Retrieval and Validation of Ionospheric Indices for Ship-based Monitoring over the Arctic

M. Semmling (1), H. Sato (1), M. Kriegel (1),
F. Fohlmeister (2), Y. Jin (3), J. Berdermann (1),
M. Hoque (1)

(1) Institute for Solar-Terrestrial Physics DLR-SO, Neustrelitz, Germany
(2) Institute of Communication and Navigation DLR-KN, Oberpfaffenhofen, Germany
(3) University of Oslo UiO, Oslo, Norway

IAG Assembly, Rimini, September 2025

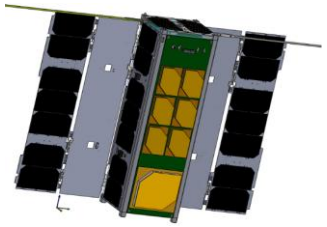
Photo Polarstern: Peter Lemke, AWI

Outline

- Motivation GNSS Remote Sensing
- MOSAiC Expedition and GNSS Data in the Arctic
- Processing and Masking of Ship-based Data
- Results of Scintillation Index Analysis
- Conclusions

Motivation GNSS Remote Sensing

- A: Low Earth Orbiter



Wickert et al. 2016
Semmling et al. 2016

- B: Aircraft

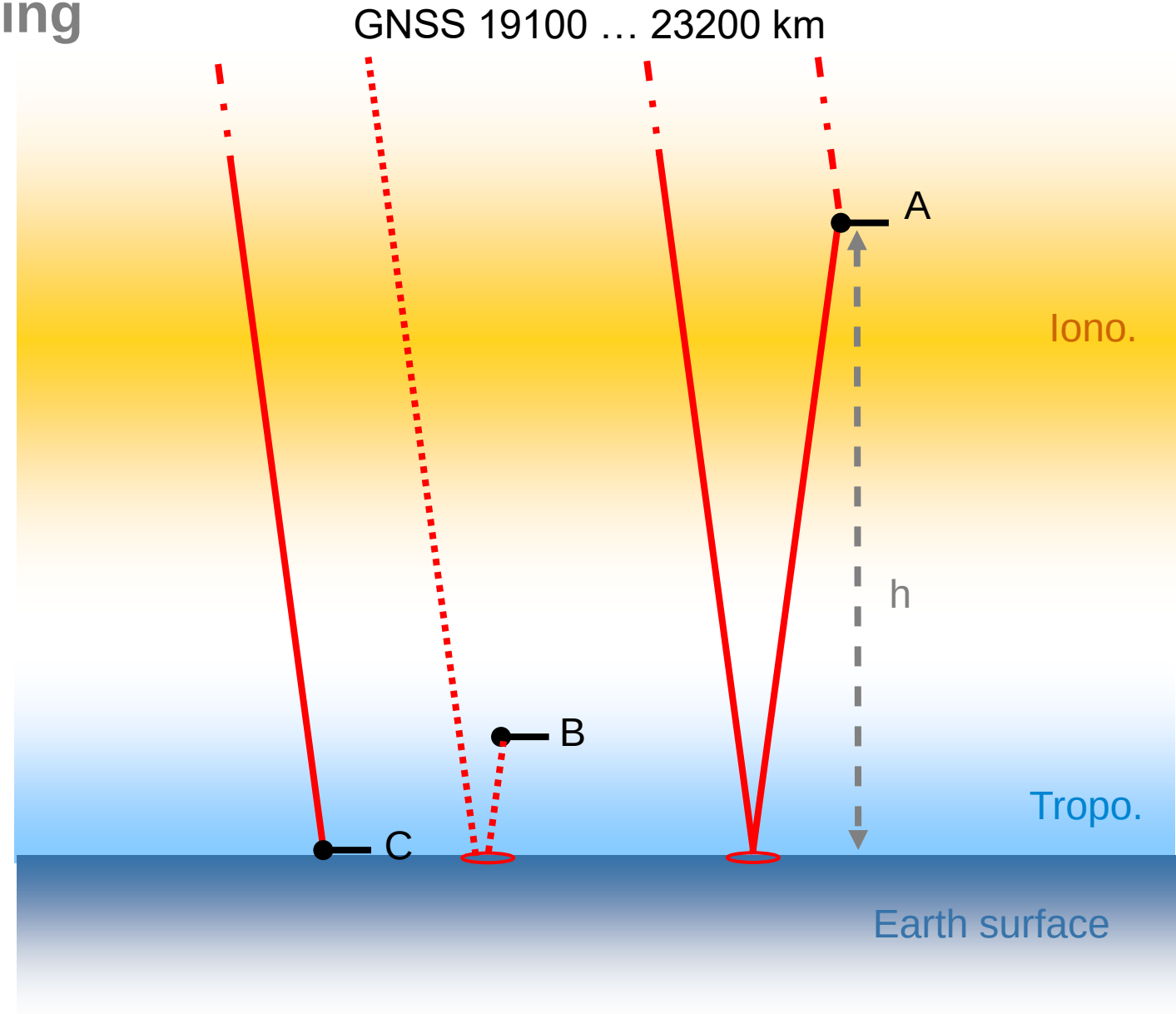
Semmling et al. 2014
Moreno et al. 2021

- C: Research Vessels

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

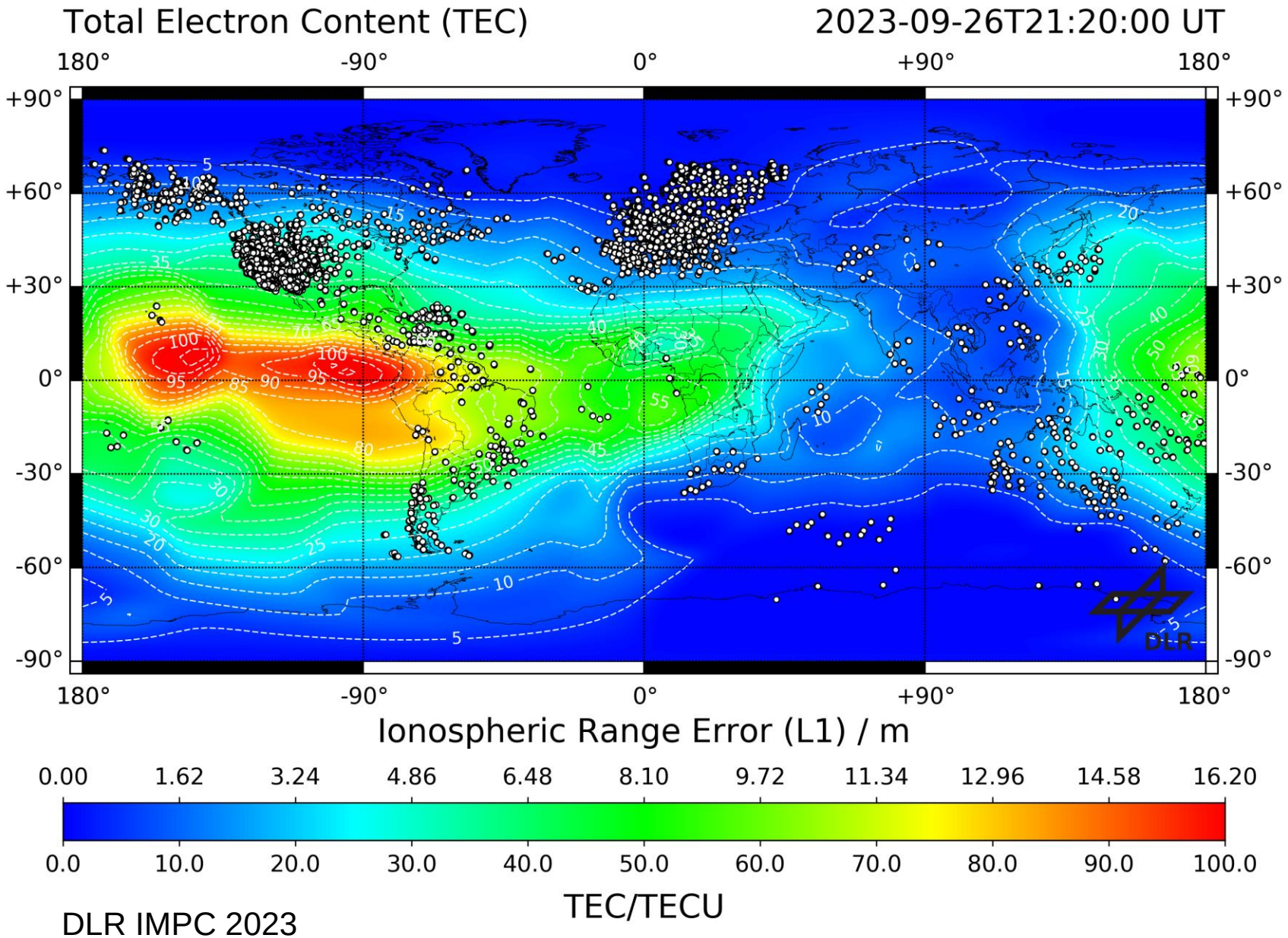
- Application

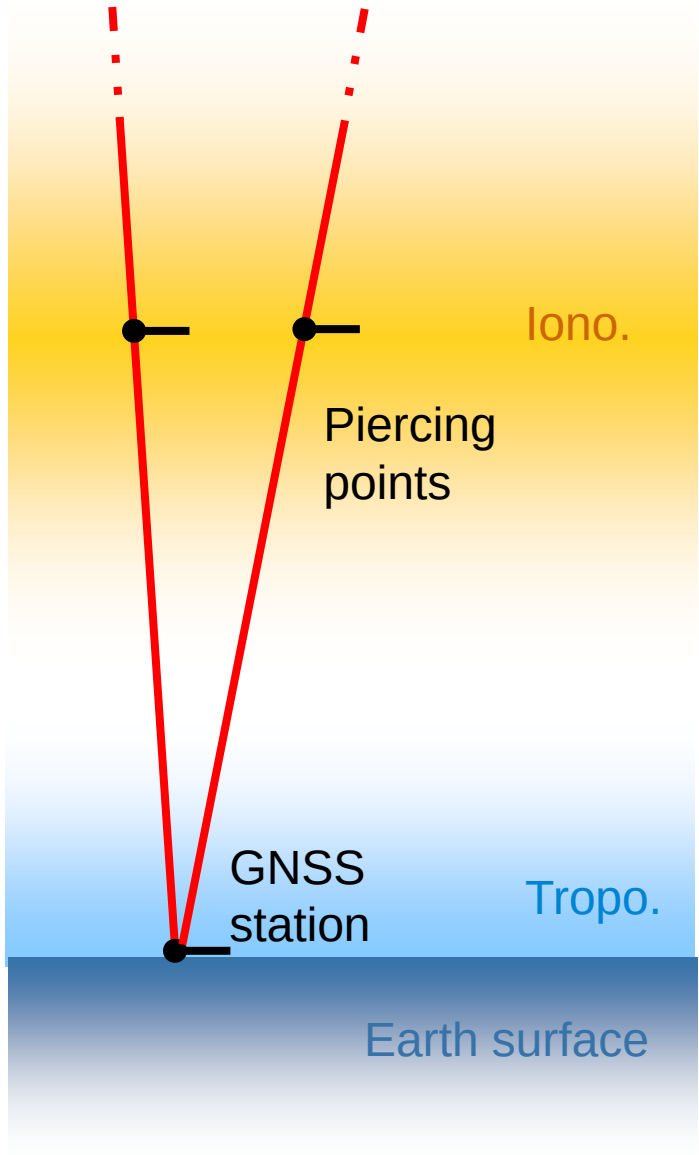
sea surface altimetry
sea state estimation
sea-ice detection
water vapor estimation
iono. scintillation detection



