Arctic Sea-Ice Permittivity Derived from GNSS Reflectometry Data of the MOSAiC Expedition

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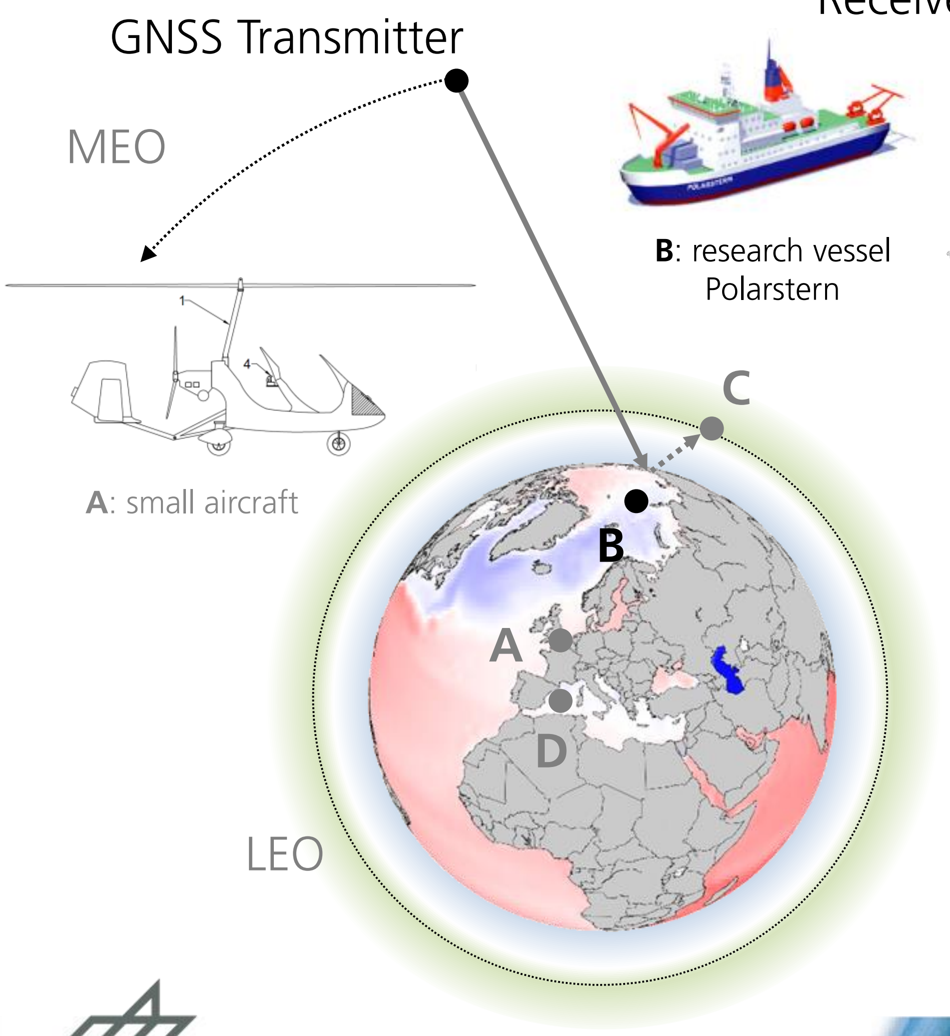
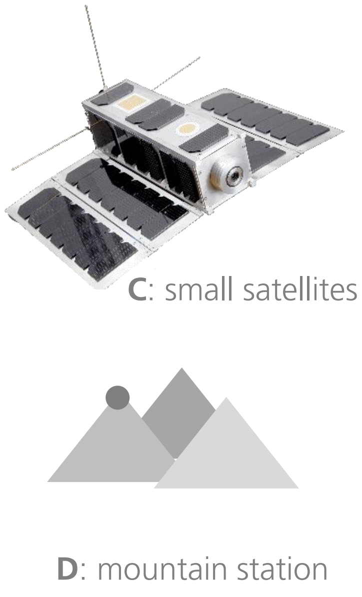
Photo: Sea Ice in Fram Strait, August 2016

Motivation for Reflectometry

Receiver platforms





A: small aircraft,	h ~ 700 m
B: research vessel,	h ~ 20 m
C: small satellite,	h ~ 650 km
D: mountain station,	h ~ 1430 m

