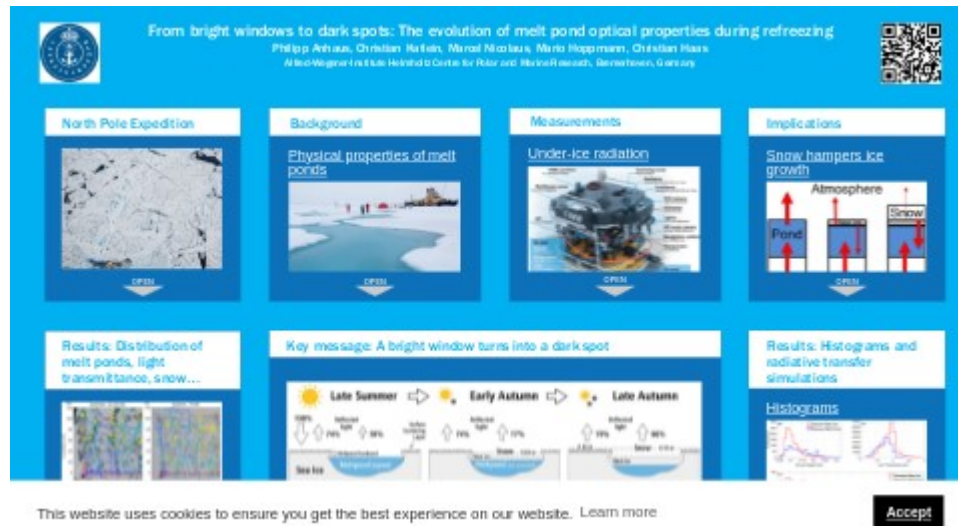# From bright windows to dark spots: The evolution of melt pond optical properties during refreezing
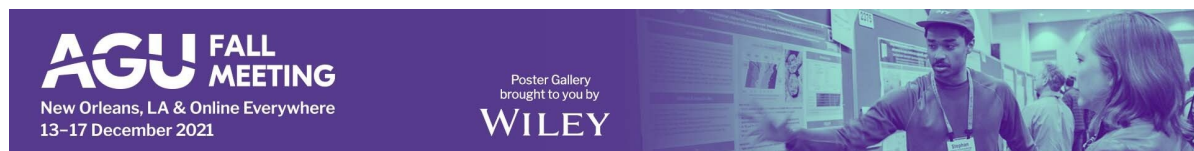
Philipp Anhaus, Christian Katlein, Marcel Nicolaus, Mario Hoppmann, Christian Haas

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PRESENTED AT:

NORTH POLE EXPEDITION

Figure: Aerial image taken during a low helicopter flgiht on 14 August 2018. Photo credit: Lars Lehnert, SPRS.

- Arctic Ocean 2018 MOCCHA – ACAS – ICE campaign (short: AO18) onboard the Swedish icebreaker *Oden*

- Temporary ice camp on drifting, ponded multi-year ice close to the geographic North Pole

