GNSS remote sensing to study sea-ice and ionospheric irregularities in the central Arctic

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Photo Polarstern: Peter Lemke, AWI

GGOS Topical Meeting, Potsdam, Oct. 2024

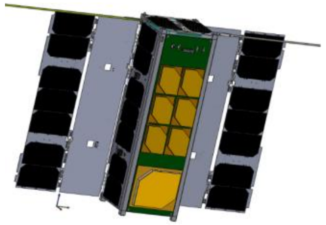
Outline

- GNSS Remote Sensing for Arctic Monitoring
- MOSAiC Expedition and GNSS Data in the Arctic
- Results of Sea-ice Reflectometry Analysis
- Results of Scintillation Index Analysis
- Conclusions

Motivation GNSS Remote Sensing

- A: Low Earth Orbiter

  Wickert et al. 2016
  Semmling et al. 2016



- B: Aircraft

  Semmling et al. 2014
  Moreno et al. 2022

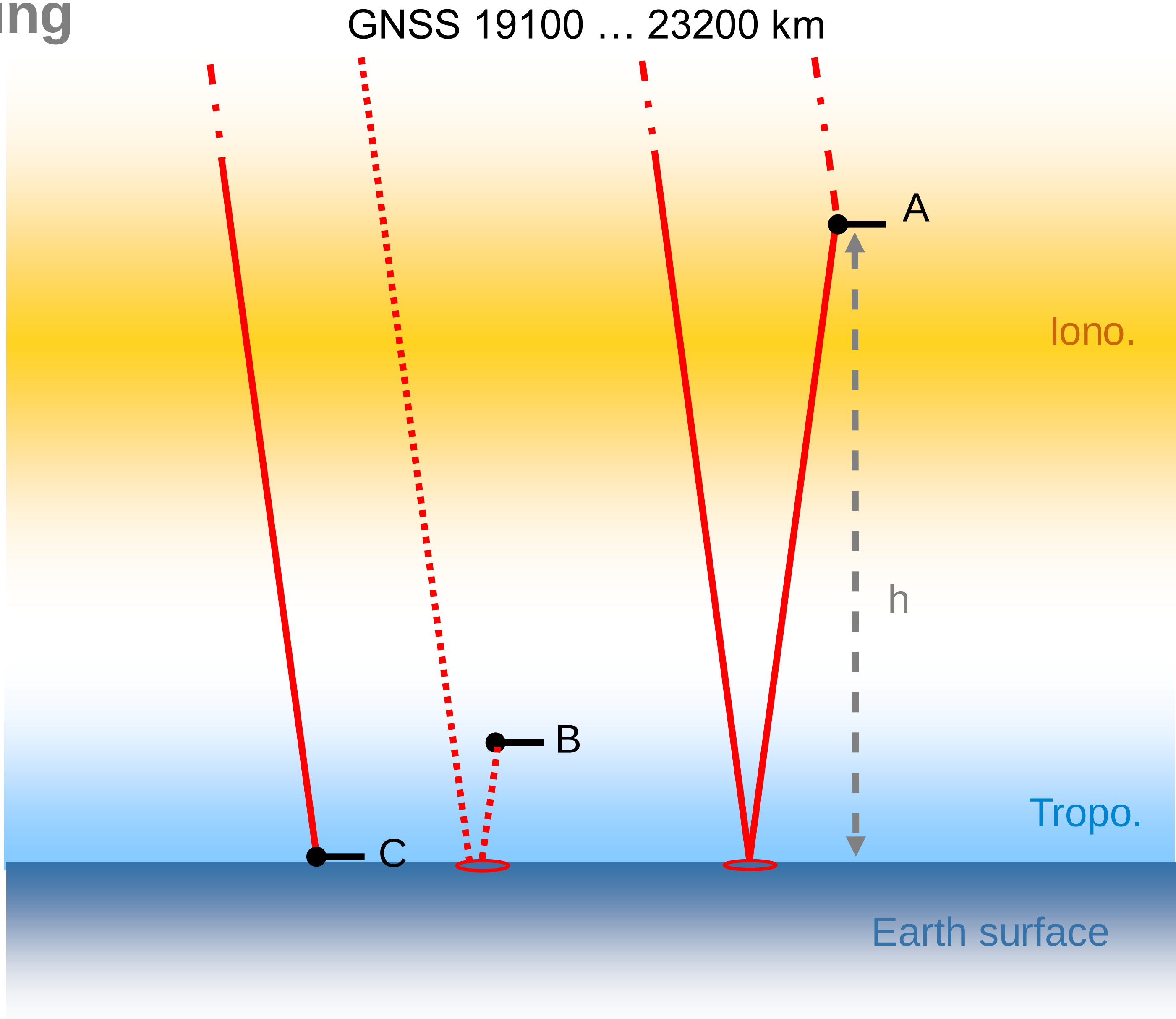
- C: Research Vessels

  Wang et al. 2019
  Semmling et al. 2019, 2022
  Semmling et al. 2023

- Application

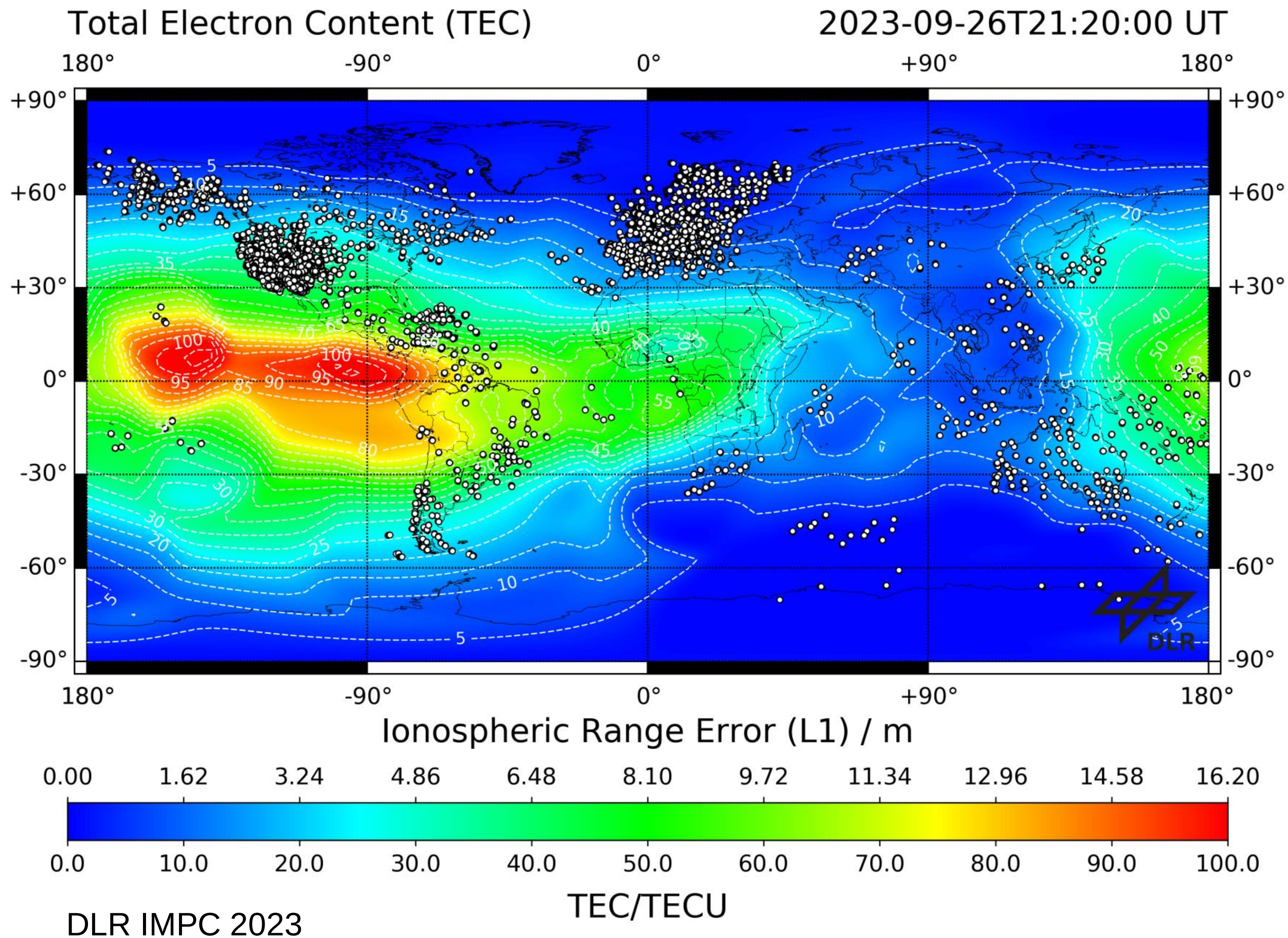
sea surface altimetry
sea state estimation
sea-ice detection

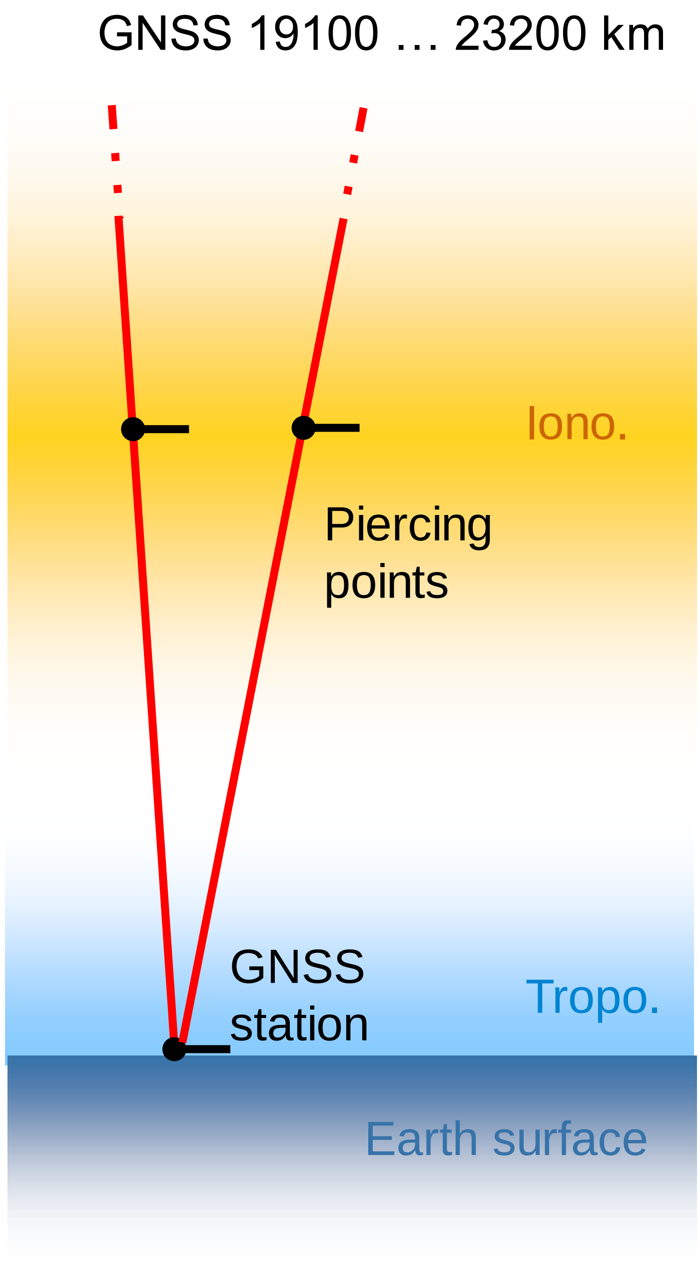
water vapor estimation
iono. scintillation detection



