

Climatology of mixed-phase clouds and their radiative effects when coupled to sea ice; study based from observations at the western Arctic

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Abstract

The current contribution presents wintertime climatology from 2012 to 2020 of mixed-phase clouds and their radiative effects when coupled to the sea ice states. Measurements from the U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) at the North Slope Alaska (NSA) site in Utqiagvik, Alaska are being analyzed.

Classification of cloud hydrometeors in the liquid, ice or mixed-phase states was primary determined by the Cloudnet algorithm, developed by the Finnish Meteorological Institute, and applied to a set of ground-based remote sensing instruments from NSA . To evaluate the influence by sea ice, which plays an important role on the Arctic surface-atmosphere interaction, the statistics are separated into cases when clouds are coupled or decoupled to specific sea ice conditions, like presence of leads or polynyas in the vicinity of NSA .

We found that clouds coupled to sea ice with presence of leads have shown distinguished features like the increase of total liquid content, lower cloud base heights and less ice content when compared to decoupled cases. Nevertheless, these results rely on Cloudnet accurately detecting cloud droplets within mixed-phase clouds.

Arctic cloud radiative effects (CRE) have already been studied from short expeditions like the SHEBA campaign (Shupe et al., 2004) and middle-term ground observations in Barrow (Shupe et al., 2015) and Ny-Ålesund, Svalbard (Ebell et al., 2020). We extend similar CRE studies for 8 years during wintertime, where longwave up- and down-welling flux measurements from NSA are used to estimate surface net fluxes and other cloud radiative features for cases when clouds are coupled or decoupled to sea ice conditions and their sensitivity to different gradients of air-surface temperature when leads or polynyas are present.

Climatology of Mixed-phase Clouds and their Radiative Effects when Coupled to Sea Ice

Study based from Observations at the Western Arctic

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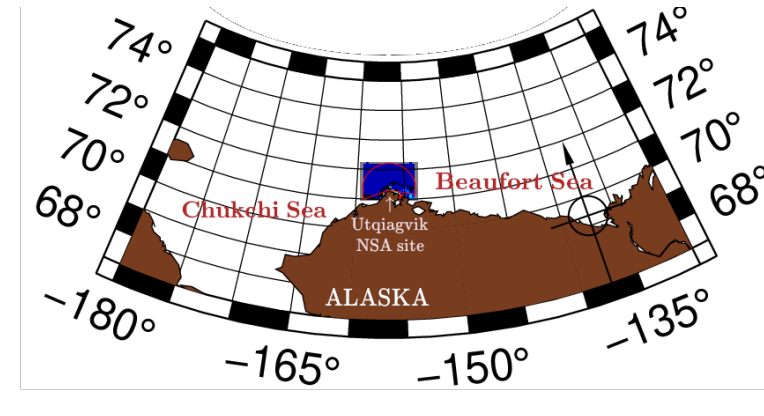


1.- Research Objectives

The study focuses on the Western Arctic to address the following research questions:

- How are macro- and microphysical cloud properties influenced by the presence of leads or polynyas?
- Are cloud radiative effects different during different sea ice conditions?
- In which way does the coupling/decoupling of clouds to moisture-layer impact the cloud's properties?

The Atmospheric Radiation Measurement's (ARM) North Slope of Alaska (NSA) site (71.23° North, 156.61° West) in Utqiagvik, Alaska.



NSA provides long-term high-quality observations for clouds and radiation. To exclude solar shortwave radiative effects this study is centered on Arctic winters (Nov. to Mar.) from 2012 to 2020.

2.- Coupling Sea Ice and Clouds

Daily sea ice concentration (SIC) is primarily obtained from satellite retrievals provided by the University of Bremen [1], the following analysis is performed to couple sea ice conditions with cloud observations above NSA:

- SIC AMSR2 products is analyzed for a sector 50 km around the NSA site (red star in Fig. 1).

