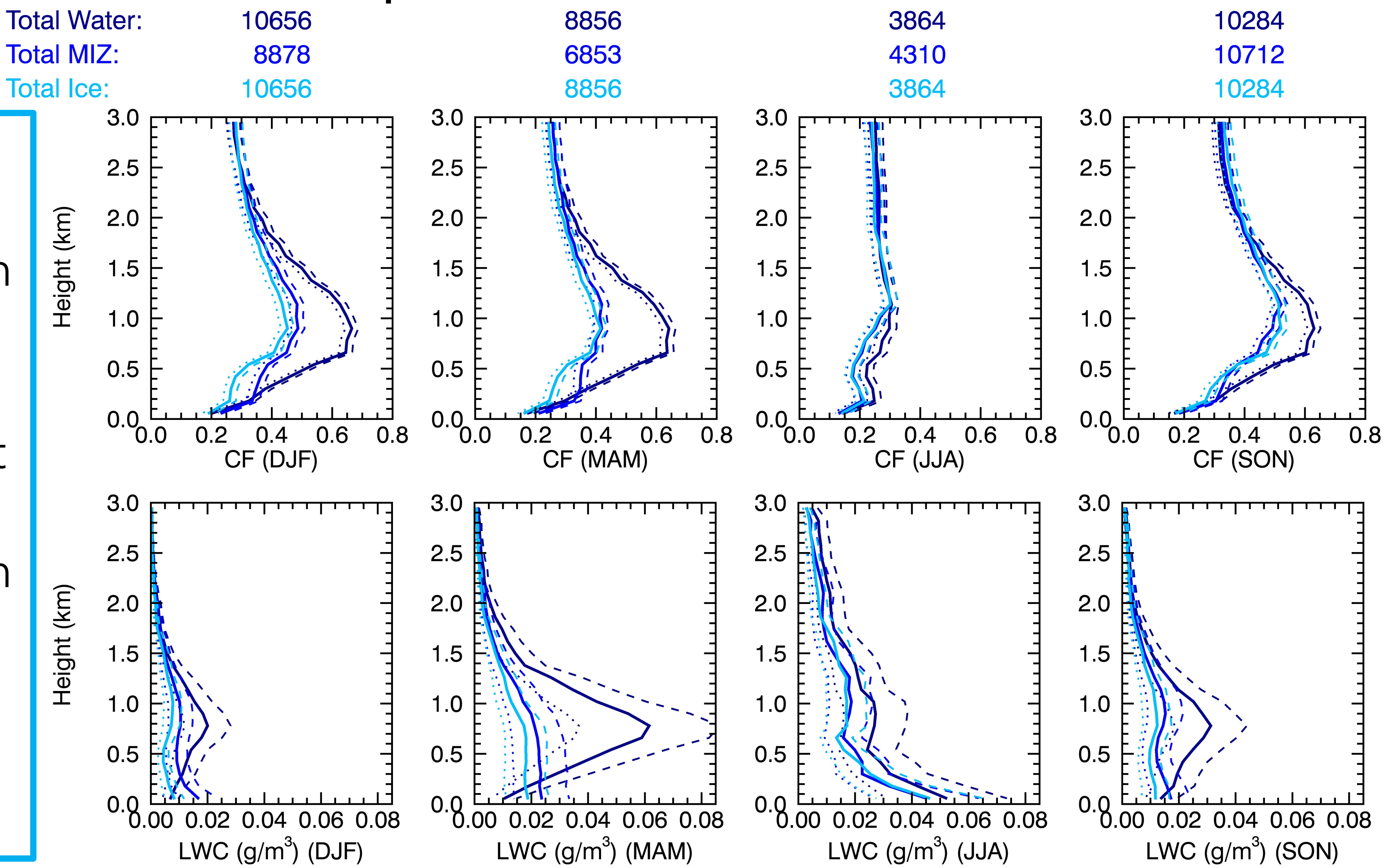
Annual Mean Cloud Property Profiles

Annual mean cloud property profiles over the MIZ closely resemble sea ice footprints.



Water footprints exhibit statistically significantly larger cloud fraction and liquid water content than sea ice footprints between 300 m and 1.5 km in the annual mean.