Photo Polarstern: Peter Lemke, AWI

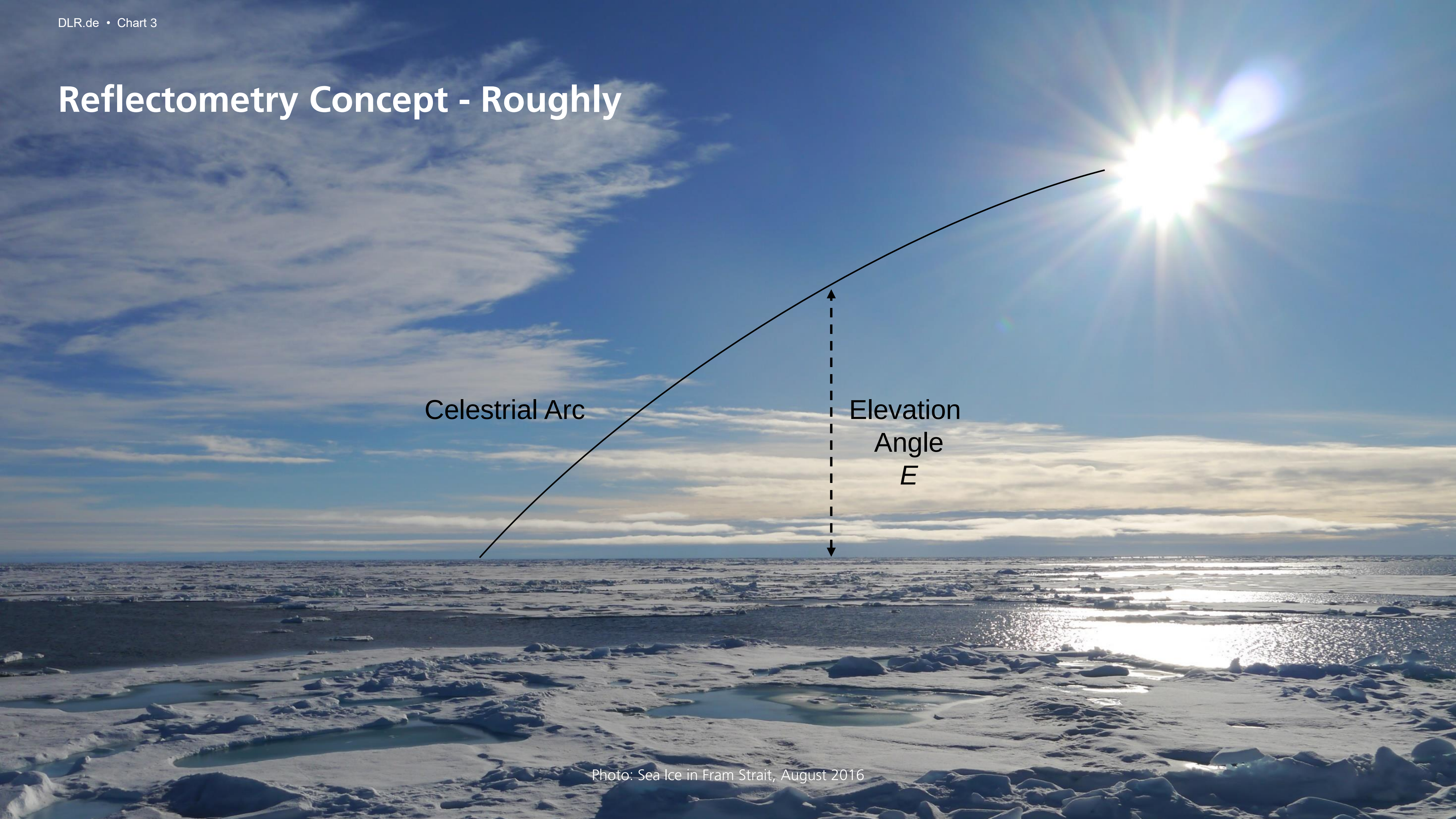
* GFZ GNSS-R setup

Belmonte Rivas et al. 2010

Alonso-Arroyo et al. 2017

Semmling et al. 2019