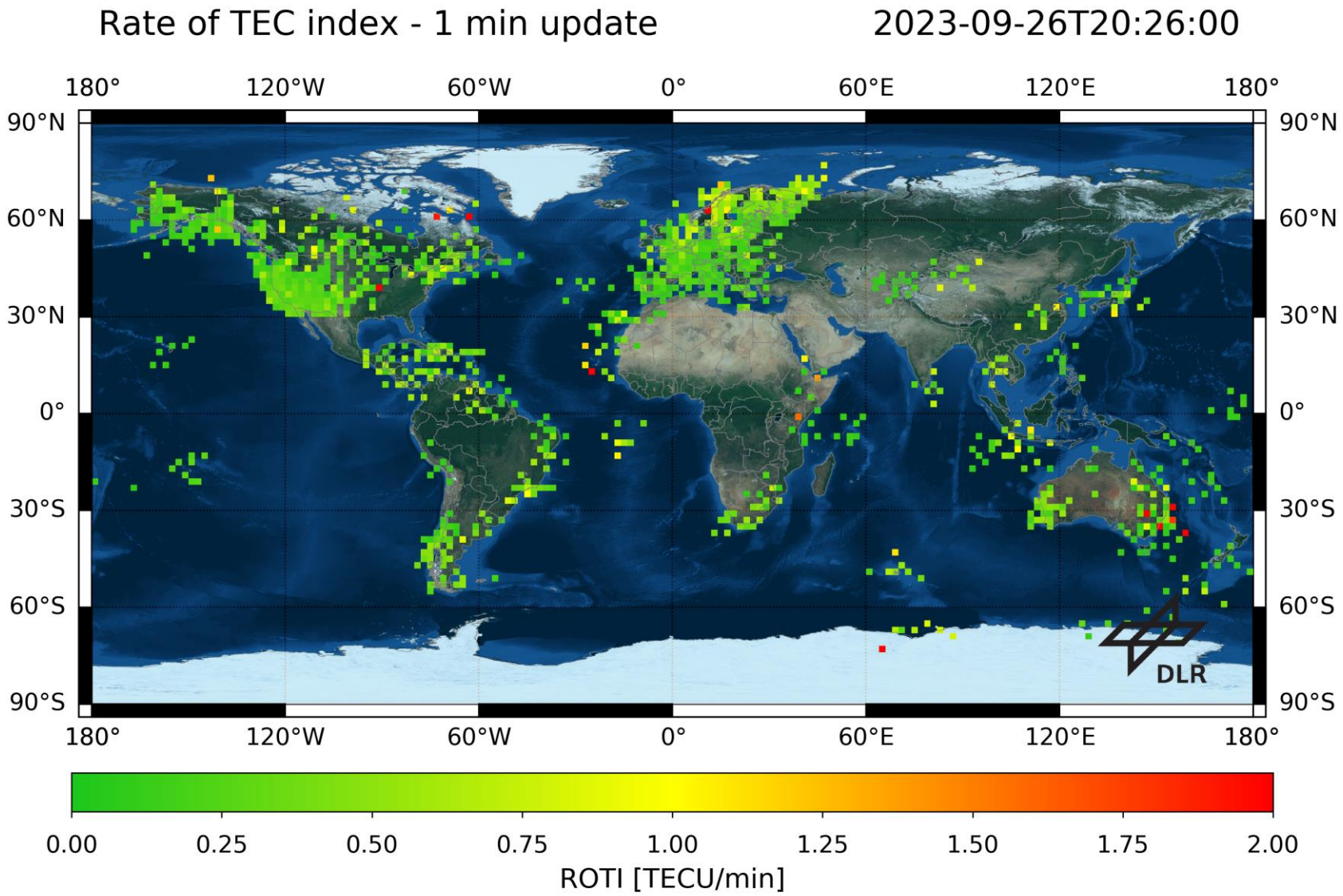
A: e.g. PRETTY, h ~ 500 km
B: e.g. HALO, h ~ 3500 m
C: e.g. Polarstern, h ~ 25 m

