Abstract No. 34

Snow Depth Retrieval using Under-Ice Hyperspectral Radiation Measurements

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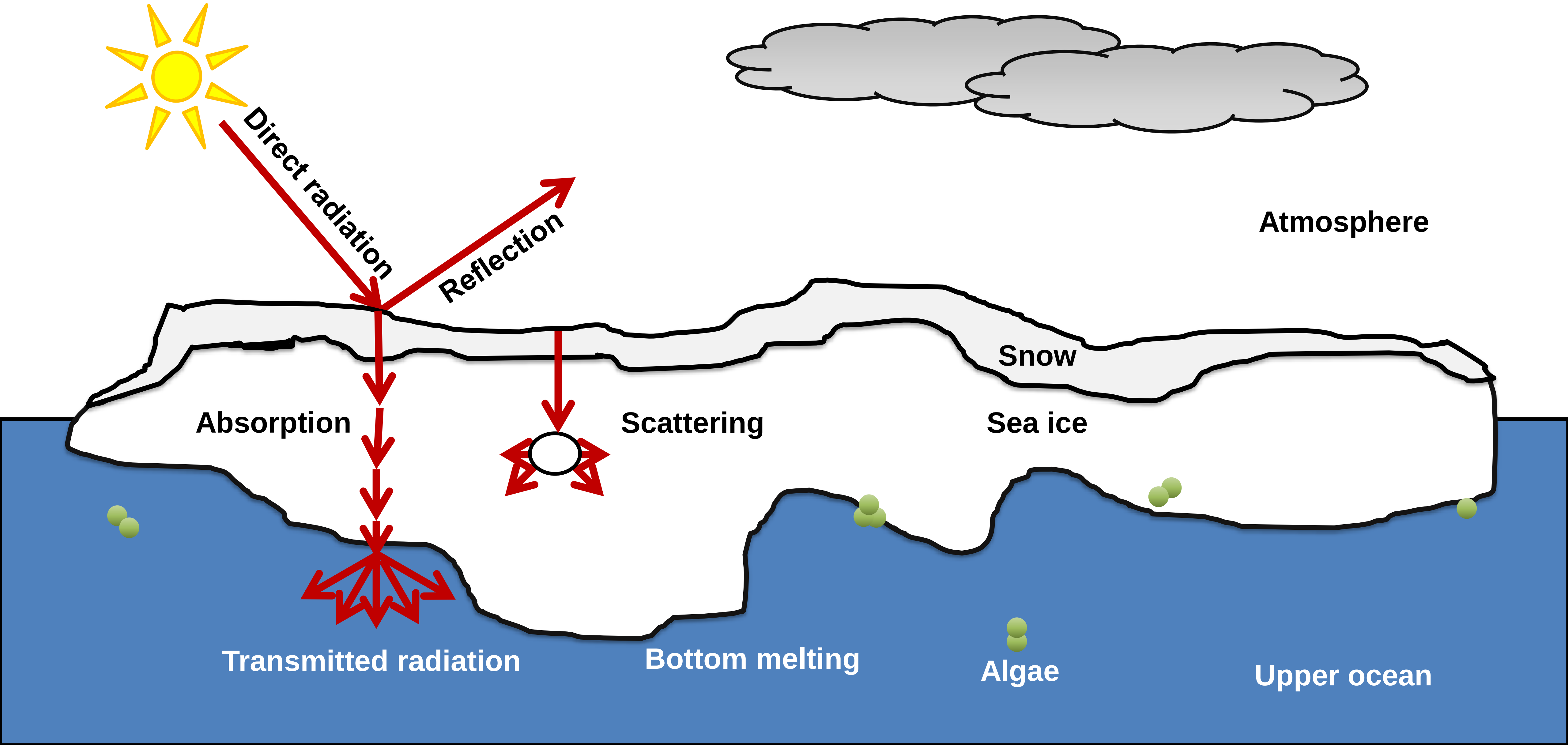
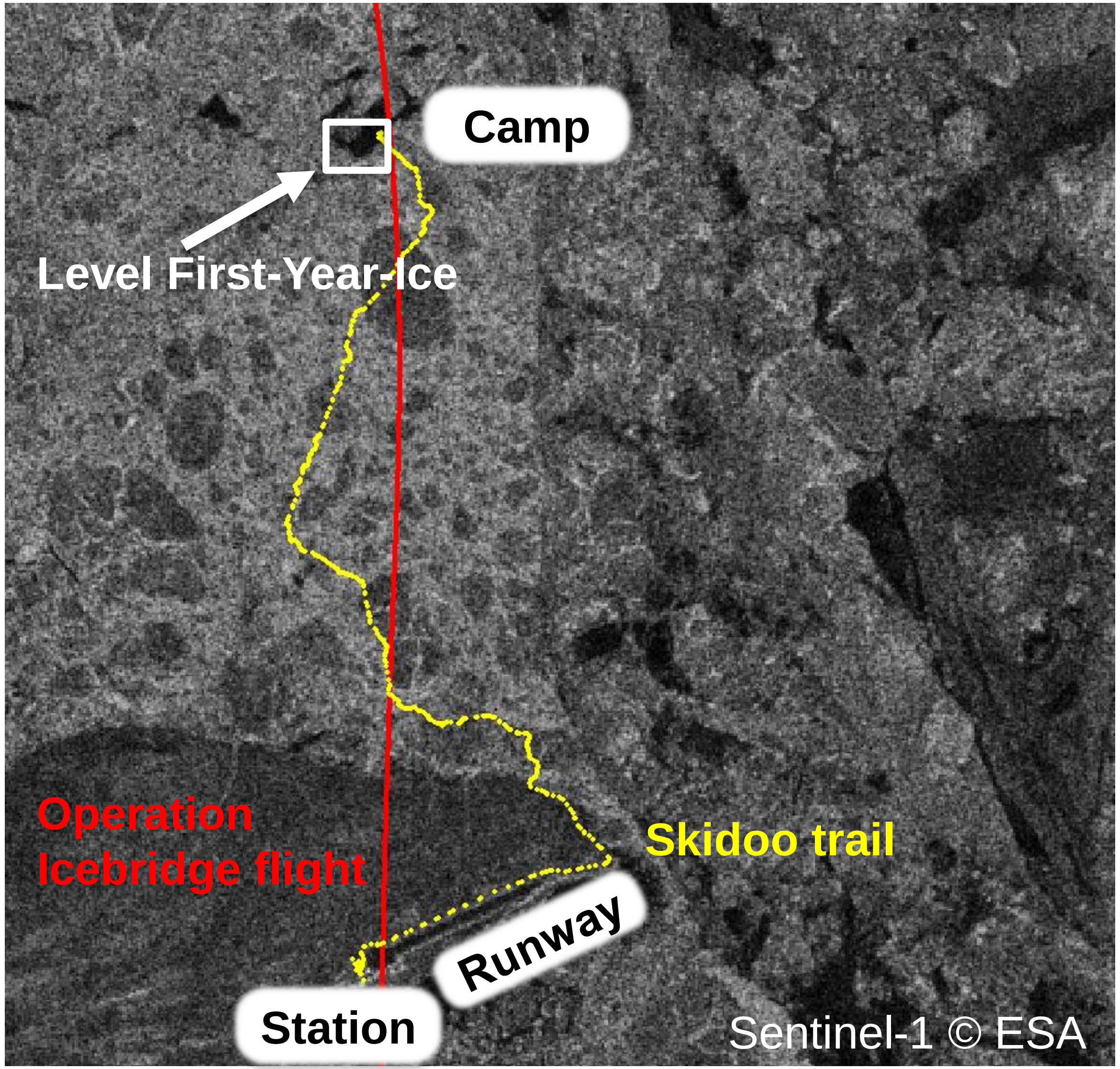

