Sea-Ice Reflectivity Modelling and Estimation: GNSS Reflectometry Results from Expeditions to the Arctic

M. Semmling (1), J. Wickert (2,3), M. Hoque (1),
D. Divine (4), S. Gerland (4), G. Spreen (5)

(1) German Aerospace Center DLR-SO, Neustrelitz, Germany
(2) German Research Centre for Geosciences GFZ, Potsdam, Germany
(3) Technische Universität Berlin, Germany
(4) Norwegian Polar Institute NPI, Tromsø, Norway
(5) University of Bremen, Germany

GFZ Helmholtz Centre Potsdam

Universität Bremen

Photo: Sea Ice in Fram Strait, August 2016

Outline

- Motivation & Concept
- Reflectivity & Permittivity Results
- Reflectivity Anomalies
- Summary & Outlook

Motivation & Concept

Motivation: Monitoring Earth System using GNSS Reflectometry

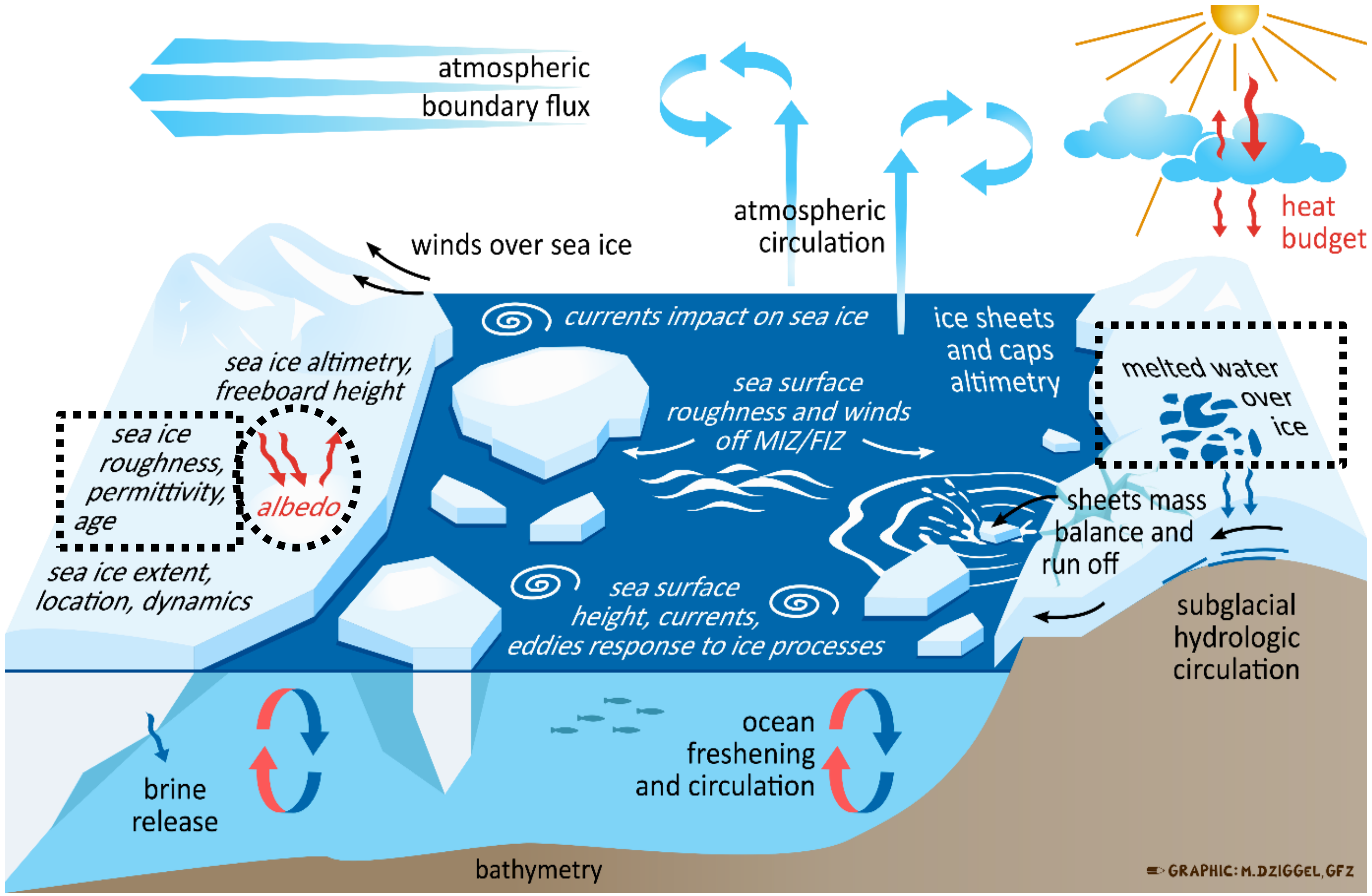
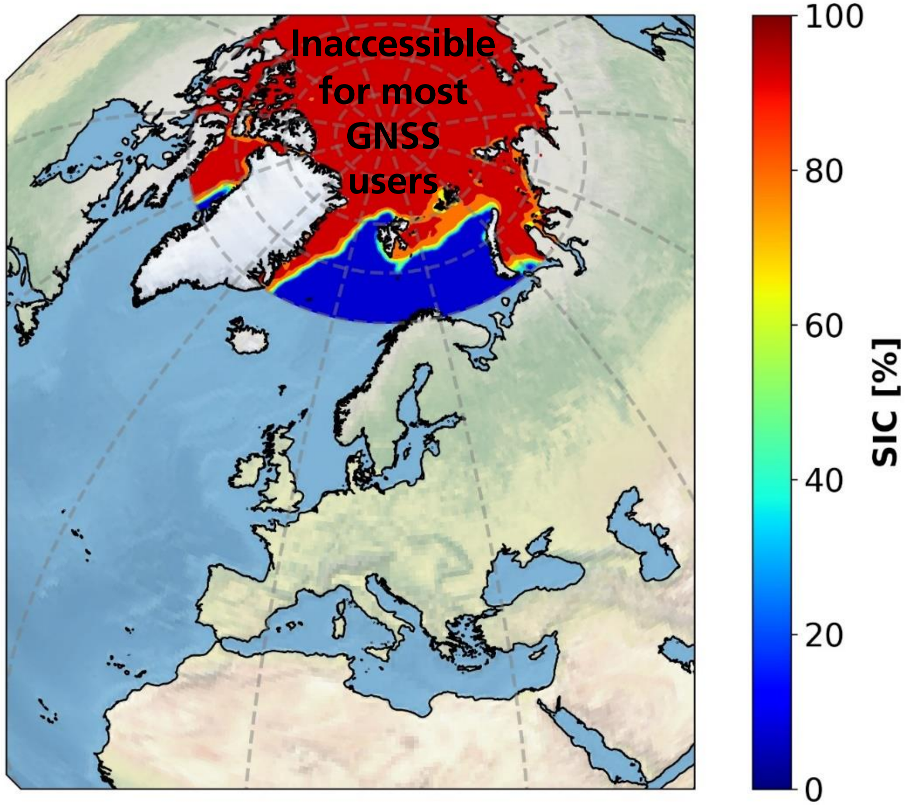