A: e.g. PRETTY, h ~ 500 km
B: e.g. HALO, h ~ 3500 m
C: e.g. Polarstern, h ~ 25 m

Ionosphere TEC Monitoring with GNSS





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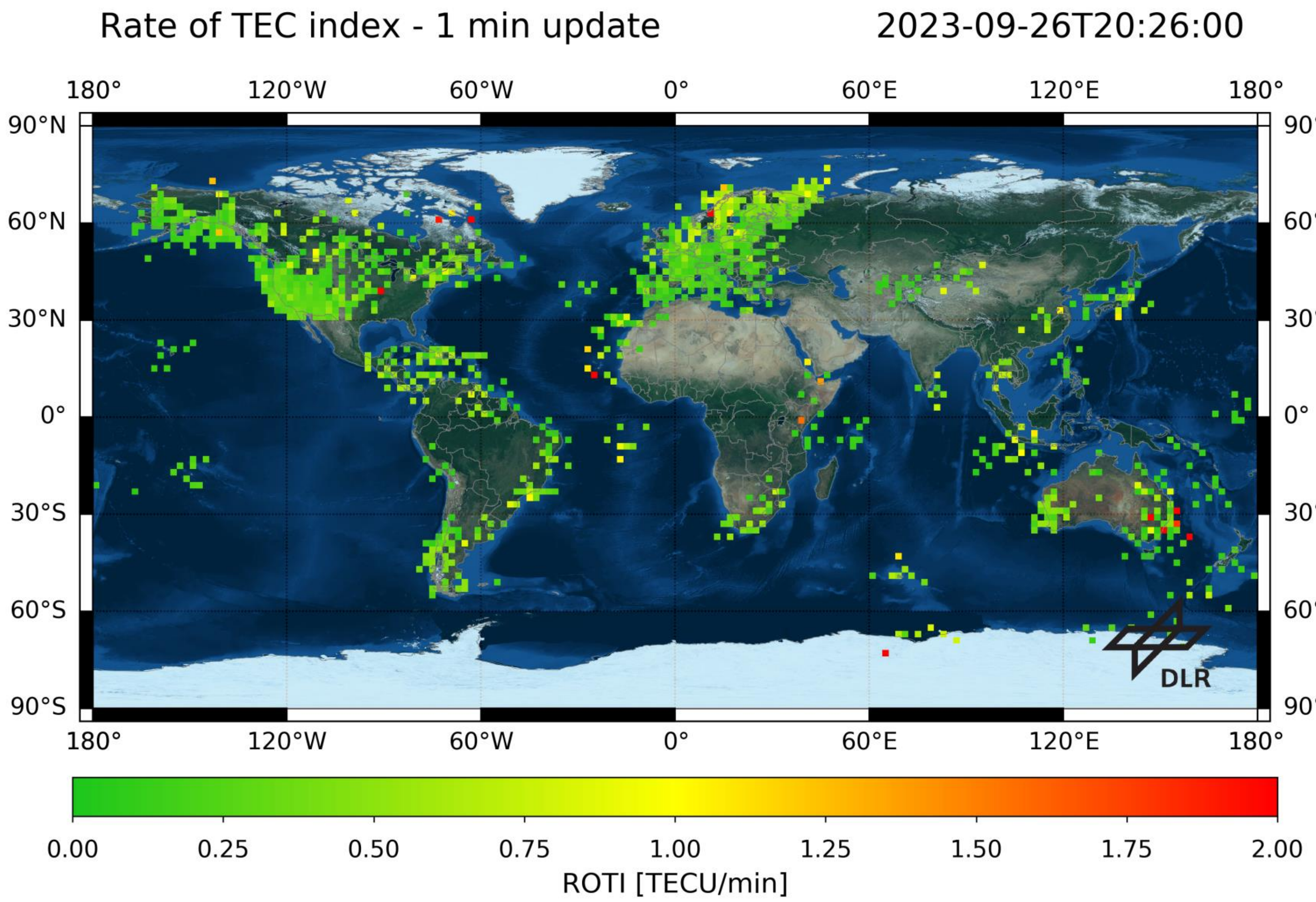
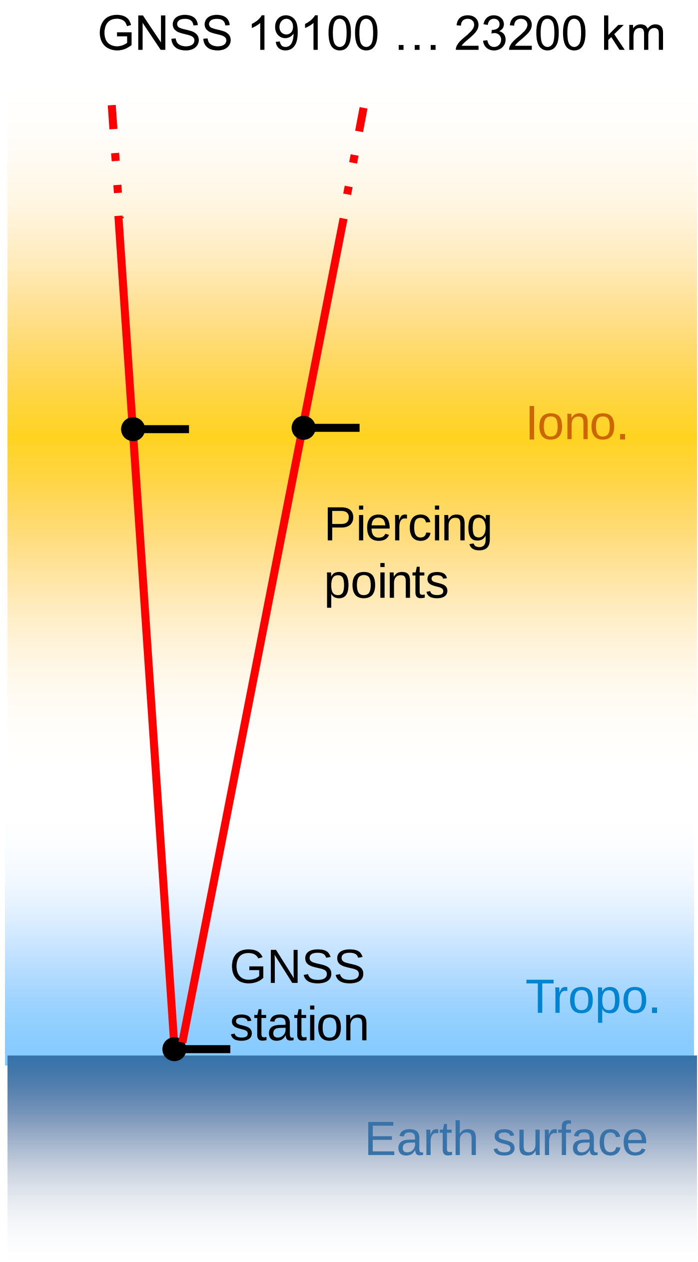
Ionosphere Disturbance Monitoring with GNSS





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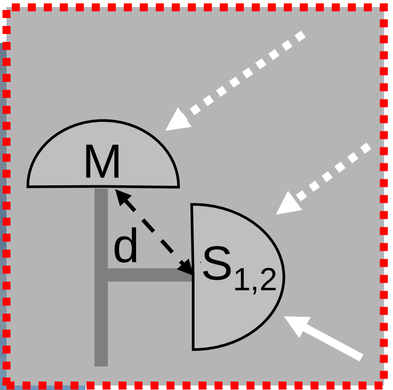
Can we benefit from ship-based data?

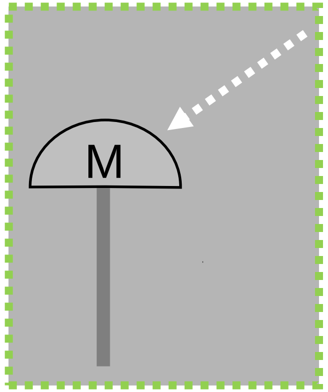
MOSAiC Expedition and GNSS Data in the Arctic

