Effects of heterogeneous sea ice properties on radiative energy fluxes and the influence on Arctic amplification

C01

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1. Summary

Research questions

Q1 What are the most relevant scales (time and space) that govern radiative fluxes for sea ice?

Q2 How well is the temporal evolution of sea-ice development and associated radiative energy fluxes represented in models?

Q3 How do regional and seasonal changes in sea-ice surface properties contribute to Arctic amplification?

Contributions to CCA2 & SQ1

2. Achievements phase II

Melt season progress of Arctic sea ice

MOSAiC observations show how **critical surface conditions and heterogeneity** are to better understand the seasonal evolution of Arctic sea ice

- **Surface energy budget is event-driven,** strong contrasts - even on same ice floe (by factor 3)
- Summer surface albedo has two modes (ponds, ice)
- Bridging point measurements to floe-scales

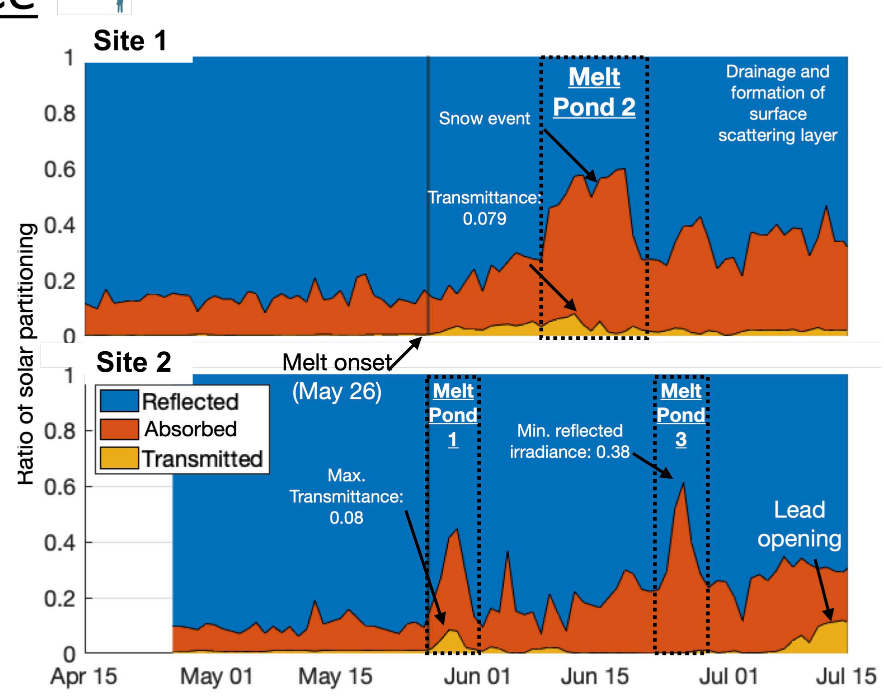


Fig. 1: Temporal evolution of solar partitioning.

Revised methods for retrievals of melt pond fraction and snow grain size

B02

- **New melt pond fraction (MPF) and open water fraction satellite product:** (Sentinel-2, 10 m resolution) ➜ maximum uncertainty of 6 %
- **Upscaling from local to Arctic-wide observations:** (Sentinel-3, 300 m / 1 km resolution) ➜ improved satellite retrieval for melt pond fraction and surface albedo
- **New airborne snow grain size approach**: reduced uncertainty (<25 %) vs. former methods (< 100 %)

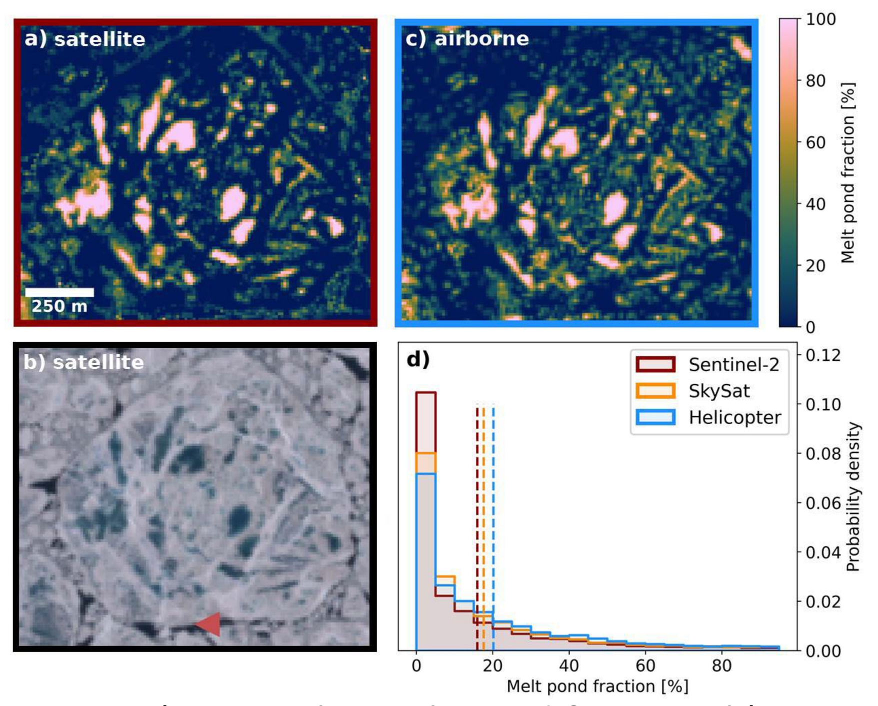


Fig. 2: a) Sentinel-2 melt pond fraction. b) Sentinel-2 RGB composite. c) Downscaled helicopter melt pond fraction. d) Histograms of melt pond fraction distributions.