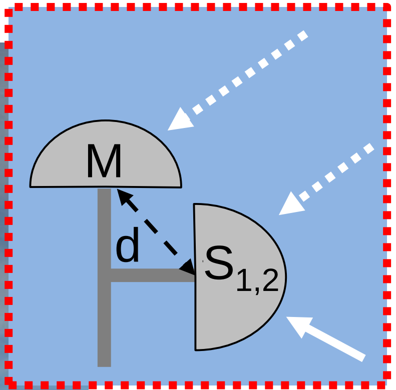
Figure: Cardellach et al. 2018



Arctic Sea Ice Concentration,
Jan 1st 2020

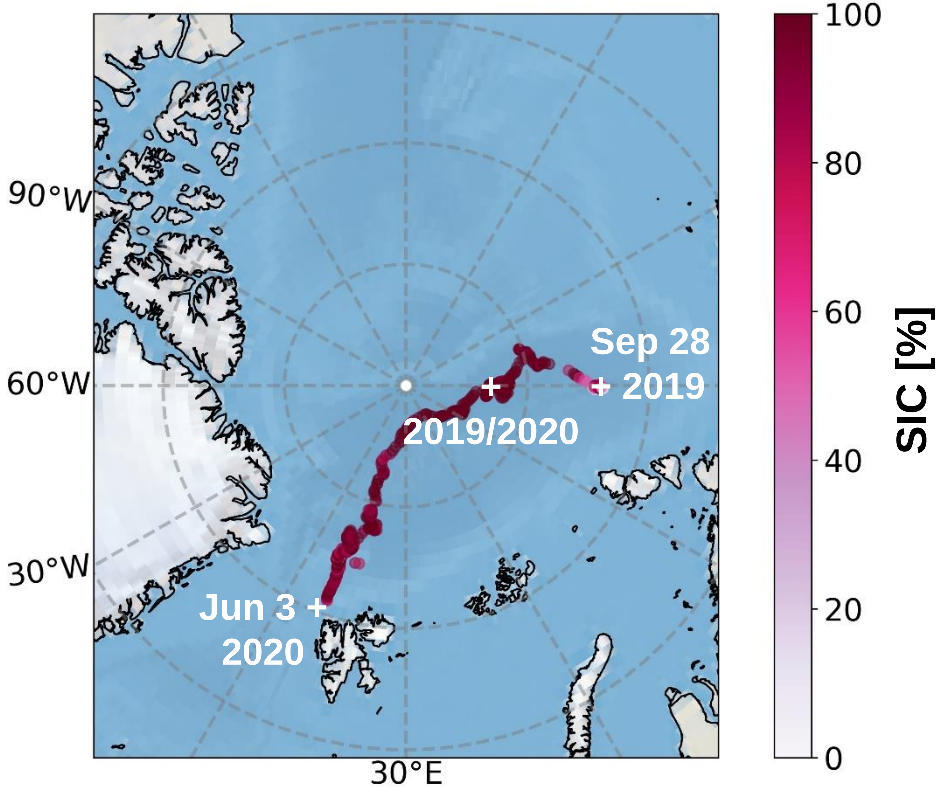
Setup & Measurements

* GFZ GNSS-R setup * DLR GNSS-R setup



h = 22 m
d = 20 cm

MOSAiC first drift: Sep 2019 - Jun 2020



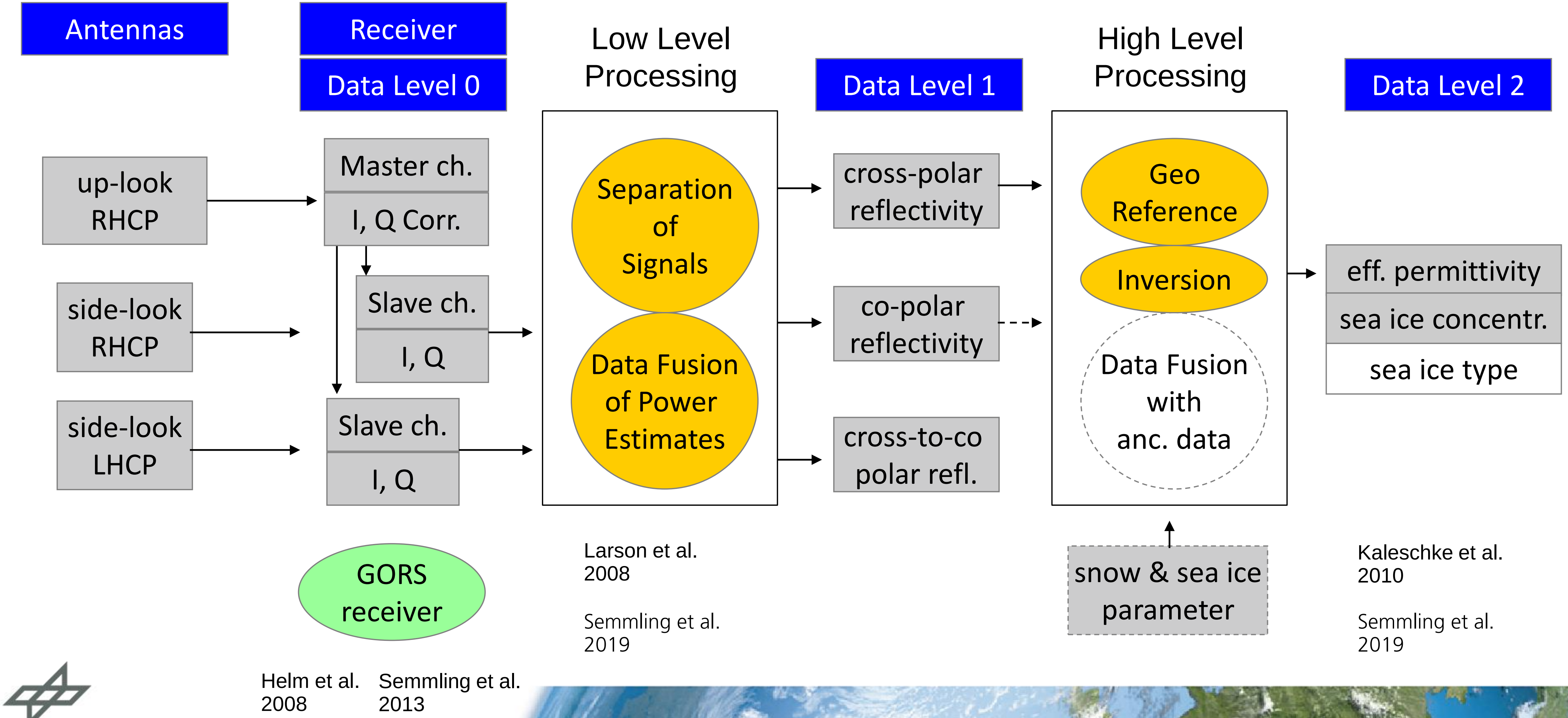
Marginal Ice Zone (MIZ): late Sep 2019, SIC increase
Compact Ice Zone (CIZ): Dec 2019, permanent high SIC