Seasonal Average Cloud Property Profiles

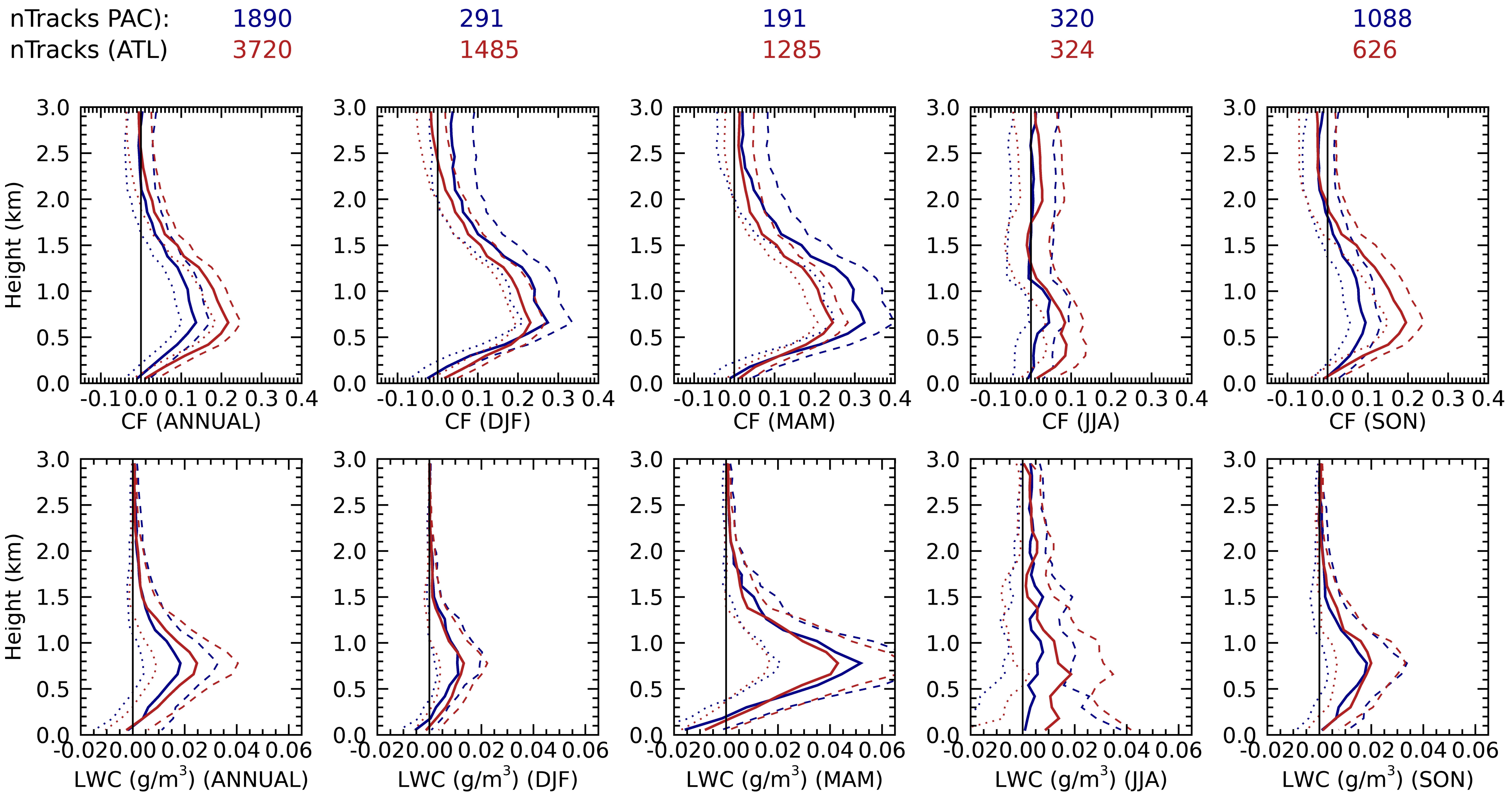


- Non-summer months exhibit statistically significant differences in Cloud Fraction and LWC.
- Summer months exhibit **no** statistically significant differences in Cloud Fraction or LWC.
- Largest cloud property differences in spring, not fall.

Our results are consistent with previous work suggesting that changing the surface type from sea ice to ice-free ocean results in increased cloud fraction and LWC

Pacific vs. Atlantic Sectors

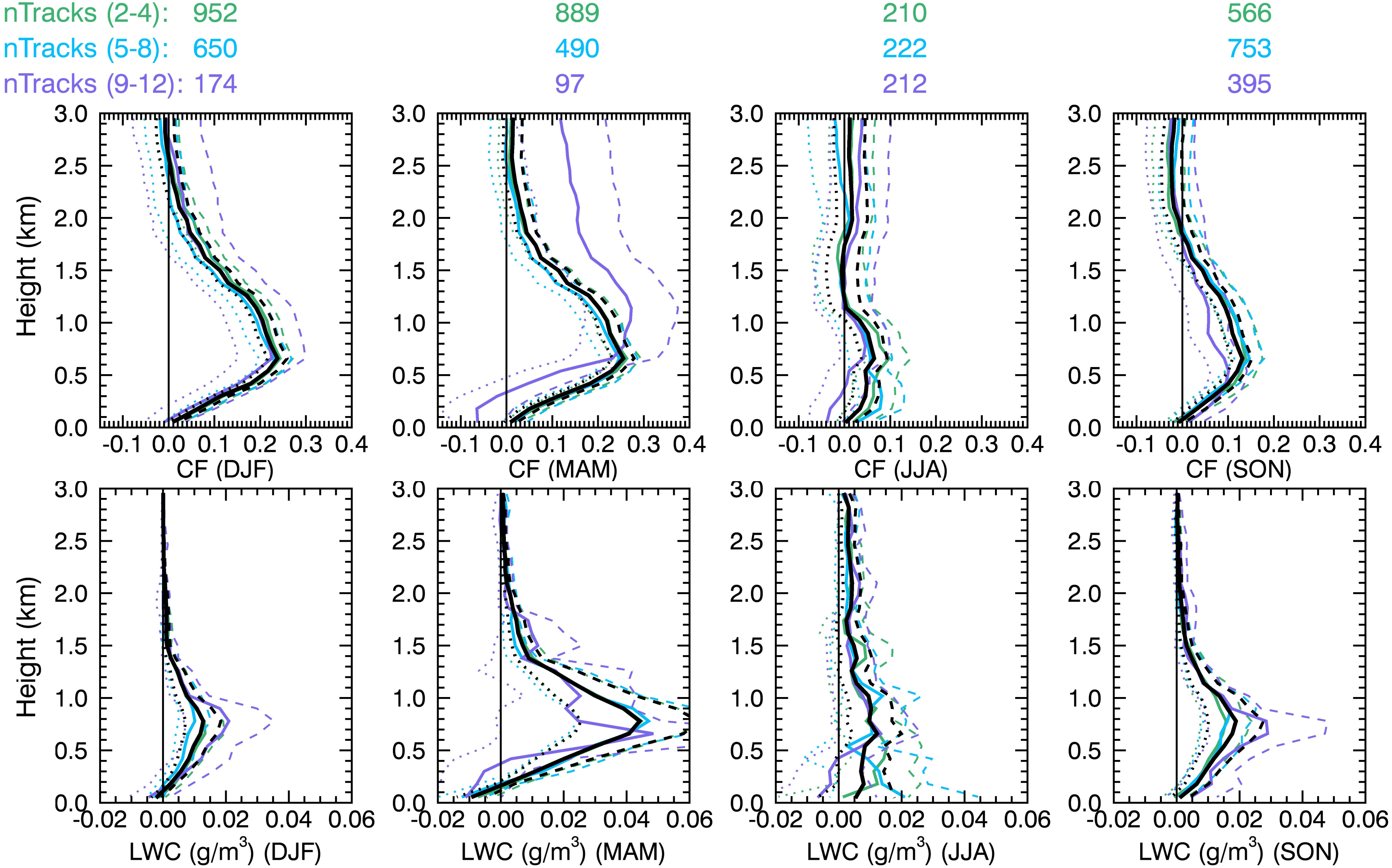
- Greater differences between water and sea ice cloud properties in the ATL vs. PAC in annual mean.
- Differences vary strongly by season as does the number of samples.



