Dielectric sea-ice properties examined by GNSS reflectometry: Findings of the MOSAiC expedition

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Photo: Sea Ice Albedo, Isfjorden,Svalbard, Apr 2018

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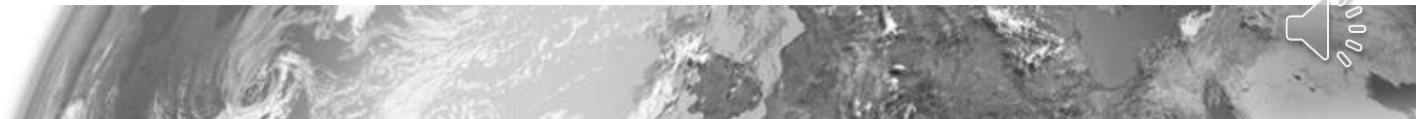
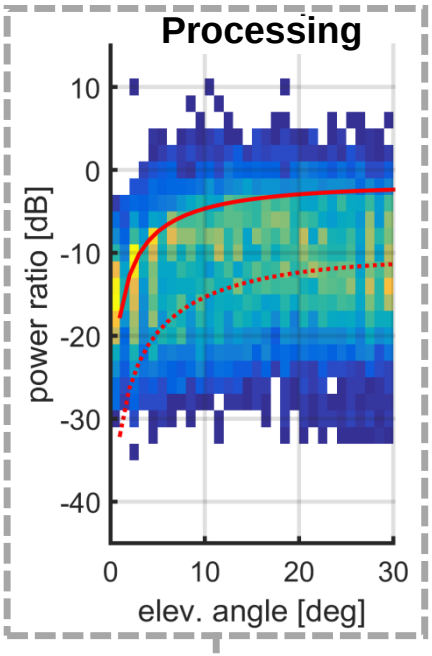
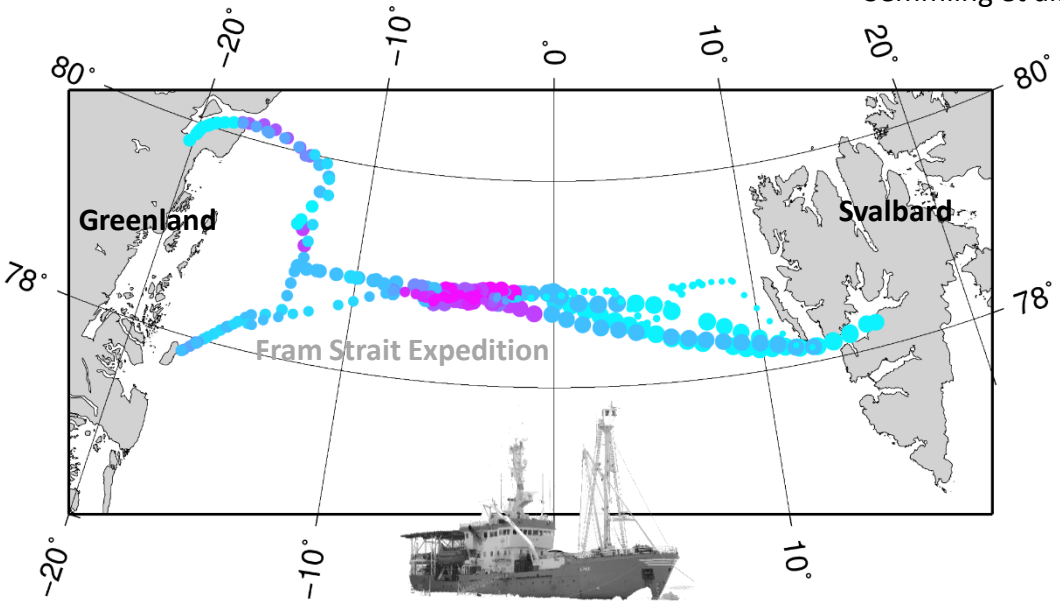
Introduction

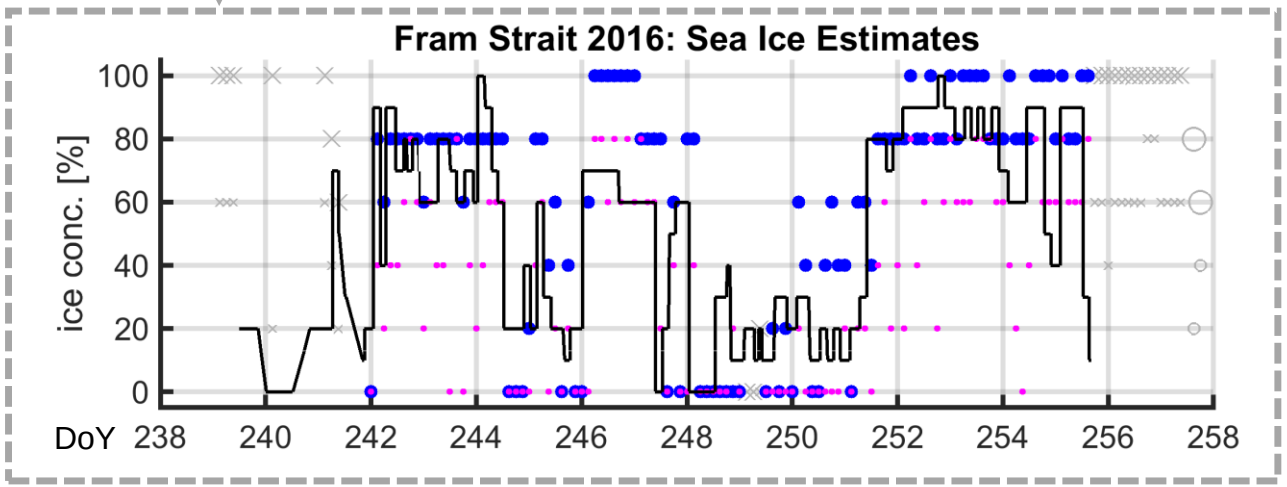


Previous Fram Strait Study



Semmling et al. 2019





Next opportunity

MOSAiC International Arctic Drift Expedition

AWI GRAPHIC © Martin Künsting

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Motivation for Sea-Ice Reflectometry

1. Importance of Sea Ice:
   - crucial effect on Earth's radiation budget
   - crucial factor for maritime activities in the Arctic

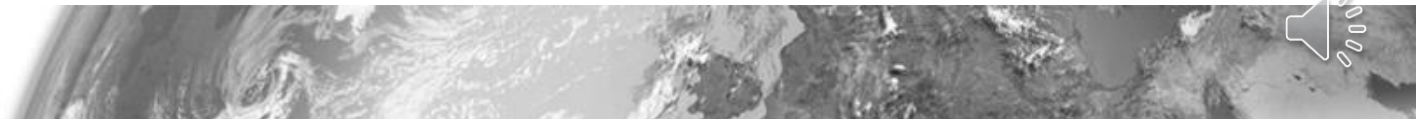
2. Challenge for GNSS reflectometry:
   - sea-ice concentration from permittivity contrast
   - retrieve permittivity level from sea-ice type?
   - relation of reflectivity and sea-ice thickness?