Setup cf.: Helm et al. 2007; Semmling et al. 2013

Master link (M): up-looking ant. RHCP
Slave links ($S_{1,2}$): side-looking ant. LHCP, RHCP

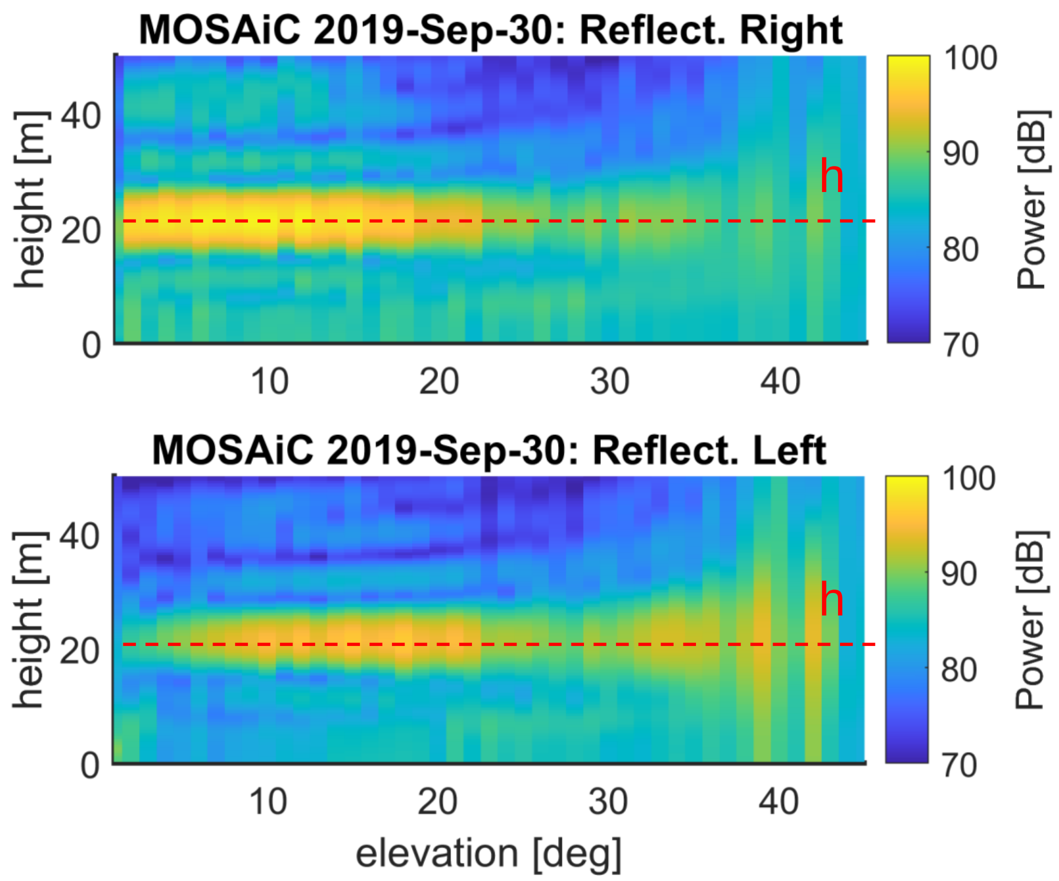
Semmling et al. 2021, 2022

Processing Concept for Permittivity Inversion

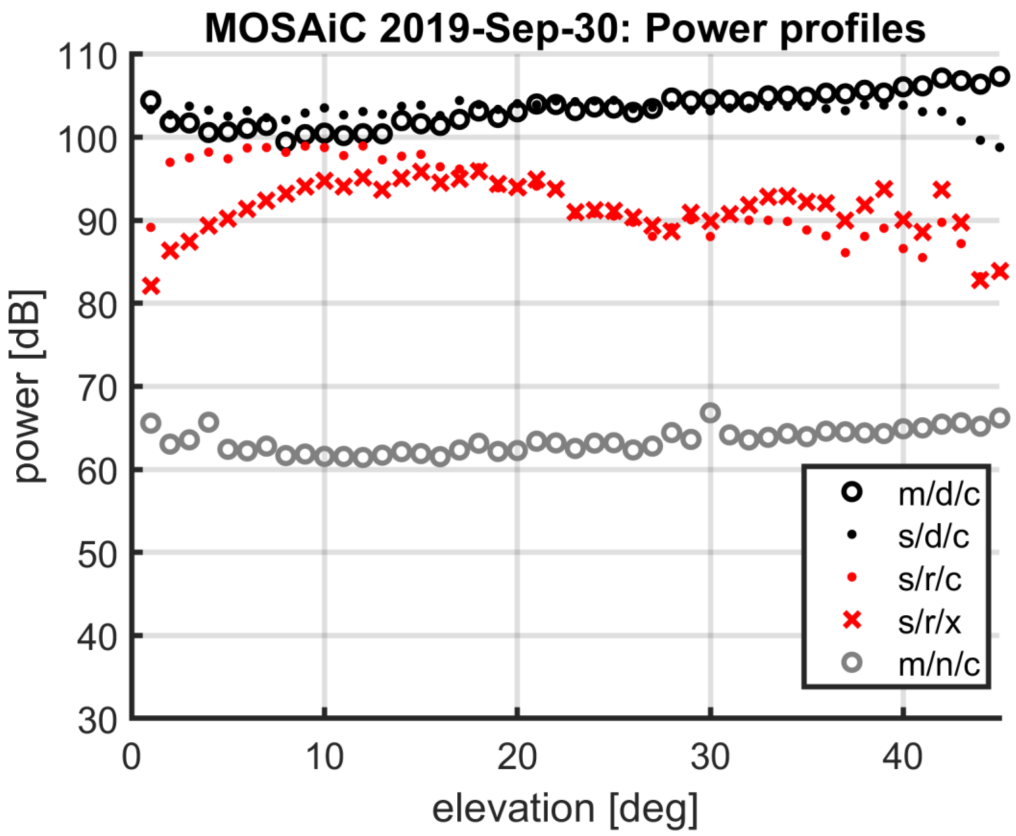


Reflectivity & Permittivity Results

Low Level Processing



Peraza et al. 2017 Semmling et al. 2019

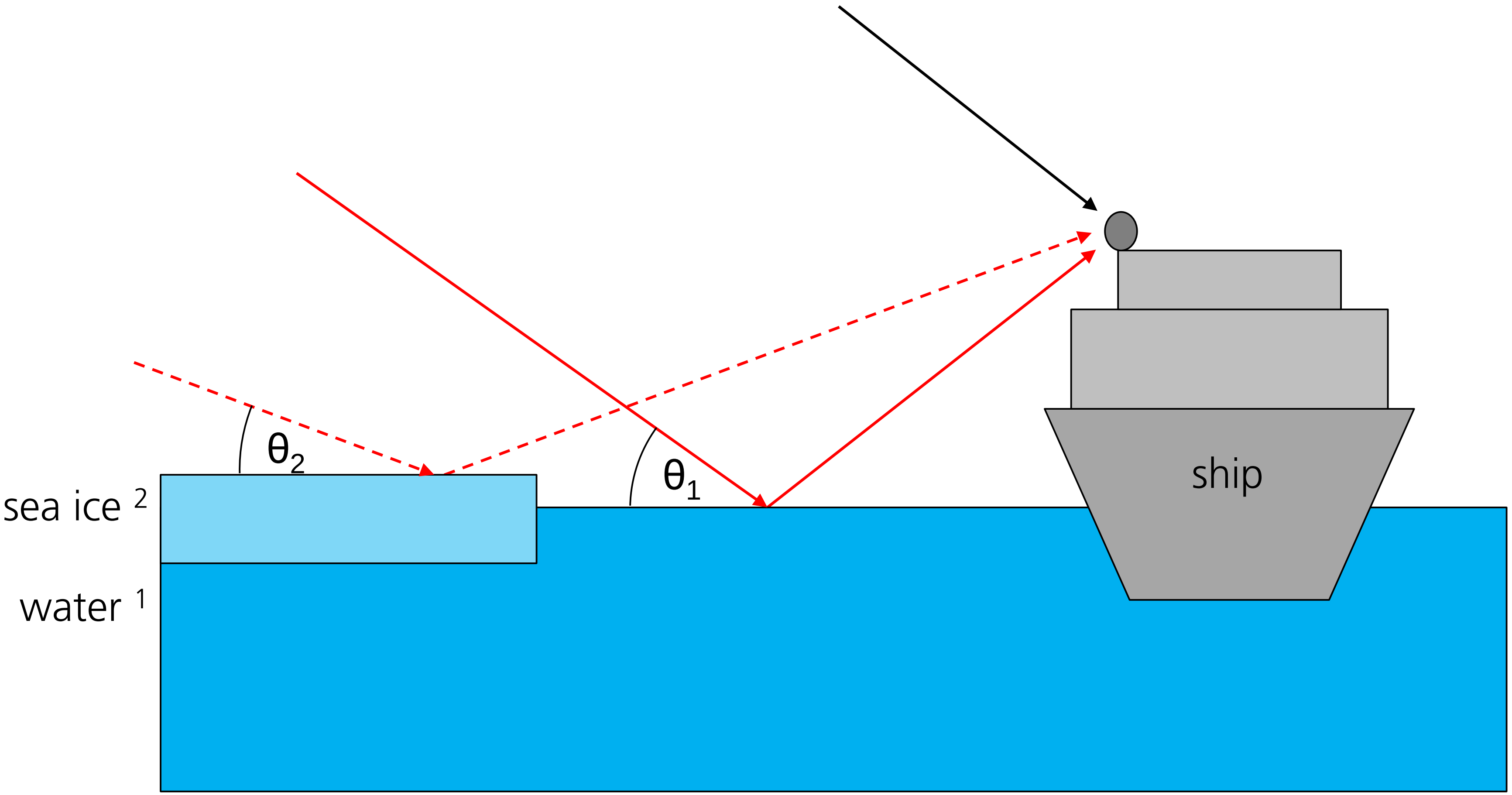


Fusion of Power Estimates

- ➢ cross-pol. reflectivity
- ➢ co-pol. reflectivity

Semmling et al. 2022