While the results point to some regional differences generally the differences between the Pacific and Atlantic sectors are statistically indistinguishable.

Sensitivity of cloud property differences to MIZ Width

- Water minus sea ice cloud property profile differences are sorted into three MIZ width bins by the number of footprints.
  - Narrow (2-4)
  - Medium (5-8)
  - Wide (9-12)
- The cloud differences between the MIZ width bins are statistically indistinguishable.



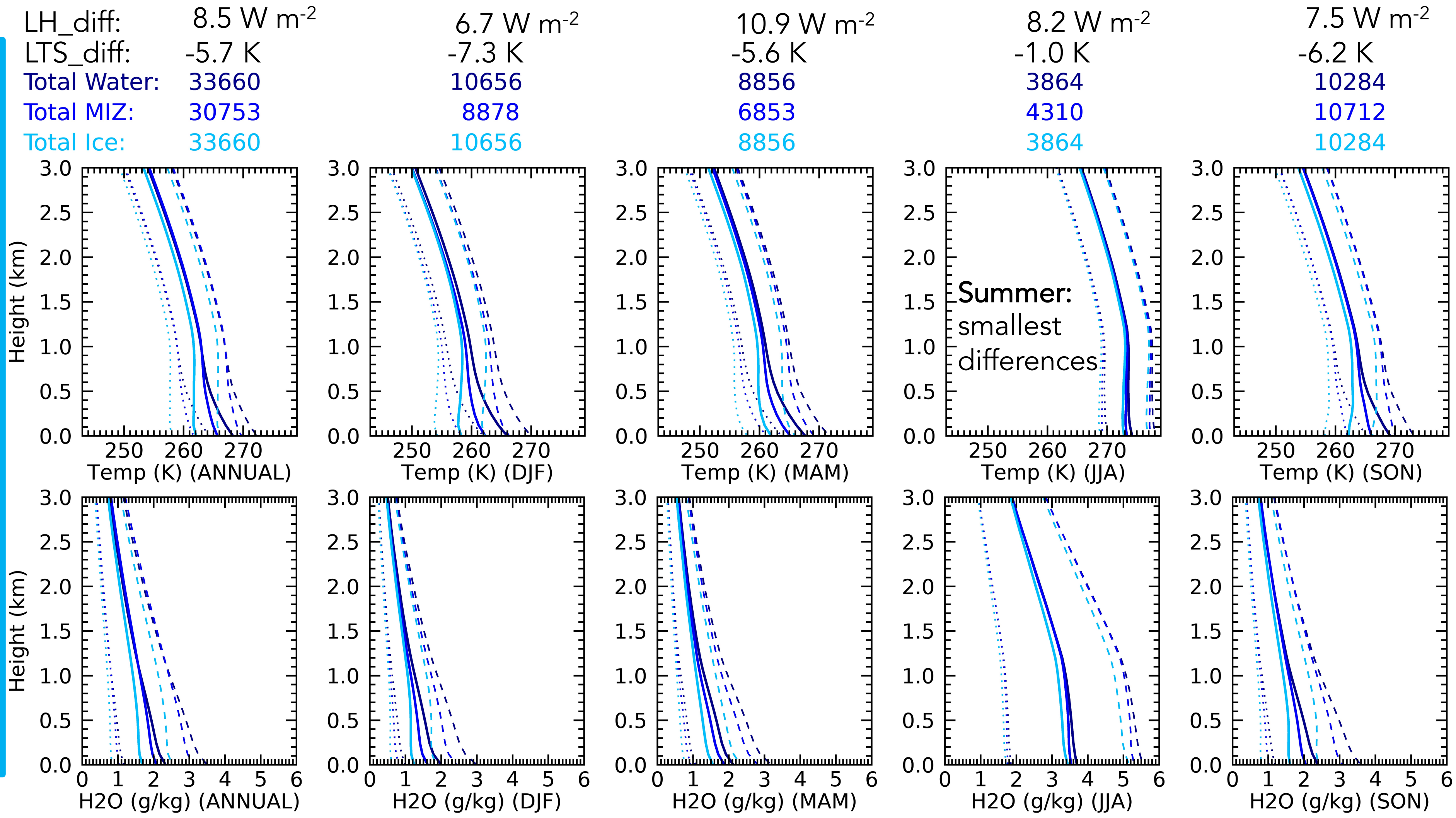
Results insensitive to MIZ widths 2-12 footprints (40-240 km).