Direct radiation
Reflection
Atmosphere
Snow
Absorption
Scattering
Sea ice
Transmitted radiation
Bottom melting
Algae
Upper ocean

Snow Depth Retrieval from Hyperspectral Optical Data

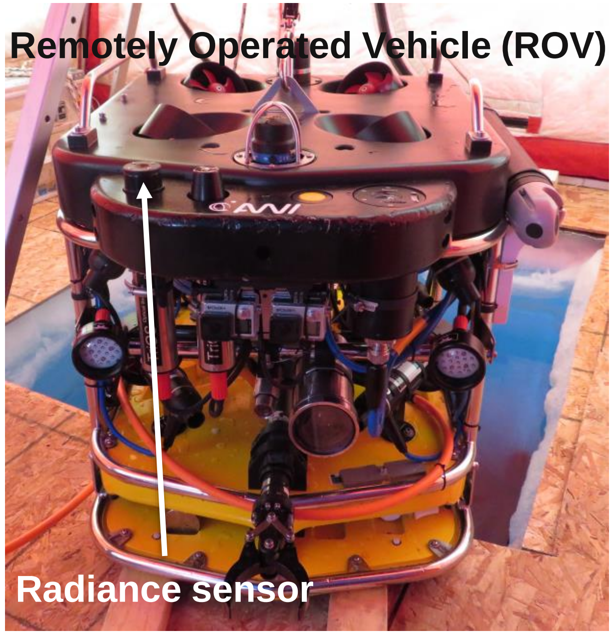
- **Relationships between transmitted radiation and snow depth and sea ice thickness**
- Auxiliary data for under-ice ROV and AUV measurements
- Logistical challenges for hardly accessible areas
- Non-destructive methods
- Under-ice remote sensing tool that can increase spatial and temporal coverage of regional measurements
- Time series observations to support development and validation of snow process models

Study Site

Multidisciplinary Arctic Program (MAP) - Last Ice spring 2018 field campaign



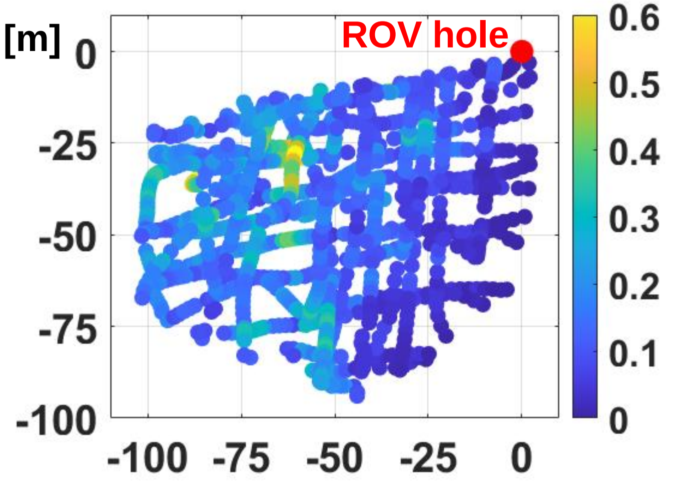
Data



Level First-Year-Ice patch ~100 x 100 m

- Under-ice hyperspectral radiance
- High resolution snow depth
- Total ice thickness

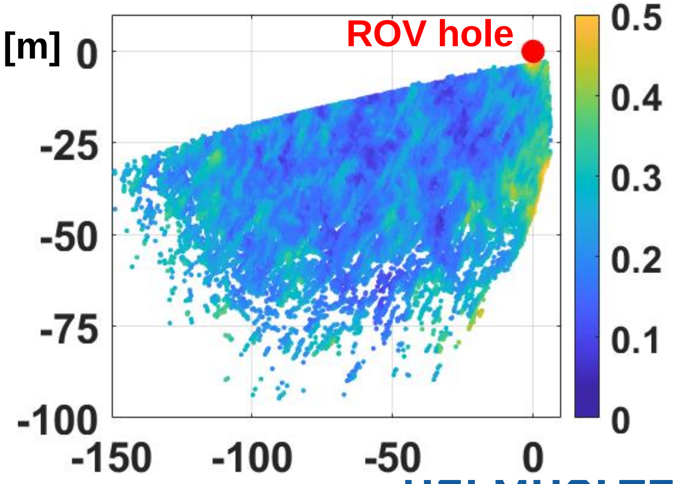
Broadband Transflectance May 22 [%]