Coherent Reflection Model



rel. permittivity: $\varepsilon_1 = 76.4 + i\,48.5$; $\varepsilon_2 = 3.31 + i\,0.11$

reflectivity: $P_r(\varepsilon)/P_d$ ⇨ SIC ⇨ ice type

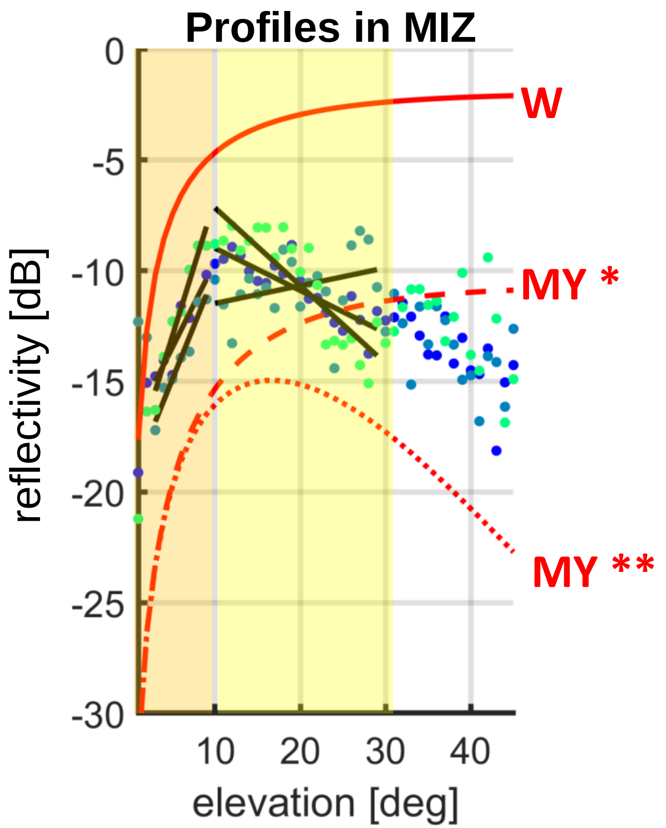
Can we estimate sea ice permittivity for ice type characterization?

Bulk-medium reflection

- signal penetration neglected
- applies for high-loss media, especially water

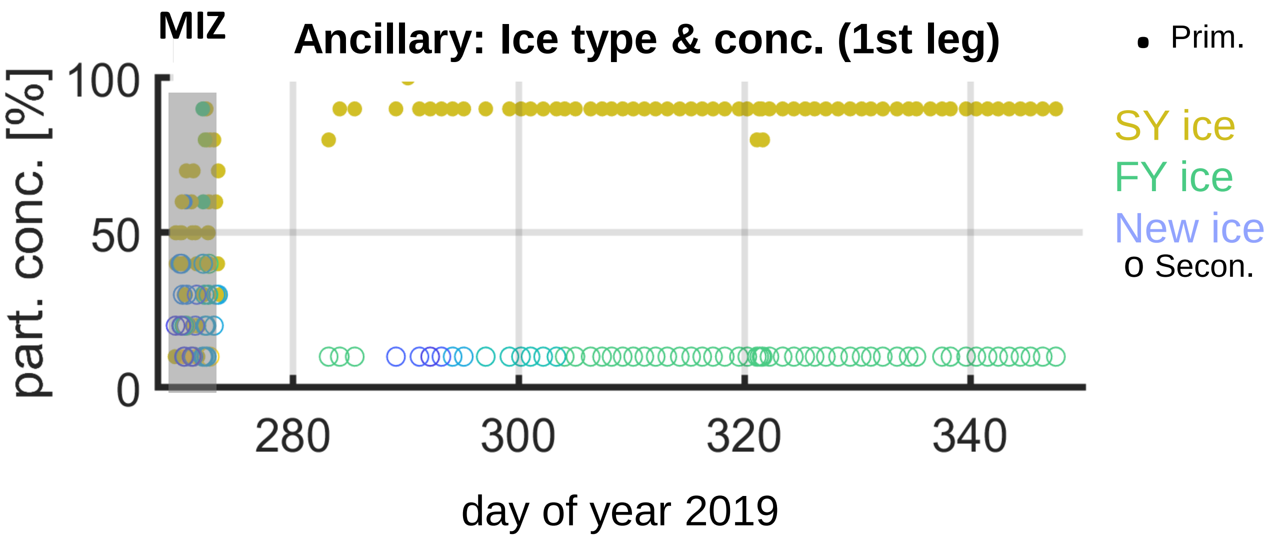
Semmling et al. 2019

Reflectivity Profiles



*** smooth; ** rough**

- daily-averaged obs. (day color-coded)