MOSAiC Expedition and Polarstern Setup

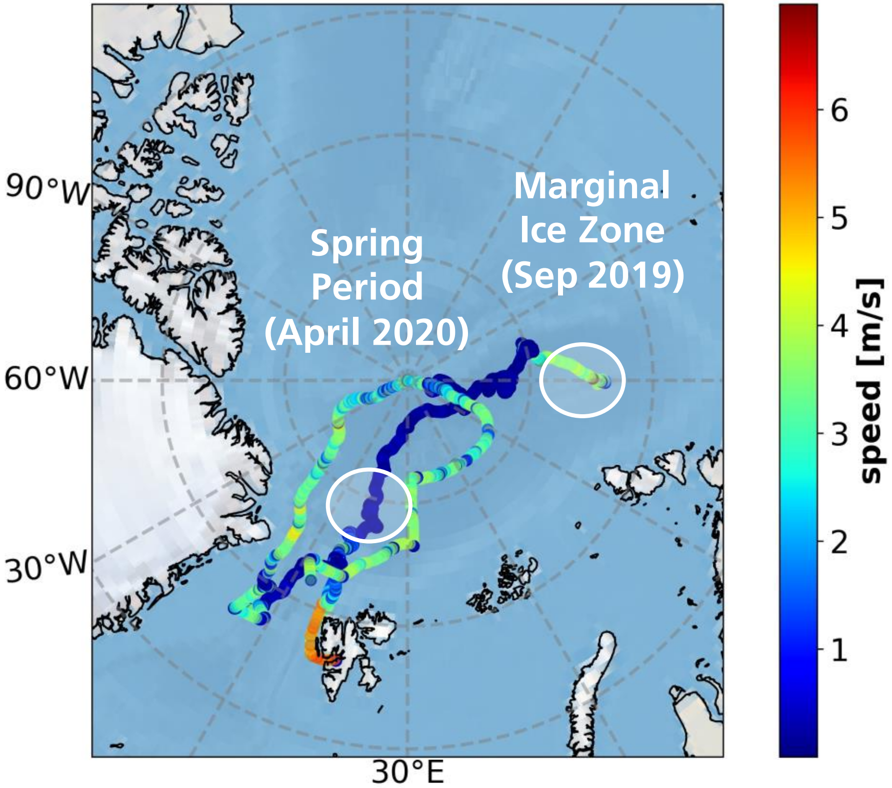
* GFZ GNSS-R setup * DLR GNSS setup



h = 22 m
d = 20 cm



MOSAiC expedition: Sep 2019 - Sep 2020

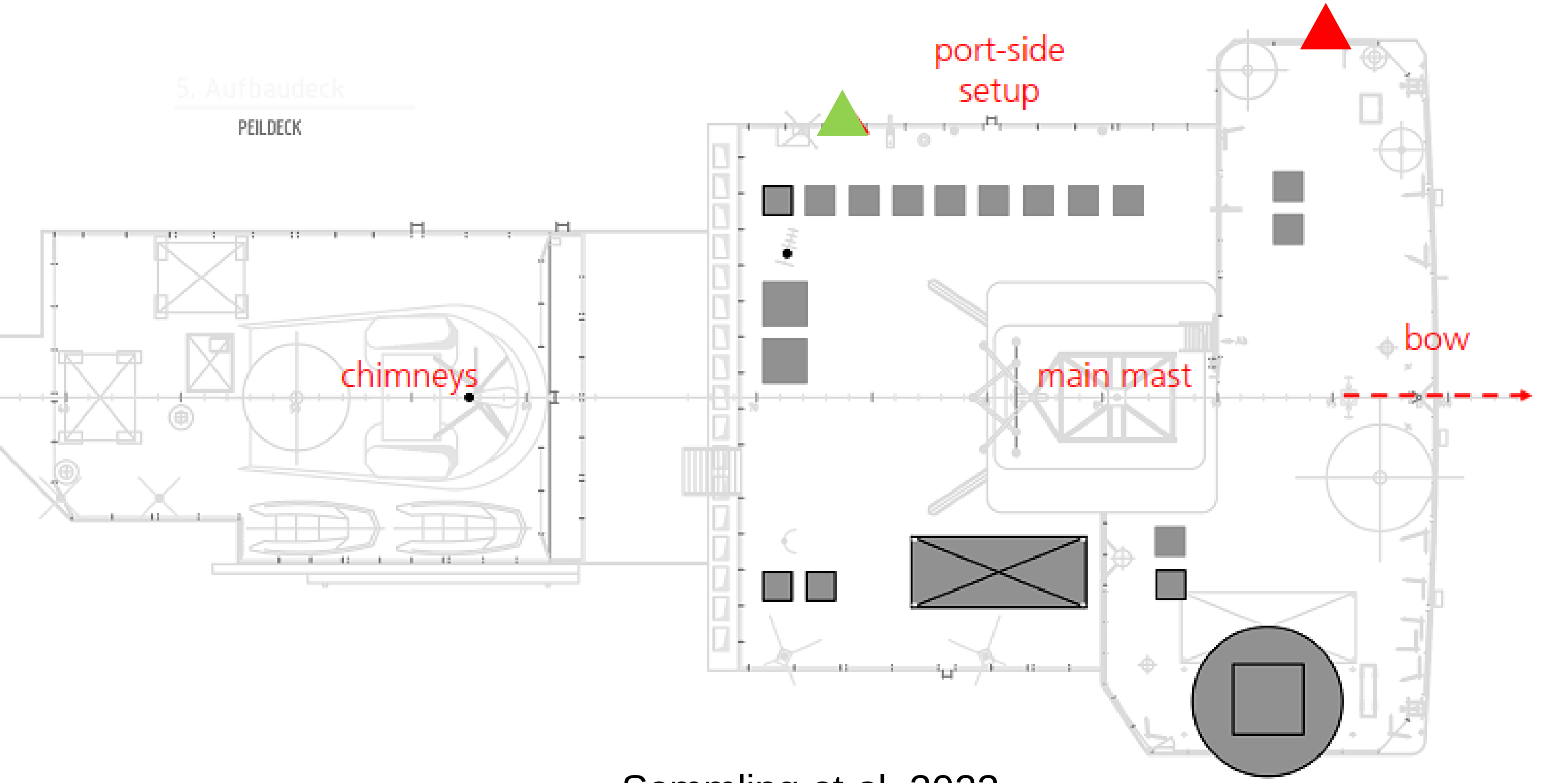


Helm et al. 2007
Semmling et al. 2013
Kriegel et al. 2017

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

Cruising Periods: speed > 1 m/s
Drifting Period: speed < 1 m/s

MOSAiC Expedition and Polarstern Setup

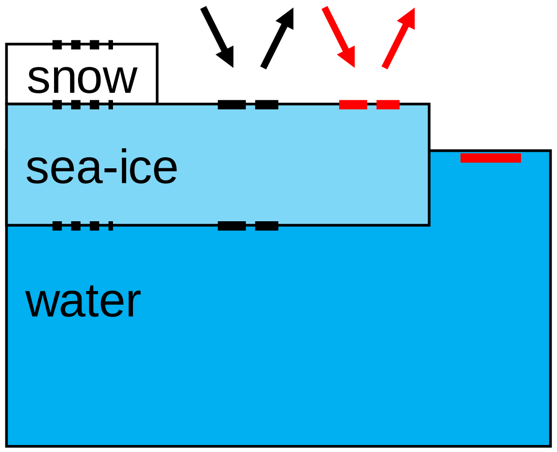


Semmling et al. 2023

Results of Sea-ice Reflectometry Analysis

How are reflectivity profiles affected by sea-ice conditions around the ship?

Some Simulations …



Bulk-medium reflection
Slab-medium reflection

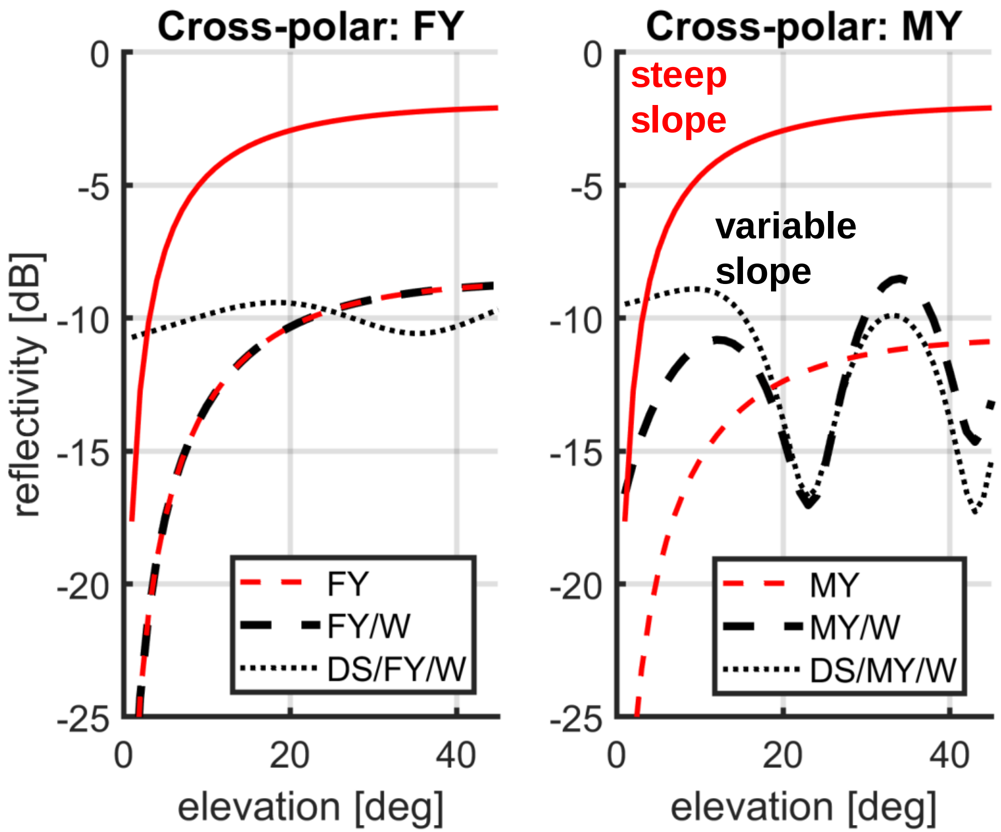
Kaleschke et al. 2010

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“

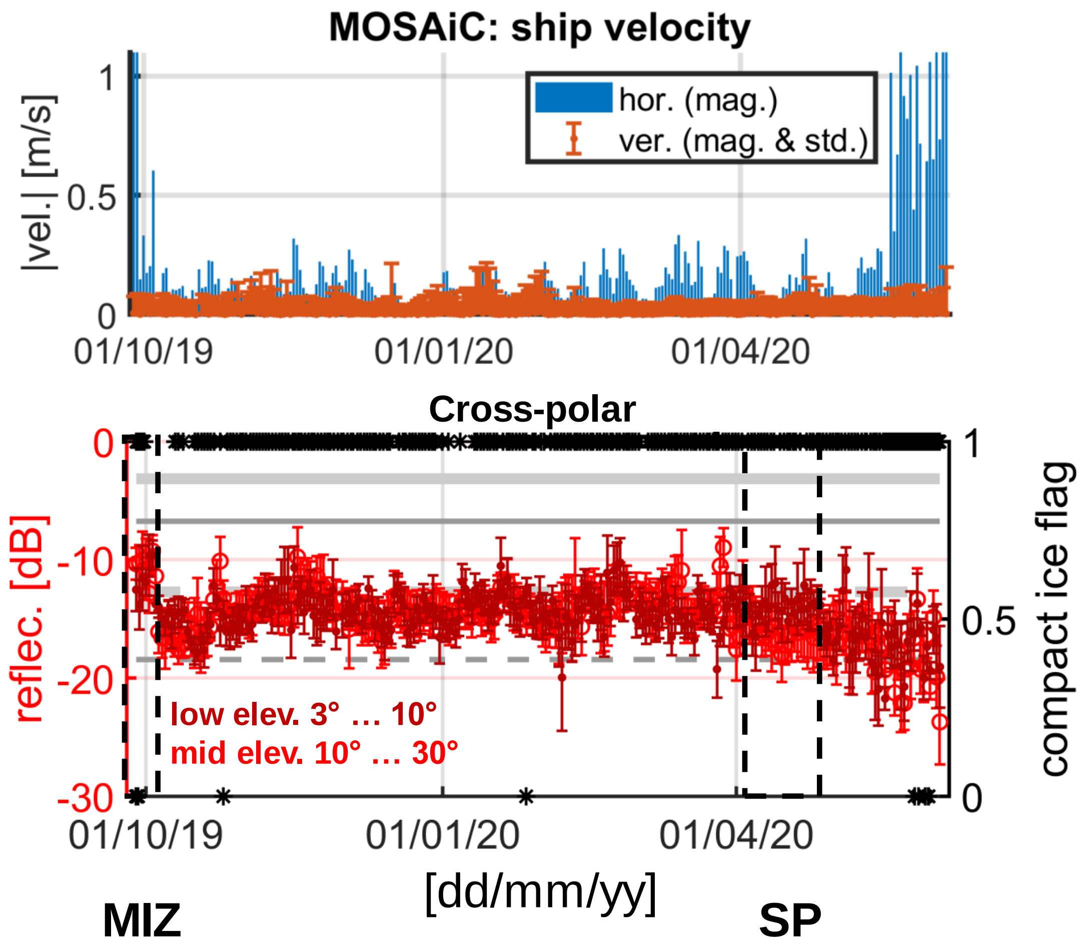
Water (W)
ε = 76.4 + i 48.5
at 2°C
„opaque“