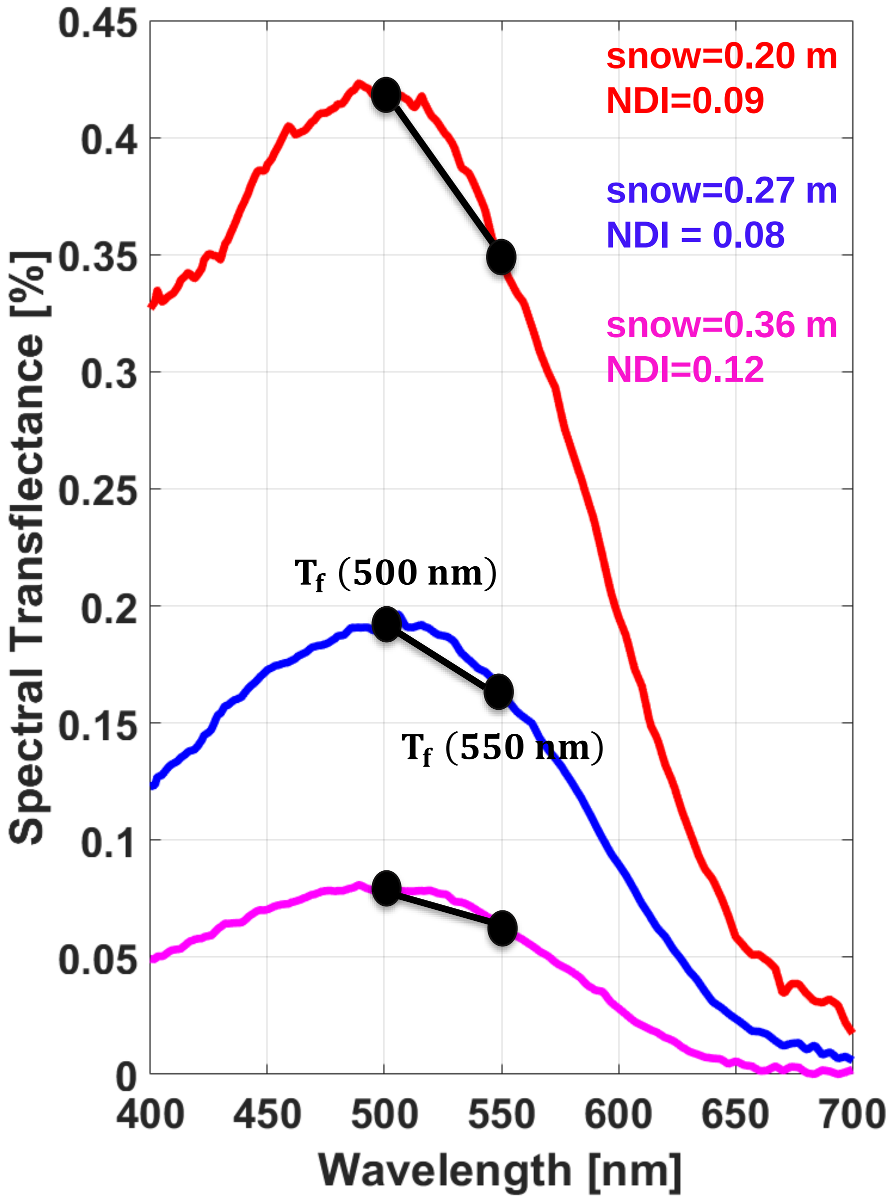
Co-location
- Sensor opening angle 7°
- Max. ROV depth 2 m
- Ice thickness and snow depth

-> Surface footprint radius 1.5 m

Snow Depth May 23 [m]



Methods



Normalized difference indices (NDIs) based on hyperspectral transflectance Tf

- $\mathrm{NDI}\ (\lambda_1, \lambda_2) = \frac{\mathrm{Tf}\,(\lambda_1) - \mathrm{Tf}\,(\lambda_2)}{\mathrm{Tf}(\lambda_1) + \mathrm{Tf}\,(\lambda_2)}$
- Correlation between NDI and snow depth and linear regression

T_f: transflectance, $\lambda_{1,2}$: specific wavelength pair

Radiative transfer model & extinction coefficients

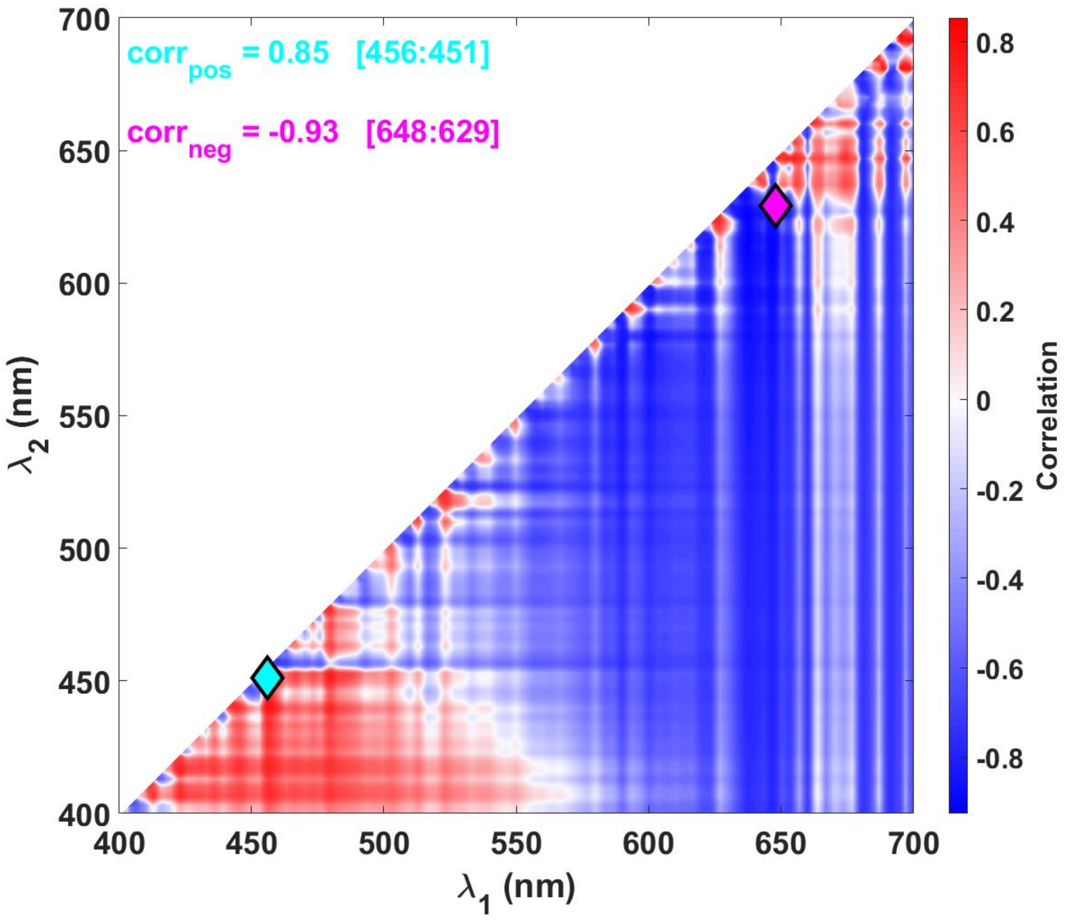
- $T_f\,(z_{snow}, z_{ice}, \lambda) = i_0 \exp(-\,k_{snow}(\lambda) \cdot z_{snow} - \,k_{ice}(\lambda) \cdot z_{ice})$