Low-Elevation Range (1° to 10°)

- reflect. between MY and W
- steep slope of bulk model
- no roughness effect

Mid-Elevation Range (10° to 30°)

- reflect. above MY
- moderate slope (decrease)
- small roughness effect

⇩

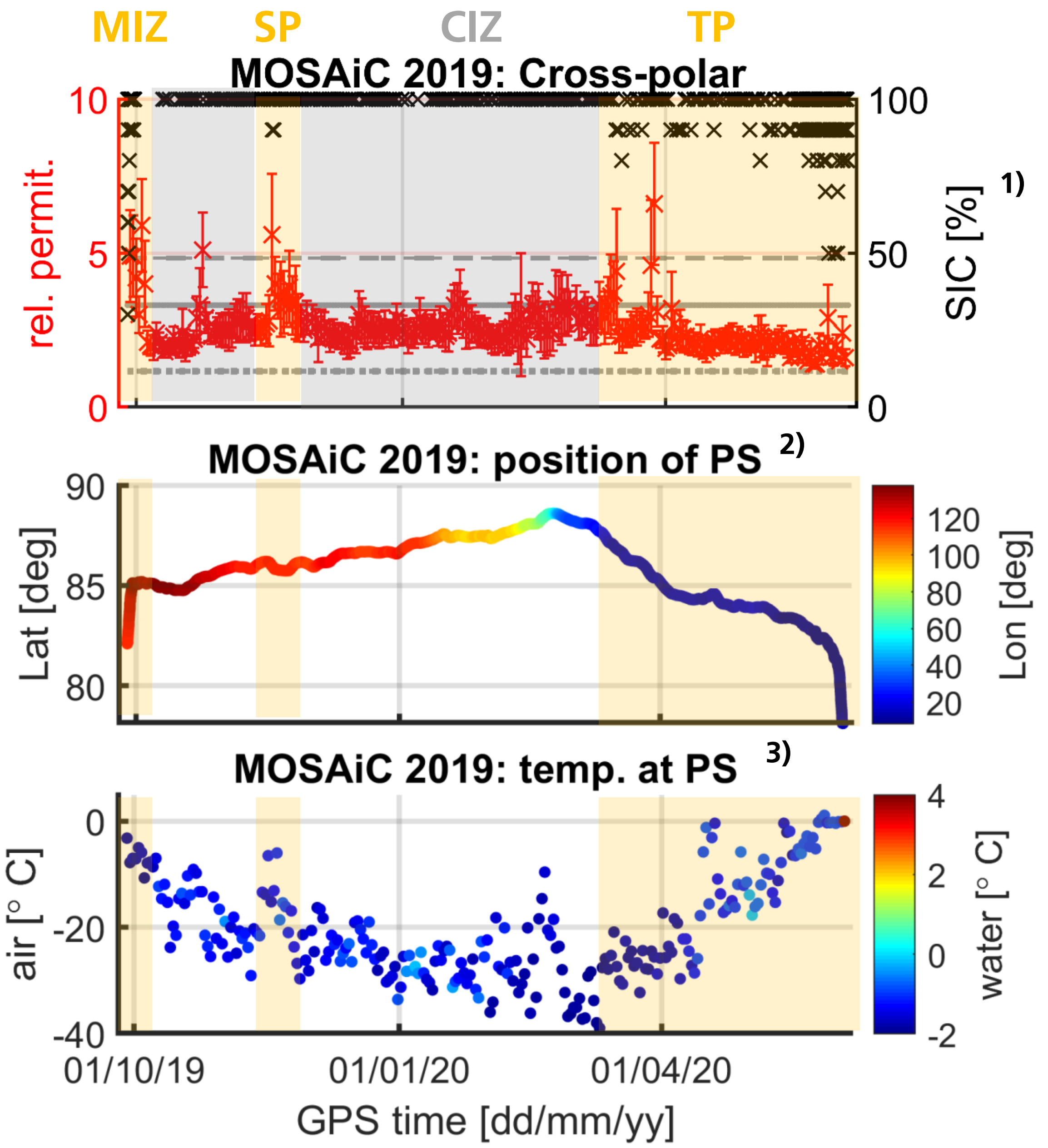
permittivity inversion

Semmling et al. 2022

Inverted Permittivity – First drift

Features & Anomalies

- **Marginal Ice Zone** (**MIZ**)
  ship sailing, SIC < 100%,
  permit. peak > 5
- **Compact Ice Zone** (**CIZ**)
  ship drifting, SIC at 100%,
  permit. baseline < 3
- **Storm Period** (**SP**)
  ship drifting, ice breaking,
  permit. peak > 5
- **Compact Ice Zone** (**CIZ**)
  ship drifting, SIC at 100%,
  permit. baseline < 3
- **Transition Period** (**TP**)
  ship drifting, SIC decreasing,
  <u>however</u> baseline < 3