- 14 August to 14 September 2018

BACKGROUND

Physical properties of melt ponds

Figure: The surface of melt ponds is lower than that of adjacent bare ice.
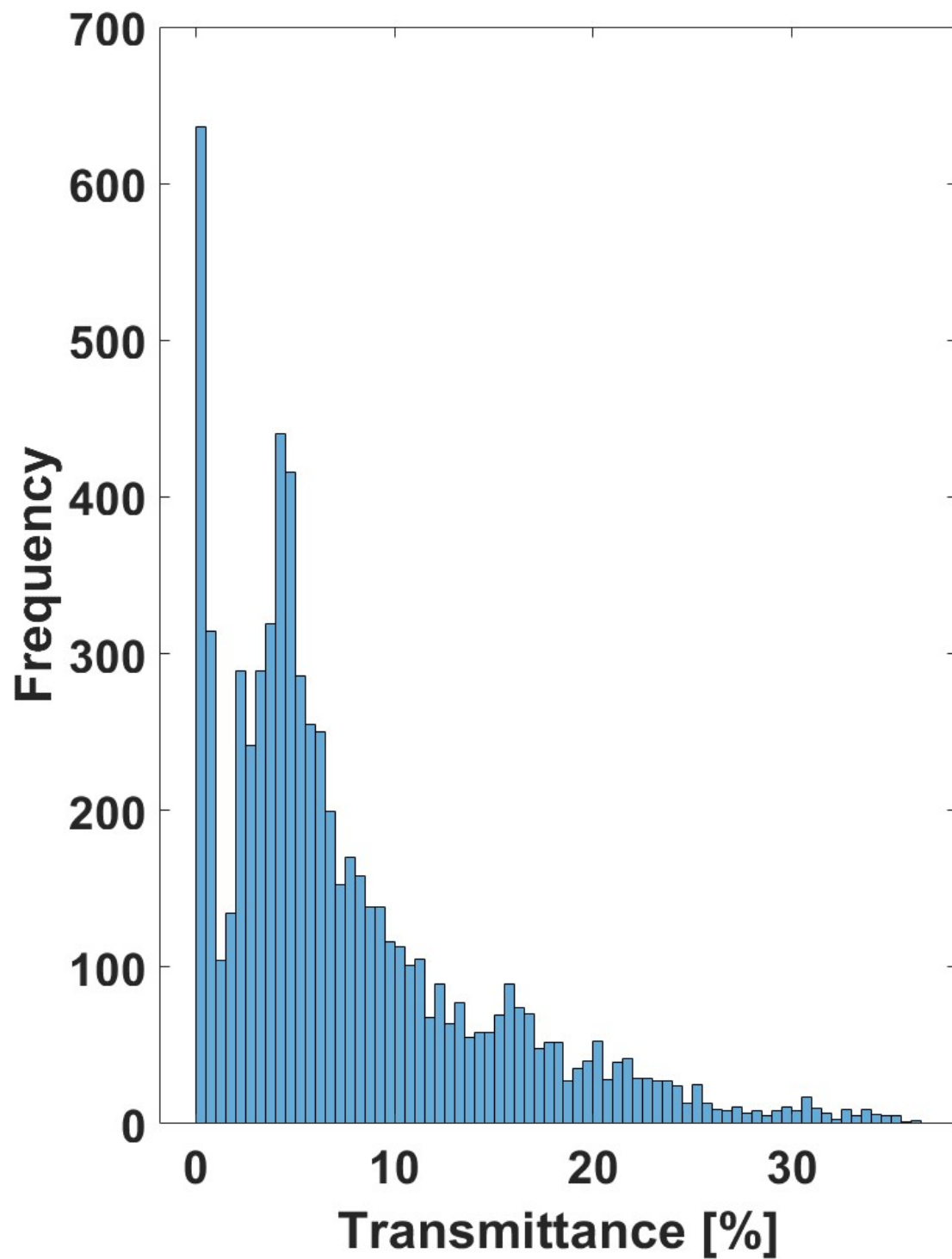
- Melt ponds are topographic lows

Figure: Histogram of light transmittance for typical Arctic summer sea ice.

- **Bi-modal transmittance** distribution on **summer** Arctic sea ice

- Mode of **0.5%** is associated with **bare ice** and **4.5%** with **melt ponds**

- **Translucent melt ponds** cause **higher light transmittance**

- In the existing literature, it is documented that in the transition to autumn the transmittance of melt ponds and bare ice decreases equally, so that the transmittance of melt ponds remains always higher than that of bare ice (e.g., Katlein et al., 2019)

- This is why melt ponds are considered bright windows of Arctic sea ice, also during autumn

Ecological properties of melt ponds

Figure: Biomass underneath open melt ponds (Lee et al., 2011).