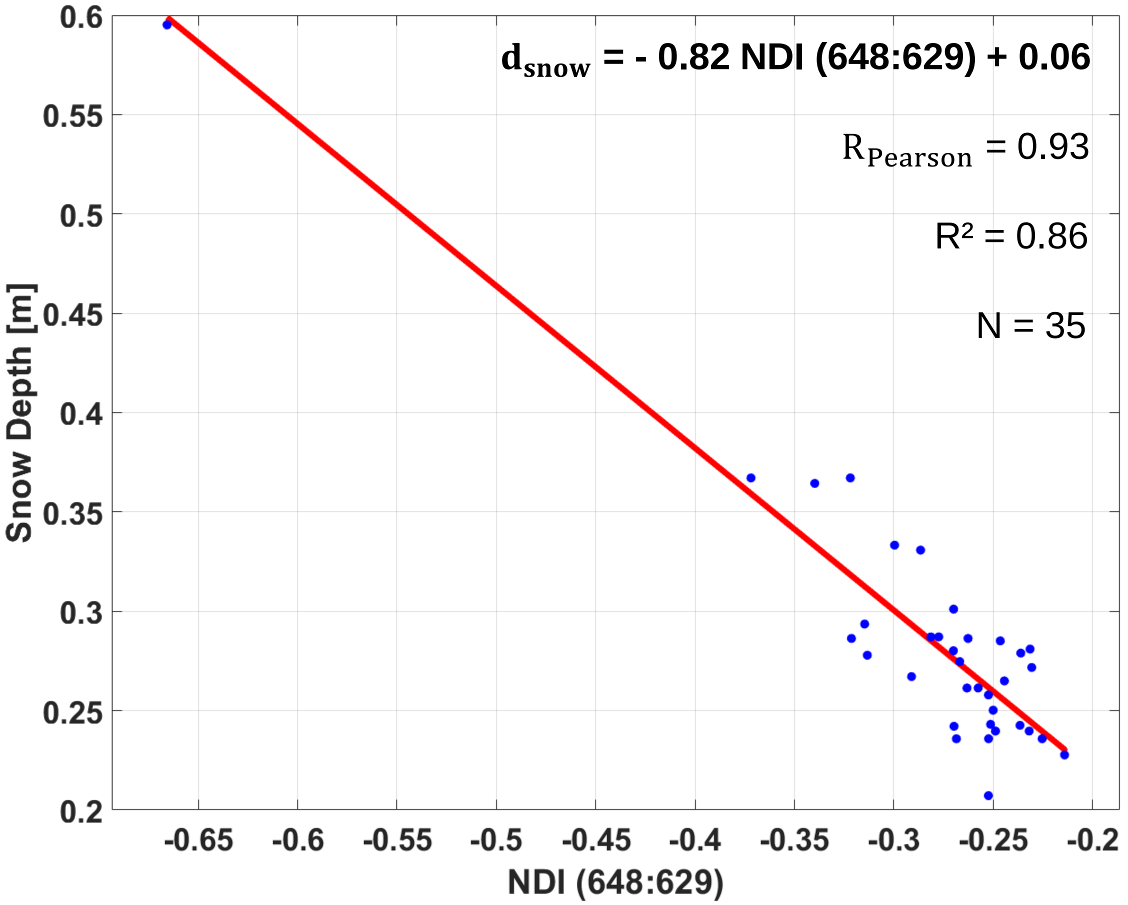
λ: 400 – 700 nm, $i_0 = 0.35$ (Grenfell and Maykut, 1977)

Results - Normalized Difference Indices

Spectral correlation surfaces between NDIs and snow depth

Highest correlation (-0.93) between NDIs and snow depth for the wavelength pair 648:629 nm





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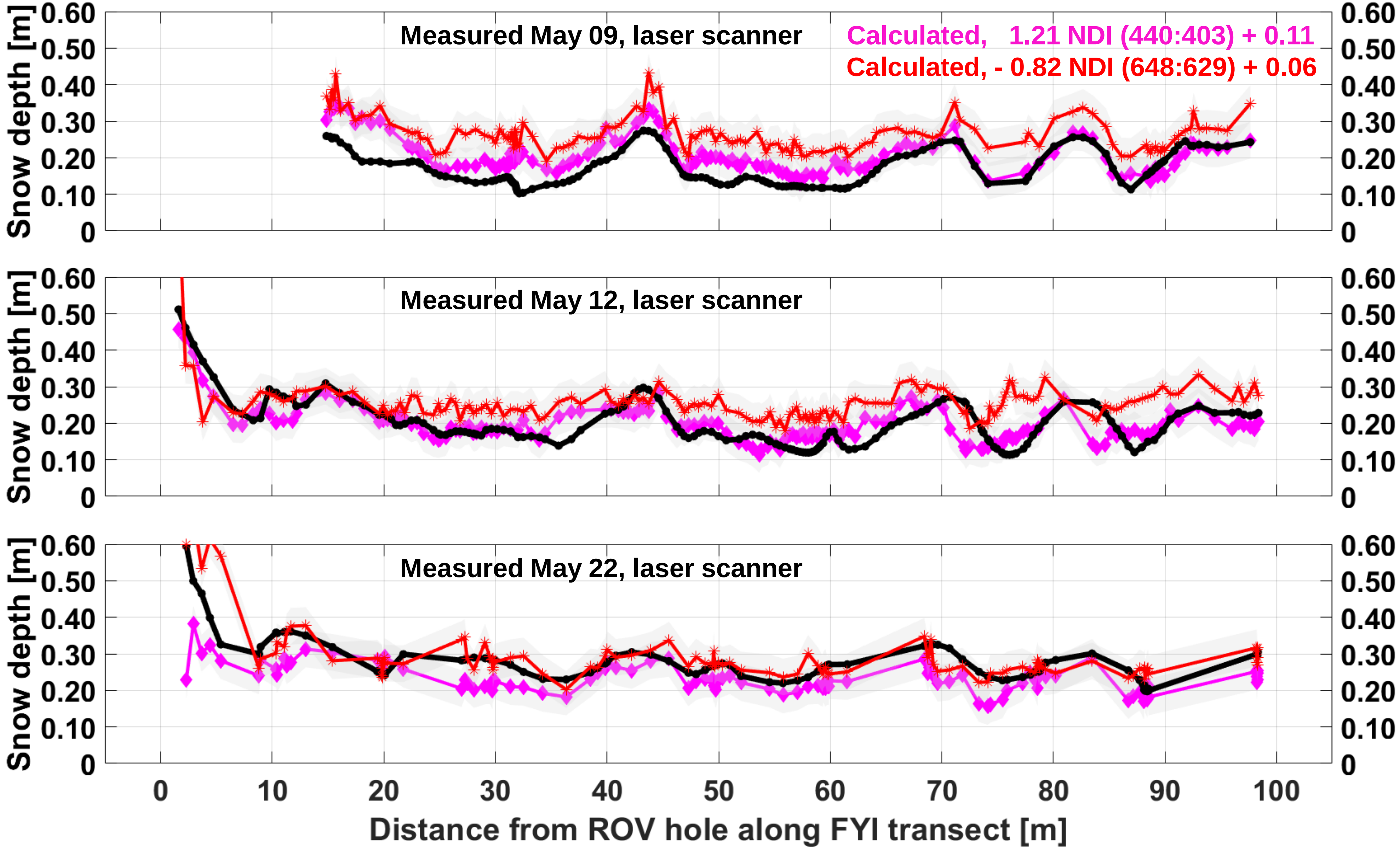
Results - Normalized Difference Indices