Ionosphere TEC Monitoring with GNSS

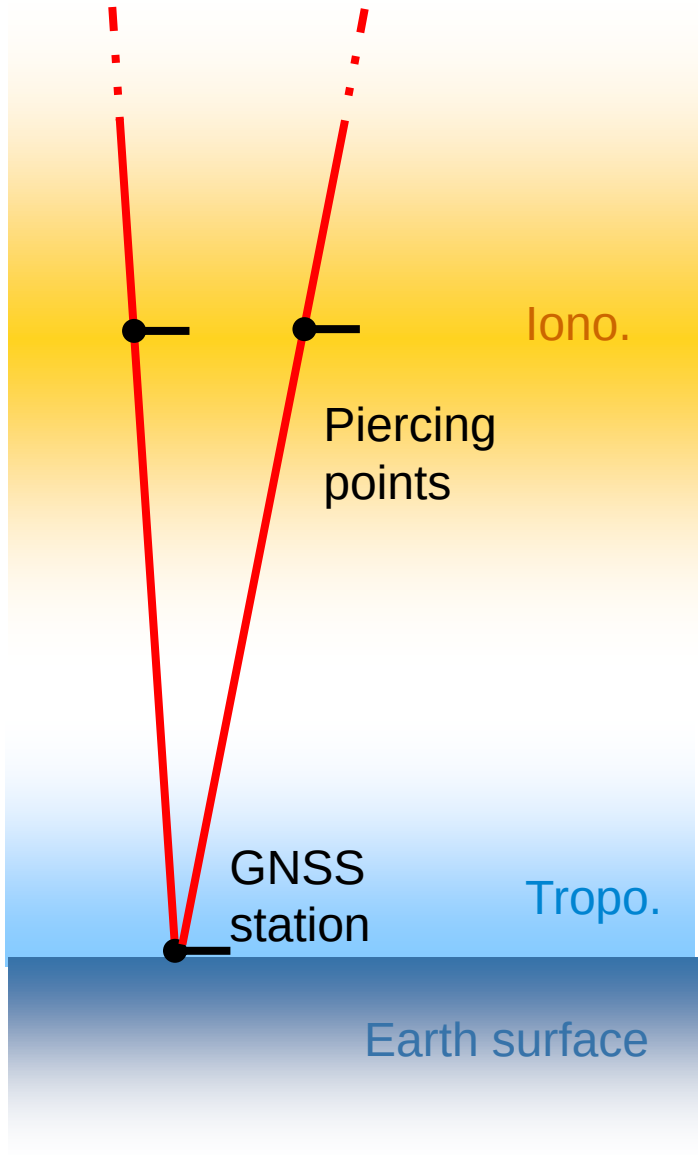




Ionosphere Disturbance Monitoring with GNSS



DLR IMPC 2023

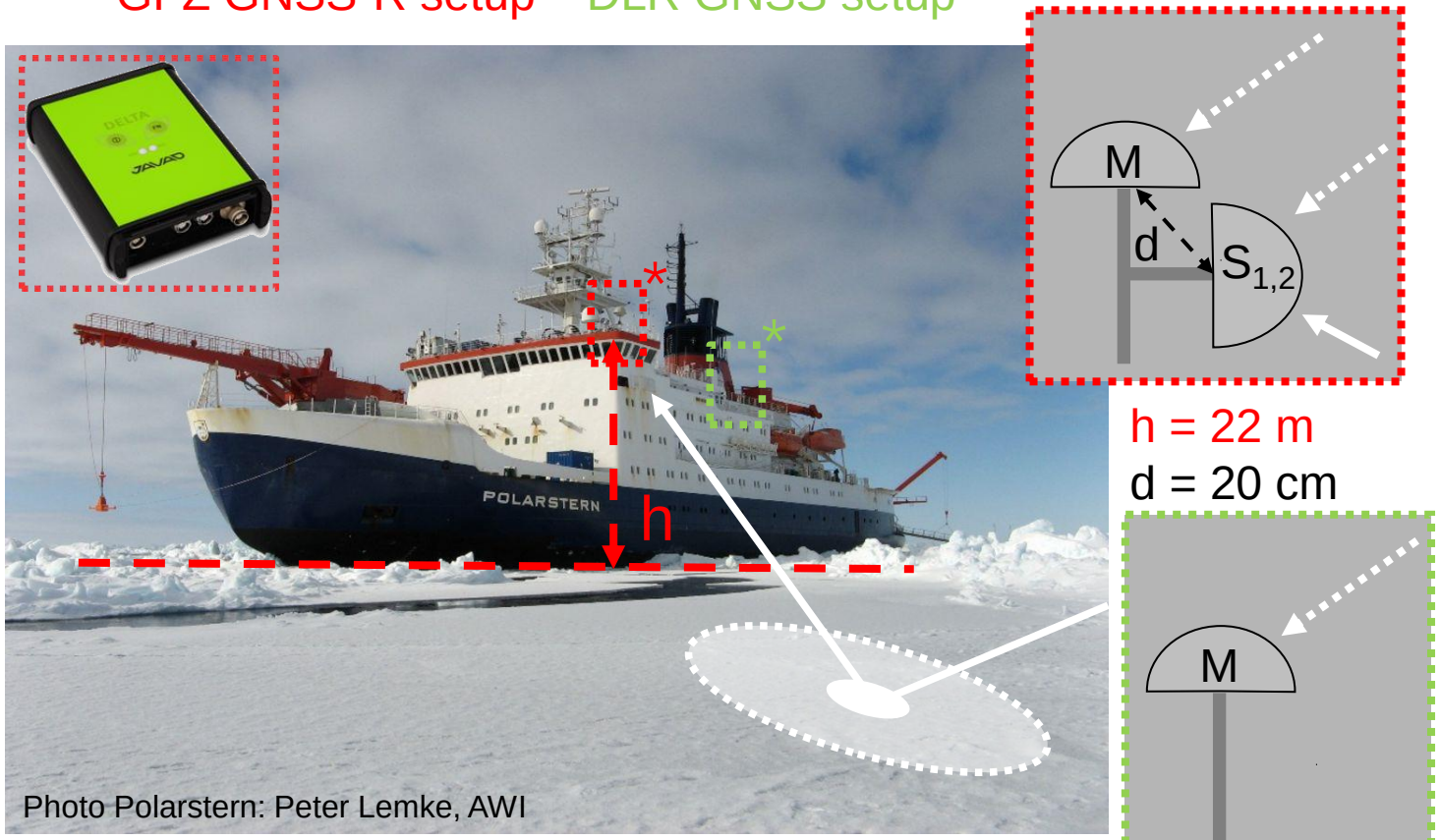


Can we benefit from ship-based data?

MOSAiC Expedition and GNSS Data in the Arctic

MOSAiC Expedition and Polarstern Setup

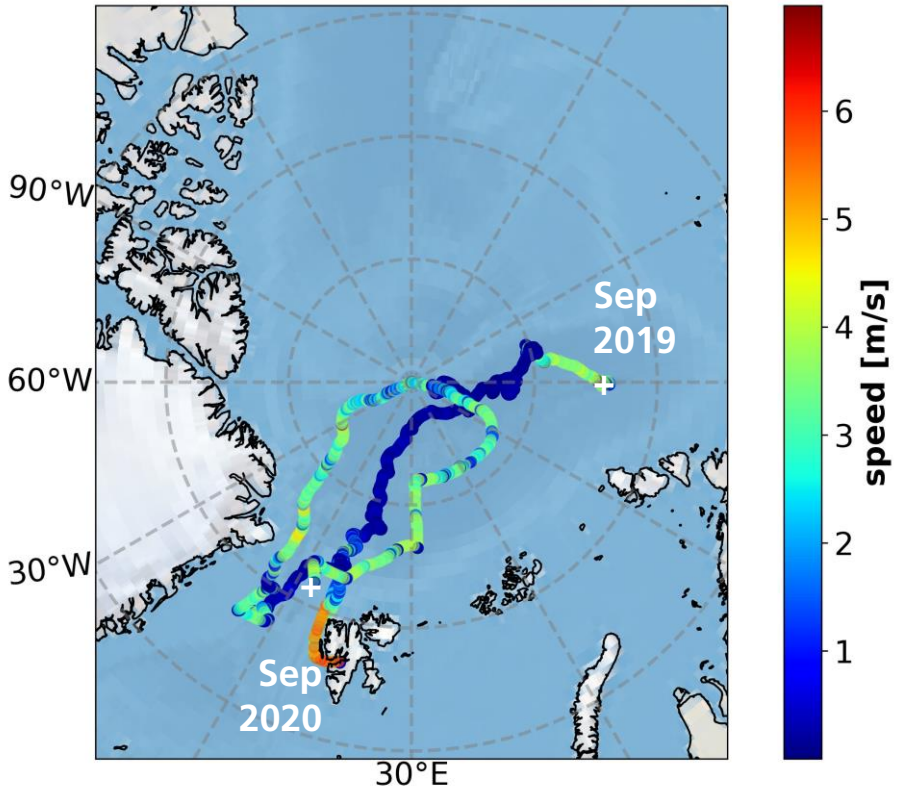
* GFZ GNSS-R setup * DLR GNSS setup



Helm et al. 2007
Semmling et al. 2013, 2022
Kriegel et al. 2017
Semmling et al. 2023