Evaluation of adjusted HIRHAM-NAOSIM surface albedo scheme

D03

- **Seasonal and cloud dependent agreement**
  subtype albedo: weakening for spring (below thin clouds)
  subtype fractions: too small variability in summer
- **Implications for net irradiance (F_{net}):** negative bias (median: -6.4 W m^{-2}) for optical thin clouds

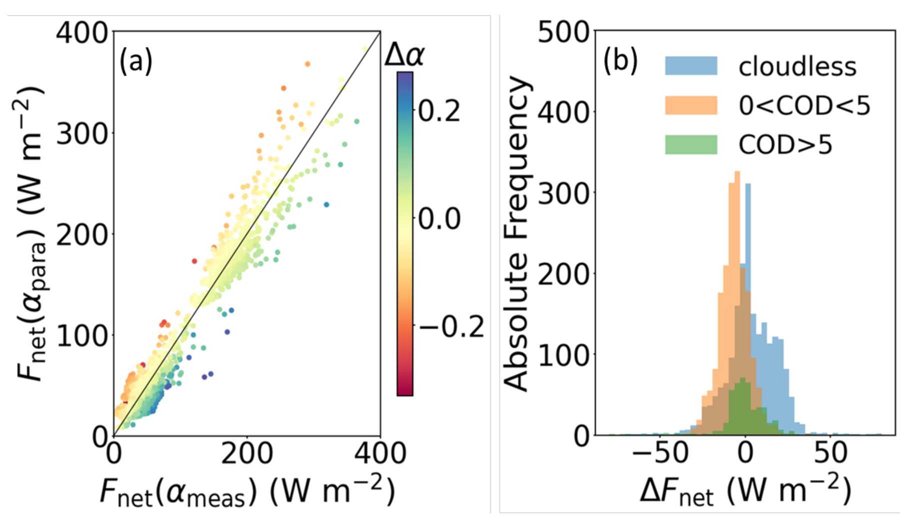


Fig. 3: (a) Scatterplot of F_{net} based on measured and parameterized surface albedo. (b) Frequency distribution of ΔF_{net} separated into three cloud classes depending on cloud optical depth (COD).

Hypothesis

Changing sea ice properties and associated radiative fluxes enhance Arctic amplification.

3. Research plan phase III

General goals

- Upscaling of local observations to airborne, satellite and model scales
  - merging analysis of field observations (e.g., MOSAiC) into numerical models
- Parametrization improvement:
  - surface albedo (new functional cloud dependence, melt pond and surface type fractions)
  - vertical radiative processes through the sea ice into the ocean
- Implementation in models (HIRHAM-NAOSIM, FESOM2-ICEPACK)
  - analysis of the relative importance of improved characteristics and near-surface processes in the Arctic (CCA2)
- Identification of regional and seasonal differences in surface properties
  - feedback of amplification to surface conditions
- Identification of long-term changes and impact on Arctic amplification
  - spatio-temporal melt pond fraction and surface albedo changes 2016 – today (extended back to 2002 by Envisat)
  - causes of changes (ice topography, roughness, ice type)