Interpretation:

What controls the magnitude of the surface type cloud property differences?

Thermodynamic controls on surface type impact

- Water footprints tend to be warmer and moister than sea ice footprints
- Largest differences near the surface and decay with altitude.
- Water footprints have a weaker lower tropospheric stability.

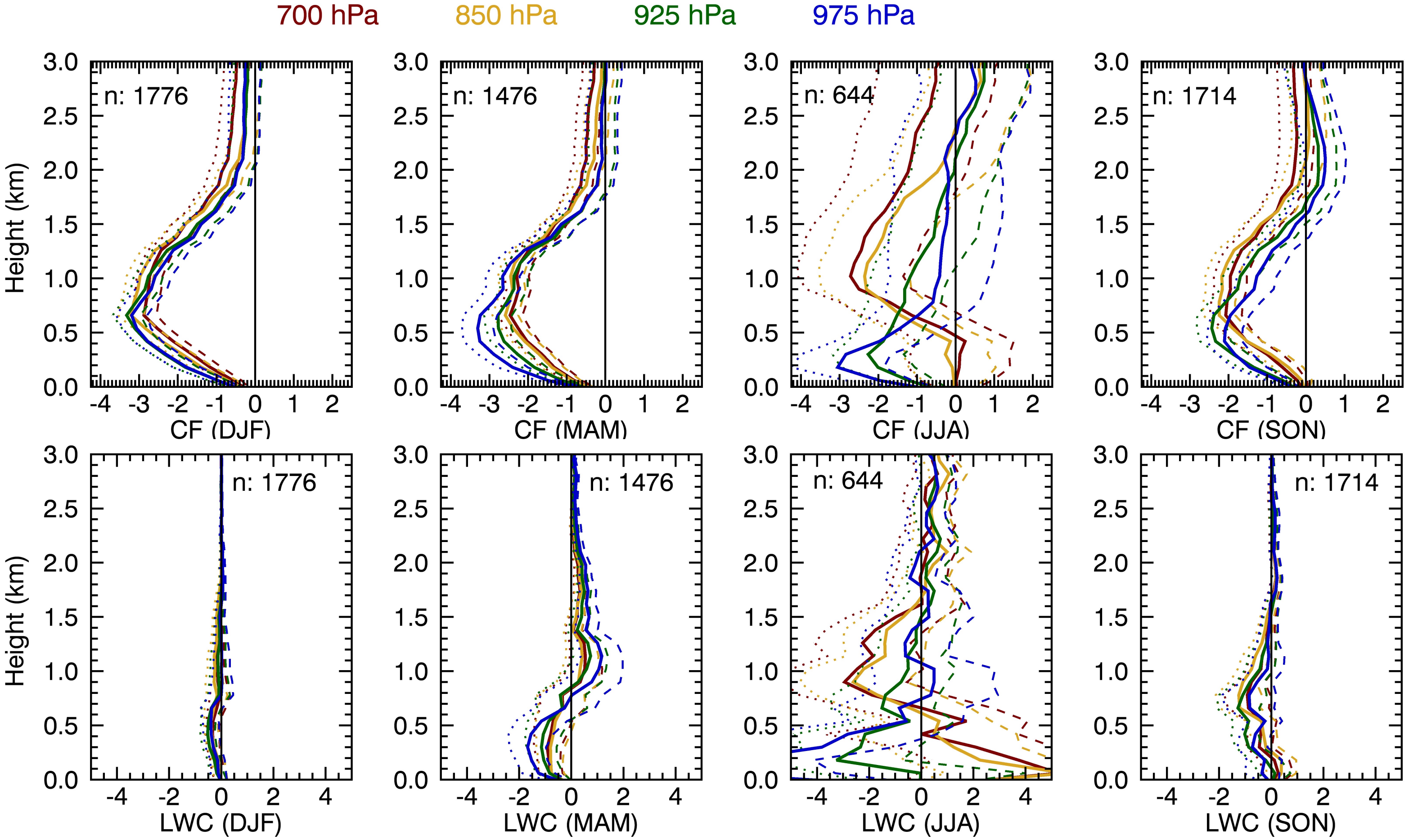


Surface type influences cloud properties through modulations of the lower tropospheric thermodynamic structure.