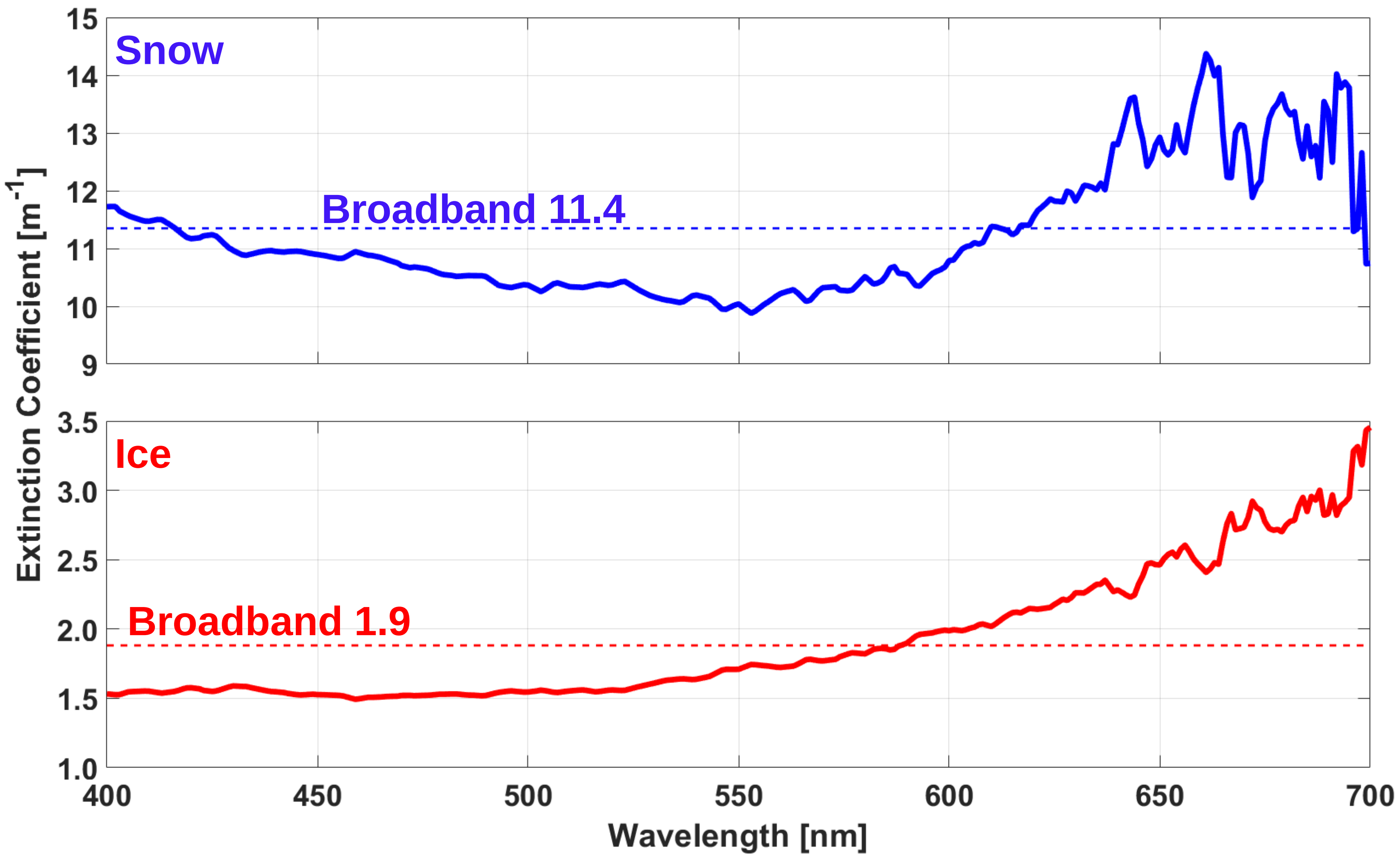


Spatial variability can be well described by the two NDI algorithms

Red algorithm overestimates the magnitude

Results – Radiative transfer model & extinction coefficients

$$T_f\,(z_{snow}, z_{ice}, \lambda) = i_0 \exp(-\,k_{snow}(\lambda) \cdot z_{snow} - \,k_{ice}(\lambda) \cdot z_{ice})$$