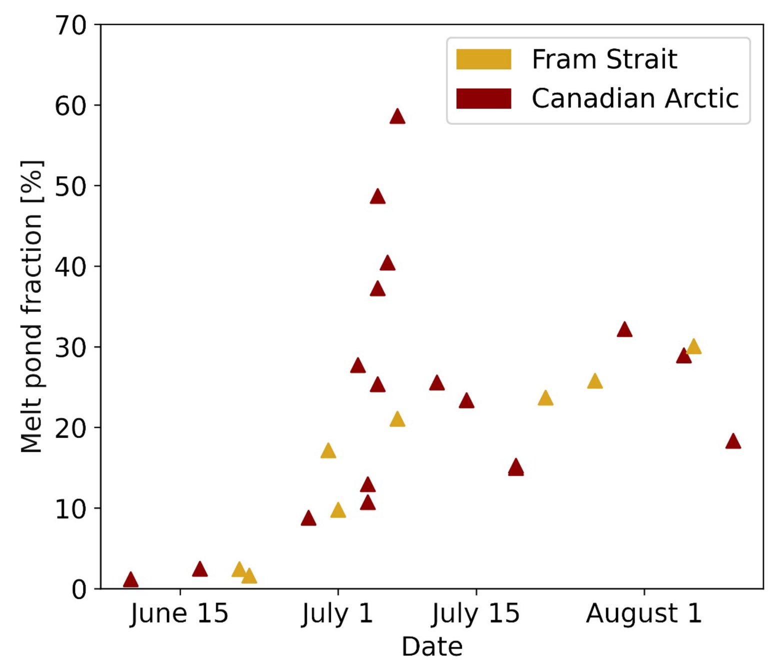
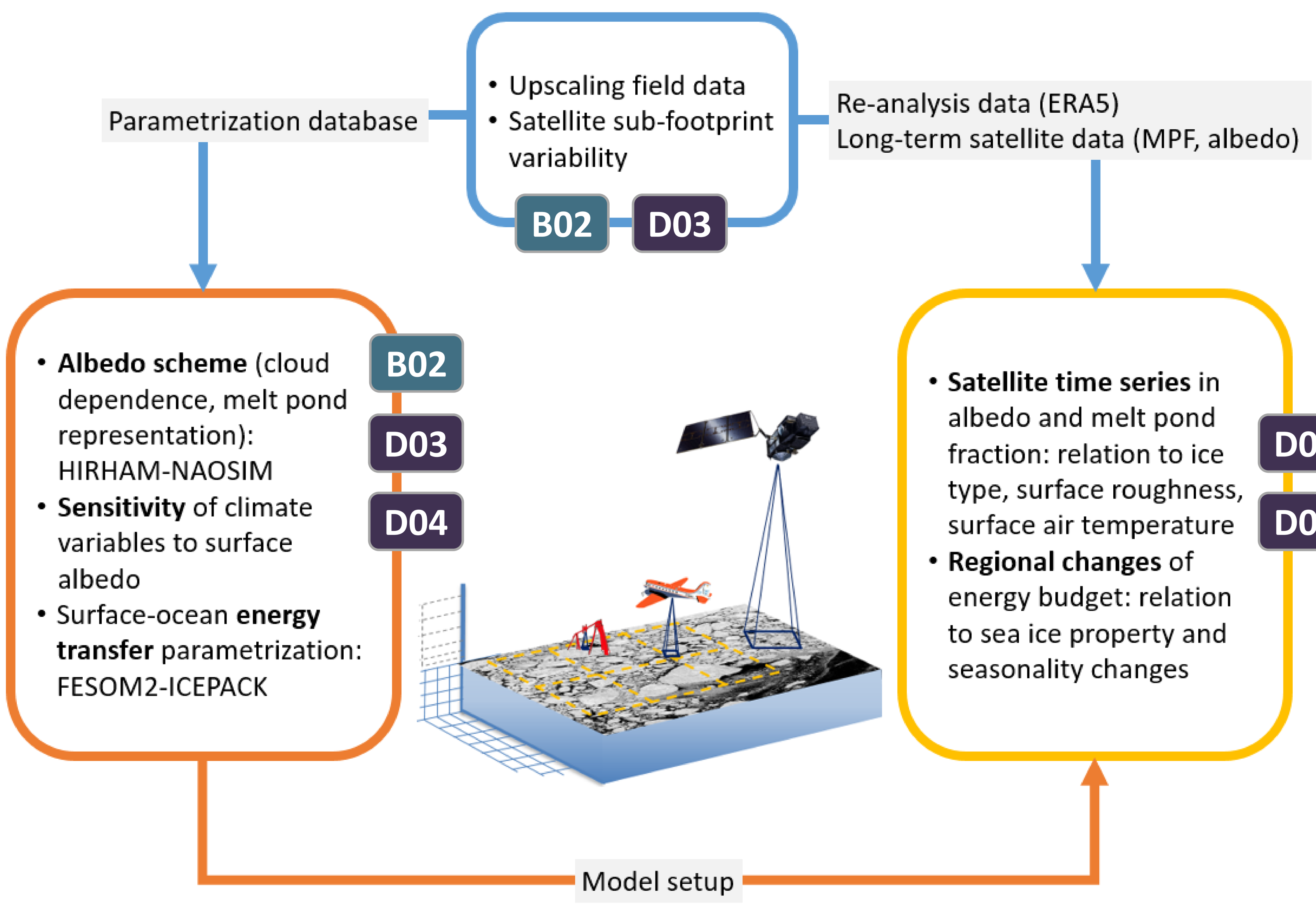


Fig. 4: Sentinel-2 melt pond fraction seasonal development (years 2017 – 2021).

Work packages and Collaborations

- WP1: Synergistic analysis of field data over different spatial scales ➜ Q1
- WP2: Model representation ➜ Q1, Q2
- WP3: Long-term changes and Arctic amplification ➜ Q3



4. Legacy & Major expected results

Project Legacy

- Year-round observations of radiative fluxes for different sea ice and snow conditions
- Long-term albedo and melt pond fraction satellite records
- Set of new parametrizations for implementation into climate models

Major expected results within phase III

- Parameterizing in-situ observation of sea ice albedo and transmittance
- Improving representation of modeled radiative transfer between sea-ice and ocean
- Determine the uncertainties and sensitivities of model simulation to radiative fluxes and sea ice properties
- Arctic-wide estimates of energy fluxes over the last decades
- Conclusions on trends in surface albedo and melt pond fraction and their relationship to Arctic amplification

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