Cardellach et al. 2018

3. Opportunity of MOSAiC expedition:
   - R/V Polarstern as platform for one year Arctic operations
   - access to ice deep in central Arctic

Munoz-Martin et al. 2020

Measurement & Model

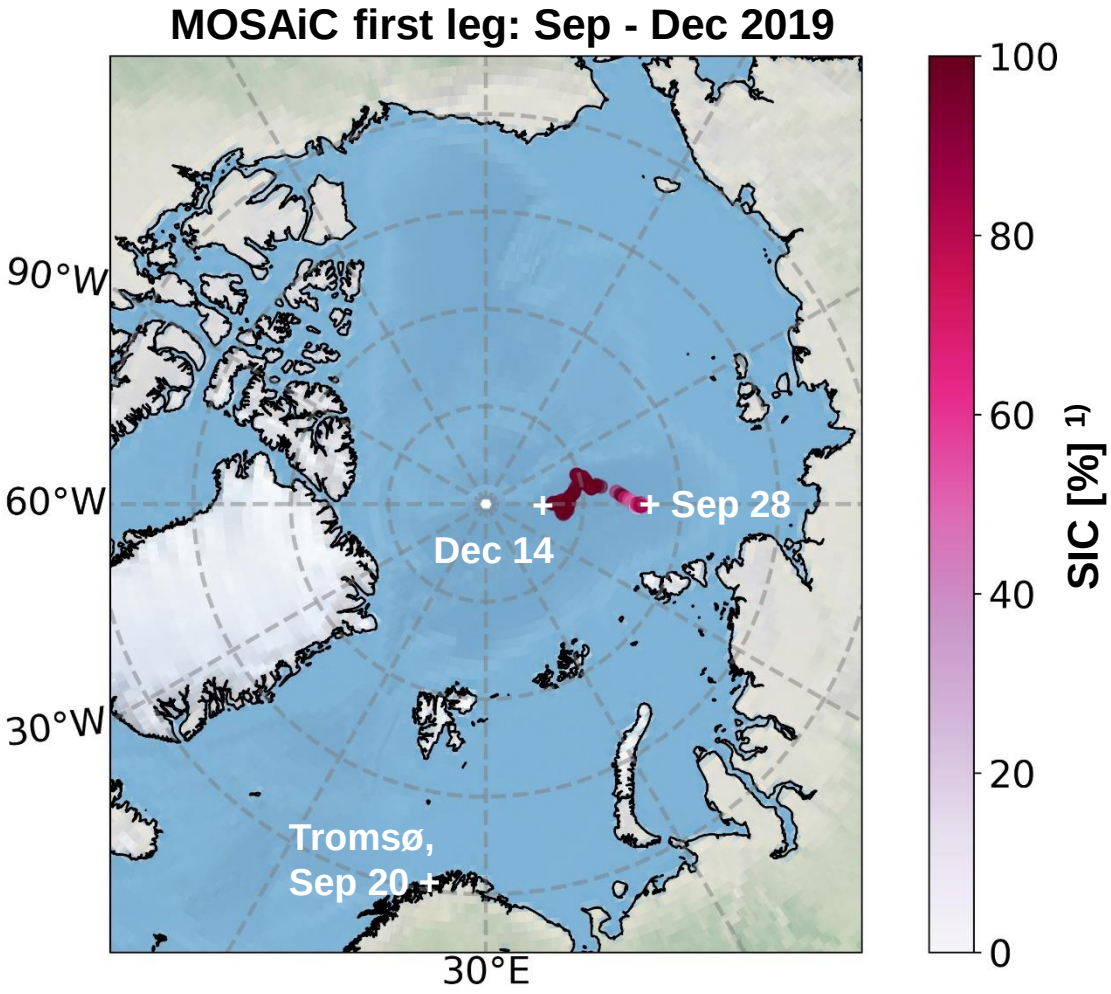


Polarstern Measurements

MOSAiC expedition 1st leg:
- from Tromsø into the central Arctic
- 86 days (Sep 20 – Dec 14, 2019)
- **data permission after Sep 26**