Reflectometry Concept - Roughly



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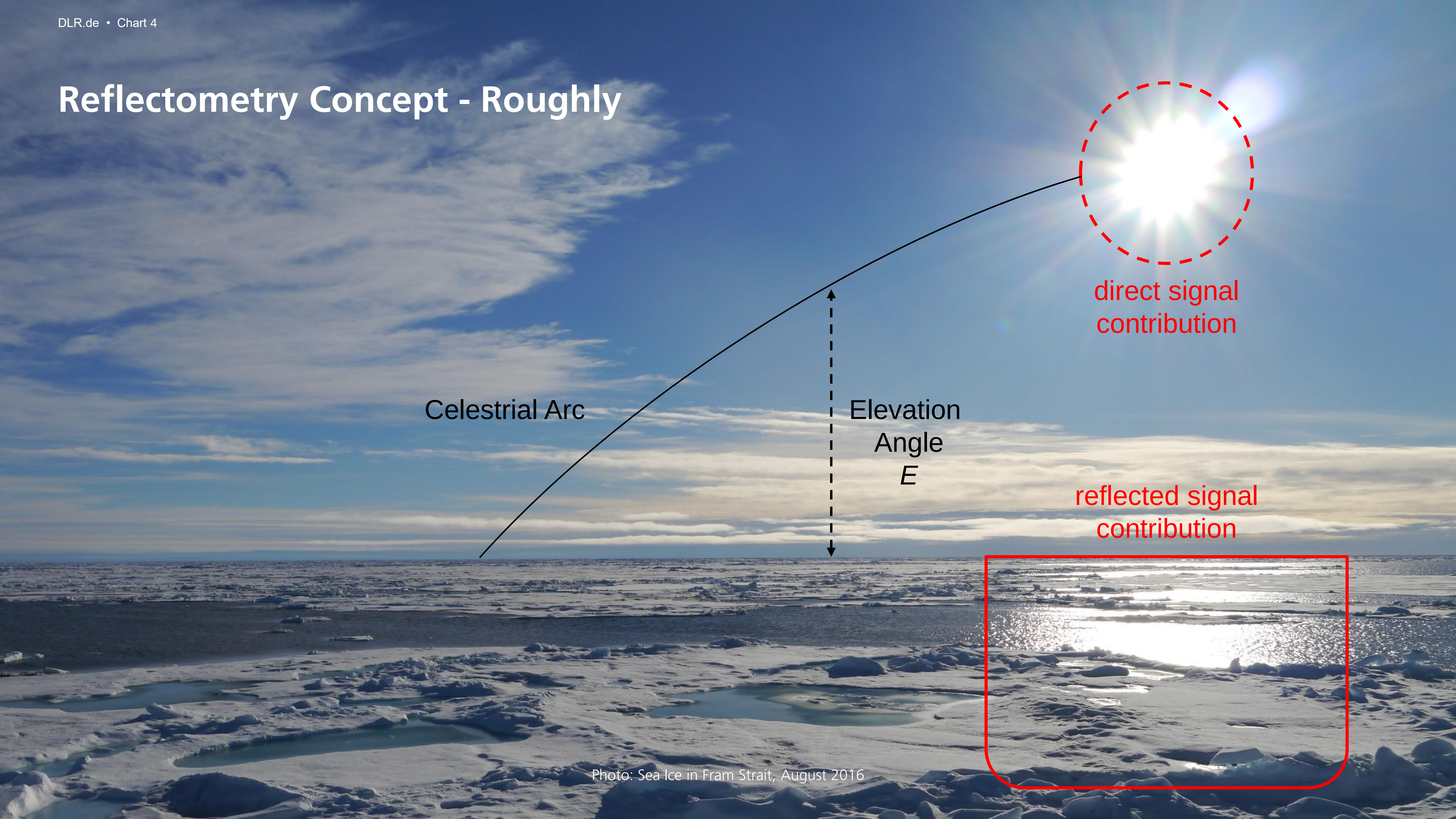
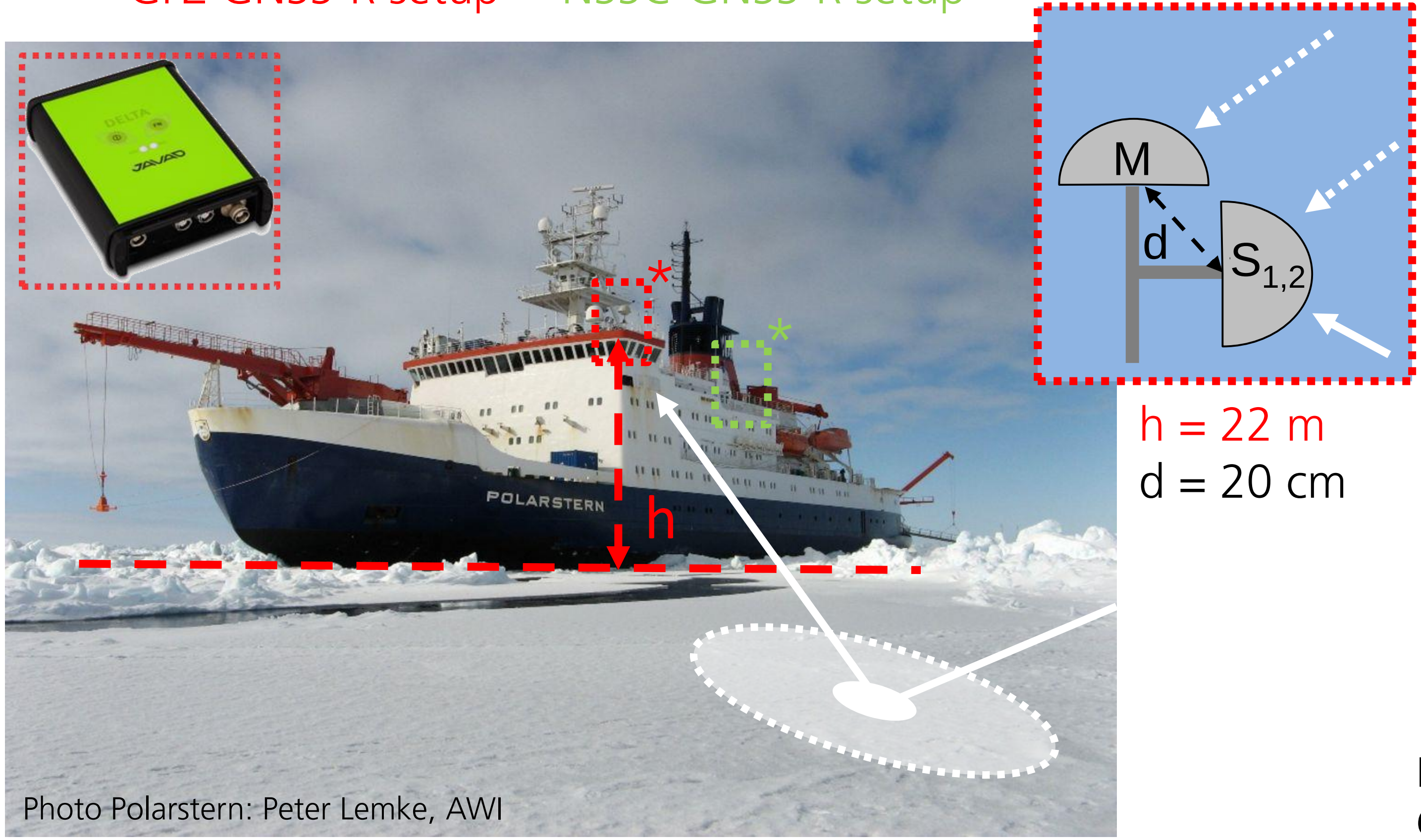
Reflectometry Concept - Roughly