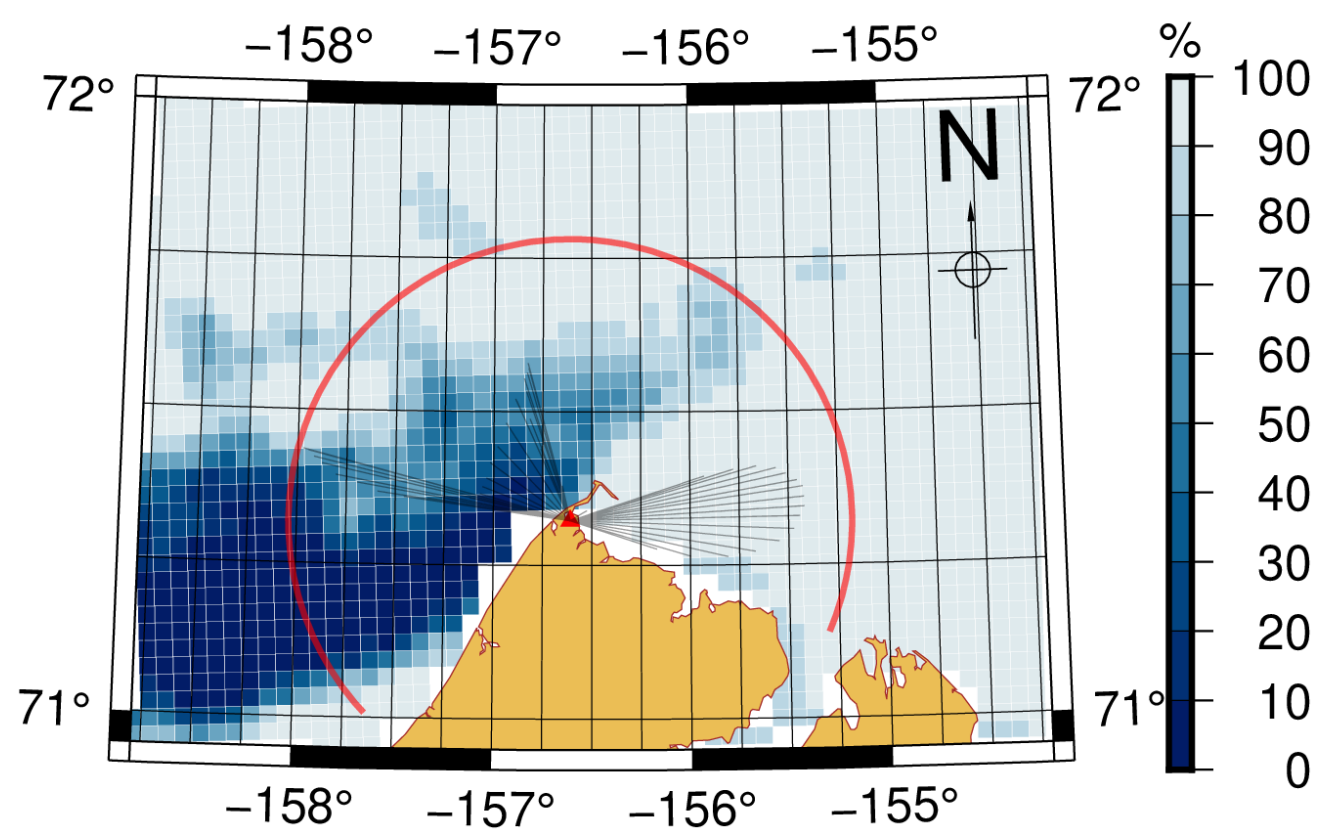


Figure 1: SIC (see colorbar) and wind direction at maximum water vapour transport (red barb indicates NSA location). Only SIC from those directions are considered.

- Sea ice - atmosphere coupling conceptual model
- Gradient of water vapour transport ($\nabla_z WVT$) is calculated from humidity and radiosonde wind profiles. The direction of maximum transport (see grey lines in Fig. 1) is used to relate SIC with zenith observations at NSA.