- **Biomass** accumulates also under **refrozen melt ponds** in **autumn** due to **more light** (Lee et al., 2011).
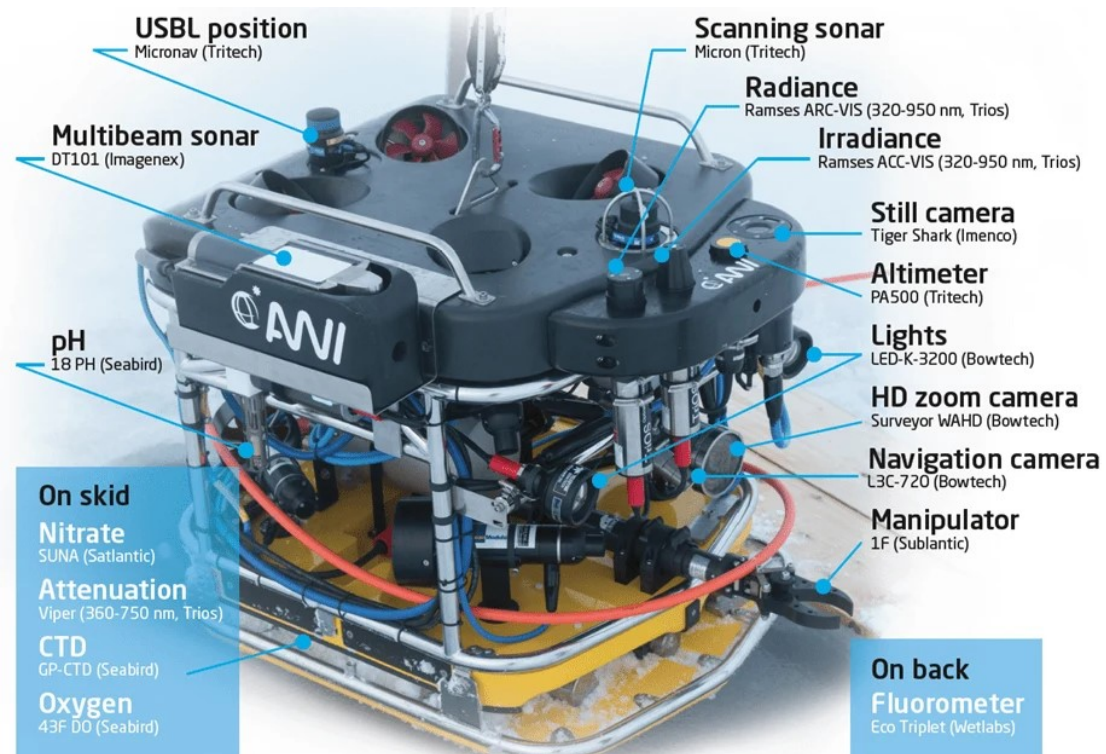
MEASUREMENTS

Under-ice radiation

Figure: Remotely operated vehicle *BEAST* (Ocean Modules, Åtvidaberg, Sweden, Katlein et al., 2017).

- operated underneath the sea ice
- measures under-ice irradiance
- transmittance = under-ice irradiance / surface irradiance

Total ice thickness

Figure: Ground-based electromagnetic induction sounding device (GEM-2, Geophex Ltd, Raleigh, NC, USA, Hunkeler, 2016; Hunkeler et al., 2016).

Snow depth

Figure: Magnaprobe (Snow-Hydro, Fairbanks, AK, USA, Sturm and Holmgren, 2018). Photo credit: Pierre Coupel, DFO