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

MOSAiC expedition: Sep 2019 - Sep 2020

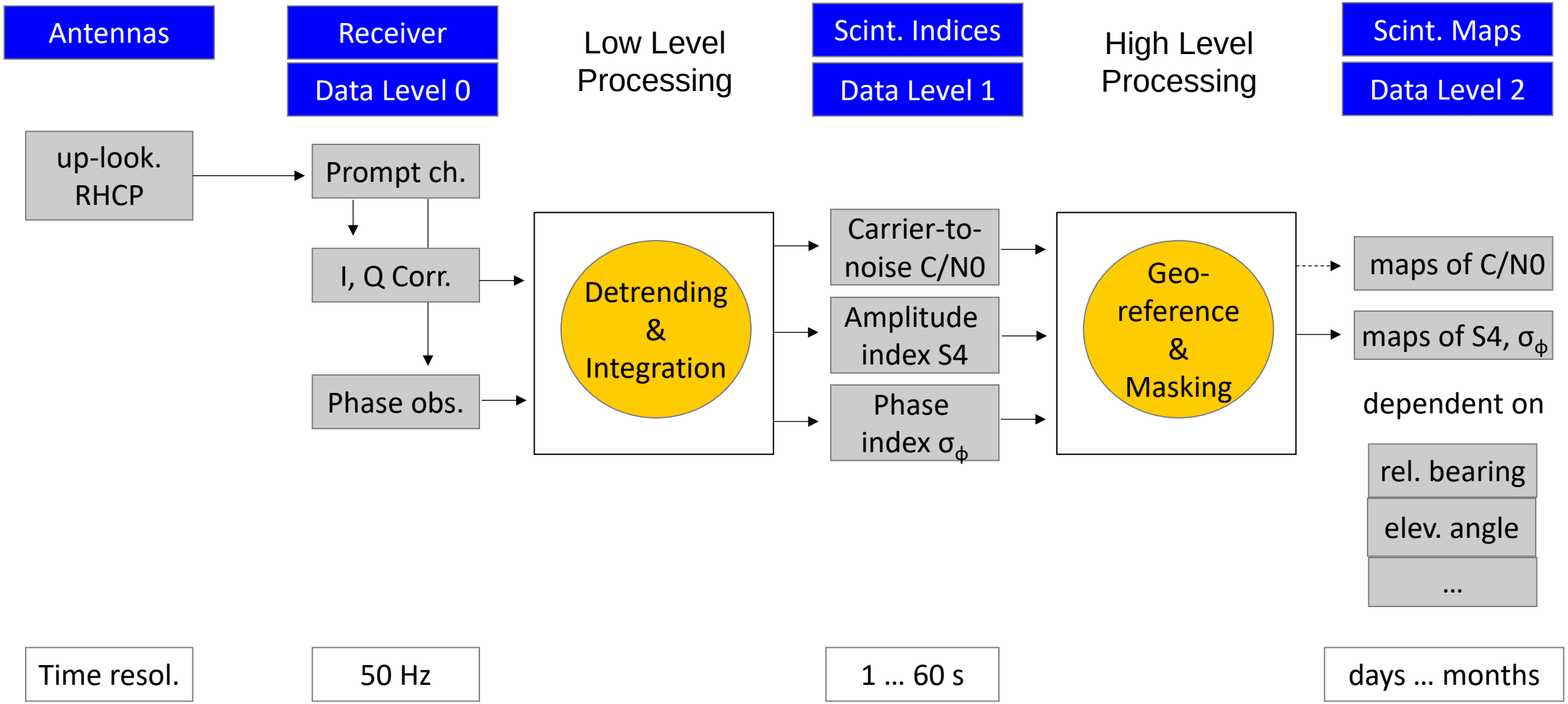


Cruising Periods: speed > 1 m/s
Drifting Period: speed < 1 m/s

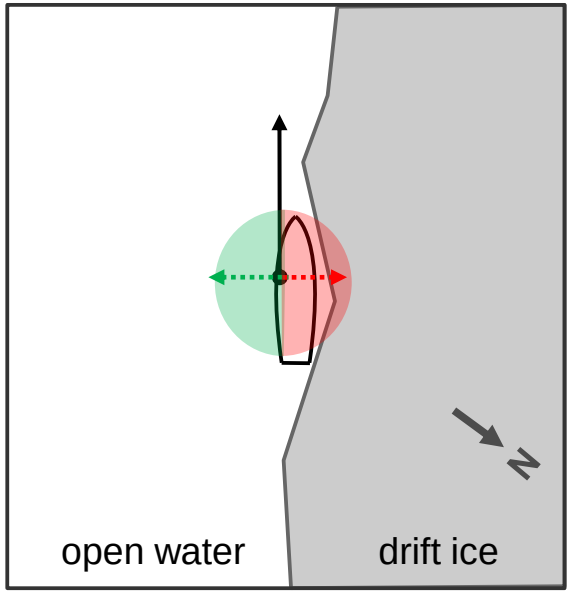
MOSAiC Expedition and Polarstern Setup

Processing and Masking of Ship-based Data

High-rate GNSS Data Processing



Limits of Visibility from the Ship

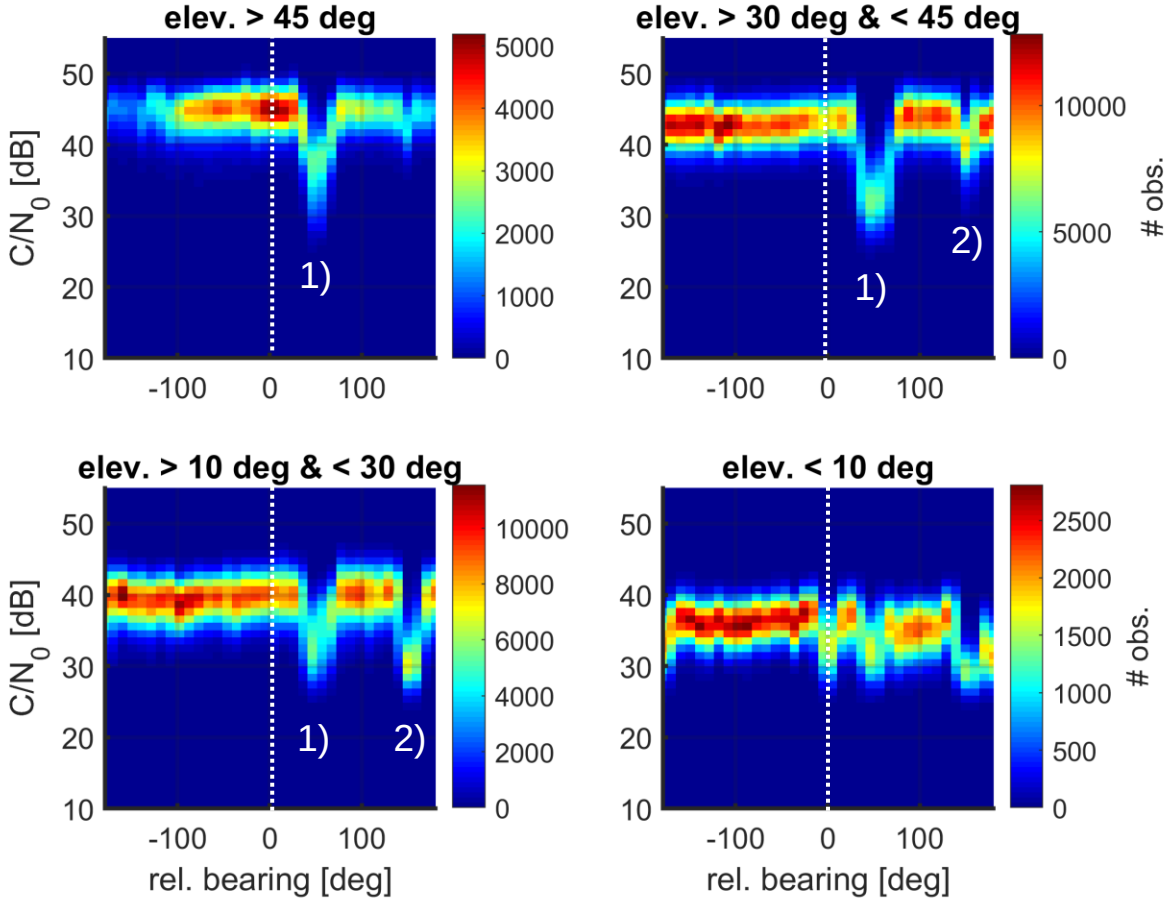