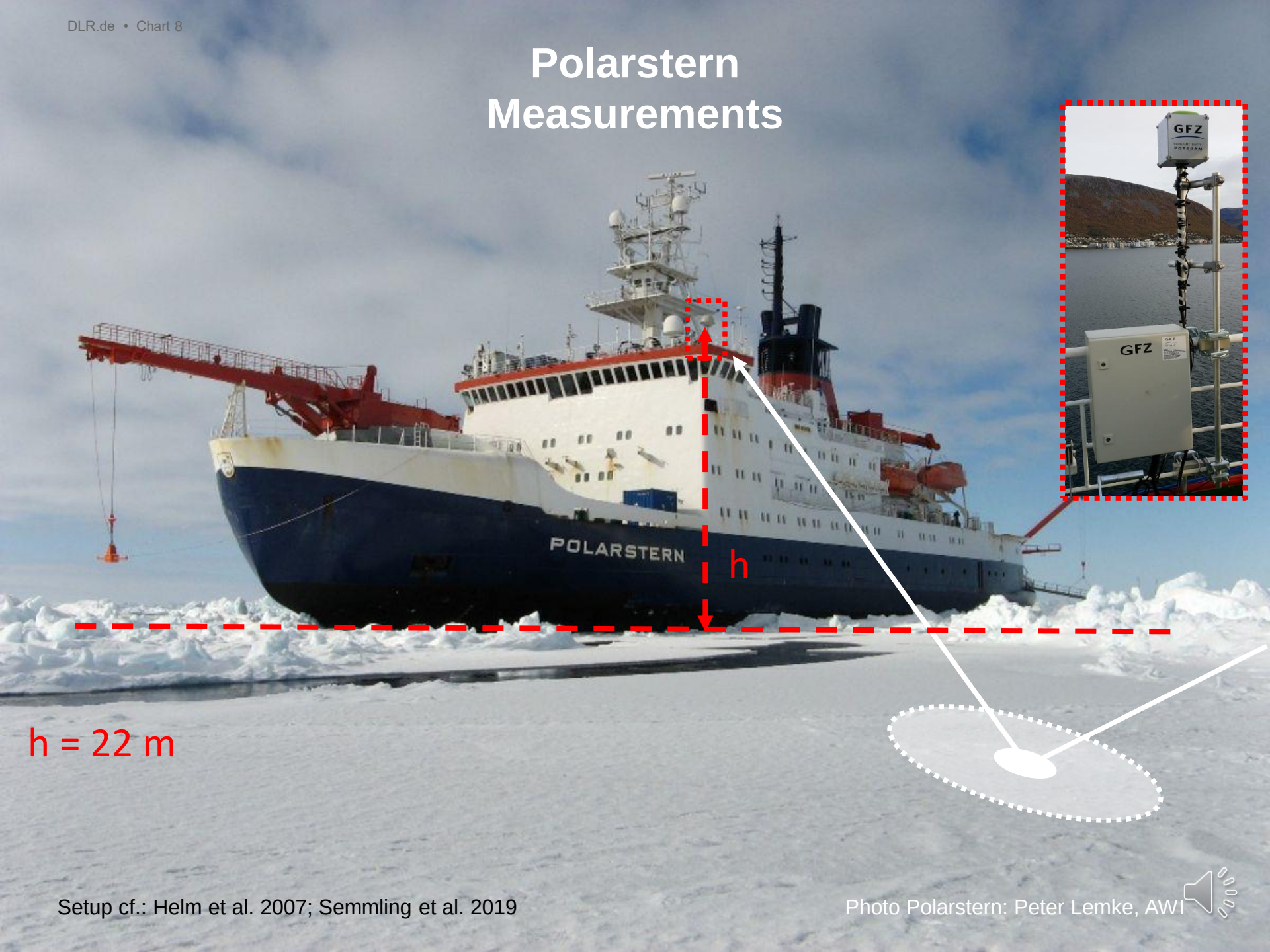
Marginal Ice Zone (MIZ):
- Siberian sec. lat. 82°N to 85° N
- 3 days (Sep 28 – 30, 2019)
- **variable sea-ice concentration**

Central Arctic (CA):
- during/after mooring to ice floe
- 14 days (Dec 1 – 14, 2019)
- **permanently compact sea ice**