IMPLICATIONS

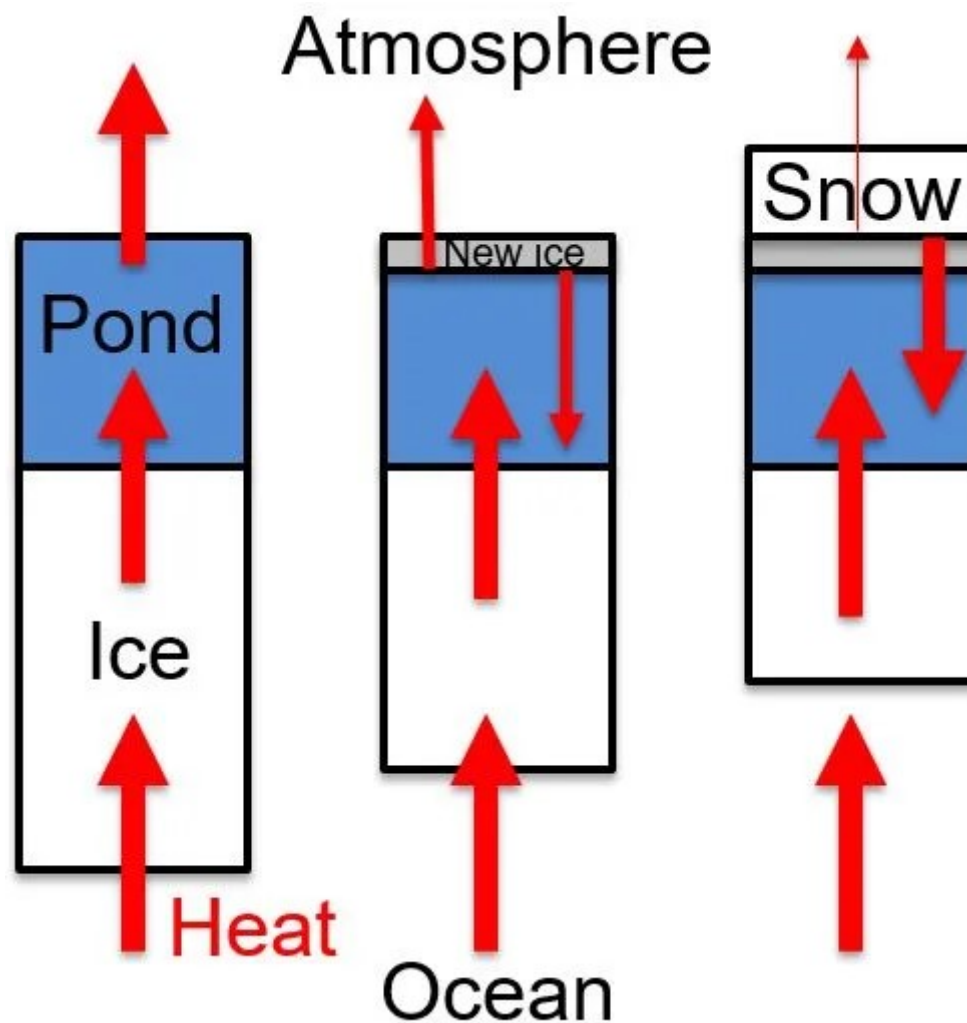### Snow hampers ice growth

Figure: Schematic of heat transfer for ice-ocean-atmosphere system.

- Thinner ice more vulnerable to dynamic and warming events

- Induces rougher bottom topography, affects mass, momentum, heat, and salt fluxes

Biomass accumulates also under refrozen melt ponds in autumn due to more light -> food source (Lee et al., 2011)

Figure: Biomass underneath open melt ponds (Lee et al., 2011).

However, snow decreases light under melt ponds

Effects on where, which, and how biomass is distributed udner sea ice

RESULTS: DISTRIBUTION OF MELT PONDS, LIGHT TRANSMITTANCE, SNOW DEPTH, AND ICE THICKNESS
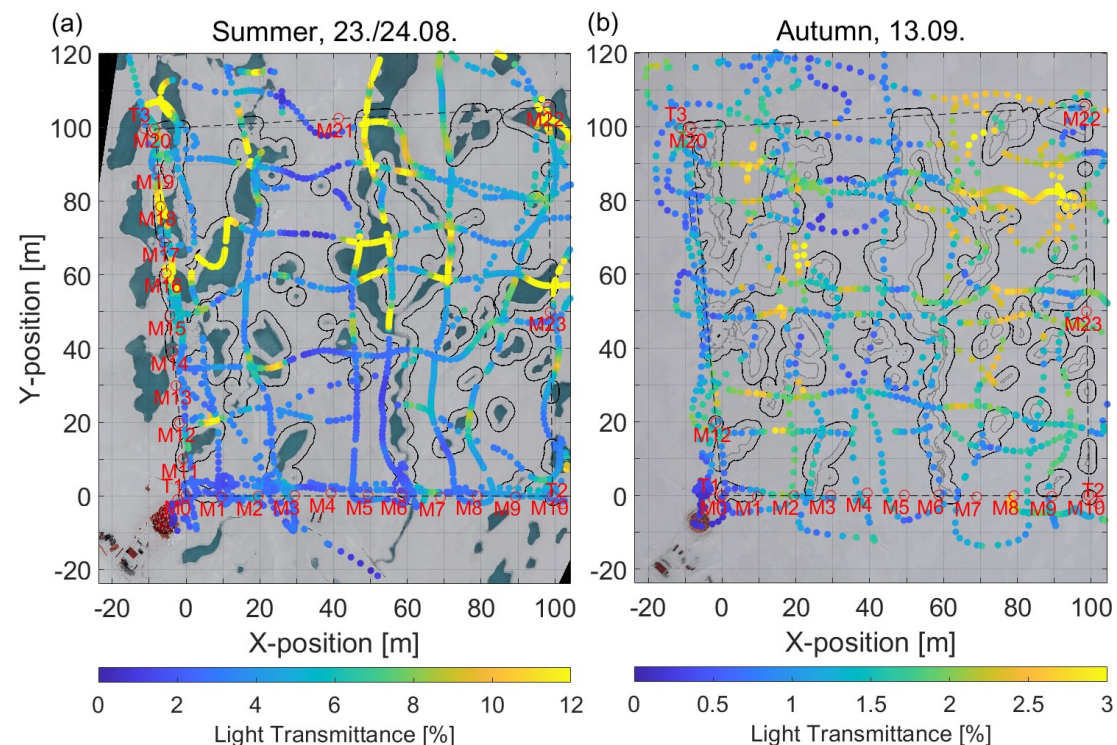