clear view
to port-side

left rel. Bearing:
-180° to 0°

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

C/N0 over rel. bearing

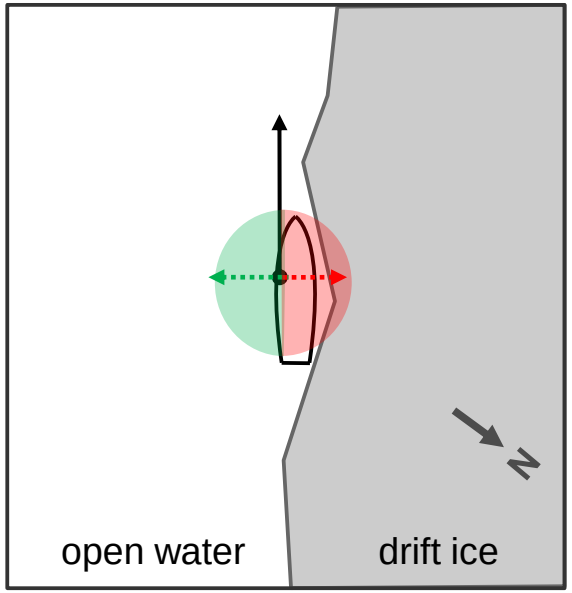


1) ship‘s main mast
2) ship‘s chimney

Sep 2019 … Sep 2020

Semmling et al. 2023

Limits of Visibility from the Ship

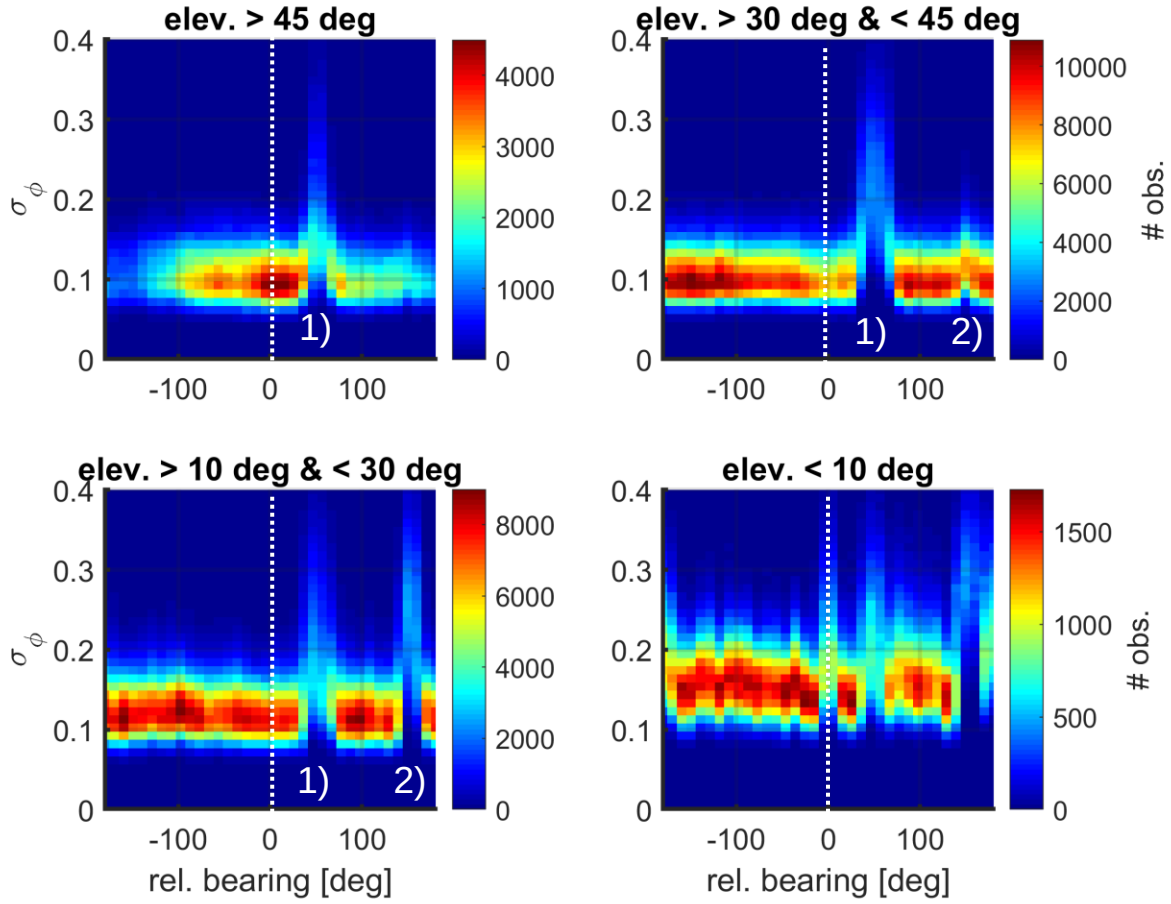


clear view
to port-side

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