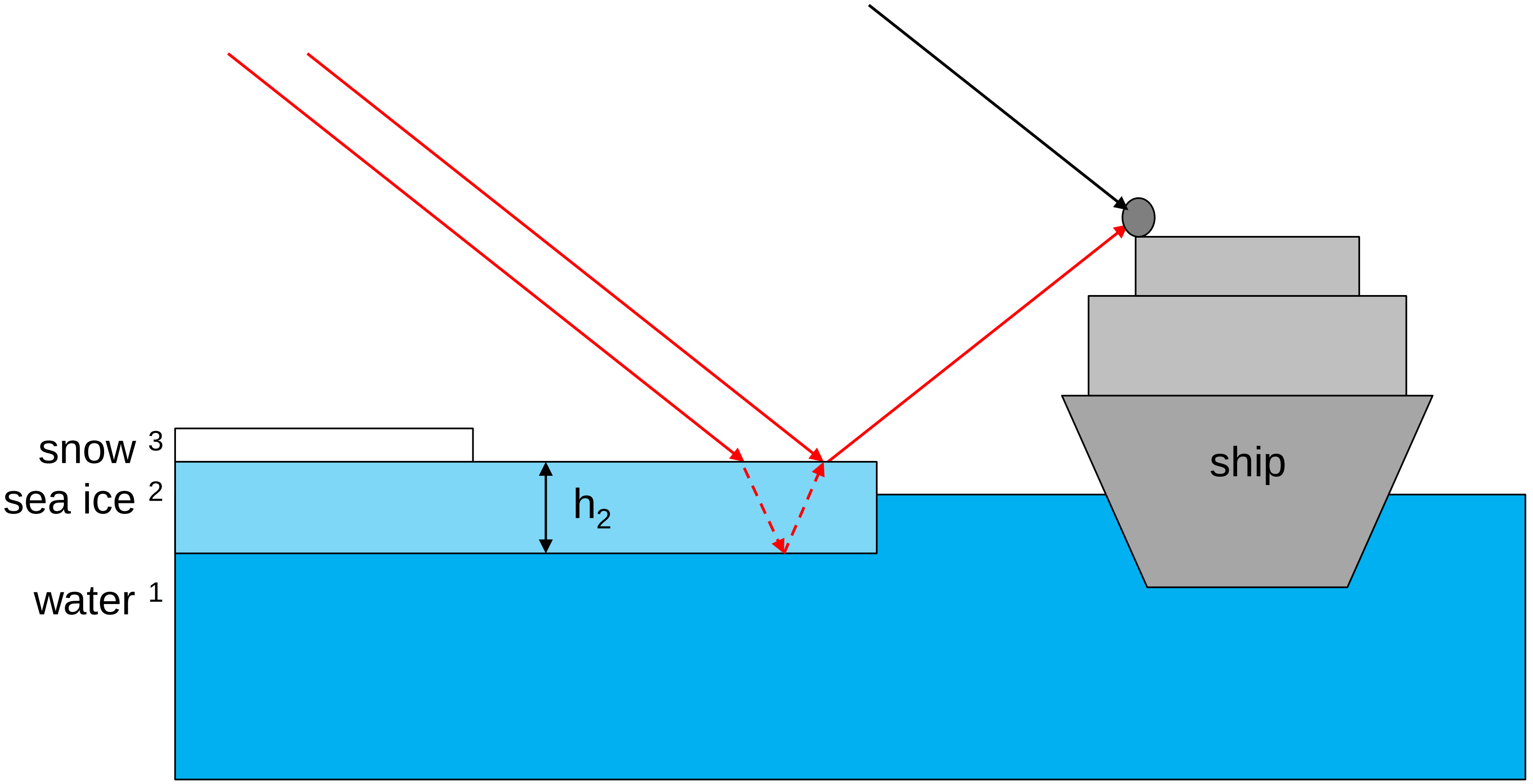


1) ASSIST protocol, in-situ data
2) GNSS based data, GFZ/DLR
3) DSHIP data base, AWI

DLR

Reflectivity Anomalies

Coherent Reflection and Penetration Model



rel. permittivity: ε_1 = 76.4 + i 48.5 ; ε_2 = 3.31 + i 0.11 ; ε_3 = 1.76 + i 0.00

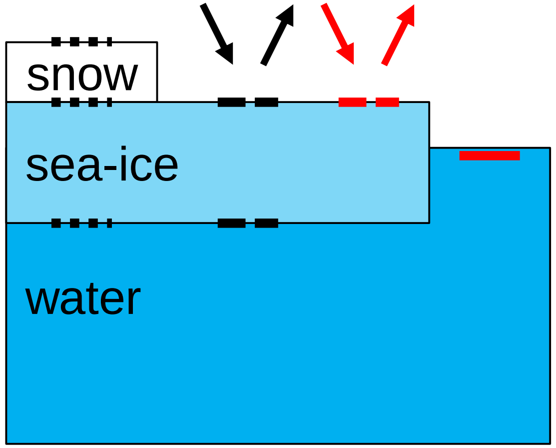
reflectivity:
$P_r(\varepsilon_1, \varepsilon_2, h_2)/P_d$ ⇨ ice type
⇨ thickness (h_2) *

Slab-medium reflection

- signal penetration considered
- applies for low-loss media e.g. sea-ice, snow

* Munoz-Martin et al. 2020

Some Simulations …



Bulk-medium reflection

Slab-medium reflection

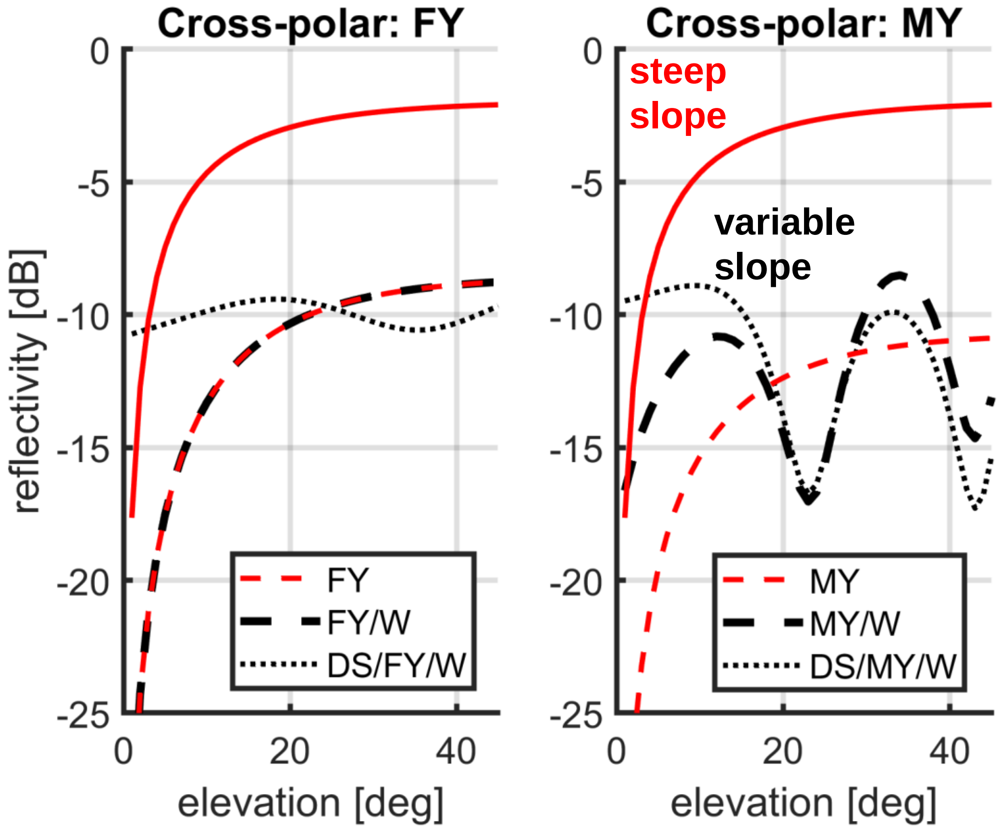
Kaleschke et al. 2010

Dry Snow (DS) cover:
ε = 1.76 + i 0.00
20cm thick
„transparent“

Multiyear (MY) ice type:
ε = 3.31 + i 0.11
at -1°C, 1m thick
„transparent“

First-year (FY) ice type:
ε = 4.75 + i 0.91
at -1°C, 1m thick
„opaque“

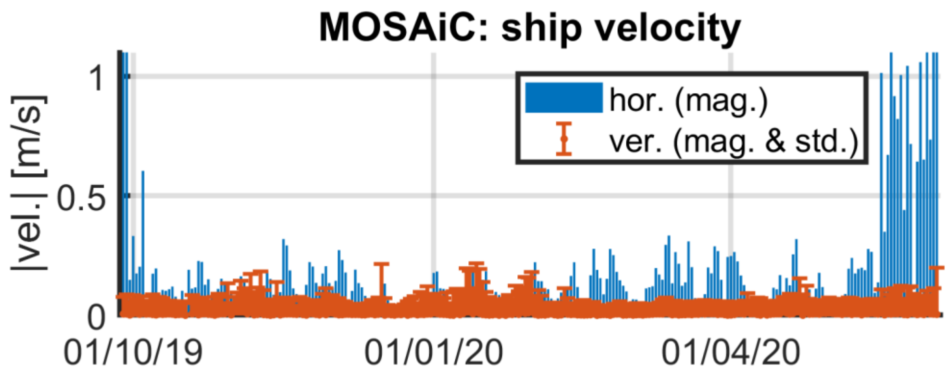
Water (W)
ε = 76.4 + i 48.5
at 2°C
„opaque“