Surface type cloud differences metric

Lower Tropospheric Stability (LTS) = (ϑ_plev- ϑ_sfc), ϑ=> potential temperature

- Shown are regression relationships between cloud property and LTS differences (water minus sea ice).
- Surface-type differences in the **cloud fraction vertical profiles** are largely explained by the differences in LTS in non-summer months.
- LTS differences are do not constrain LWC differences

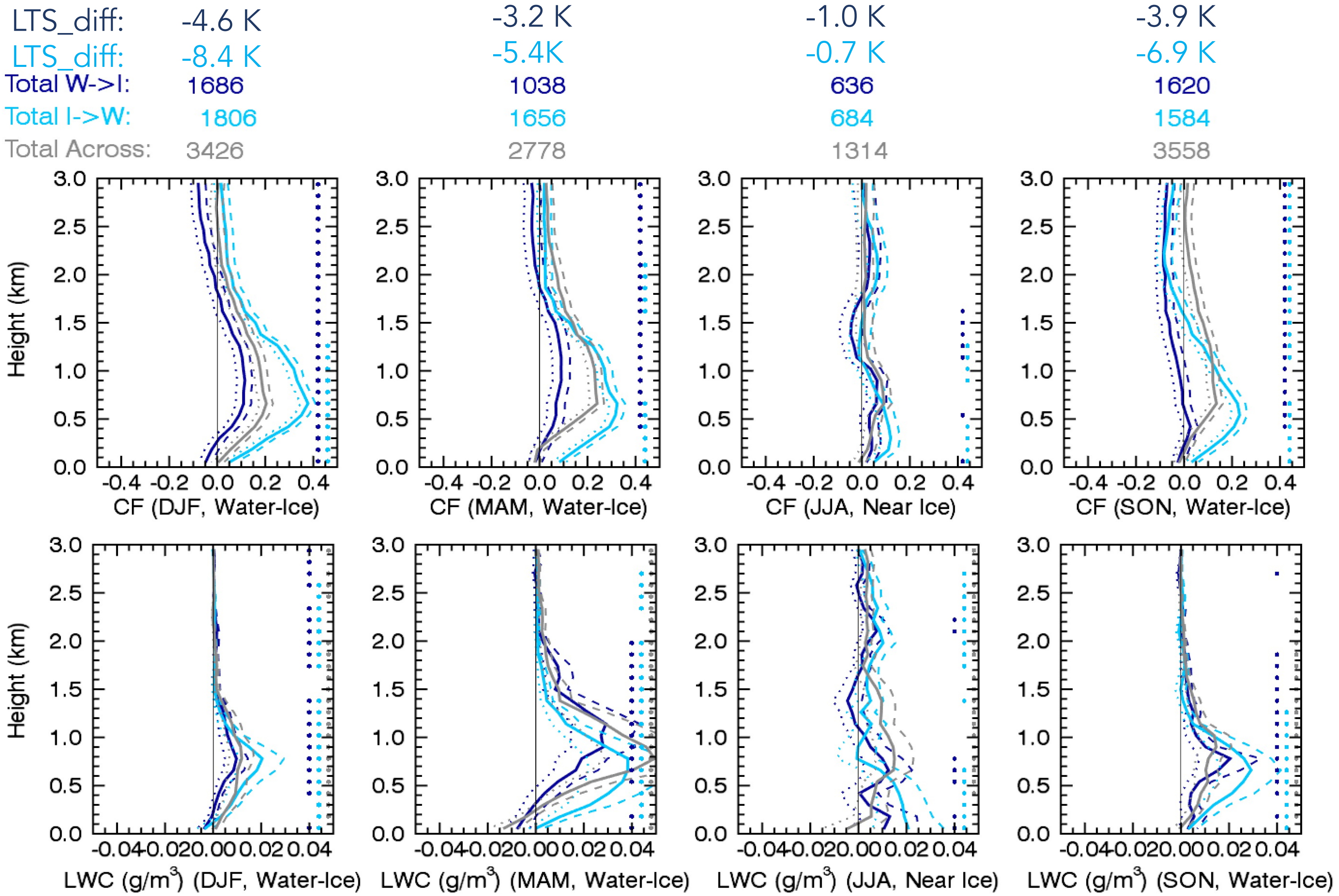


Differences in LTS significantly contribute to the variability in ocean minus ice Cloud Fraction differences and are not as important for LWC

Stratifying by wind direction

Stratifying by wind direction allows for the assessment of the influence of surface turbulent fluxes perturbations.

- Water-to-ice winds—weak surface turbulent fluxes
- Ice-to-Water winds—strong surface turbulent fluxes.