1) ASSIST 2016

Polarstern Measurements

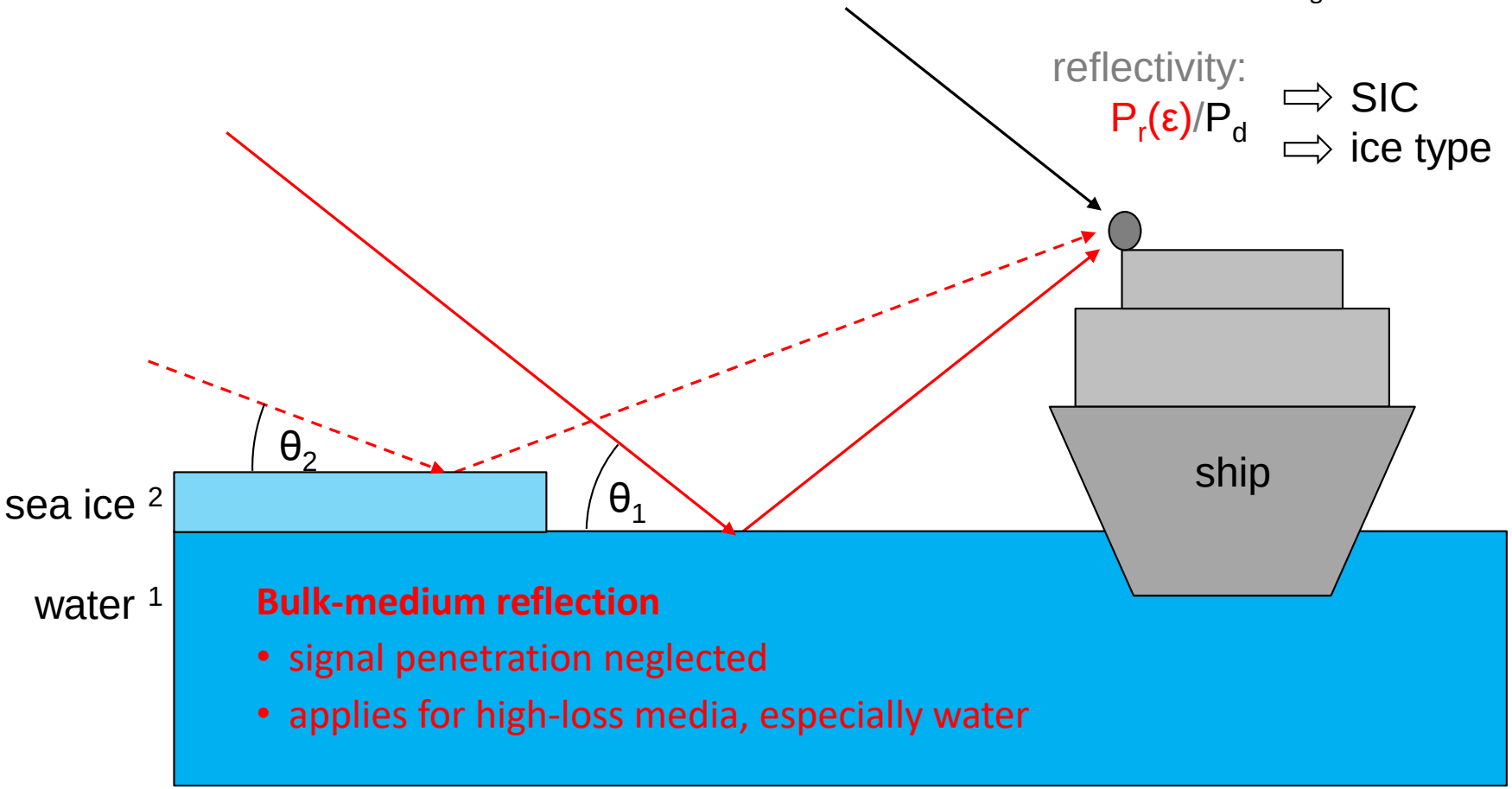


Setup cf.: Helm et al. 2007; Semmling et al. 2019

Photo Polarstern: Peter Lemke, AWI

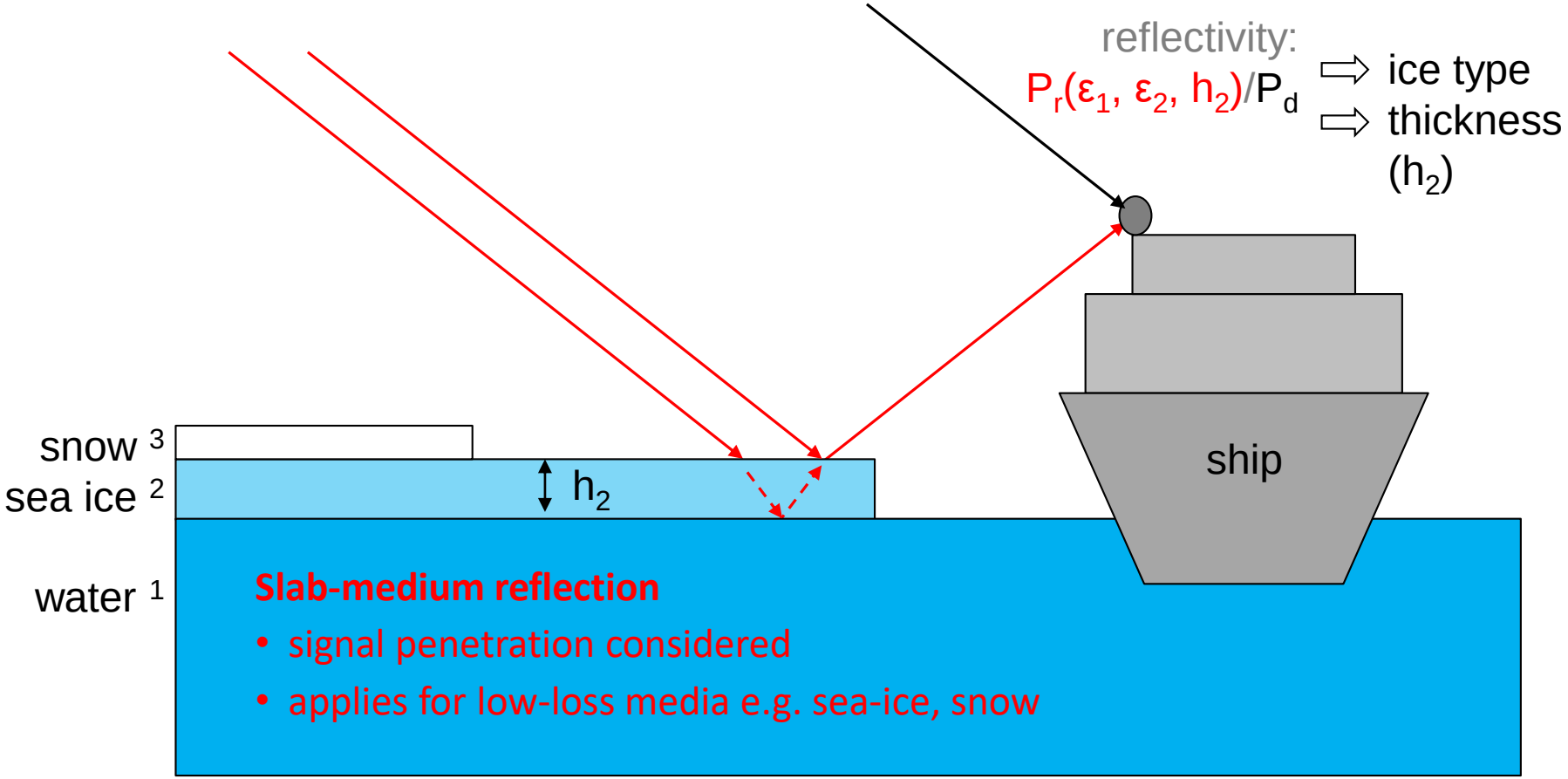
Reflection Model

Semmling et al. 2019



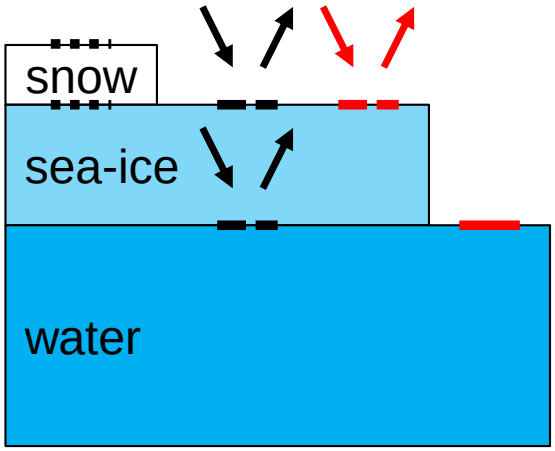
rel. permittivity: $\varepsilon_1 = 76.4 + i\ 48.5$; $\varepsilon_2 = 3.31 + i\ 0.11$

Reflection Model



rel. permittivity: $\varepsilon_1 = 76.4 + i\ 48.5$; $\varepsilon_2 = 3.31 + i\ 0.11$; $\varepsilon_3 = 1.76 + i\ 0.00$