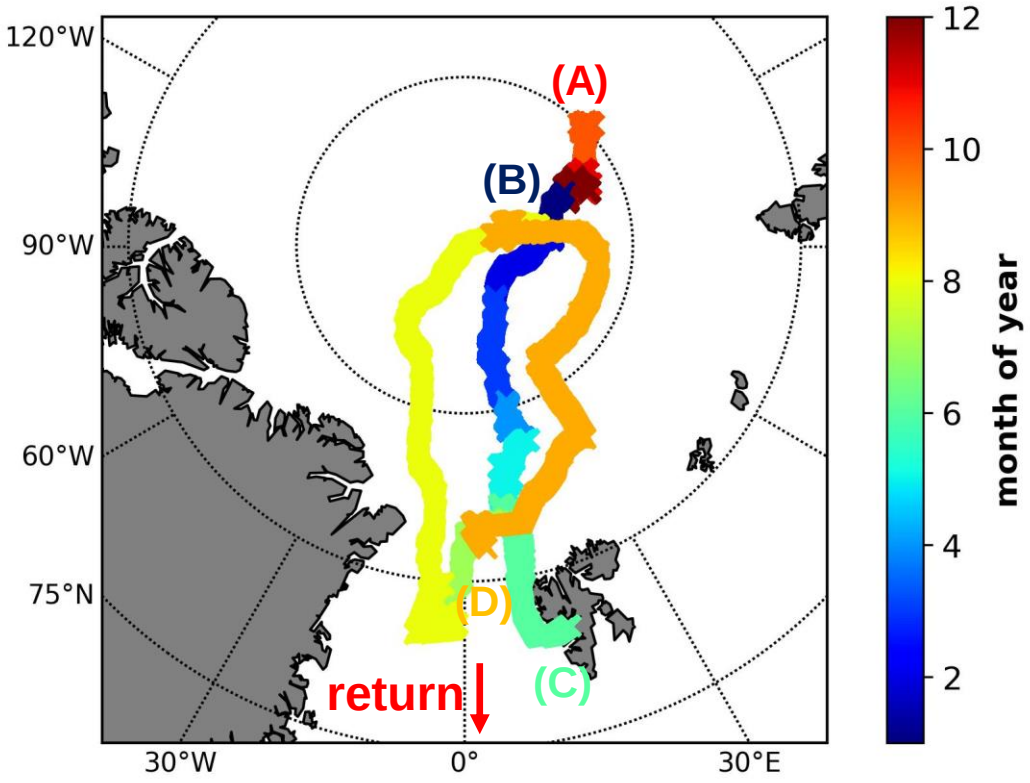
Sep 2019 … Sep 2020

Results of Ionospheric Index Analysis

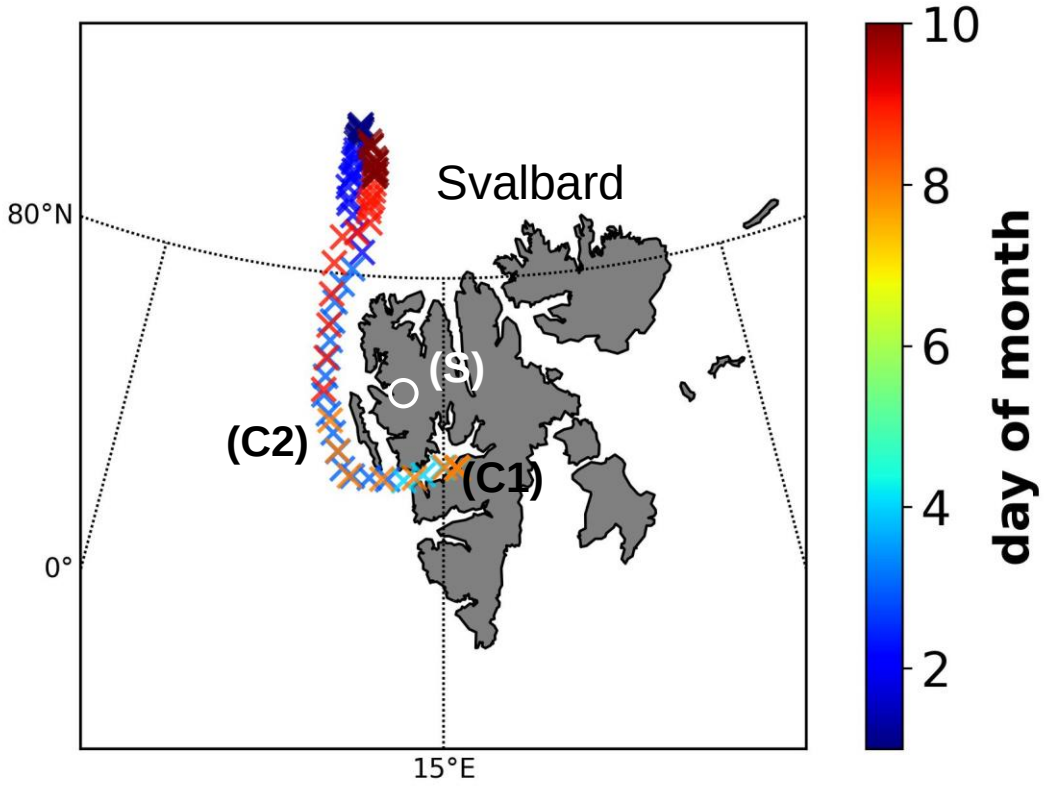
Are the results comparable to station data?

Track of R/V Polarstern (PS)

Oct 2019 to Sep 2020



Jun 2020



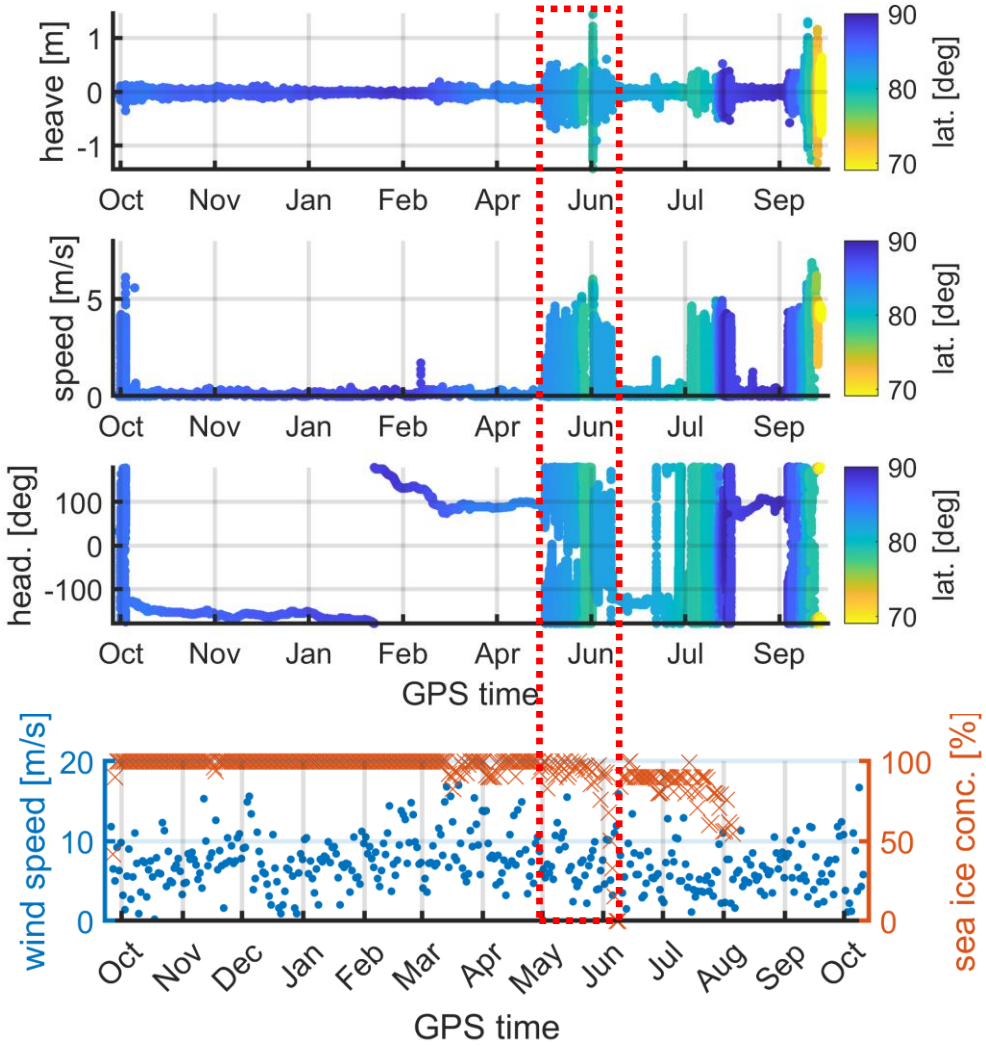
(A) Oct 1, 2019 — before drift
(B) Jan 15, 2020 — in ice
(C) Jun 5-8, 2020 — near Svalbard
(D) Sep 30, 2020 — before return