Perovich, 2007; Warren, 1982

10 - 100 m^{-1}

Low snow extinction coefficients k_{snow}

Light et al., 2008; Perovich, 1996

0.8 - 1.5 m^{-1}

High sea ice extinction coefficients k_{ice}

Katlein et al., 2015

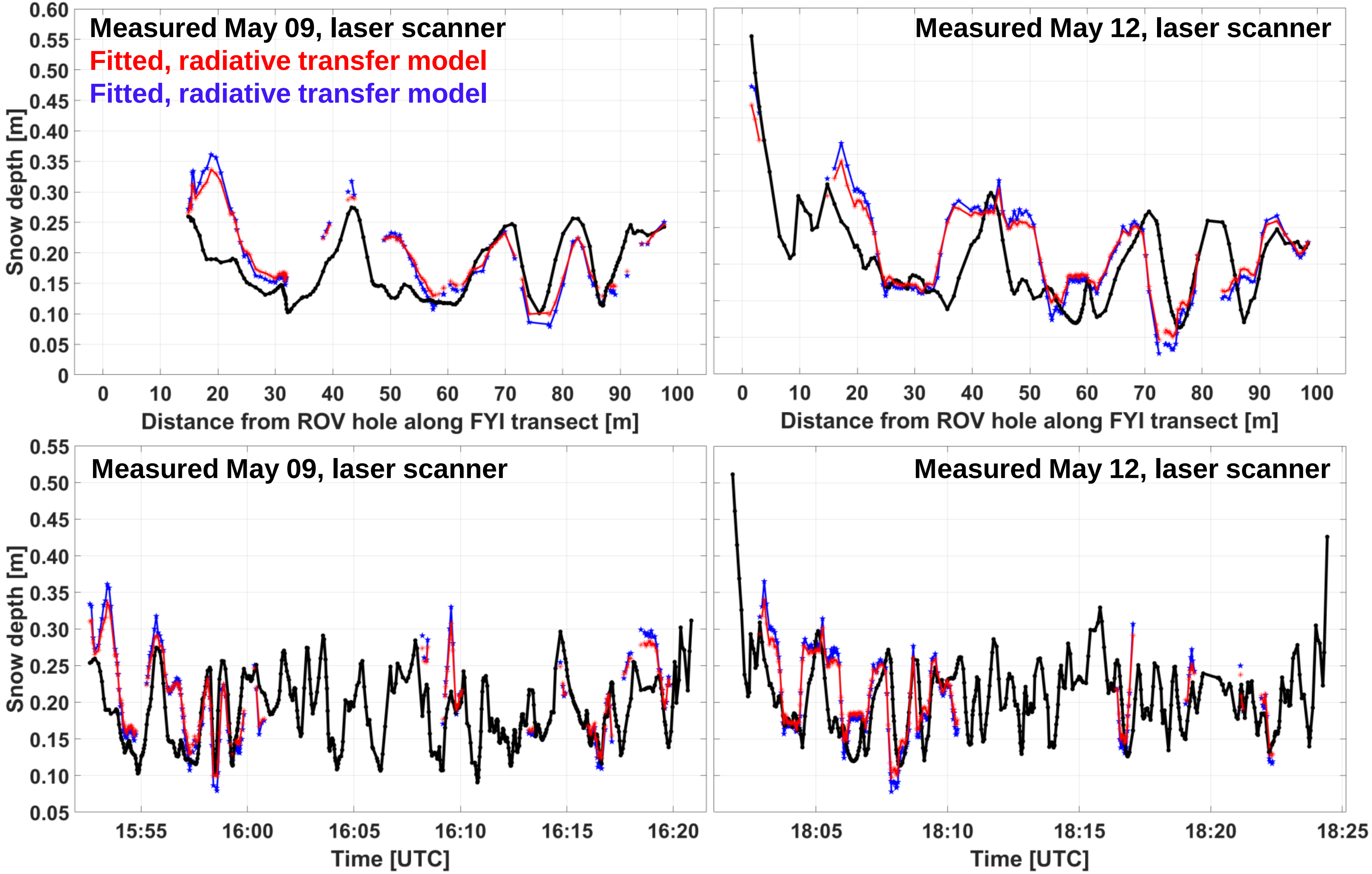
Broadband values between 1.1 to 3 m^{-1}

Katlein et al., 2019

Seasonal changes between 0.8 and 9 m^{-1}

-> high k_{ice} somewhat consistent

Results – Radiative transfer model & extinction coefficients

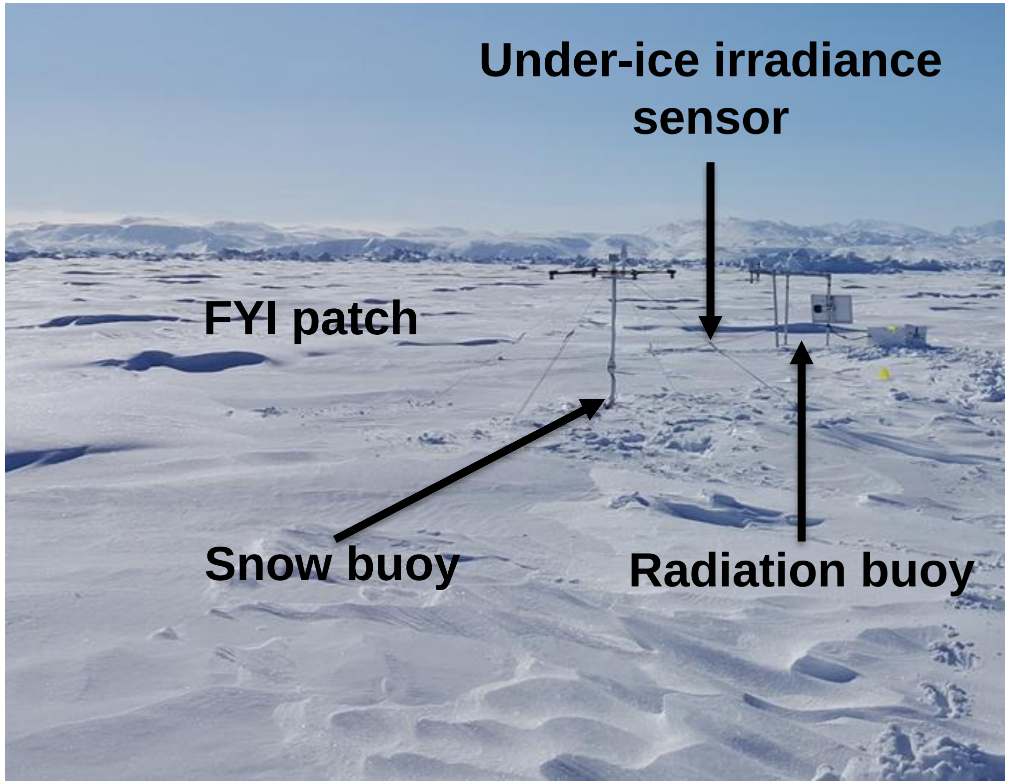


Data gaps are due to lacking ice thickness data within 1.5 m radius of transflectance data

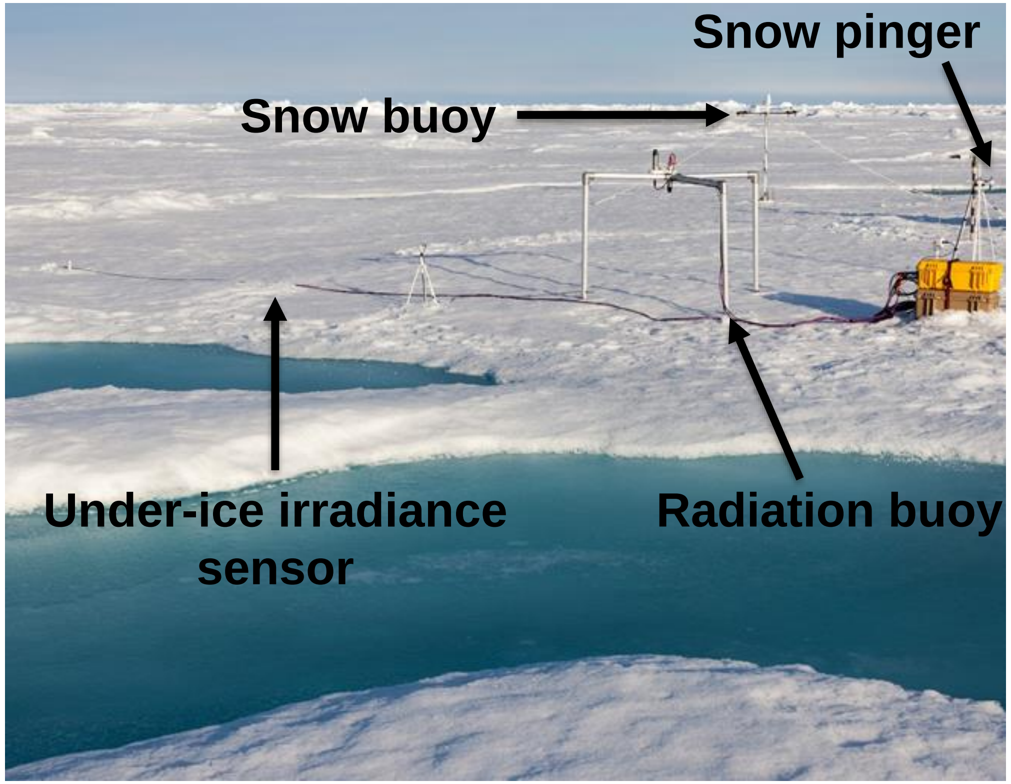
Spatial variability can be well described by fitted snow depths using a simple radiative transfer model