Figure: Distribution of melt ponds and bare ice on drifting MYI in the Central Arctic during the transition from (a) summer to (b) autumn. The surfaces of the melt ponds were partly open and partly refrozen in (a) and completely refrozen and snow-covered in (b). Overlaid is light transmittance as measured using an ROV. The background images are orthorectified aerial images acquired during (a) a low altitude helicopter flight and (b) a drone flight. Pixels within the study area that were classified as melt pond and used for further analysis are outlined by the melt ponds themselves in (a) and by the grey line in (b). The surfaces of the melt ponds in (b) were refrozen and snow-covered but marked blue for illustration purposes. The edges around the melt ponds in (a) and (b) were dilated by a buffer of about 2 m indicated by the black line. Red labels indicate the marker (M) and transponder locations (T). The ROV tent and control hut are visible on the lower left corners of the images. Note the different range in transmittance in (a) and (b). Photo credit for (b): Lars Lehnert, SPRS.

- (a) **Summer**: **Transmittance** below melt **ponds higher** than below bare ice

- (b) **Autumn**: **Transmittance** below melt **ponds lower** than below bare ice
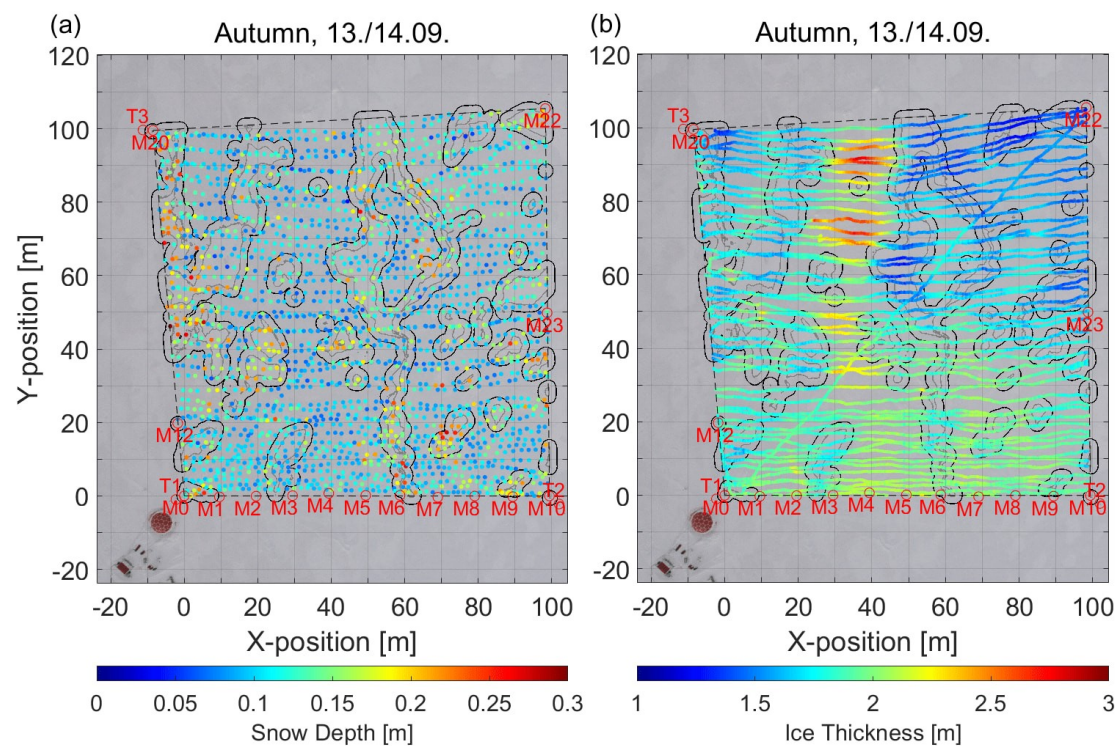
Figure: (a) Snow depth and (b) ice thickness on ponded sea ice as measured on 14 September (autumn). The background images are orthorectified aerial images acquired during a drone flight on 13 September. Pixels within the area of focus that were classified as melt pond during the summer are outlined by the grey lines to illustrate the refrozen and snow-covered ponds during autumn. The edges around the melt ponds were dilated by a buffer of about 2 m indicated by the black lines. This area is indicated by a brighter blue. Red labels indicate the marker (M) and transponder locations (T). The ROV tent and control hut are visible on the lower left corners of the images. Photo credit: Lars Lehnert, SPRS.