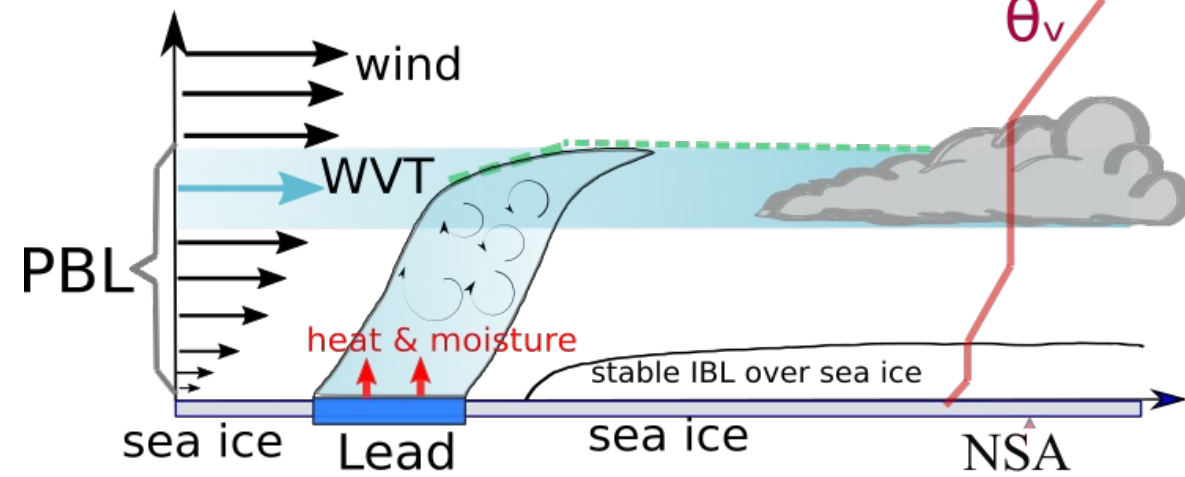
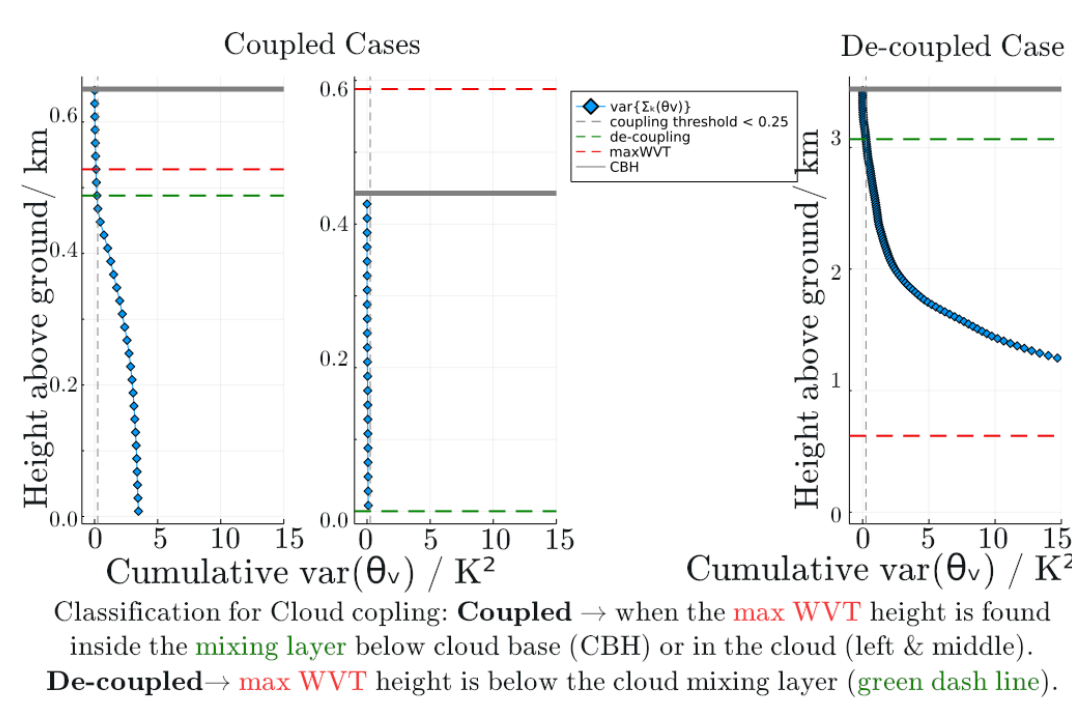


Figure 2: Sea ice interaction with observed clouds. Adapted from [9]

The virtual potential temperature θ_v is analyzed to classify cases where the WVT is coupled or decoupled to the cloud.

- Cloud coupling classification: criteria based on θ_v and location of maximum water vapour transport



- Skin temperature is estimated considering SIC values:

$$T_{skin}(sic, T_s) = SST - SIC \times (SST - T_s) \quad (1)$$

with SST being sea surface temperature (assumed as 271.34 K), SIC from 0...1, and T_s the surface temperature derived from observations as:

$$T_s = \left[\frac{F_{lw}^{\uparrow} - (1 - \varepsilon_s) F_{lw}^{\downarrow}}{\varepsilon_s \sigma} \right]^{\frac{1}{4}}$$

being $F_{lw}^{\downarrow}$ and $F_{lw}^{\uparrow}$ down- and up-welling measured LW fluxes [3, 2]. The surface LW emissivity ε_s is assumed 0.981±5% to cover characteristic NSA winter values [1, 7].