Setup & Measurements

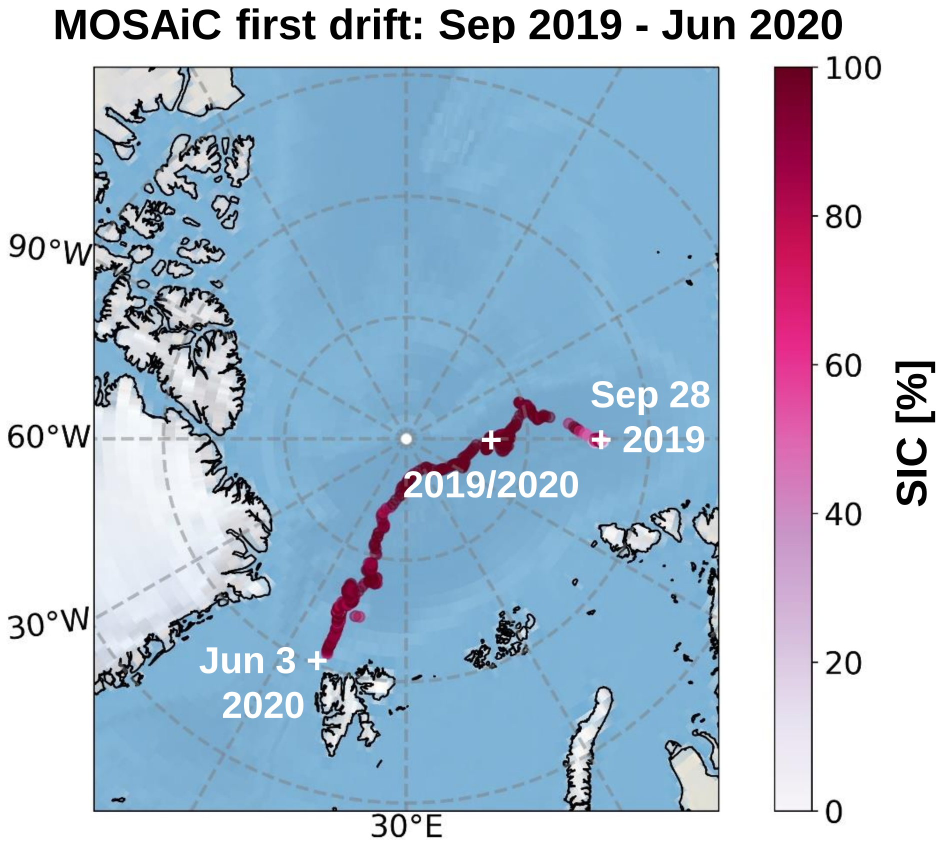
* GFZ GNSS-R setup * NSSC GNSS-R setup



h = 22 m
d = 20 cm

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

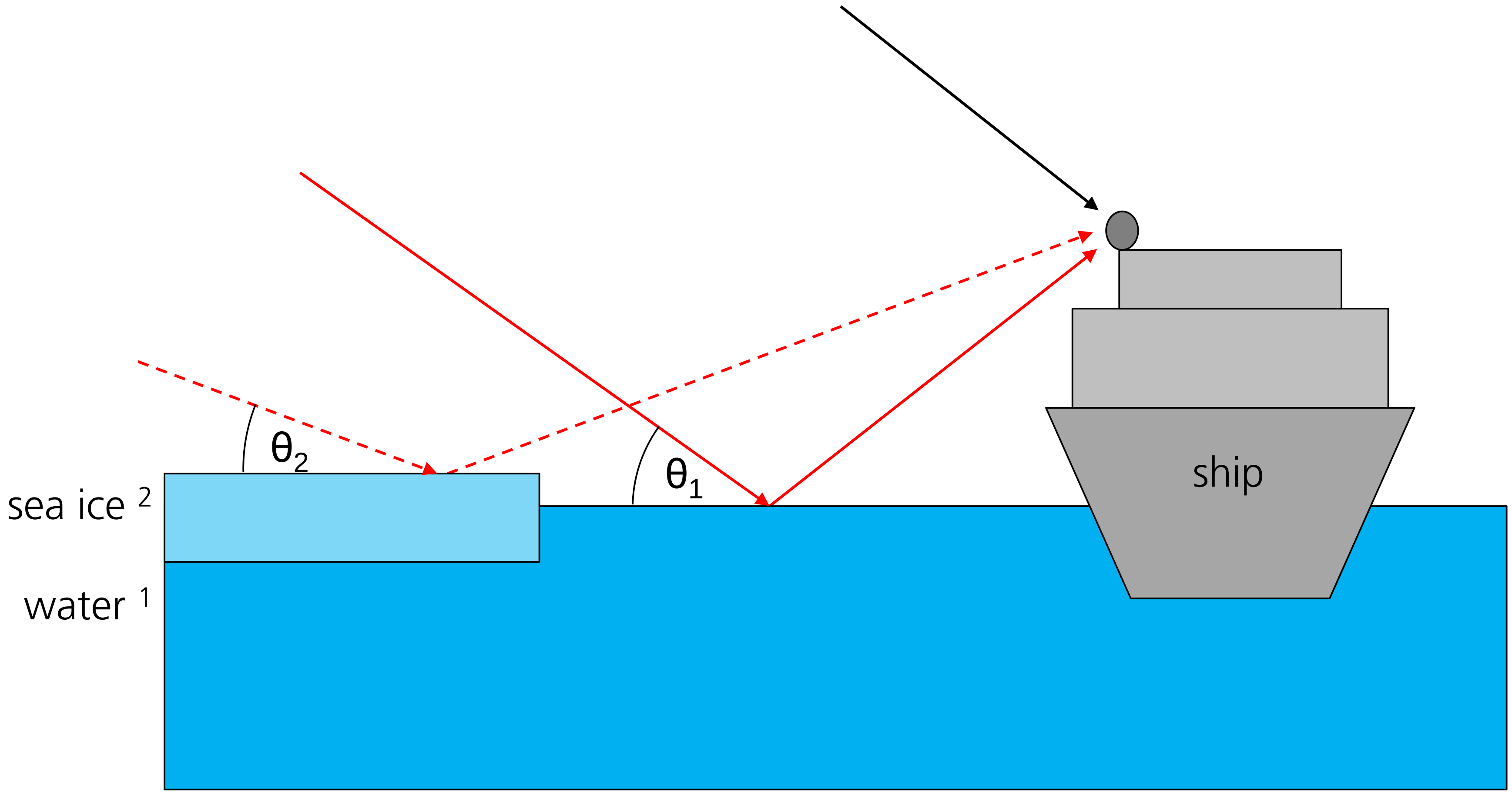
Master link (M): up-looking ant. RHCP
Slave links ($S_{1,2}$): side-looking ant. LHCP, RHCP