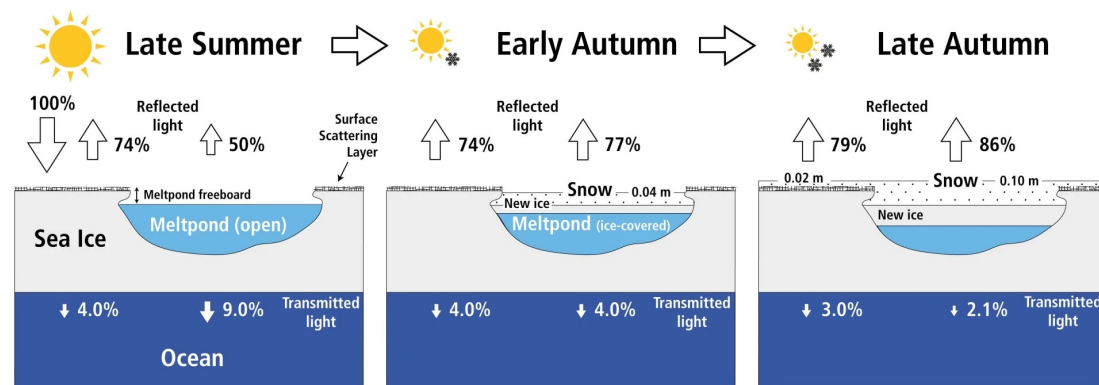# KEY MESSAGE: A BRIGHT WINDOW TURNS INTO A DARK SPOT

Figure: During the transition from summer to autumn, snow predominantly accumulated on the recessed surface of frozen melt ponds, resulting in a reversal of the light transmittance between melt ponds and bare ice. Numbers result from the radiative transfer model DORT2002.