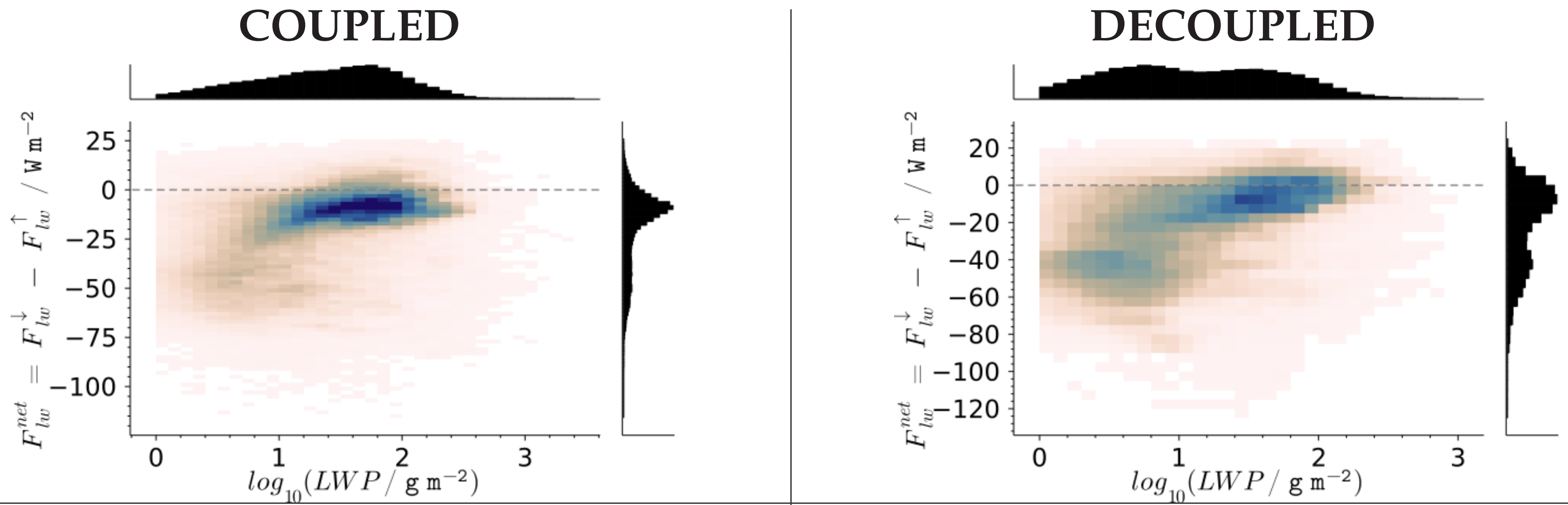
$$\Delta T = T_{skin}(sic, T_s) - T_{2m} \quad (2)$$

Here ΔT in Eq. 2 is used as proxy for SIC dependent sensible heat flux between the interface sea ice surface-atmosphere.

3.- Results for cloud-sea ice coupled and decoupled conditions

Surface longwave radiation fluxes observed at NSA are shown as function of several variables under the influence of sea ice conditions, e.g. liquid and ice water path (LWP, IWP), skin temperature based on SIC, and cloud radiating temperature (CRT):

- Distributions for Net LW radiation F_{lw}^{net} versus Liquid water path



- Distributions for Net LW radiation F_{lw}^{net} versus $\Delta T = f(sic, T_s, T_{2m})$

