Estimation of cloud radiative effects from ground-based observations in the Western Arctic

Wintertime radiative effects as function of cloud-moisture-coupling and sea ice conditions

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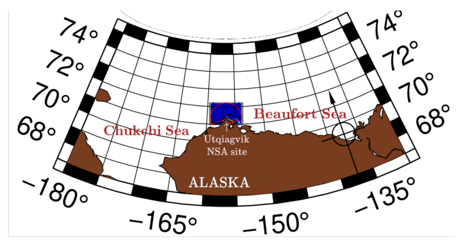
1.- Research Objectives

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).

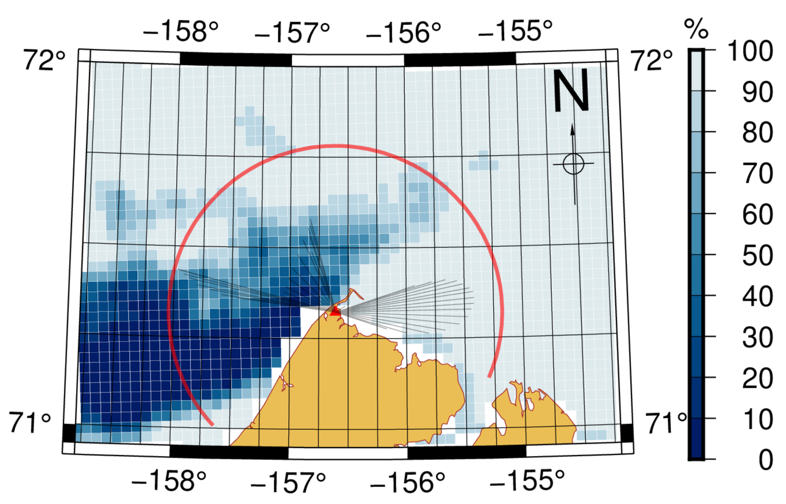


Figure 1: SIC (see colorbar) and wind direction at maximum water vapour transport (red barb indicates NSA location). Only SIC from those directions are considered.

- 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.

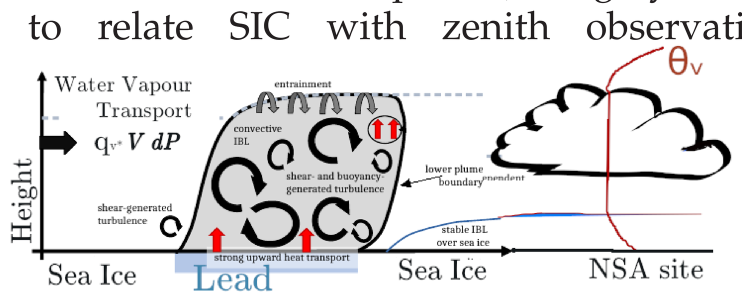
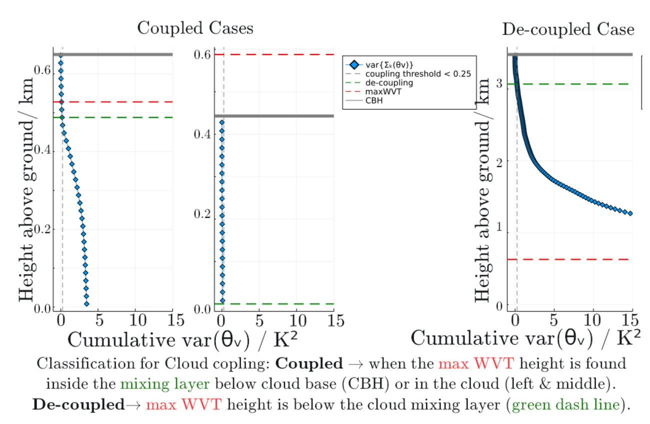


Figure 2: Sea ice interaction with observed clouds. Adapted from [9]

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 $0 \ldots 1$, and T_s the surface temperature derived from observations as:

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

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].

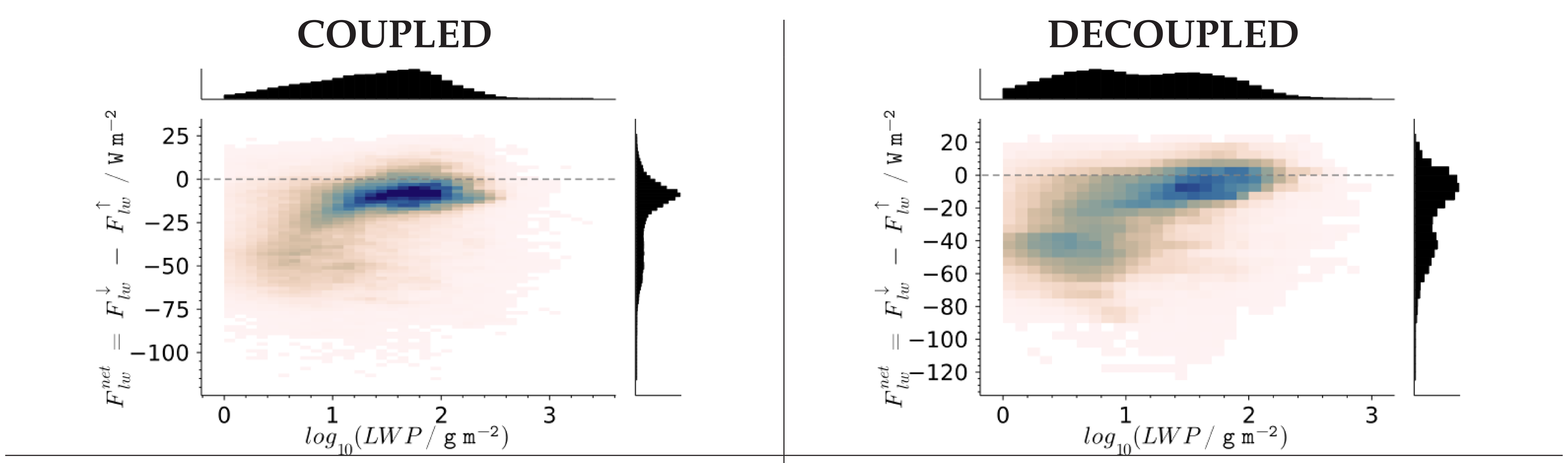
$$\Delta T = T_{skin}(sic, T_s) - T_{2m} \quad (2)$$