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

Semmling et al. 2021, 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

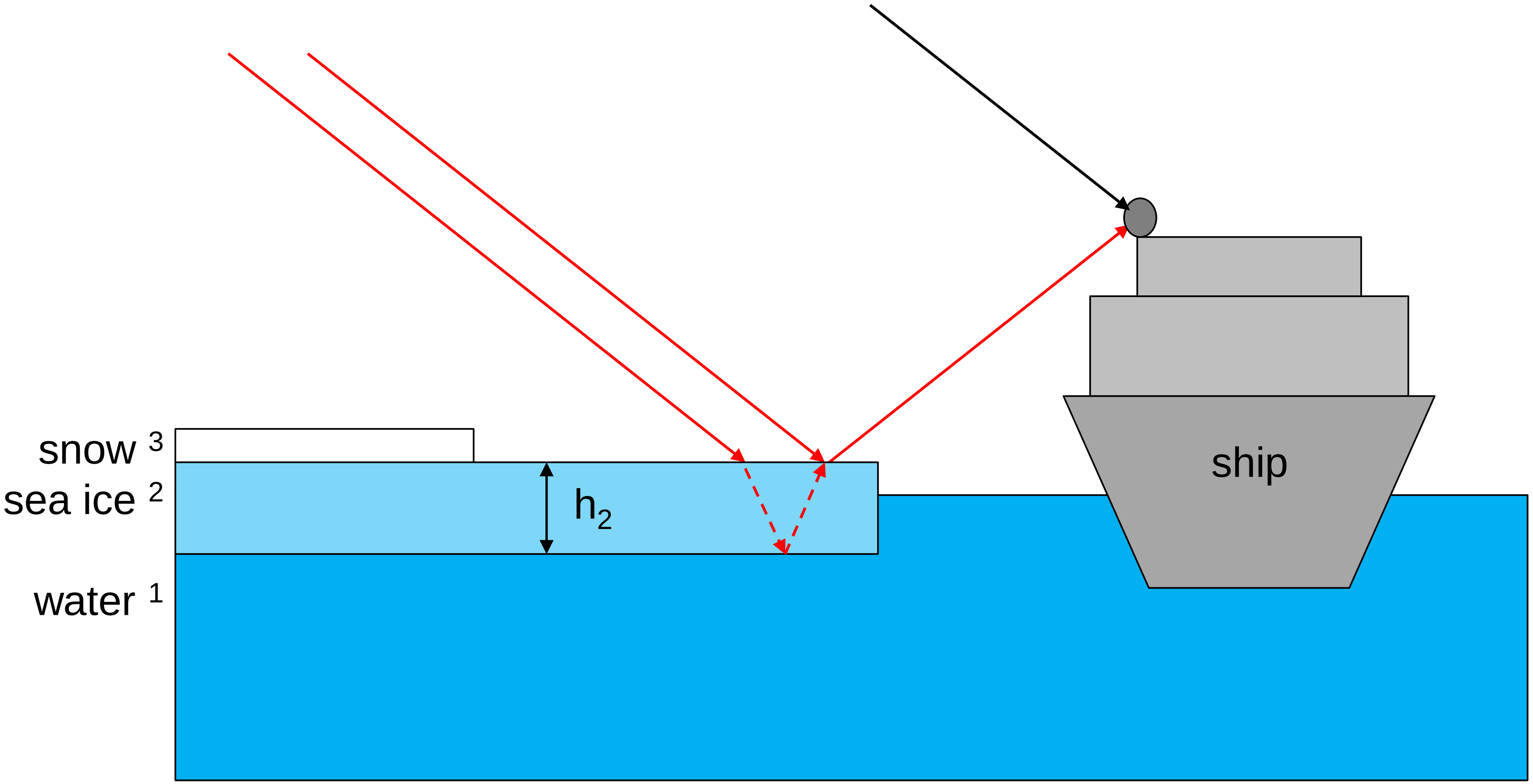
Can we estimate sea ice permittivity for ice type characterization?

Bulk-medium reflection

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

Semmling et al. 2019

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

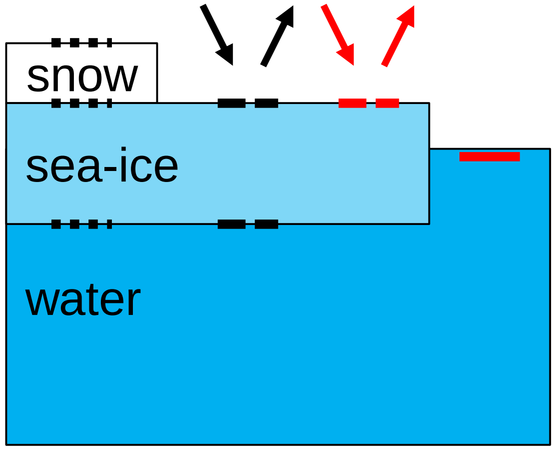
reflectivity:
$P_r(\varepsilon_1, \varepsilon_2, h_2)/P_d$ ⇨ ice type
⇨ thickness (h_2) *