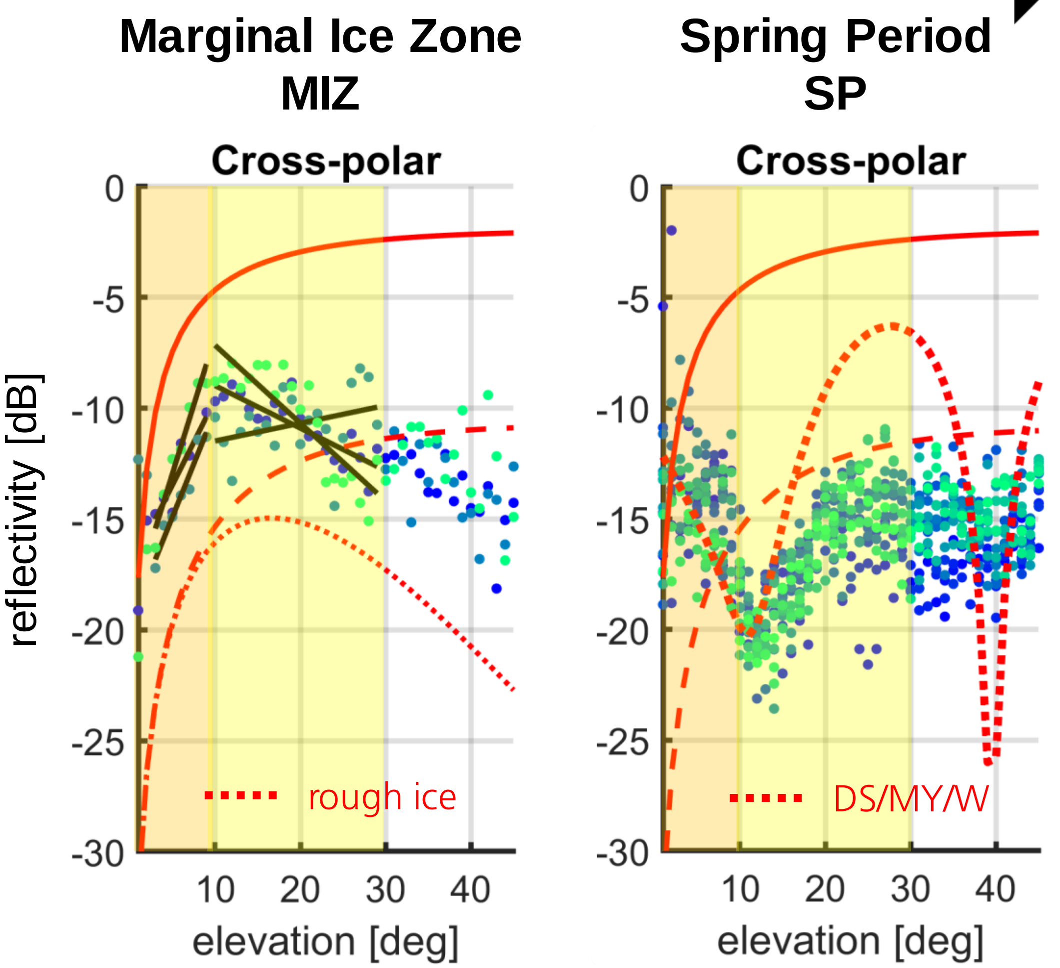


Coherent superposition of **slab reflection** result in **reflectivity fringes** (if top media are transparent).

Semmling et al. 2022

Cross-Polar Anomalies





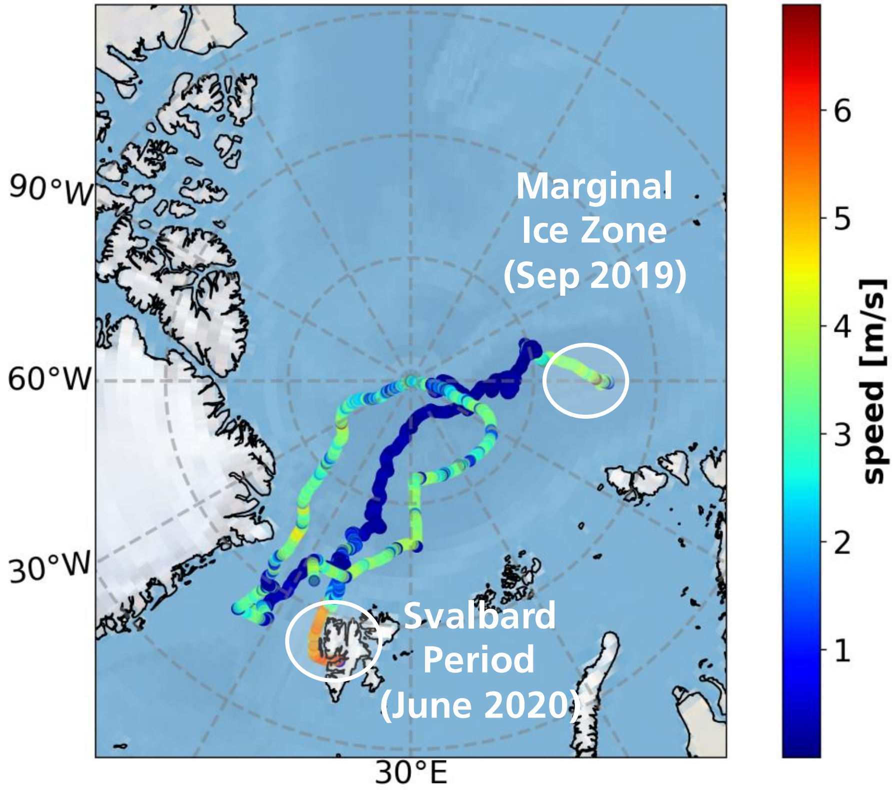
Broad **Fading in SP** due to **low conductivity snow/ice** conditions

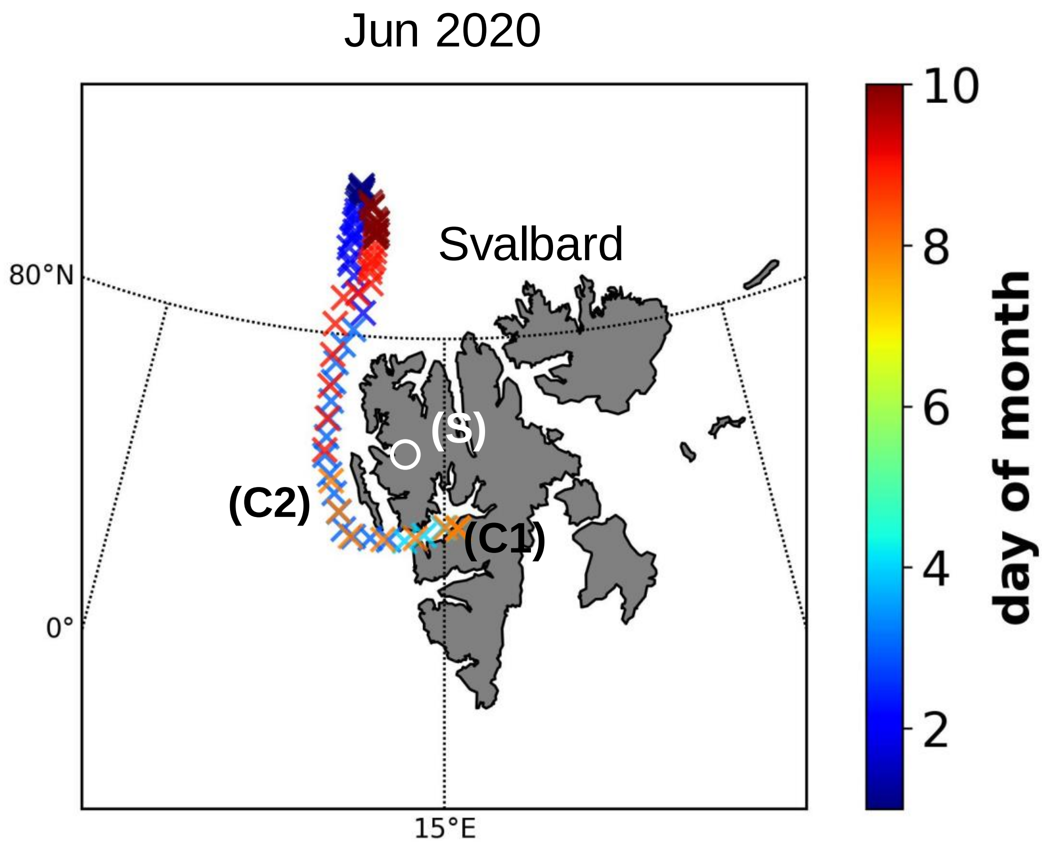
Results of Scintillation Index Analysis

Can we use ship-based scintillation index data for ionosphere monitoring?

Track of R/V Polarstern (PS)

MOSAiC expedition: Sep 2019 - Sep 2020



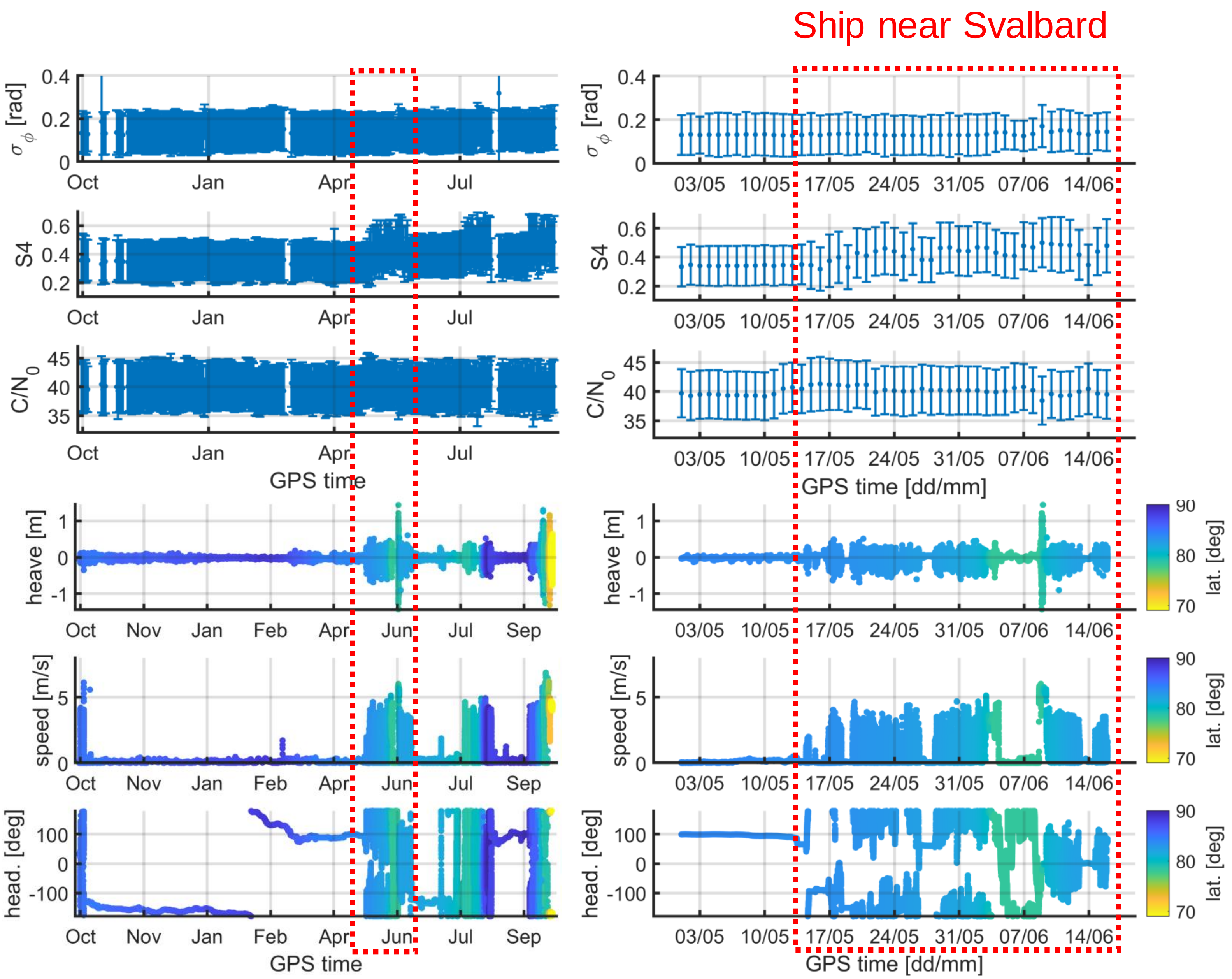


Cruising Periods: speed > 1 m/s
Drifting Period: speed < 1 m/s

(C1) noon Jun 4 to afternoon Jun 8 — calm sea, inside fjord
(C2) night Jun 8 — high sea state, outside fjord