Method validation

Time series observations of snow depth from snow buoys and under-ice transmittance from radiation buoys



Landfast level First-Year-Ice in the Lincoln Sea in spring 2018



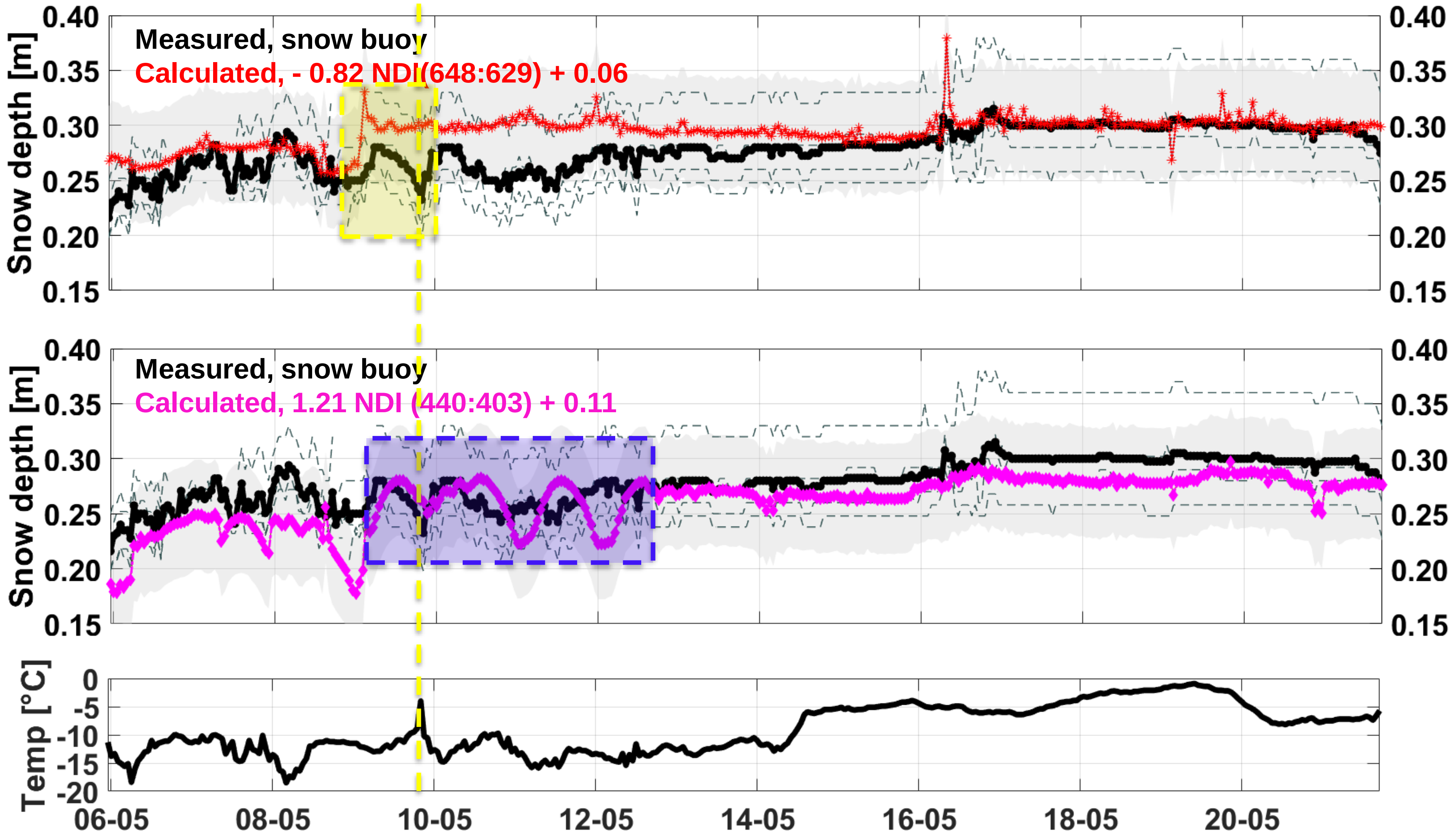
Drifting melt-pond covered Multi-Year-Ice close to the geographic North Pole in autumn 2018

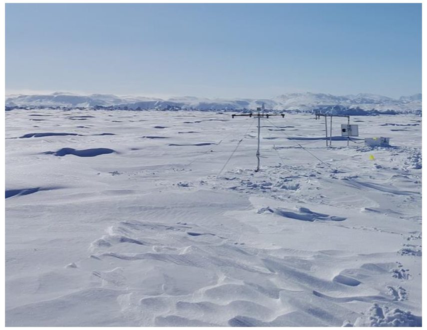
Multidisciplinary Arctic Program (MAP)

Arctic Ocean 2018 (AO18) MOCCHA - ACAS - ICE

Method validation

Landfast level FYI in the Lincoln Sea in spring 2018





Good agreement between measured and calculated snow depths

Atmospheric changes influence snow depth retrieval when using wavelengths in blue part of the spectrum (e.g., 440:403 nm)