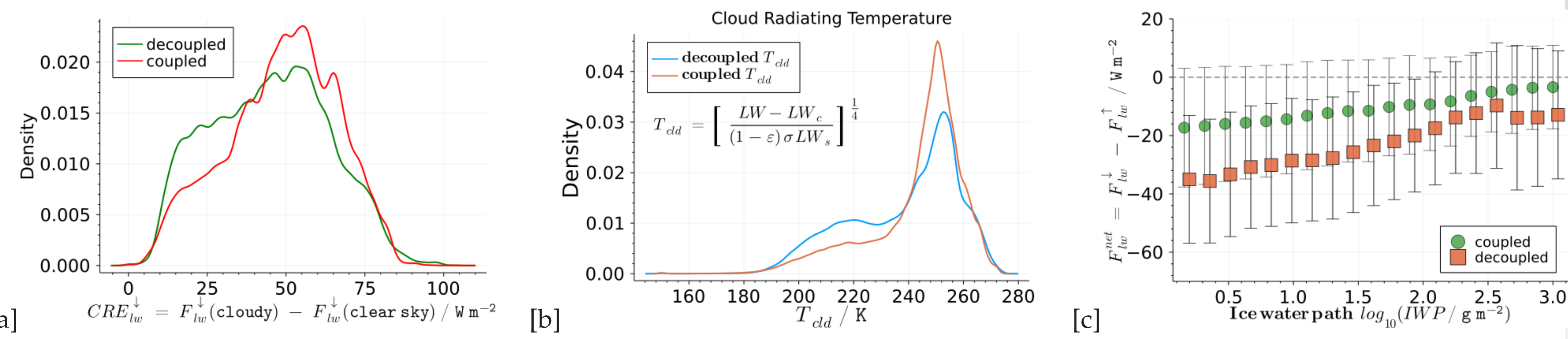
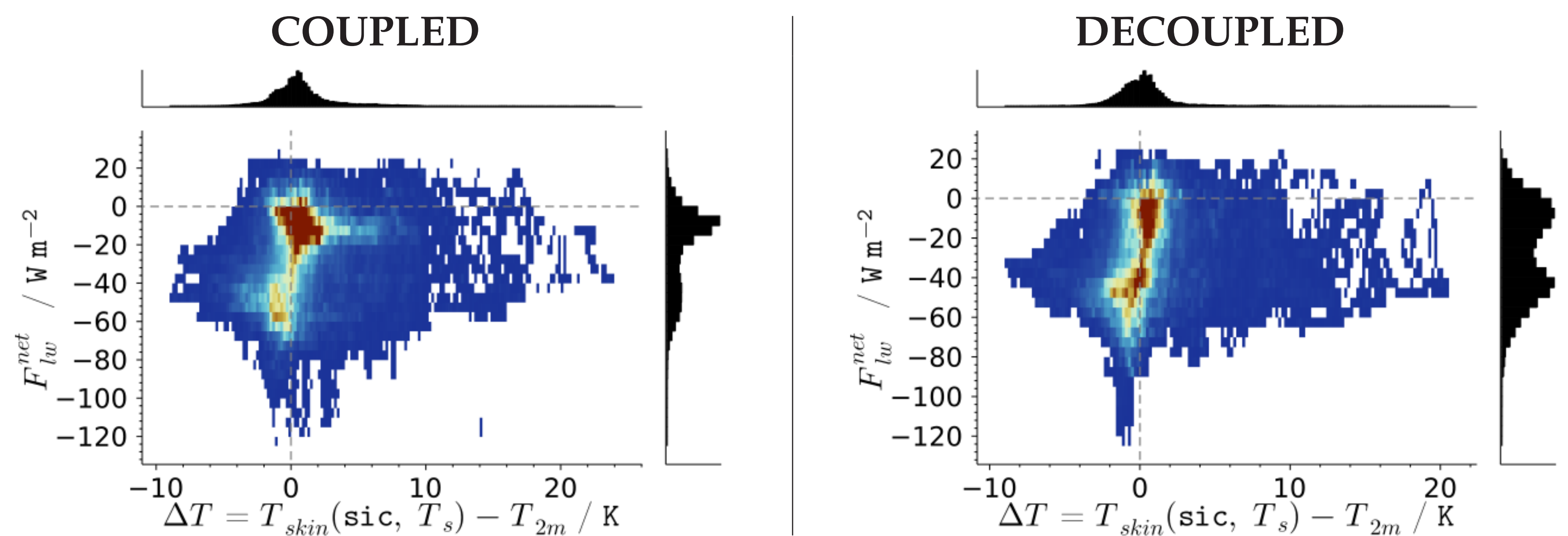


Figure 3: [a] PDF for CRE ($F_{lw}^{\downarrow}$ cloudy - clear sky) shows a more frequent occurrence for cases when the clouds are coupled. [b] CRT estimated from clear-sky LW (LW_c), fractional sky cover (LW_c), indicating that warmer clouds are more frequent for coupled cases. [c] LW net radiation as a function of observed ice water path (IWP), where coupled F_{lw}^{net} slightly decreasing when IWP approaches zero, contrasting to LWP where F_{lw}^{net} drops strongly.

CRE is calculated based on cloudy observations and corresponding clear-sky simulations following [4] and [5] for longwave downwelling radiation. Clear sky calculation is a state-of-the-art value added product from ARM [6].

4.- Conclusions

- Ground-based radiation observations at the ARM site at the North Slope of Alaska (NSA) have been analyzed for the period of winters 2012 to 2020. The data has been classified into sea ice - cloud coupled/ decoupled cases.
- Results are consistent with previous findings regarding the effect of low sea ice concentration (e.g., due to the presence of leads or polynyas) on cloud micro- and macro-physical properties [8].
- Cloud properties like liquid and ice water path (LWP and IWP), cloud base height, and cloud geometrical thickness are also variables strongly influencing the surface radiation budget.
- Our results depict a warming cloud effect on the surface is clearly enhanced by atmospheric thermodynamic and dynamic conditions which yield coupling with the sea ice situation downwind.

So far only simulation of clear-sky for longwave downwelling radiation have been considered, in the future we will include complete clear-sky simulations following [2] for the central Arctic site Ny Alesund, thus a better picture on CRE will be achieved.

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