(S) Ny-Alesund station operated by Univ. of Oslo

PS results in relation to ship's movement



	Jun 6	Jun 7	Jun 8	Jun 9
av. σ_φ [rad]	0.14	0.13	0.14	0.17
av. S4	0.41	0.48	0.47	0.50
av. C/N0 [dB]	40.0	40.6	40.8	38.4
max. heave [m]	< 0.2	< 0.2	< 0.2	> 1.0

Remarks:

- night June 8-9 ship leaves fjord
- high sea state outside leads to increased heave of the ship
- scint. indices slightly increased

Summary of Scintillation Results at High Elevations

	Feb 2020	Mar 2020	Jun 2020	Sep 2020	Oct 2020	Mar 2020	Jun 2020
Days of obs.	28	31	30	30	5	31	30
Av. Speed [m/s]	0.1+-0.1	0.2+-0.1	0.7+-1.2	0.9+-1.3	4.4+-0.3	-	-
Av. Heave [dm]	-0.2+-0.1	-0.1+-0.4	-0.1+-0.8	0.0+-0.5	-0.5+-2.3	-	-
High elev. Indices							
Av. S4 (% to ref.)	0.26 (100)	0.25 (95)	0.29 (113)	0.32 (122)	0.31 (120)	0.04 (15)	0.04 (16)
Av. σ(φ) [rad] (%)	0.12 (100)	0.11 (92)	0.11 (93)	0.11 (92)	0.12 (99)	0.05 (41)	0.05 (38)
Av. C/N0 [dBHz]	43+-2	44+-2	44+-3	43+-3	44+-3	51+-1	50+-1

Polarstern Setup during MOSAiC

Ny-Alesund Station on Svalbard

S4 scint. is …

Weak 0 … 0.5
Moderate 0.5 … 0.8
Strong > 0.8

σ(φ) [rad] scint. is …

Weak 0 … 0.4
Moderate 0.4 … 0.7
Strong > 0.7

Conclusions

- **GNSS remote sensing** from a ship requires adapted processing (separate reflected signals, consider movement and mask out ship structure disturbance)
- **Sea-ice**: reflectivity profiles are retrieved and fading in profiles indicate presence of transparent layer (dry snow and multiyear ice)
- **Phase Scintillation**: for MOSAiC period index in weak scintillation regime (higher than station data)
- **Amplitude Scintillation**: index mainly in weak regime, however, increased (by ~20%) in periods of increased movement (e.g. heave) or increased multipath (calm water reflection)
- sensitivity to moderate and strong iono. scintillation expected, more data needed

Acknowledgements

Support from MOSAiC team
G. Spreen, L. Kaleschke, R. Ricker, A. Tavri
Logistics at AWI & Crew of R/V Polarstern
Werkstatt and IT staff at DLR and GFZ
Ny-Ålesund Station data by Y. Jin

Data used here were produced as part of MOSAiC project.

Thank you for your attention.

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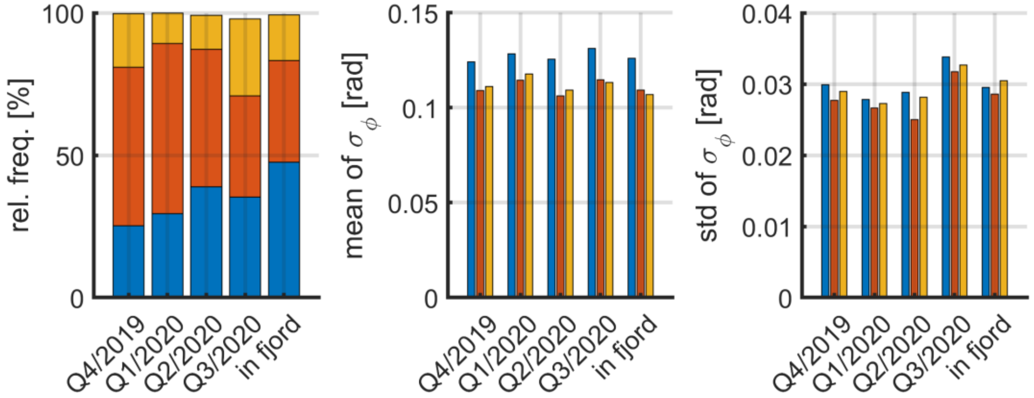
  URSI Radio Science Letters
- DLR IMPC 2023: Ionosphere Monitoring and Prediction Center
  https://impc.dlr.de/products/

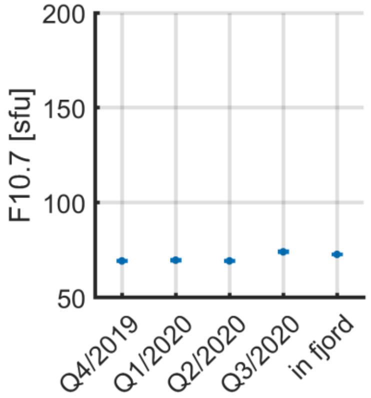
Appendix

σ_φ statistics comparing PS with station data

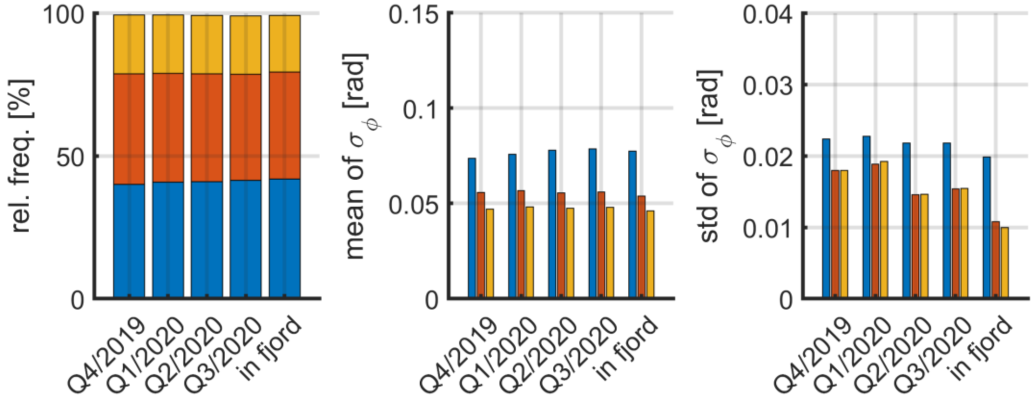
σ_φ on PS during MOSAiC – all weak (< 0.3 rad)



Solar radio flux – permanently low



σ_φ at Ny-Alesund station – all weak (< 0.3 rad)

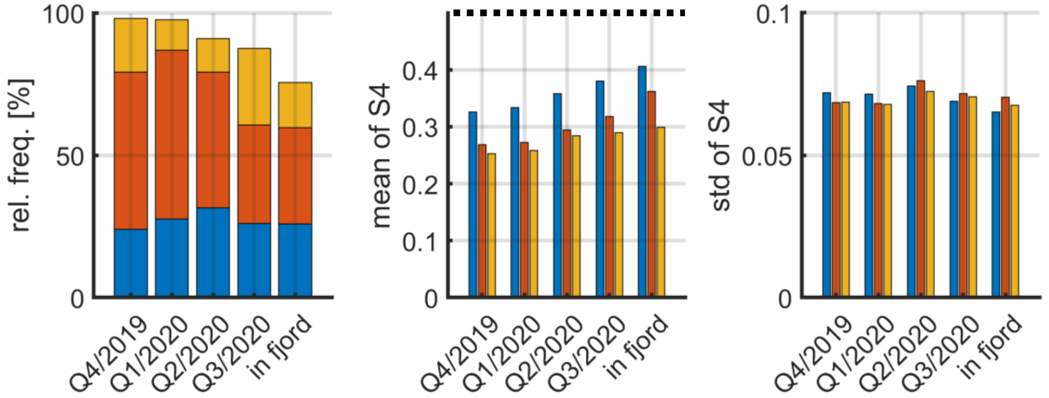


Remarks:

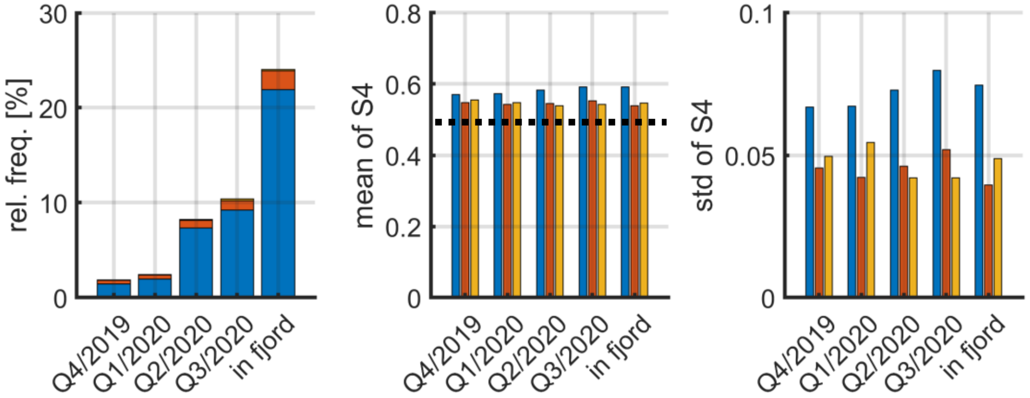
- In general, all σ_φ on PS and at the station are classified weak scint.
- σ_φ on average significantly higher on PS than at the station (0.05 rad to 0.1 rad)
- almost no changes over the year