- **Snow** mainly accumulated on recessed **surface of frozen melt ponds**

- **Reversal** of **light transmittance** between melt ponds and bare ice

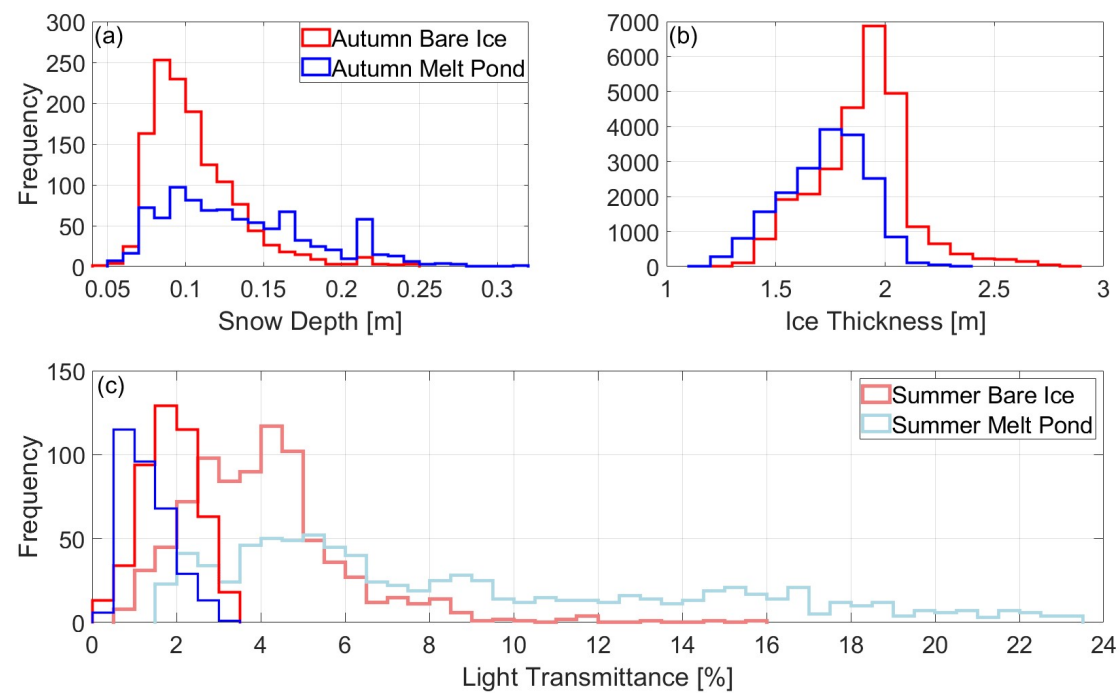# RESULTS: HISTOGRAMS AND RADIATIVE TRANSFER SIMULATIONS

Histograms

Figure: Histograms of measured (a) snow depth, (b) ice thickness, and (c) light transmittance of melt ponds and bare ice.

- (a) Thicker snow cover on melt ponds than on bare ice

- (c) **Summer**: Transmittance of melt ponds **higher** than that of bare ice

- (c) **Autumn**: Transmittance of melt ponds **lower** than that of bare ice
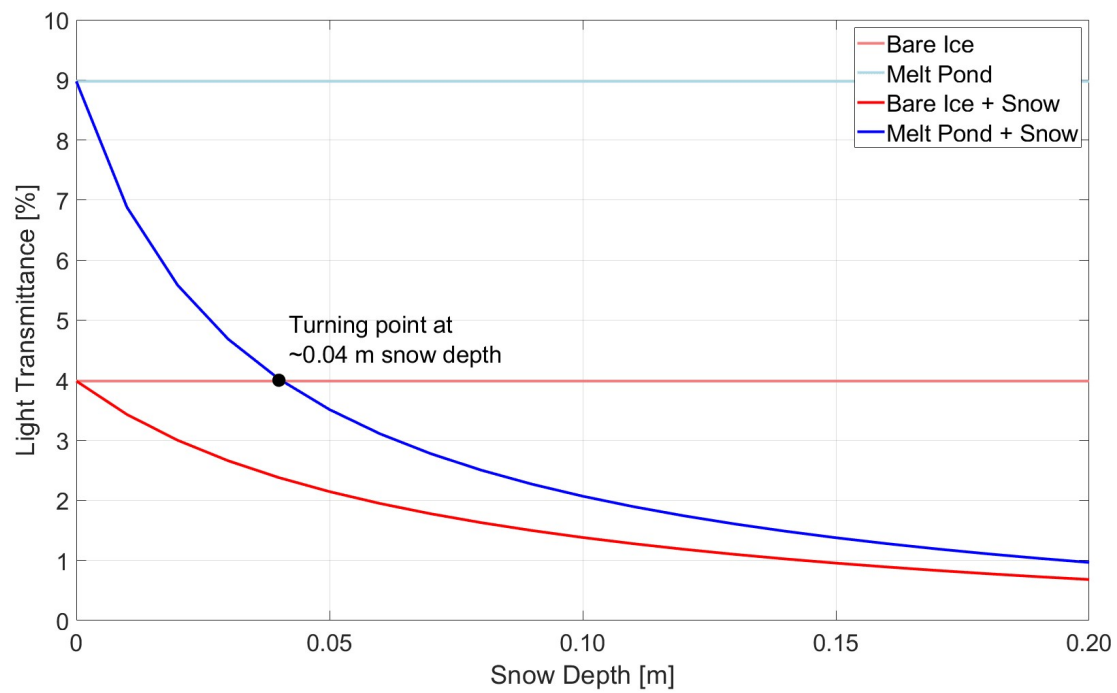
Radiative transfer model

Figure: Light transmittance simulations using the radiative transfer model DORT2002 (Edström, 2005).

- Transmittance below melt ponds become lower than that below bare ice for a snow depth of 0.04 m

AUTHOR INFORMATION

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ABSTRACT

Melt ponds have a strong impact on the Arctic surface energy balance and the ice-associated ecosystem because they transmit more solar radiation compared to bare ice. In the existing literature, melt ponds are considered as bright windows to the ocean, even during freeze-up in autumn. In the central Arctic during the summer-autumn transition in 2018, we encountered a situation where more snow accumulated on refrozen melt ponds compared to the adjacent bare ice, leading to a reduction in light transmittance of the ponds even below that of bare ice. Results from a radiative transfer model support this finding. This situation has not been described in the literature before, but has potentially strong implications for example, on autumn ecosystem activity, oceanic heat budget and thermodynamic ice growth.

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