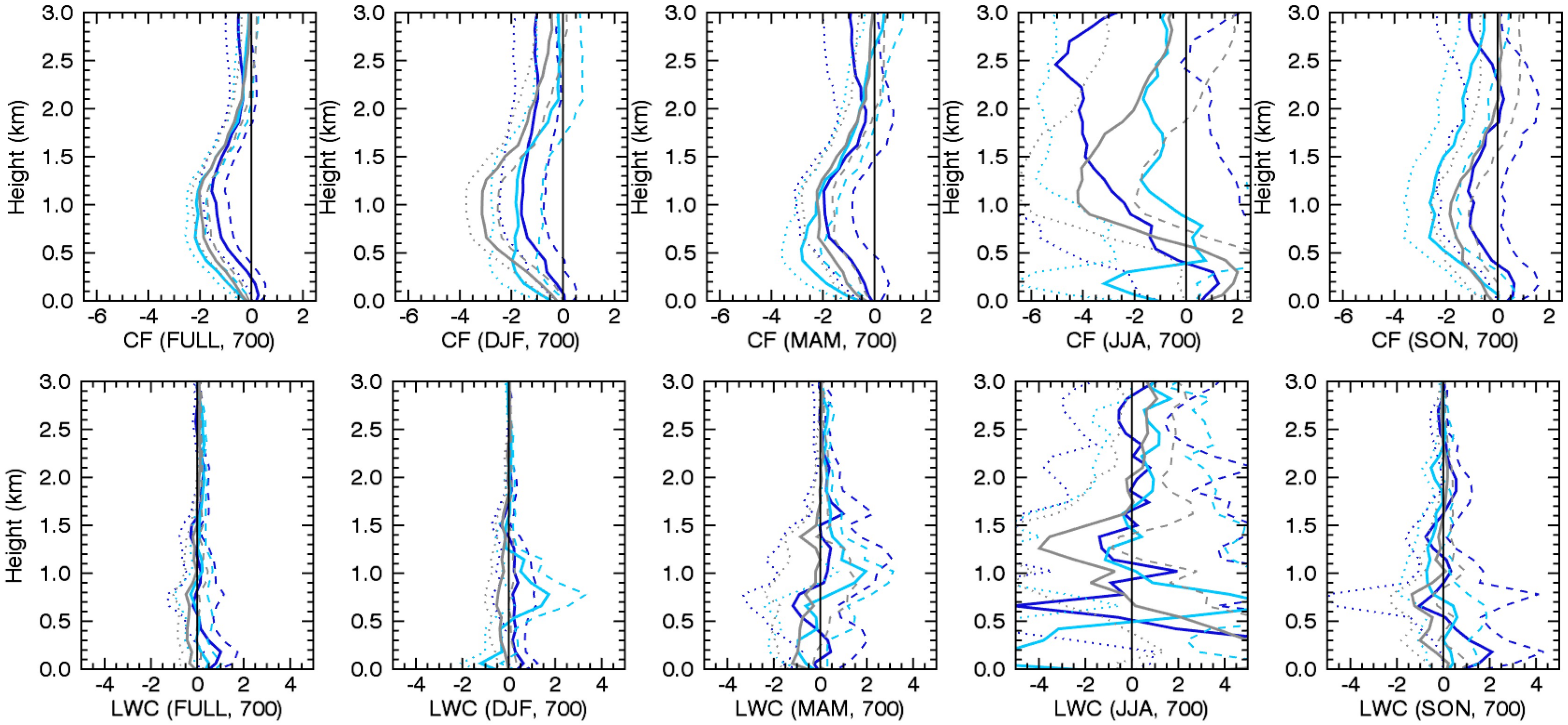


This results suggests that surface turbulent flux differences generate large surface type cloud property differences in specific wind flow regimes.

Role of Lower tropospheric stability: stratifying by wind directions

Lower Tropospheric Stability (LTS) = (ϑ_plev- ϑ_sfc), ϑ=> potential temperature

- Shown are regression relationships between cloud property and LTS differences stratified by atmospheric wind regime.
- The contributions of water minus sea ice LTS differences to cloud property differences are statistically indistinguishable given available data.