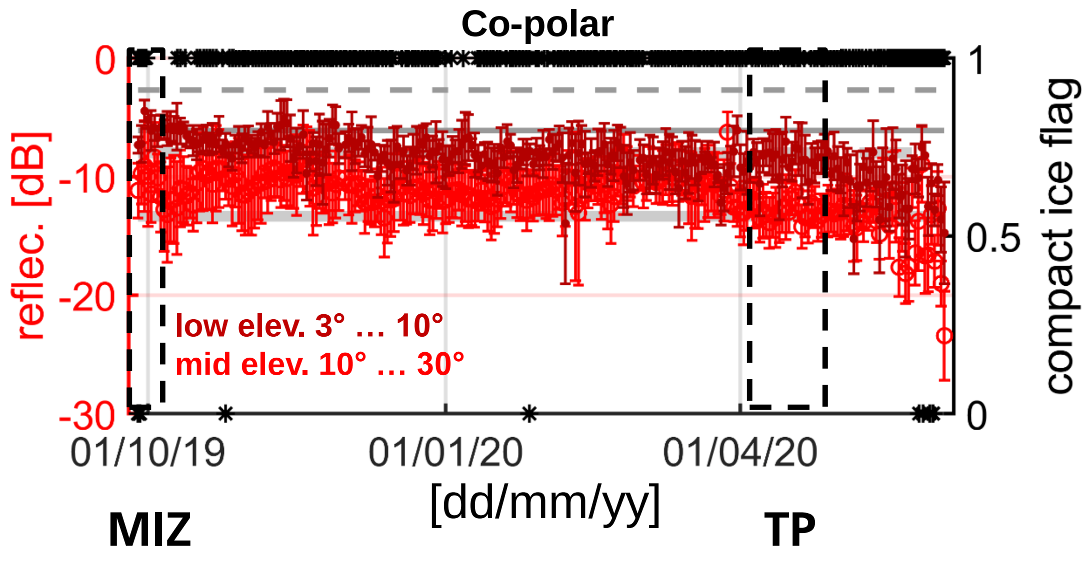


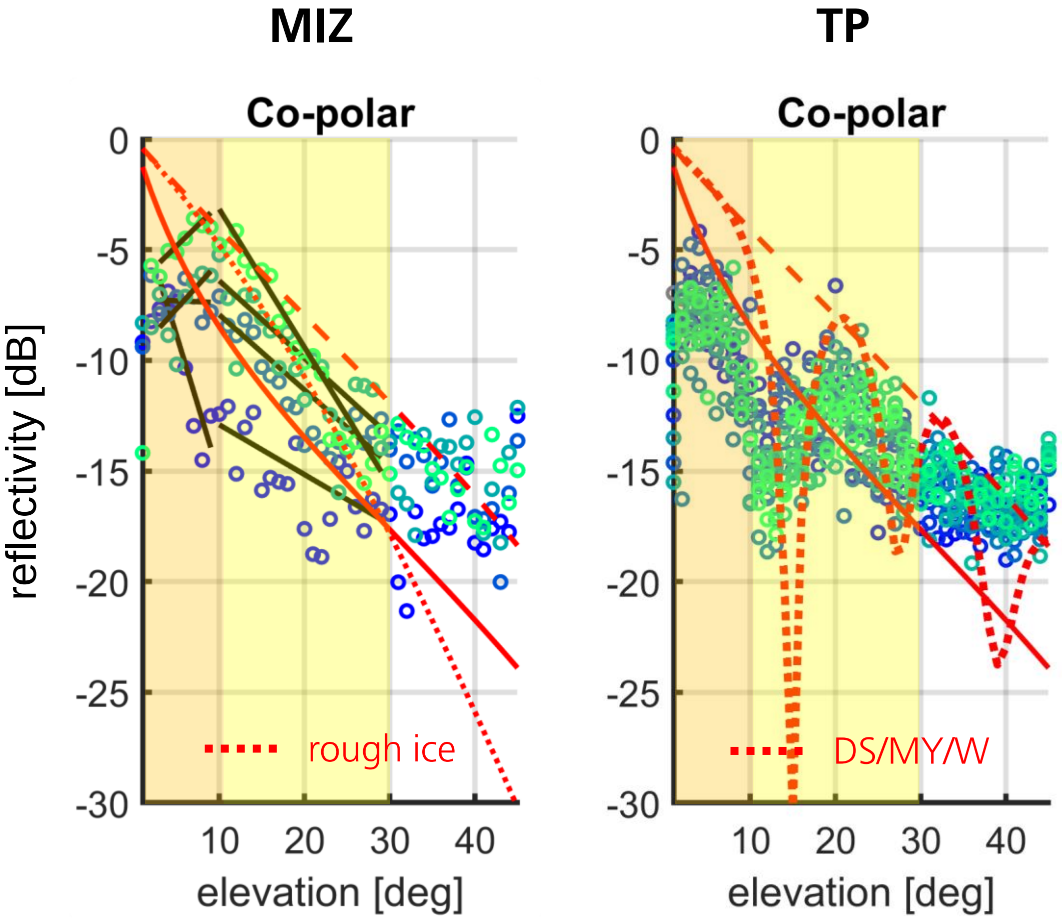
Coherent superposition of **slab reflection** result in **reflectivity fringes** (if top media are transparent).