Reflection Model

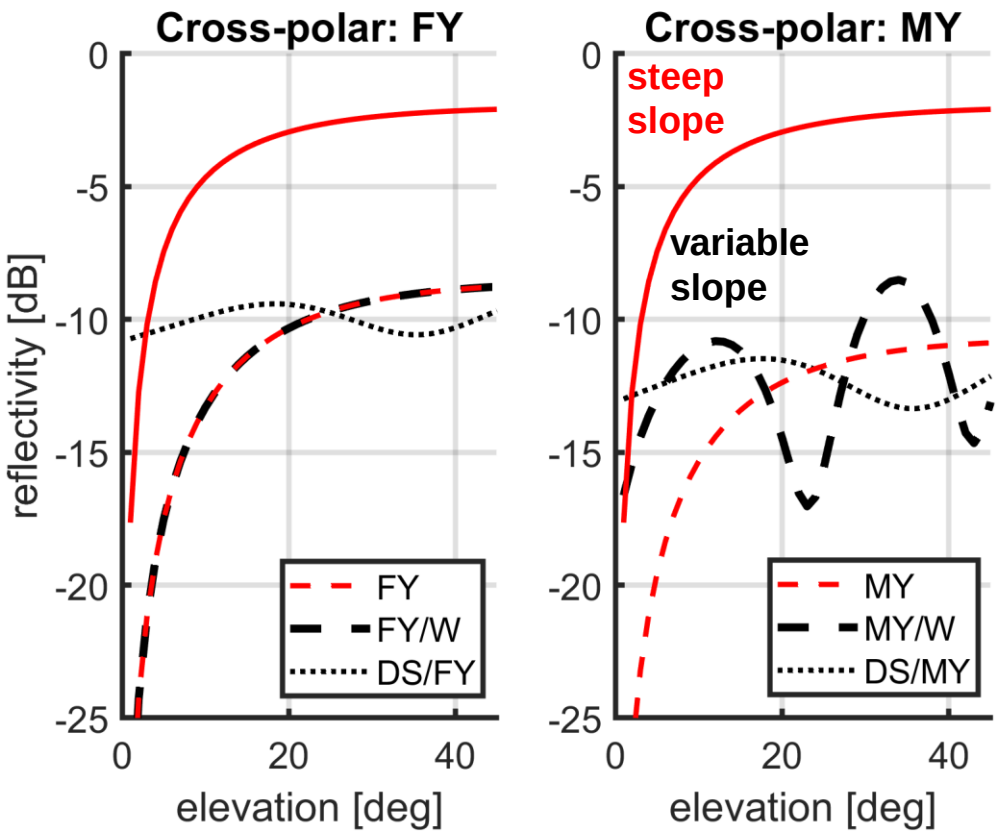


Bulk-medium reflection

Slab-medium reflection

Kaleschke et al. 2010

Semmling et al. (under review)



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

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

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

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

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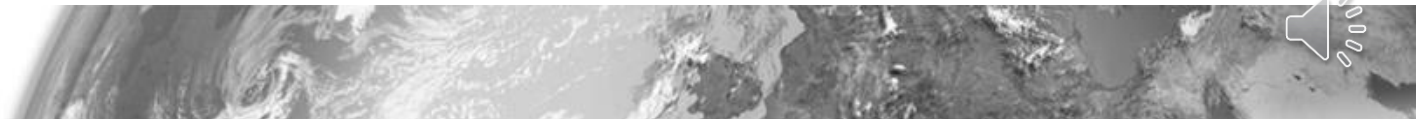
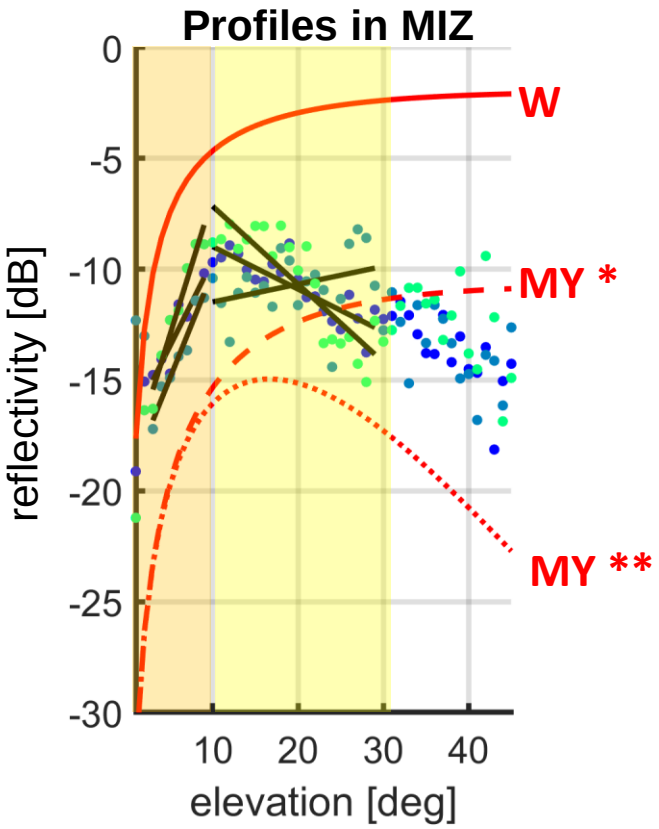
Results for MOSAiC (first leg)



Reflectivity Profiles

Semmling et al. (under review)