Slab-medium reflection

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

* Munoz-Martin et al. 2020

Reflection Model Comparison



Bulk-medium reflection

Slab-medium reflection

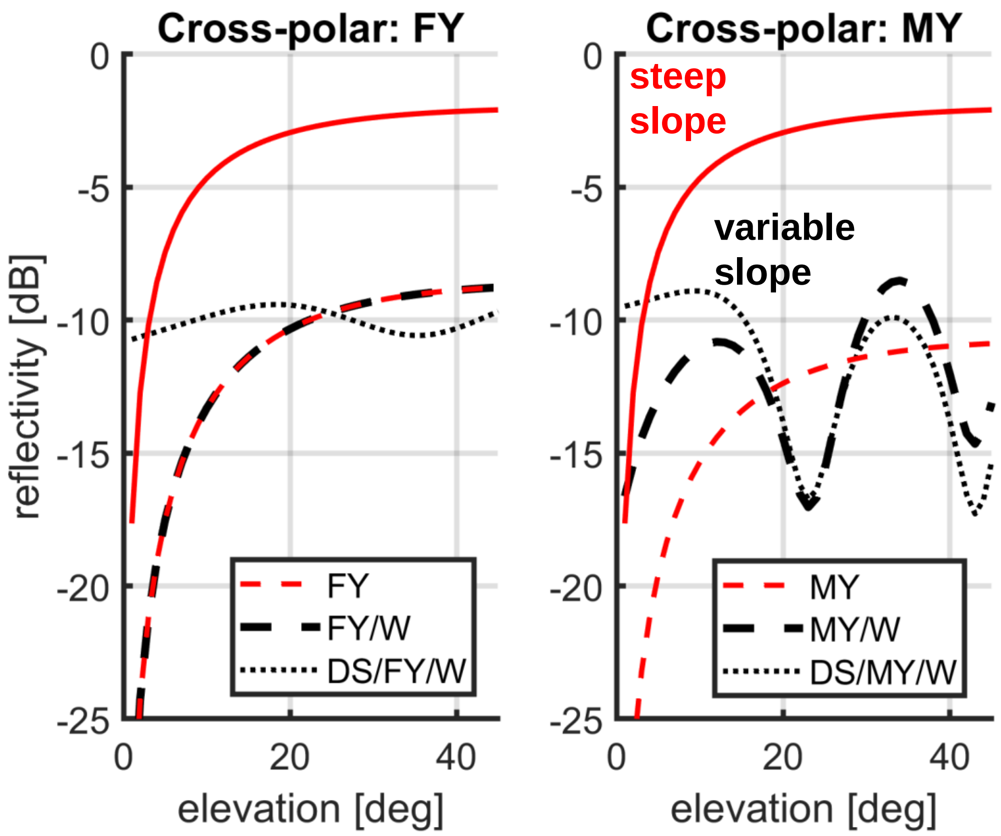
Kaleschke et al. 2010

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“

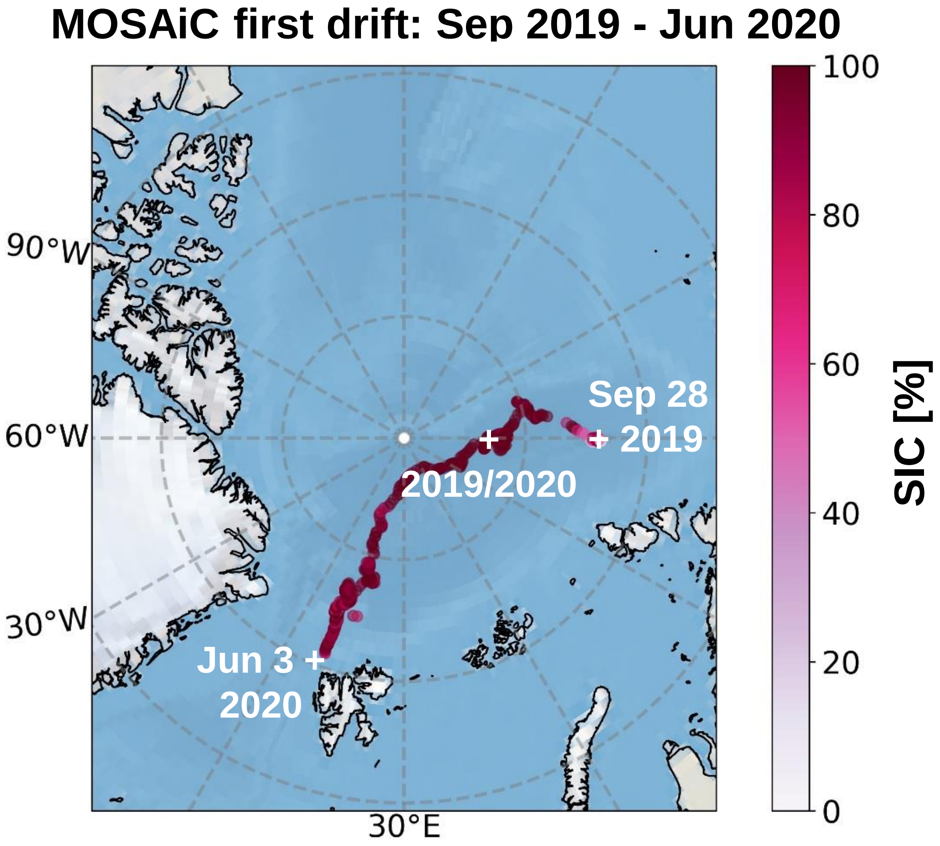
Water (W)
ε = 76.4 + i 48.5
at 2°C
„opaque“