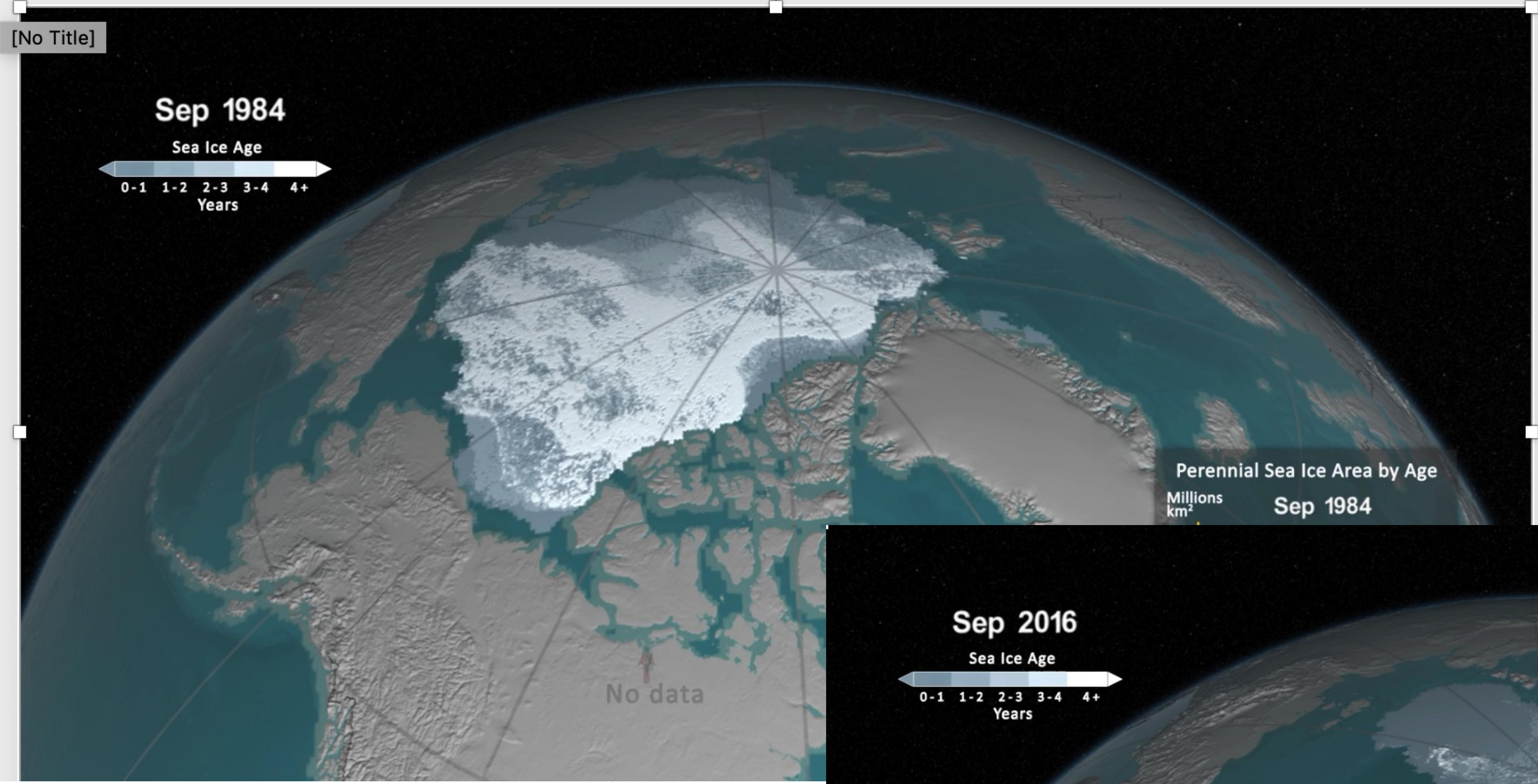


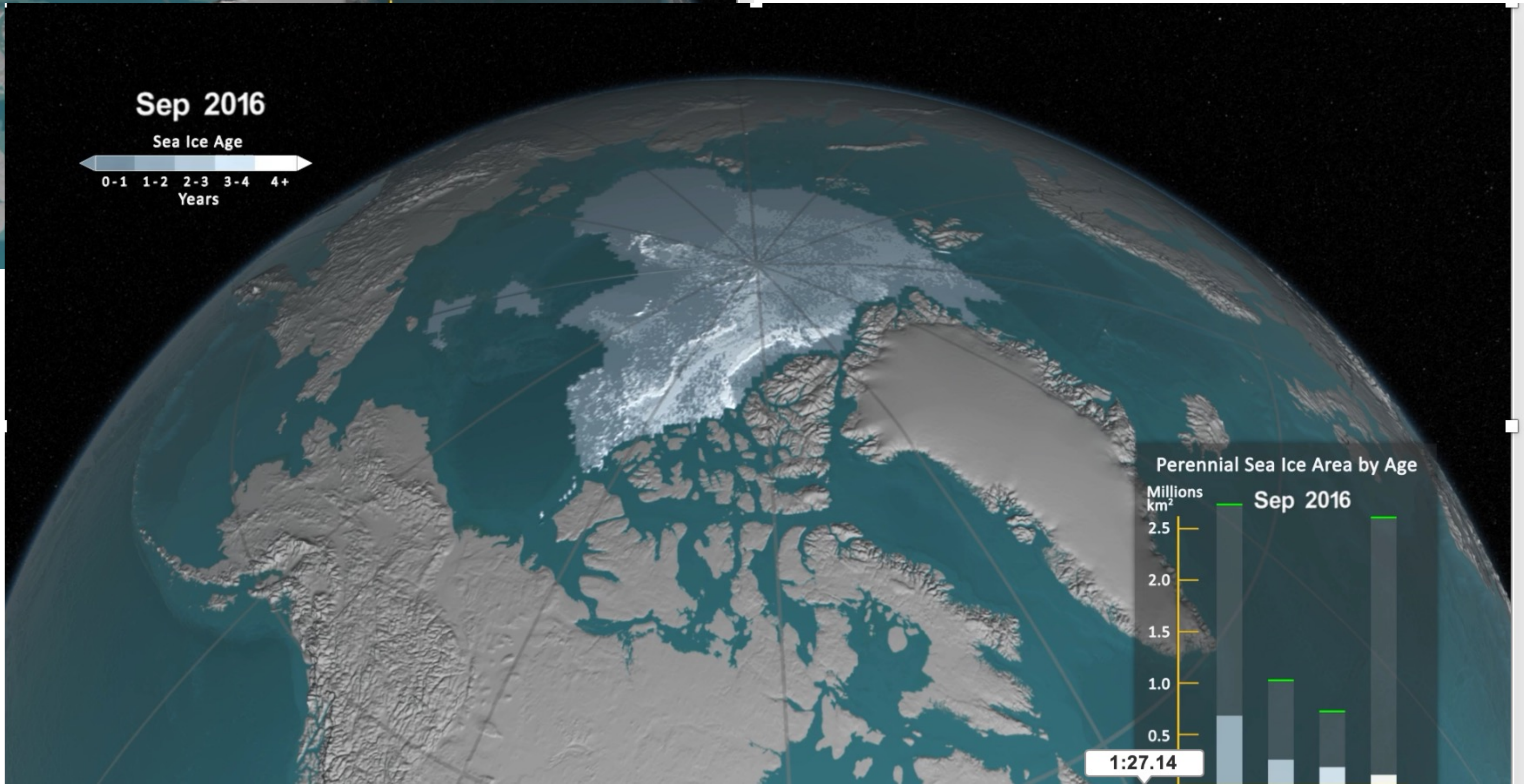
Lower tropospheric stability can be used as a diagnostic to capture the processes that drive the surface type dependent cloud property differences.