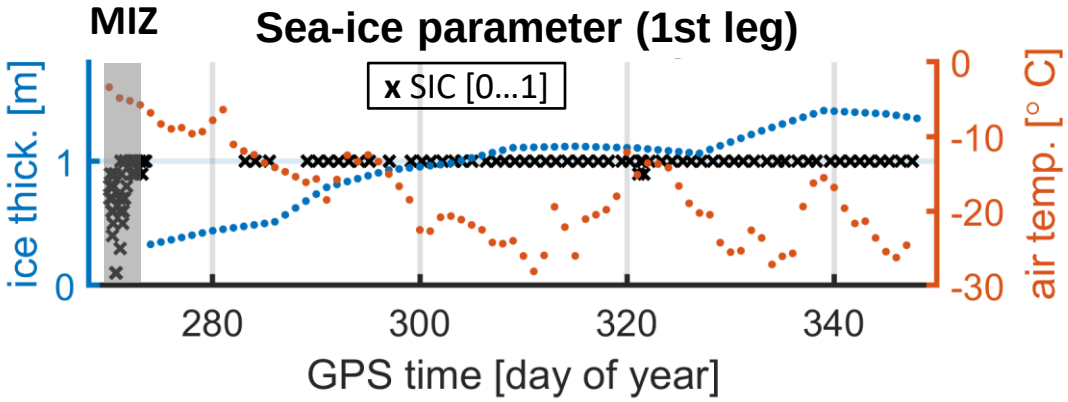
*** smooth; ** rough**

- 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

⇨ permittivty inversion

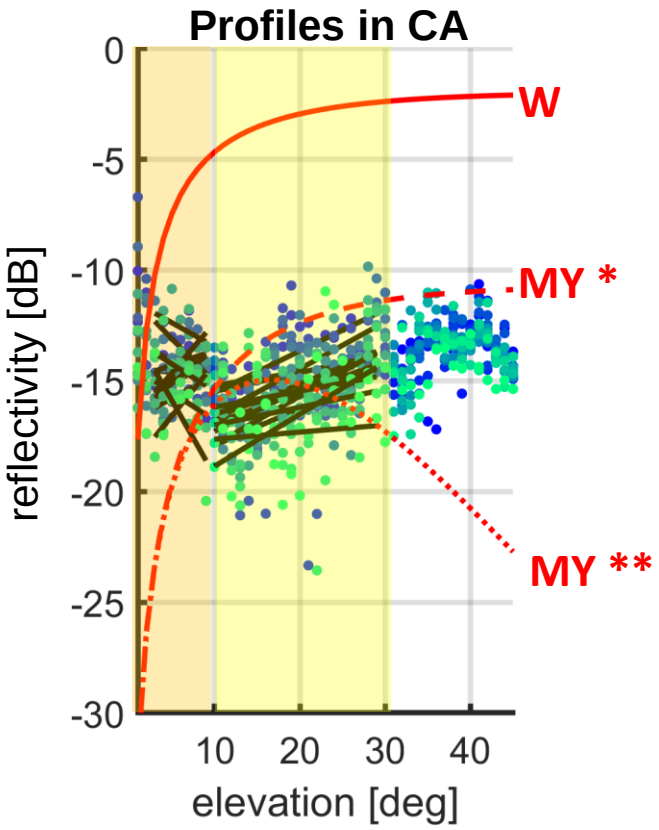


1) AWI 2020

2) ECMWF 2020

Reflectivity Profiles

Semmling et al. (under review)



*** smooth; ** rough**

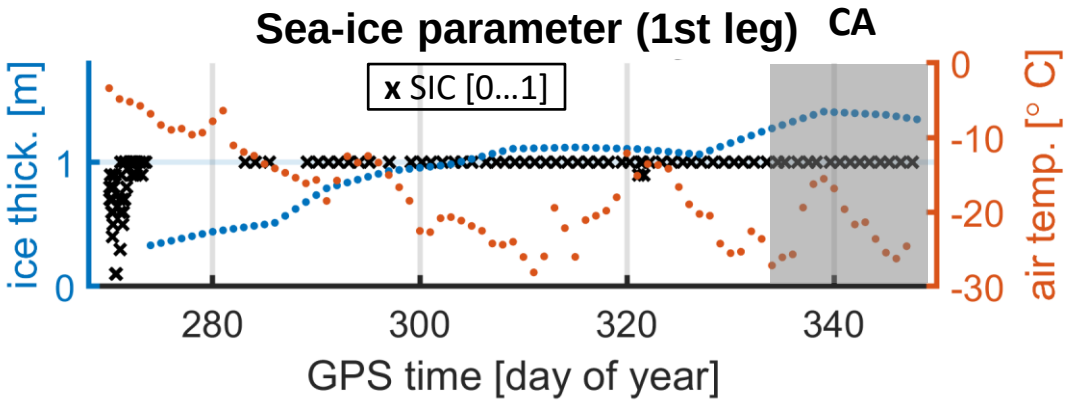
- obs. (day color-coded)

Low-Elevation Range (1° to 10°)
- reflect. between MY and W
- slope deviates from bulk model
- no roughness effect

⇨ anomaly analysis

Mid-Elevation Range (10° to 30°)
- reflect. below MY
- slope of slight increase
- no roughness effect