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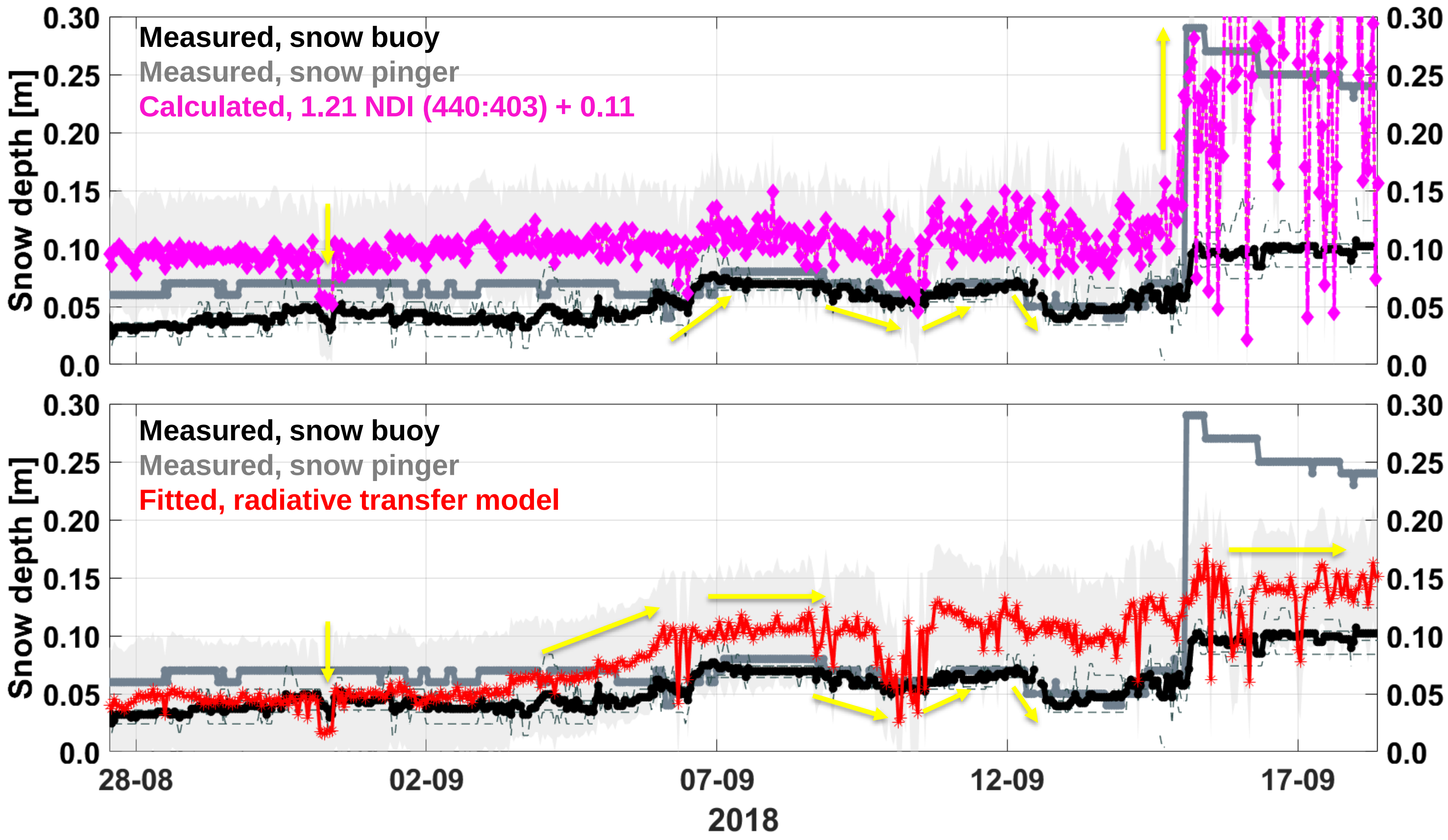
Method validation

Drifting melt-pond covered MYI close to the geographic North Pole in autumn 2018



Sudden snow depth increase in pinger data from September 15

Difference due to spatial variability/distance between snow buoy and pinger

Both methods describe temporal variability well

Thank you for your time!
Questions?

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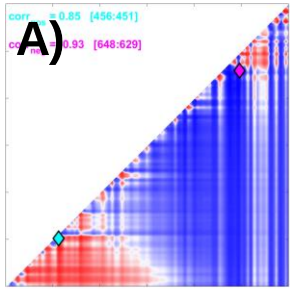
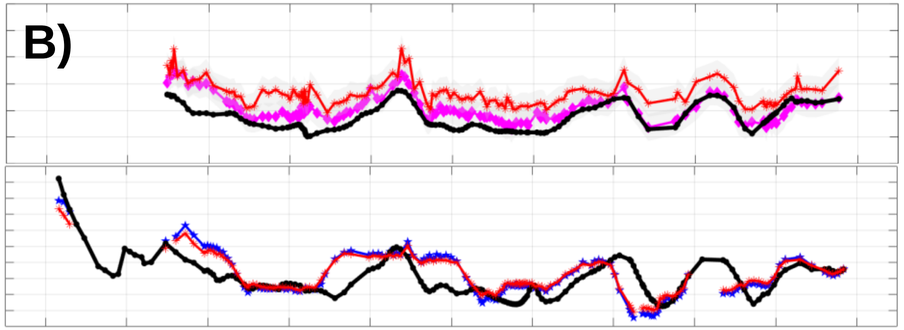


$$T_f\,(z_{snow}, z_{ice}, \lambda)\; i_0\, \exp - k_{snow}(\lambda) \cdot z_{snow} - k_{ice}(\lambda) \cdot z_{ice}$$

A) Two optical methods to retrieve snow depth

Normalized Difference Indices

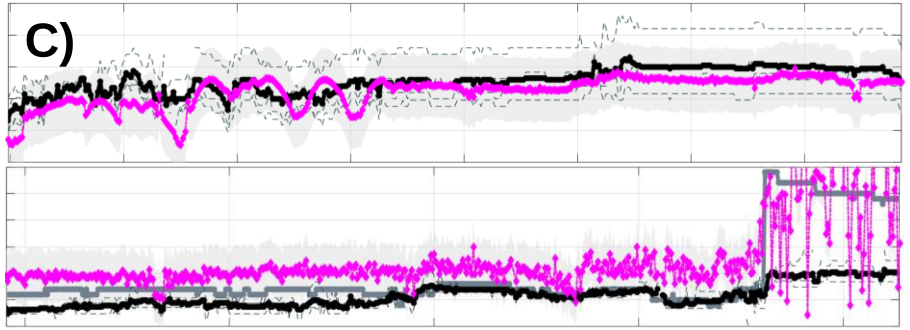
Simple radiative transfer model and extinction coefficients



B) Good agreement in spatio-temporal variability

Landfast level FYI, Lincoln Sea, spring 2018

Melt-pond covered MYI, North Pole, autumn 2018



C) Limitations

Atmospheric influence, blue spectrum (400-480 nm)

Low light levels

Implications & Outlook

- Inexpensive if sensors for two wavelengths are used
- Improve our understanding of relationships between under-ice radiation and snow depths
- ROV-based under-ice radiation from MOSAiC ROV-lead
- AUV surveys covering large regions in the Arctic

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