Semmling et al. 2022

Co-Polar Anomalies

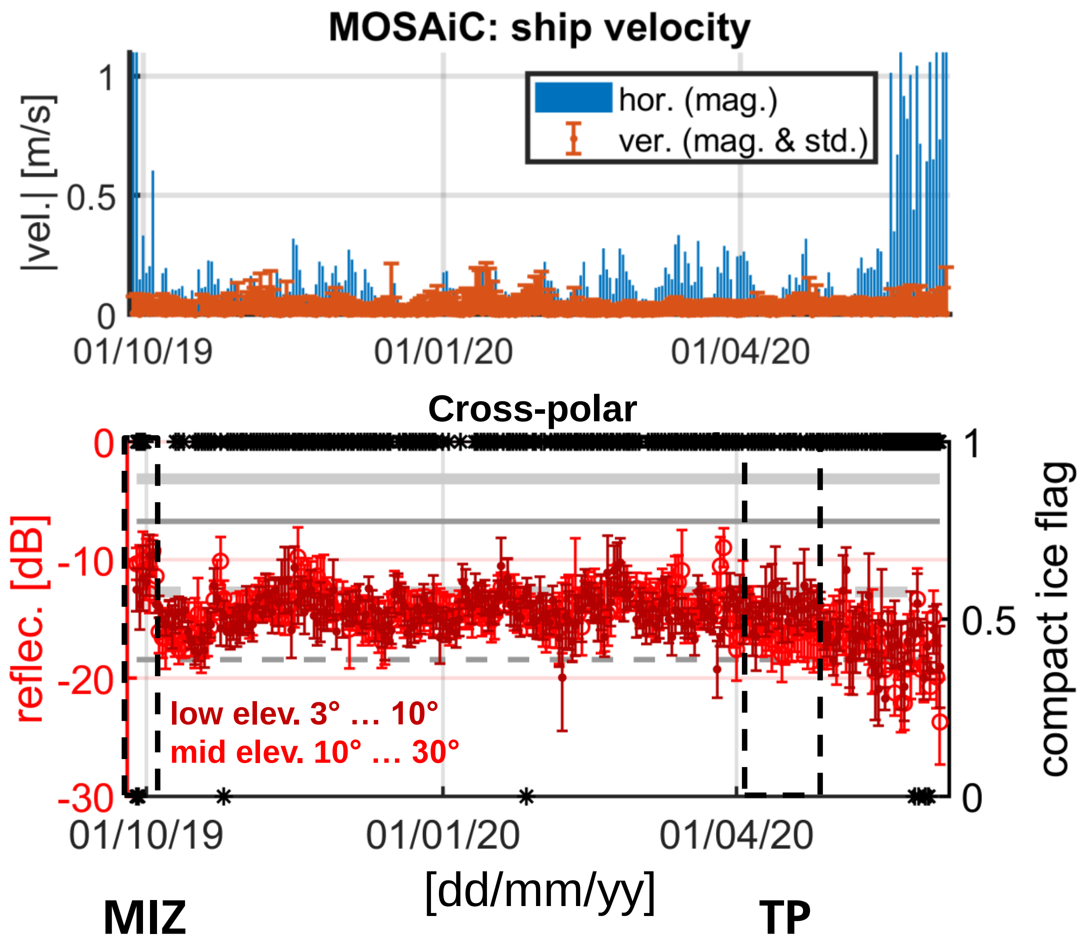


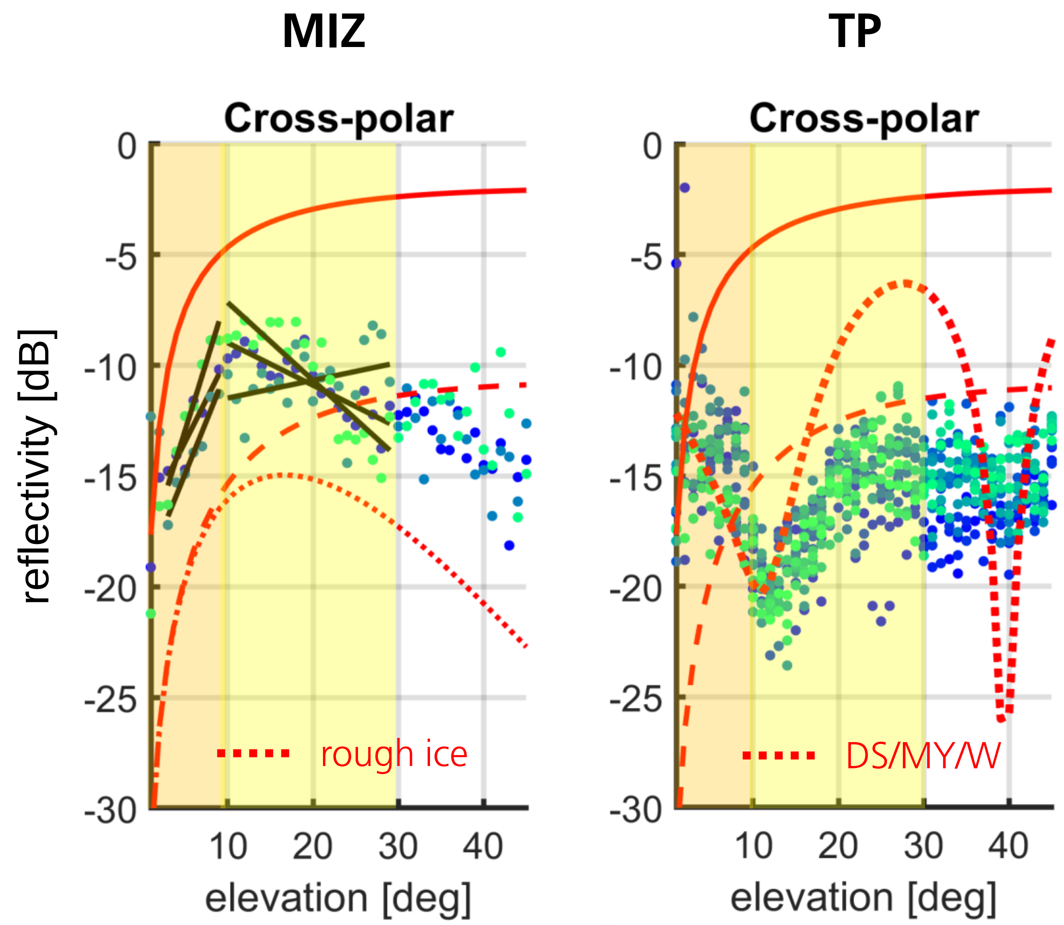




Narrow fading in TP due to snow/ice penetration
(small drop of reflectivity at mid elevation)

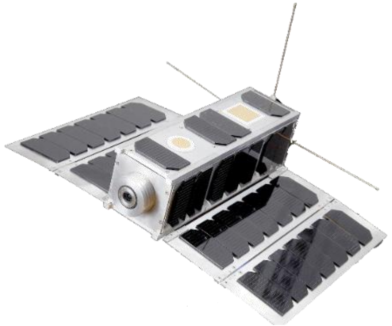
Cross-Polar Anomalies





Broad Fading in TP due to snow/ice penetration
(ratio of mid/low reflectivity changes)

Summary & Outlook



Motivation

- opportunity of GNSS obs. in the Central Arctic with MOSAiC
- derive reflectivity and exploit for ice type characterization

Permittivity Inversion and Reflectivity Anomalies

- one-year data set of direct and reflected signal power (co-, cross-polar data)
- rel. permit. estimated and related to sea ice concentration (cross-polar data)
- anomalies in transition period (April 2020) found
- fading indicates penetration of ice and snow

Outlook

- phase scintillation study using GNSS data from central Arctic (MOSAiC)
- phase altimetric study using GNSS reflectometry data from space (PRETTY mission)

DLR

Thank you for your attention.

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Data used here were produced as part of MOSAiC project.

Photo: Sea Ice in Fram Strait, August 2016

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