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

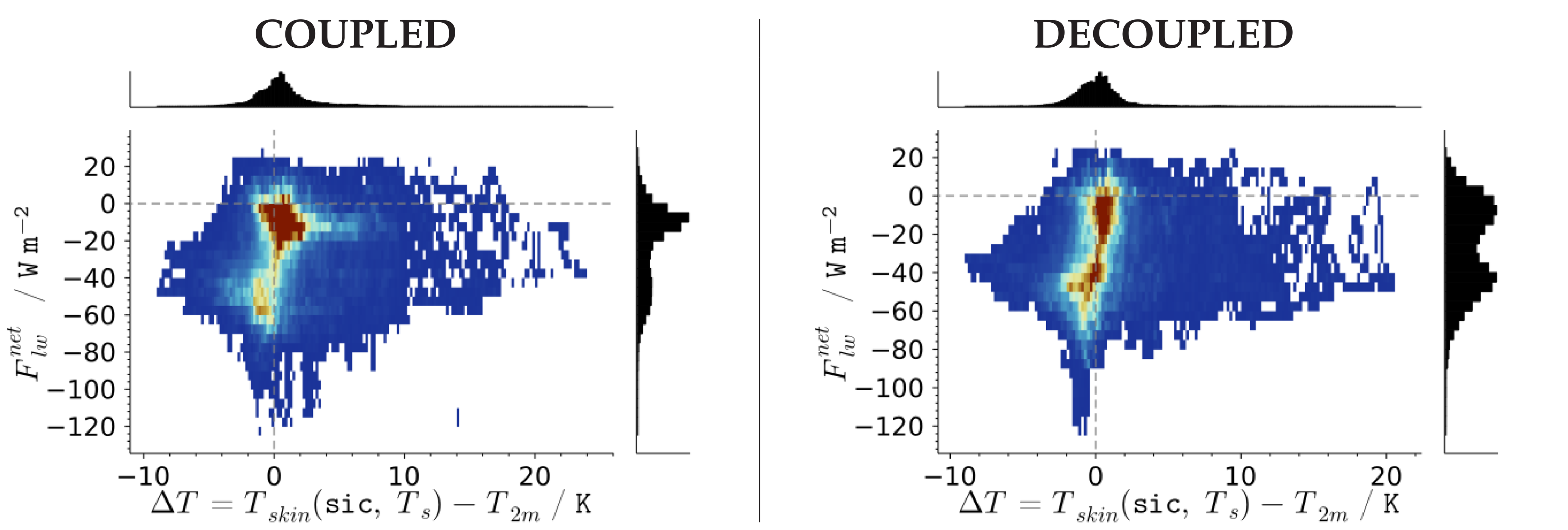
3.- Results for cloud-sea ice coupled and decoupled conditions

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 $\Delta T = f(sic, T_s, T_{2m})$



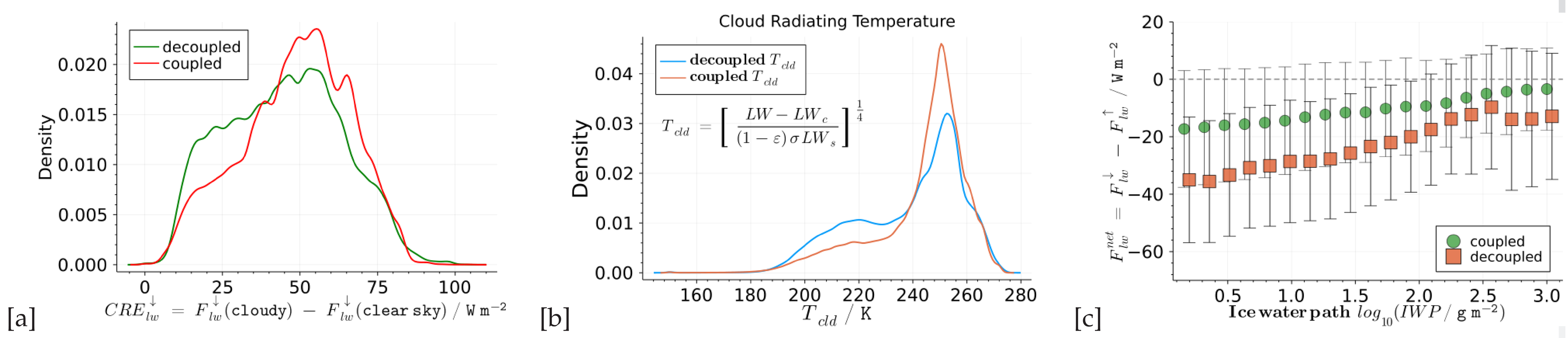


Figure 3: [a] PDF for CRE ($F_{lw}^{\downarrow}$ cloudy - clear sky) shows a more frequent occurrence for cases when the clouds are coupled. [b] CRT estimated from clear-sky LW (LW_c), fractional sky cover (LW_c), indicating that warmer clouds are more frequent for coupled cases. [c] LW net radiation 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 yiel 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.

5.- References

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