S4 statistics comparing PS with station data

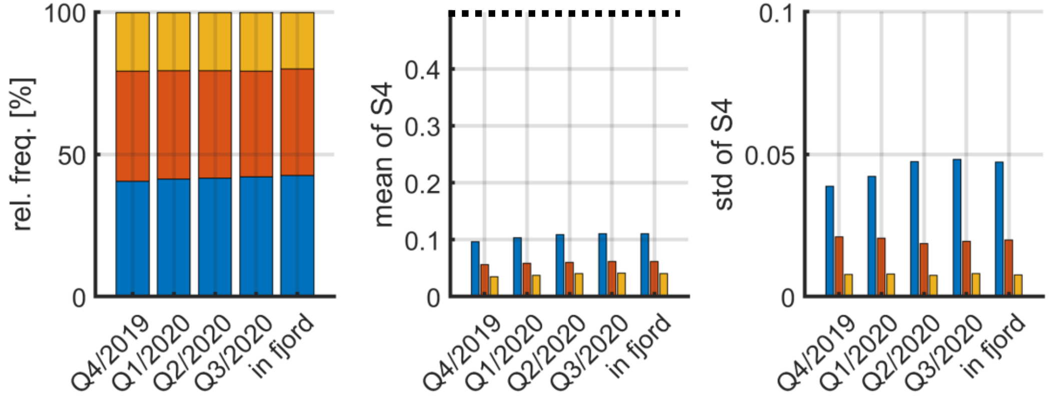
S4 on PS during MOSAiC – weak regime (< 0.5)



S4 on PS during MOSAiC – moderate regime (>= 0.5)



S4 at Ny-Alesund station – all weak (< 0.5)

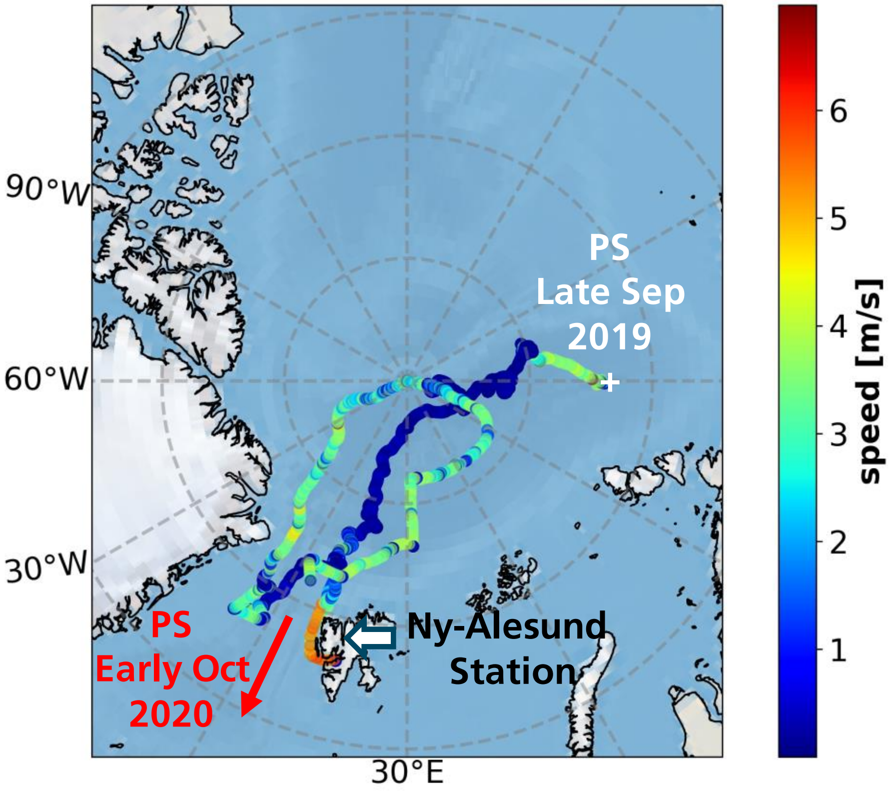


Remarks:

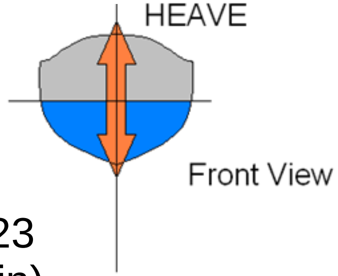
- weak part dominating (> 75%) of S4 for PS
- moderate part for PS mainly at low elev. (10°-30°), later in 2020 (Q2, Q3) and in fjord period
- S4 on average significantly higher for PS (0.25 … 0.55 rad) than for station (0.05)
- reason for increased S4 at PS ?

Movement of Polarstern

MOSAiC expedition: Sep 2019 - Sep 2020

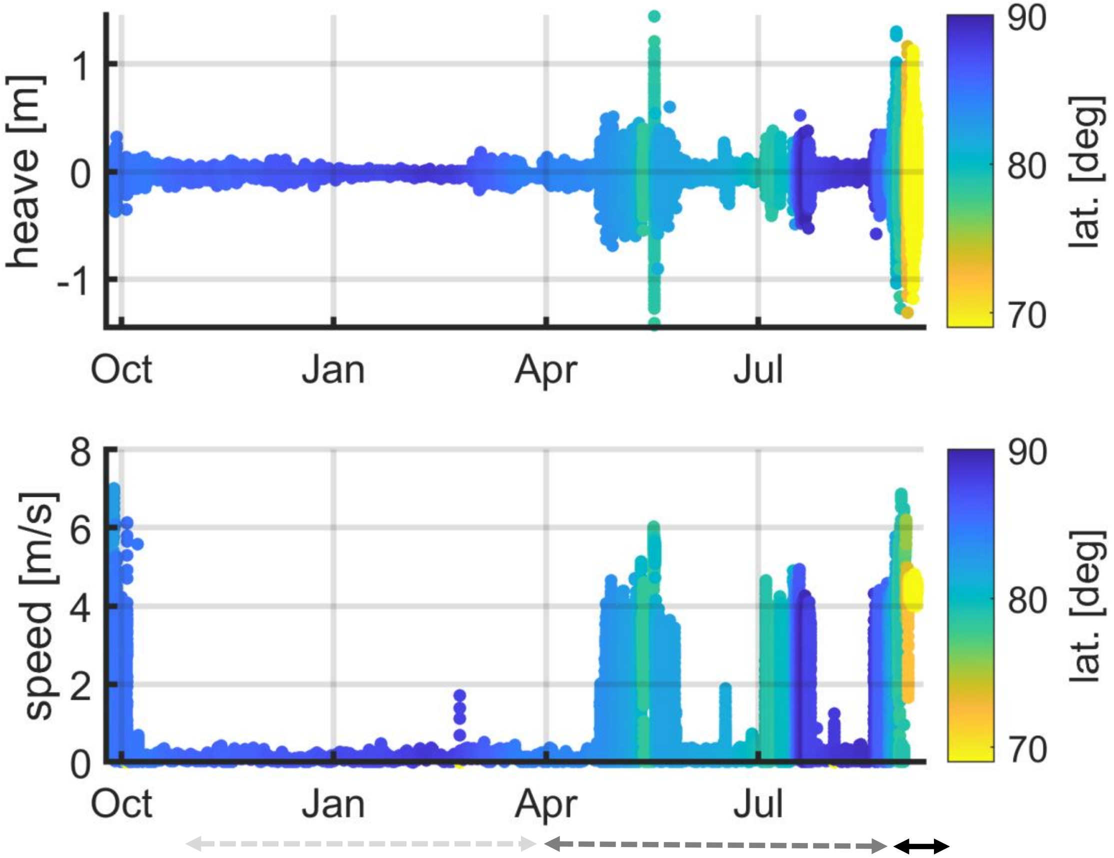


Cruising Periods: speed > 1 m/s
Drifting Period: speed < 1 m/s



Wikipedia 2023
(Public Domain)