⇨ permittivity inversion

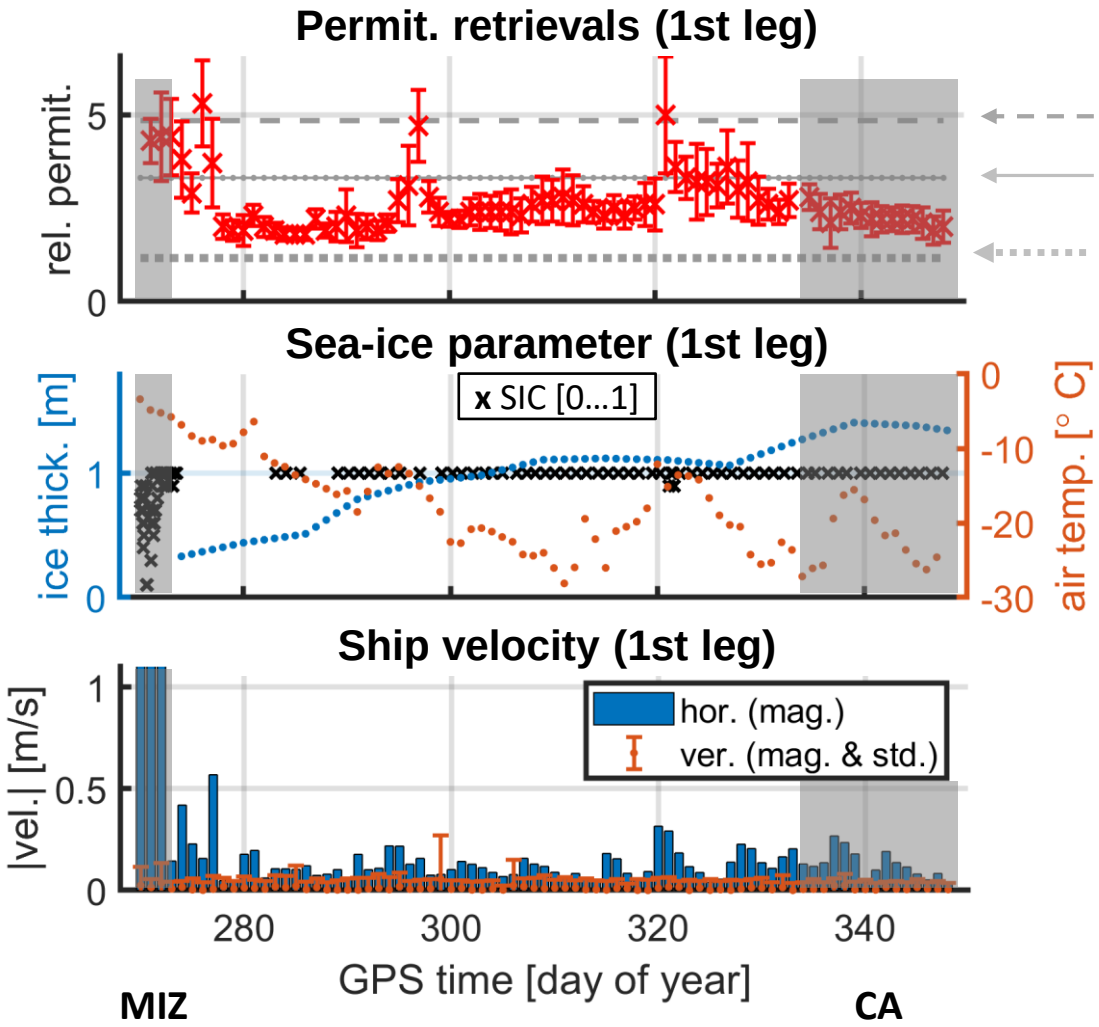


1) AWI 2020

2) ECMWF 2020

Semmling et al. (under review)

Inverted Permittivity



In Marginal Ice Zone

- ε-estimates rather high (FY to MY range)
- water occurrence (SIC < 1)

In Central Arctic

- ε-estimates low (MY to DS level)
- compact ice (SIC ~ 1)
- thickness > 1m

In general

- estimates often close to DS level impact of snow cover ?
- water occurrence (SIC < 1) has major impact (estimate increase)
- thickness has not major impact

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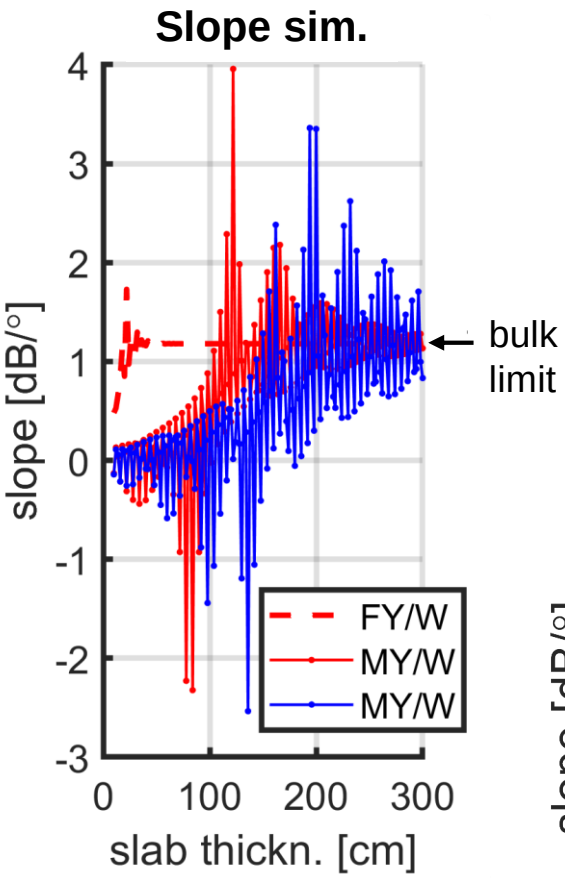
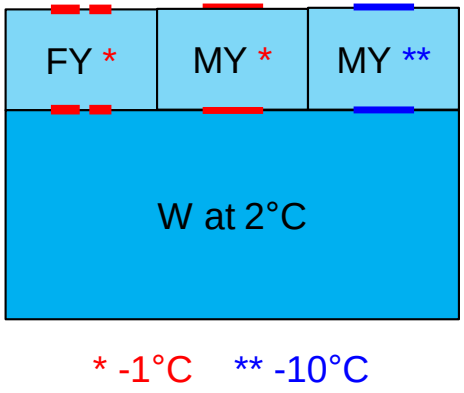
Slope Anomalies to be analysed …

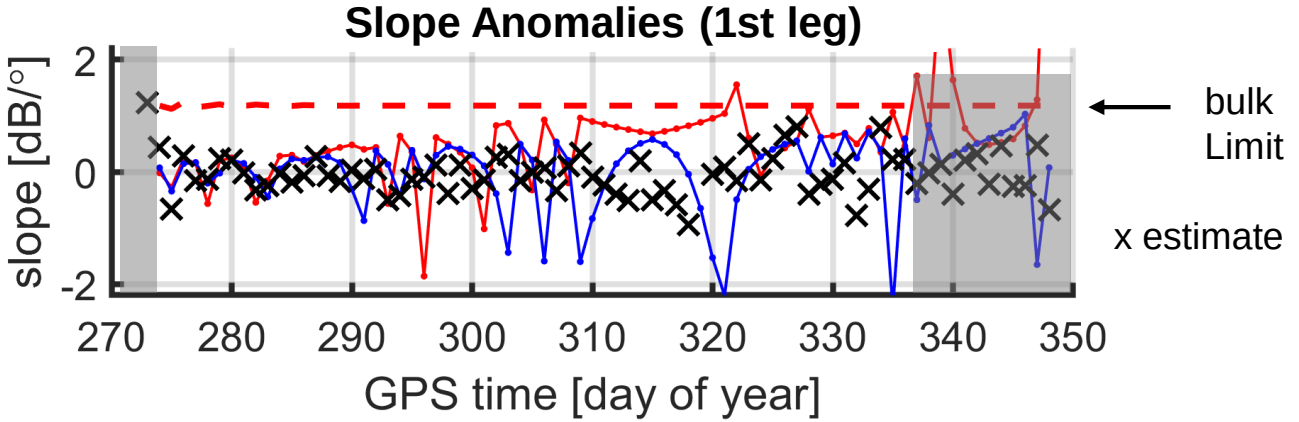




FY ice slab
- small anomaly range
- bulk limit reached h > 20cm

MY ice slab (-1°C)
- large anomaly range
- bulk limit reached h > 110cm

MY ice slab (-10°C)
- even larger anomaly range
- bulk limit reached h > 140cm
- **best agreement** with slope estim.