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

Semmling et al. 2021

Reflectivity Maps & Profiles



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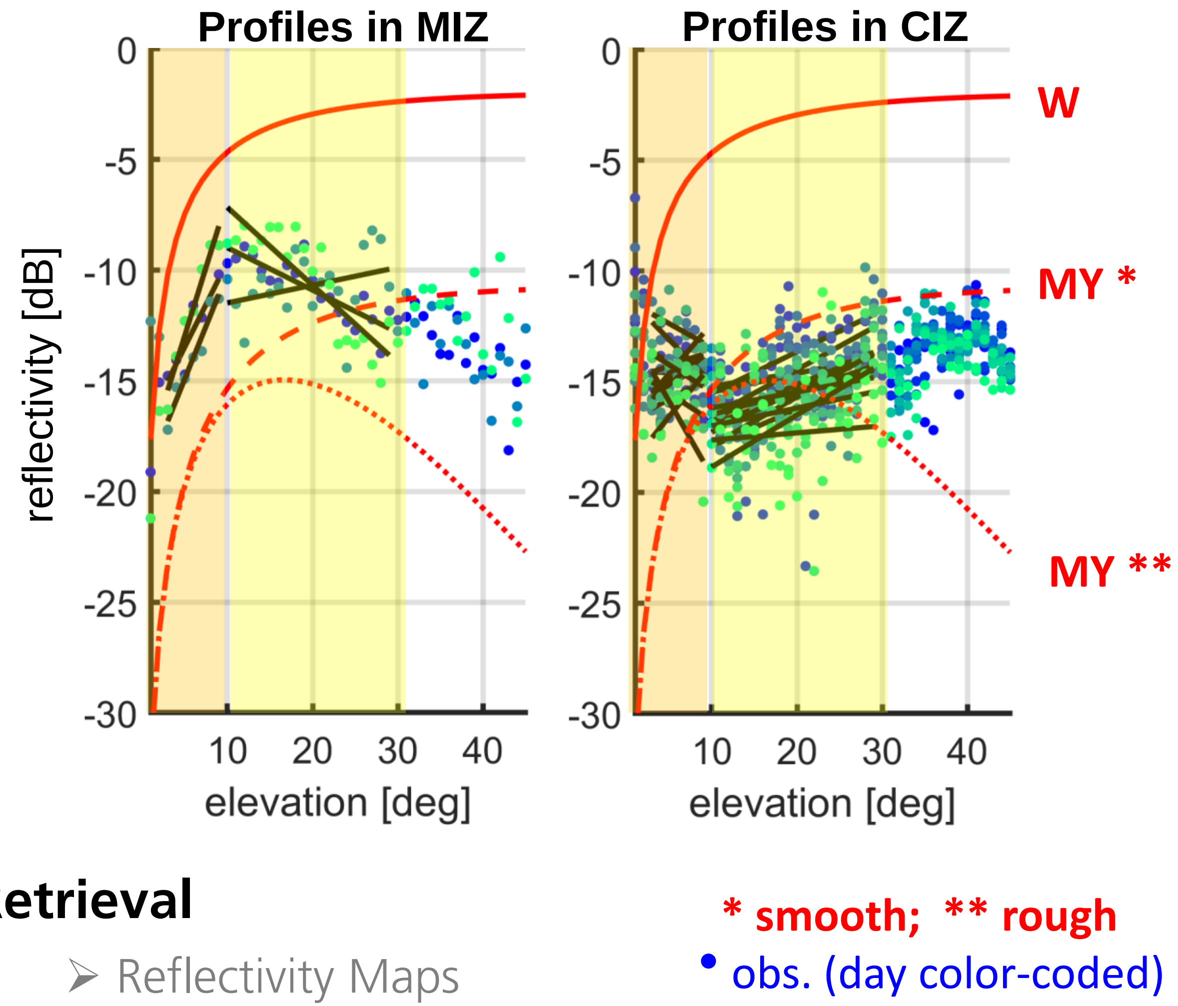
Compact Ice Zone (CIZ): Dec 2019, permanent high SIC