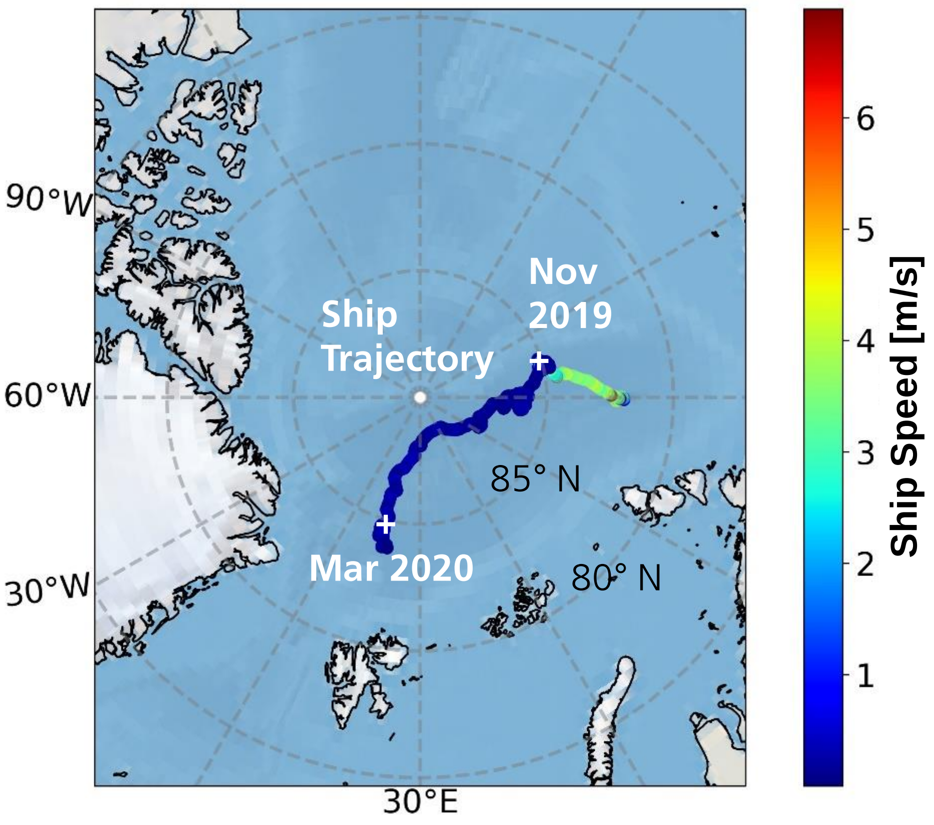
MOSAiC expedition: Polarstern 2019/2020



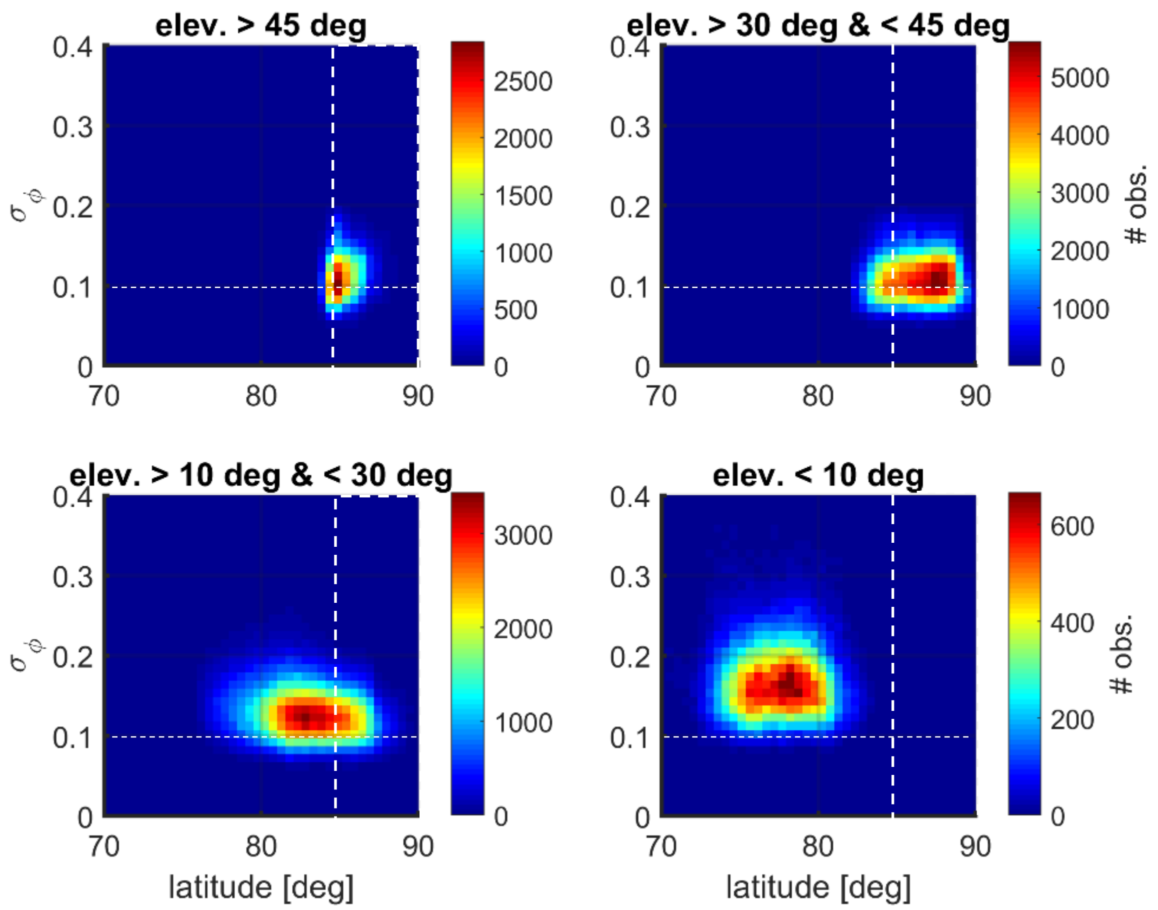
Drift (small heave) **Nov 2019 – Mar 2020**
Drift & cruise (var. heave) **Apr 2020 – Sep 2020**

Drift - High Arctic - Winter

GNSS obs. in the Central Arctic



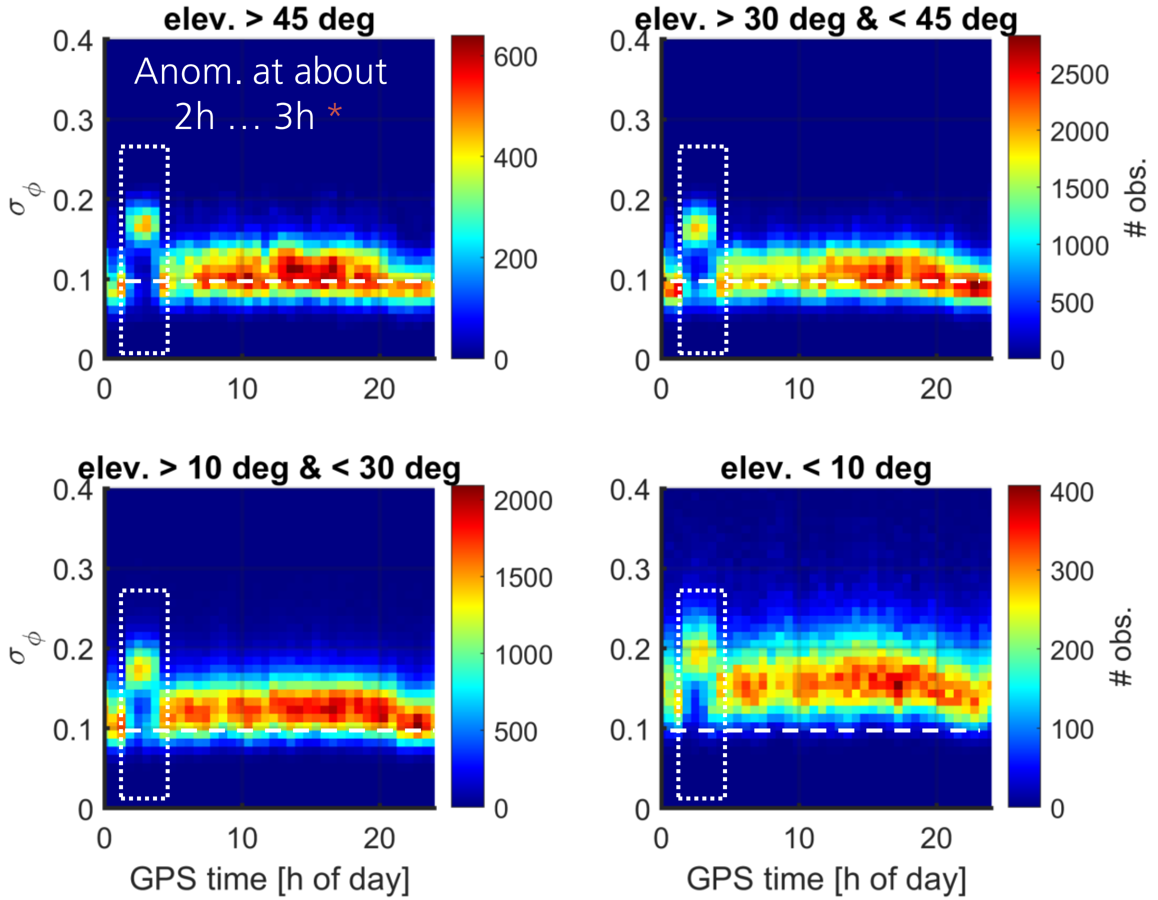
σ_φ over lat. at IPP (height 350 km)



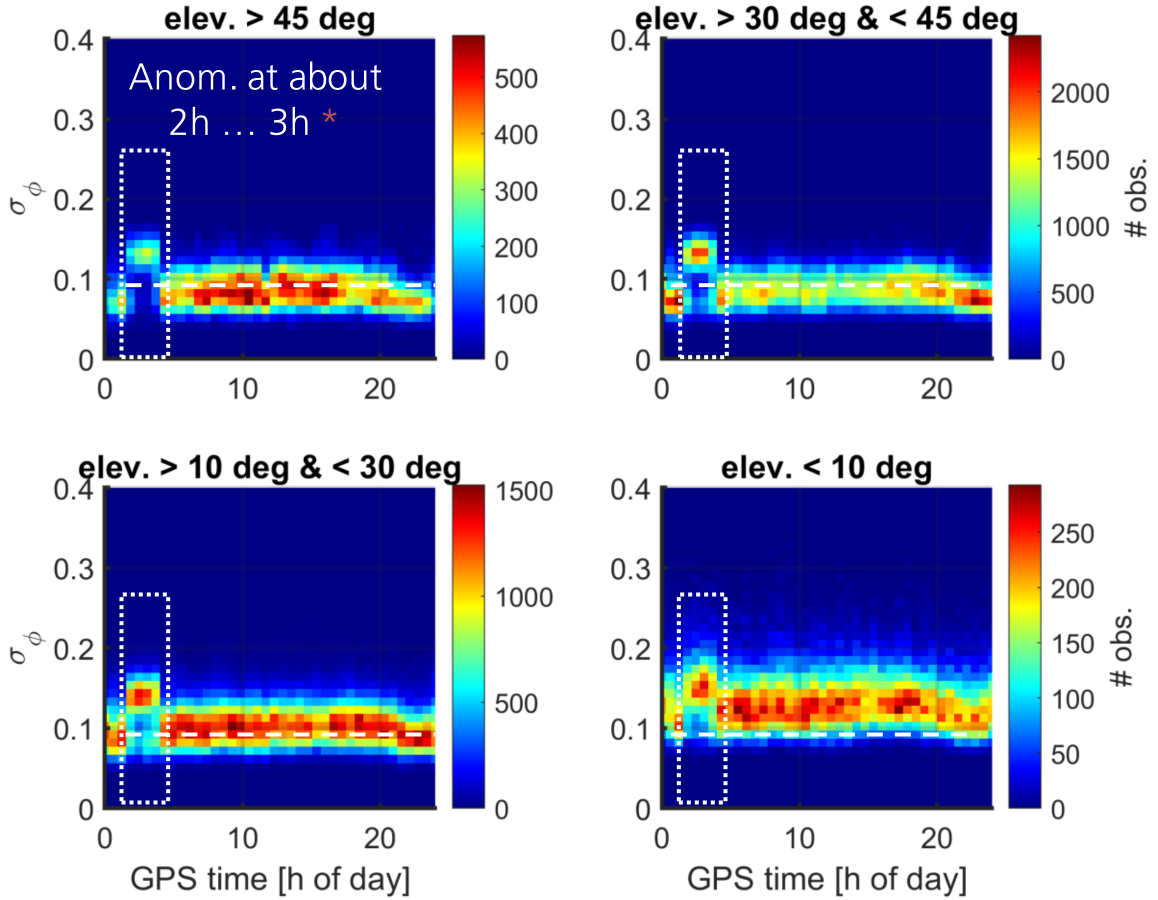
Nov 2019 … Mar 2020

Drift - High Arctic - Winter

σ_φ for GPS L1 C/A over hour of day



σ_φ for GPS L2C over hour of day



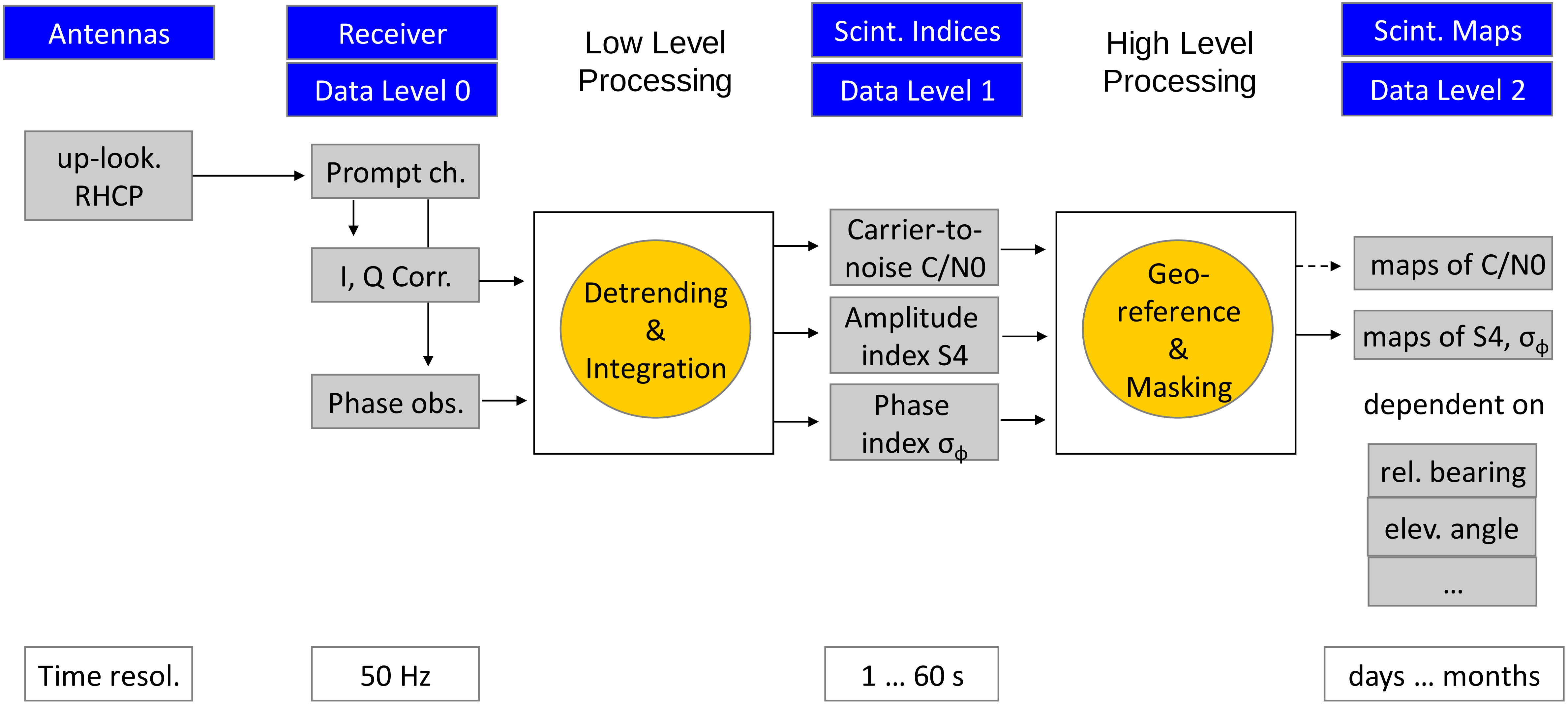
Nov 2019 … Mar 2020

* Ship effect?