Conclusions

- Using MIZ crossing events, we are able to isolate the influence of surface type on cloud properties from the influences in large-scale meteorology found.
- We find statistically significantly larger cloud fraction and liquid water content in clouds over water surfaces than sea ice for altitudes between 300m and 1.5 km in non-summer months (largest in spring).
- Cloud properties differences are strongly tied to differences in the thermodynamic profiles between the ice-free ocean and sea ice surface types.
  - Water surface are warmer, moisture, weaker lower tropospheric stability, and have more positive surface turbulent fluxes
  - This indicates that the feedbacks between the surface properties and the lower tropospheric thermodynamic profiles are critical to constraining the cloud response to sea ice loss.
- <u>Takeaway:</u> **The change in surface temperature that accompanies a change in surface type fundamentally controls the cloud response. Therefore, despite the different thermodynamic characteristics (heat capacity, surface roughness, etc.), there is no difference in cloud properties between ocean and sea ice surface types in the absence of a surface temperature difference.**

The Arctic Transformation



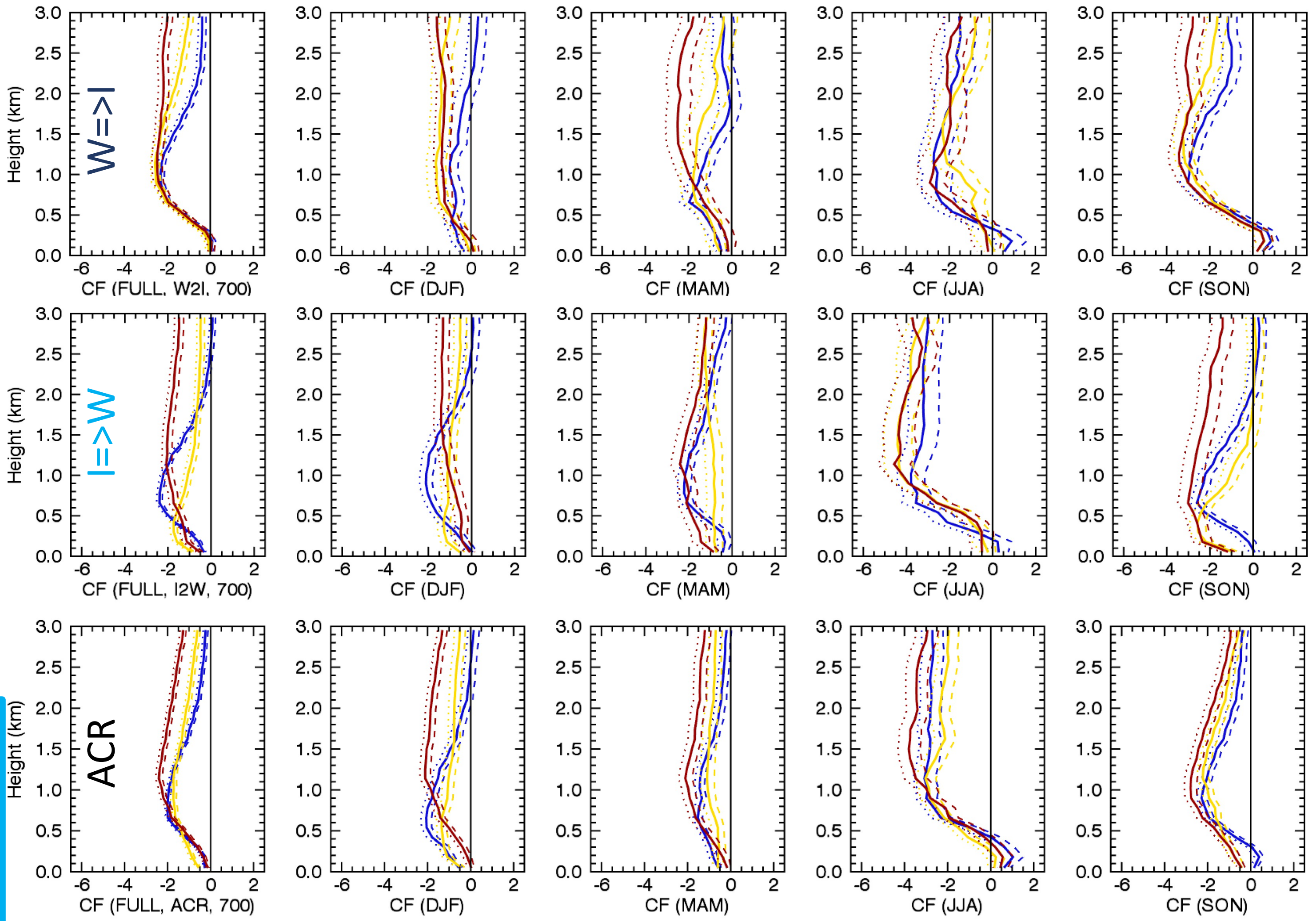


CF-LTS relationship during stratifying by wind direction

WATER
MIZ
ICE

Lower Tropospheric Stability (LTS) = (ϑ_plev- ϑ_sfc), ϑ=> potential temperature

- Shown are regression relationships between CF and LTS for each wind direction and surface type.
- The regression relationships between CF and LTS are found to vary weakly with surface type and wind direction.



The relationships between CF and LTS are consistent across atmospheric wind direction regimes.