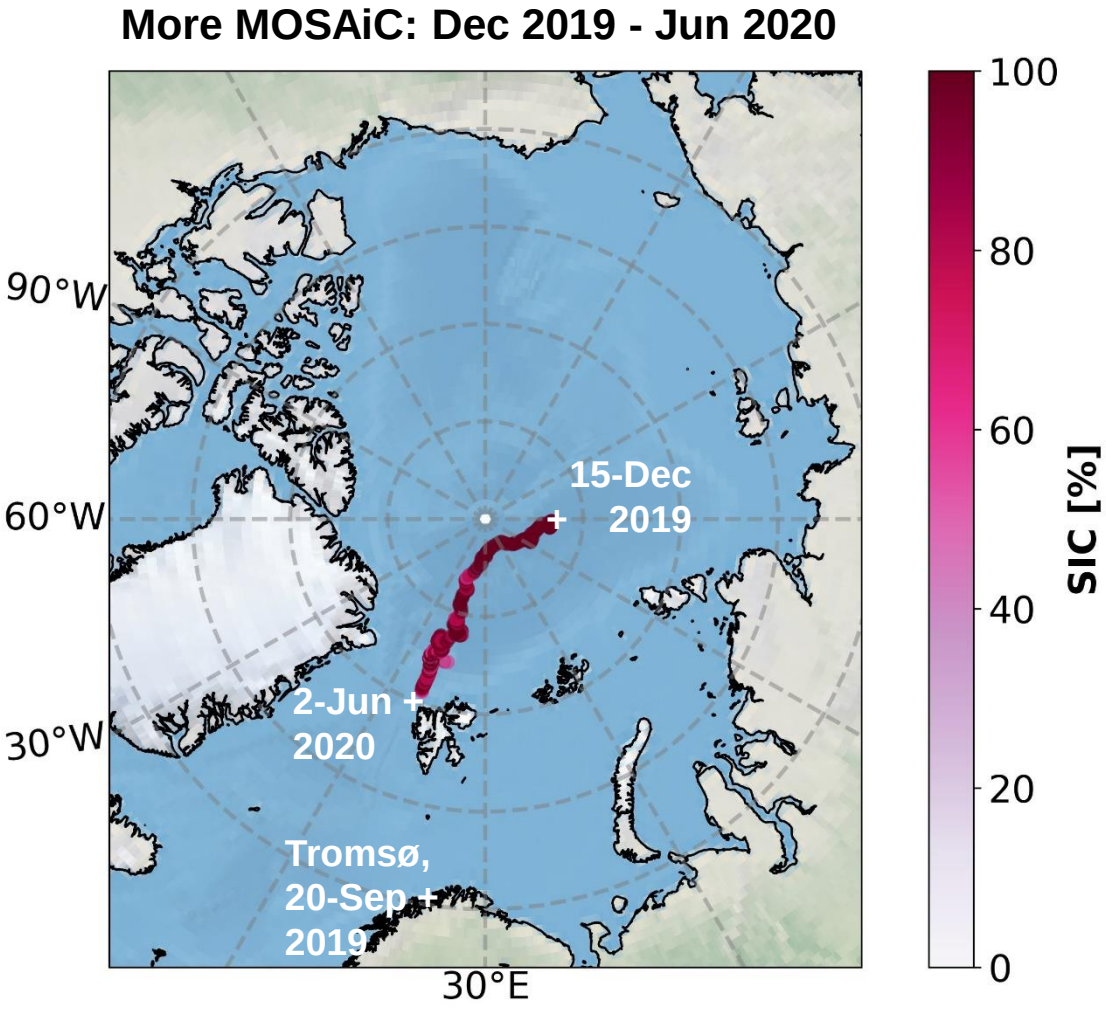


Summary & Conclusions

Permittivity Estimation
- Can we link estimates and ice type?
- Estimates range exceeds ice type values
- impact of sea-ice concentration dominates

Slope Anomalies
- Charact. bulk profiles in MIZ
- Significant slope anomaly in CA
- Ice thickness inversion difficult
- Anomalies sensitive to ice types

More data available
- for MOSAiC‘s second leg
- from central Arctic to Fram Strait
- 171 days (Dec 15, 2019 – Jun 2, 2020)



References

- Helm et al. 2007: GORS - A GNSS Occultation, Reflectometry and Scatterometry Space Receiver. ION GNSS 2007
- Kaleschke et al. 2010: A sea-ice thickness retrieval model for 1.4 GHz radiometry and application to airborne measurements over low salinity sea-ice. The Cryosphere
- ASSIST 2016: Arctic shipborne sea ice standardization tool. Technical report, International Arctic Research Center, http://www.iarc.uaf.edu/icewatch
- Cardellach et al. 2018: GNSS Transpolar Earth Reflectometry exploriNg System (G-TERN): Mission Concept. IEEE Access
- Semmling et al. 2019: Sea Ice concentration derived from GNSS reflection measurements in Fram Strait. IEEE Trans. Geosci. Rem. Sens.
- Munoz-Martin et al. 2020: Snow and Ice Thickness Retrievals Using GNSS-R: Preliminary Results of the MOSAiC Experiment. Remote Sensing
- AWI 2020: Weekly combined SMOS/CryoSat-2 product, available via https://data.meereisportal.de
- ECMWF 2020: ERA-5 reanalysis data, available via https://cds.climate.copernicus.eu
- Semmling et al. (under review): Sea-ice permittivity derived from GNSS reflection profiles: Results of the MOSAiC expedition. IEEE Trans. Geosci. Rem. Sens.

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Werkstatt and IT of GFZ Geodesy Department

Data used here was produced as part of MOSAiC project.

Thank you for your attention …

Photo: Sea Ice Albedo,
Isfjorden,Svalbard,
Apr 2018