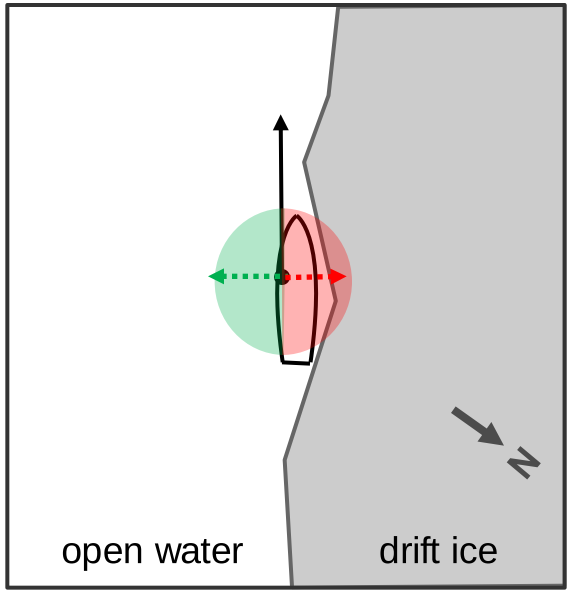
Nov 2019 … Mar 2020

Processing and Masking of Ship-based Data

High-rate GNSS Data Processing



Limits of Visibility from the Ship

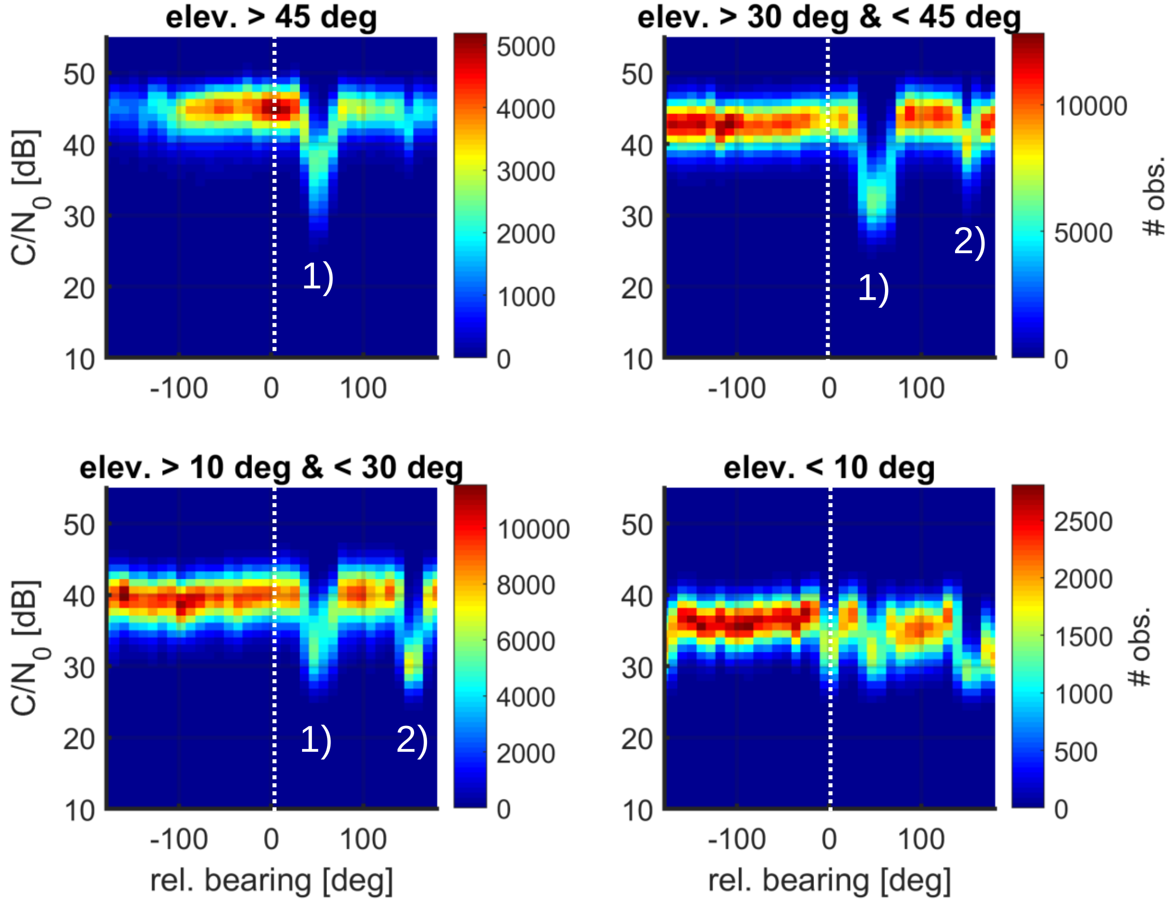


clear view
to port-side

left rel. Bearing:
-180° to 0°

heading of the ship
right rel. bearing (blocked)
left rel. bearing (clear)

C/N0 over rel. bearing

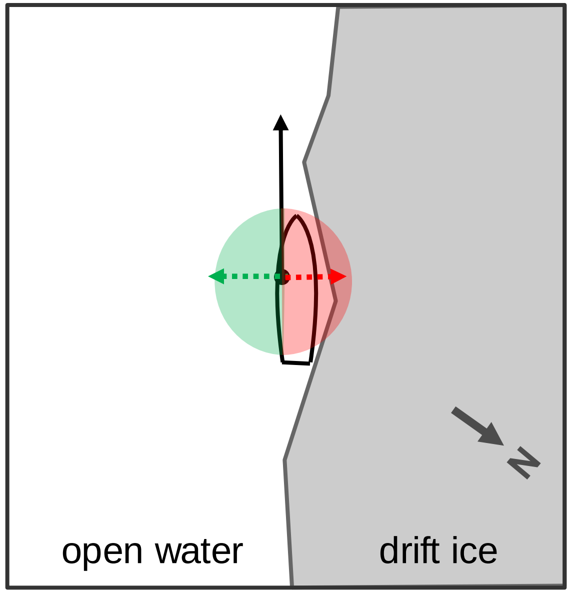


1) ship's main mast
2) ship's chimney

Sep 2019 … Sep 2020

Semmling et al. 2023

Limits of Visibility from the Ship

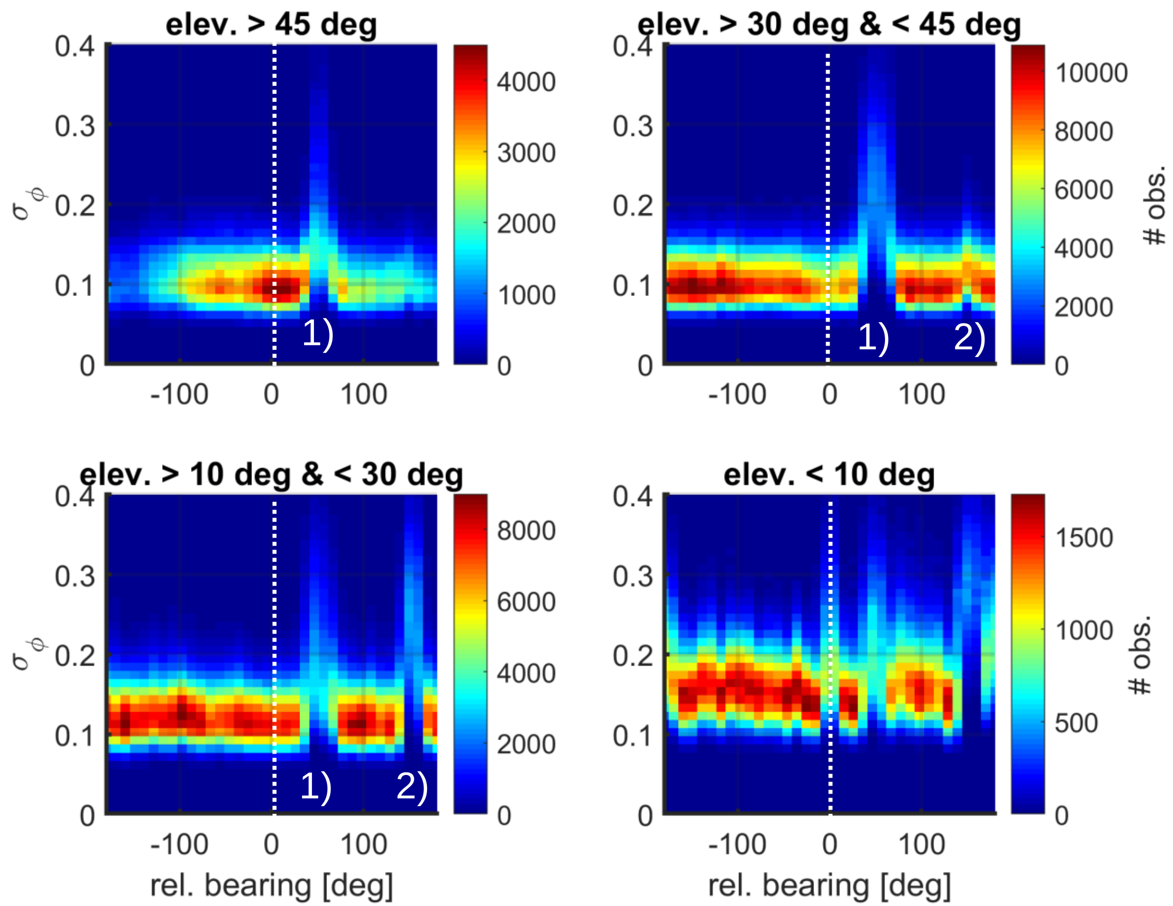


clear view
to port-side

left rel. Bearing:
-180° to 0°

heading of the ship
right rel. bearing (blocked)
left rel. bearing (clear)

σ_φ over rel. bearing



1) ship's main mast
2) ship's chimney

Sep 2019 … Sep 2020