Retrieval

- ➢ Reflectivity Maps
- ➢ Reflectivity Profiles
- ➢ Inverted Permittivity

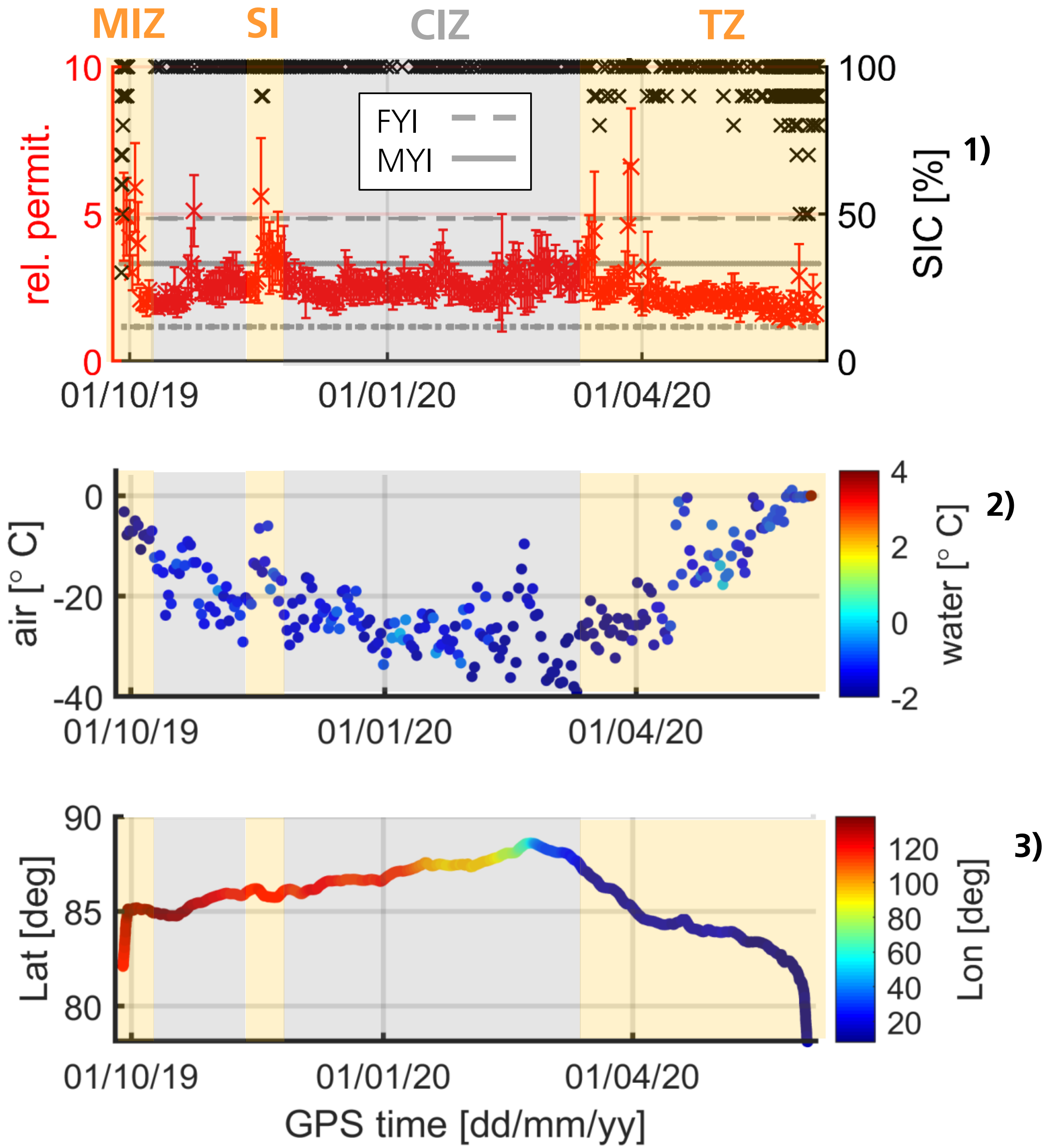
Semmling et al. 2022

Munoz-Martin et al. 2020

Inverted Permittivity

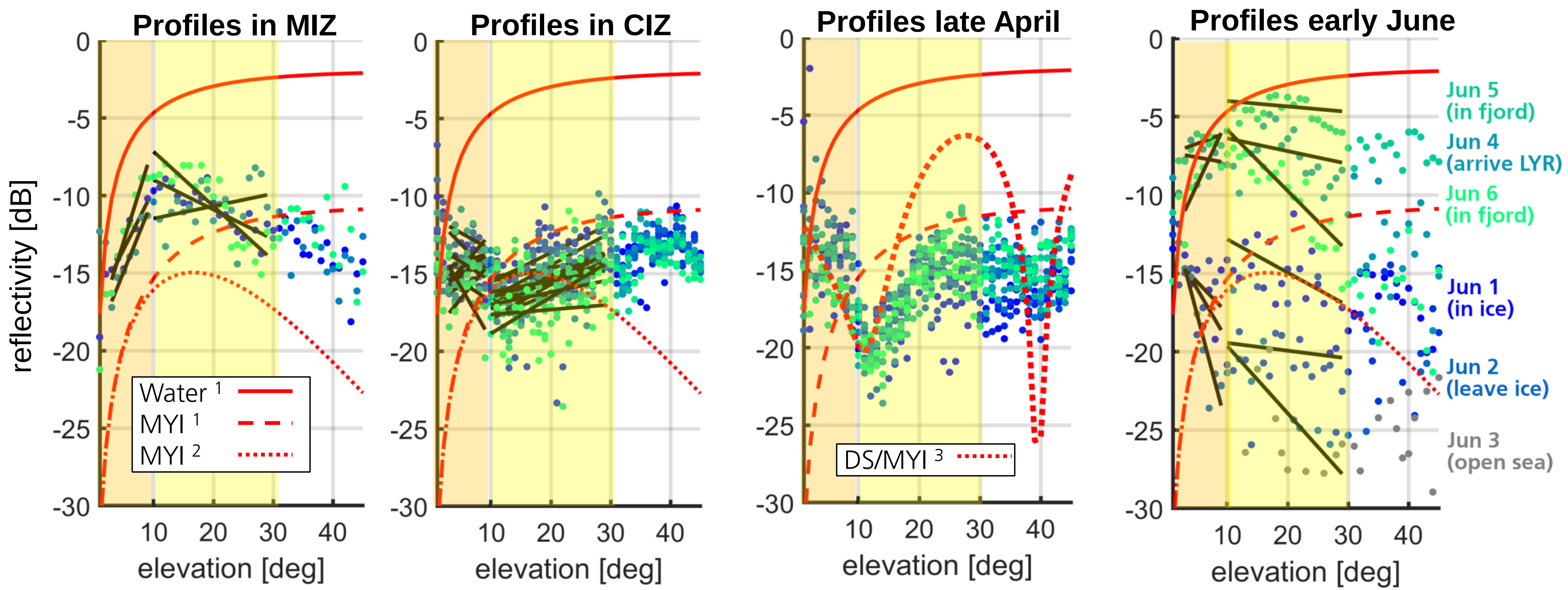
Features & Anomalies

- **Compact Ice Zone** (CIZ)
  SIC at 100% (ship drifting), rp < 3
- **Marginal Ice Zone** (MIZ)
  SIC < 100% (ship sailing), rp ~ 5
- **Storm Impact** (SI)
  SIC reduced (ice breaking), rp ~ 3 … 5
- **Transition Zone** (TZ)
  SIC variable (why?), rp ~ 3 … 5



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

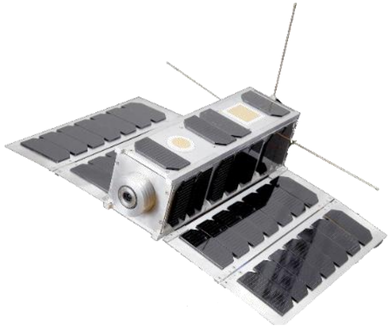
Reflectivity Maps & Profiles



[1] smooth bulk surface
[2] rough bulk surface

[3] dry-snow layer over multiyear-ice layer

Summary & Outlook



Motivation

- explore GNSS reflectometry for sea ice remote sensing
- estimate sea ice permittivity for ice type characterization

MOSAiC Data Analysis

- one-year data set of direct and reflected signal power
- rel. permit. estimated and related to sea ice
- features of layered sea-ice structure detected
  rel. permit. Estimation partly fails

Outlook

- Identify structural changes
  (ice and snow layers)
- investigate sea ice
  reflectivity
  for GNSS obs. from space
  e.g. PRETTY mission

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Werkstatt and IT of GFZ Geodesy Department

Data used here were produced
as part of MOSAiC project.

DLR

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