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

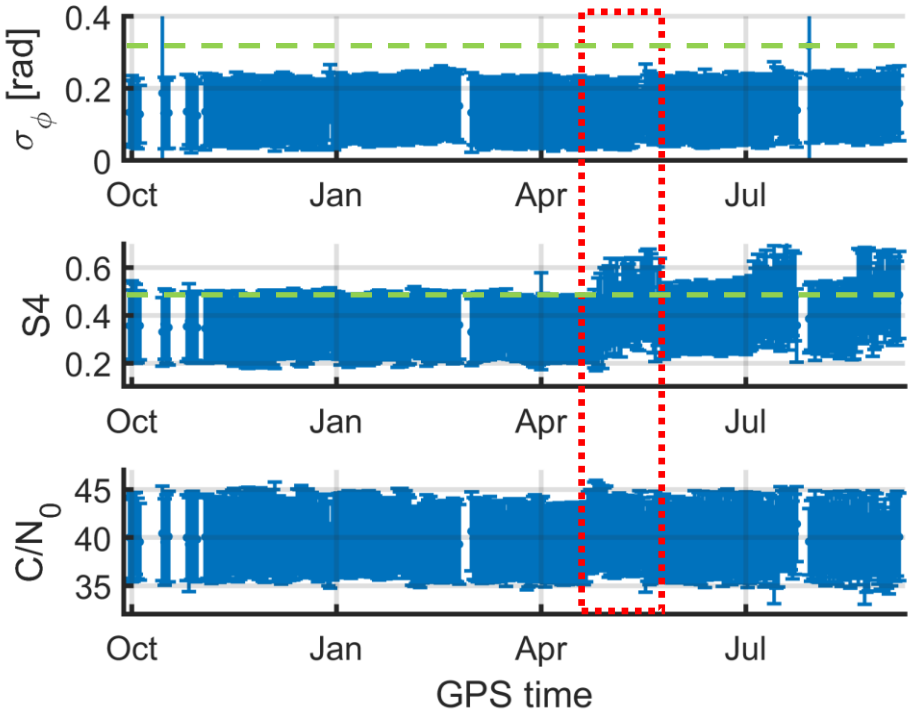
(S) Ny-Alesund station operated by Univ. of Oslo

PS results in relation to ship conditions

In Arctic Ice Approach to Svalbard



Index Data at PS



weak scint. limit
$\sigma_\varphi < 0.3$ rad

weak scint. limit
S4 < 0.5

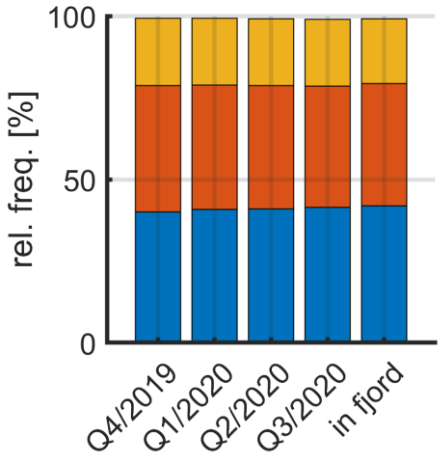
Semmling et al.
under review

parameter x	heave	head. spread	sea ice conc.
R(σϕ, x)	-0.1	0.0	-0.3
R(S4, x)	**0.6**	**0.7**	**-0.7**
R(ROTI, x)	**0.7**	**0.7**	-0.4

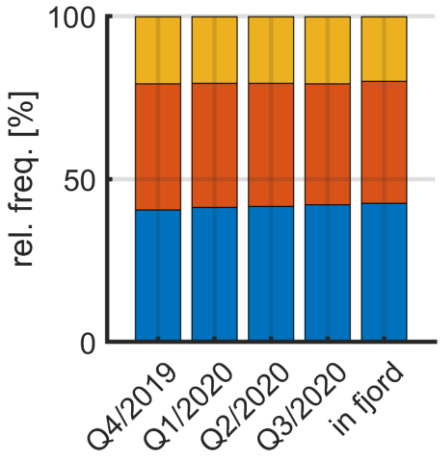
Validation with station data

1) Ny-Alesund station

σ_φ < 0.3 rad (weak)

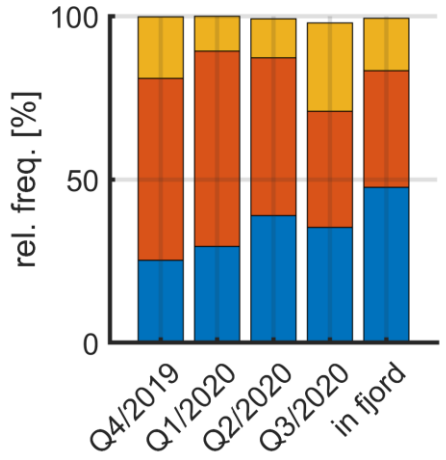


S4 < 0.5 (weak)

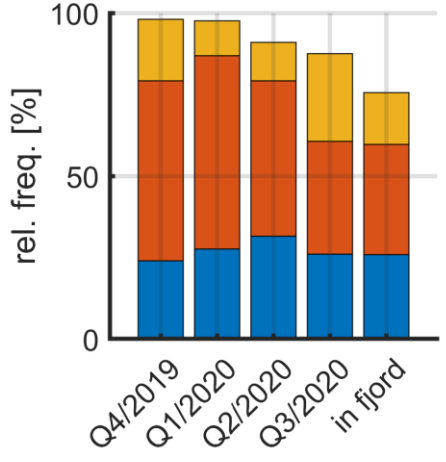


2) PS during MOSAiC

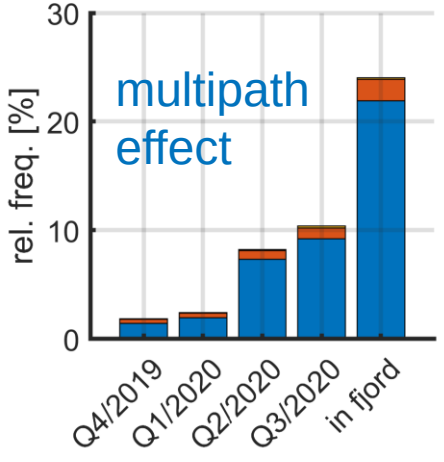
σ_φ < 0.3 rad (weak)



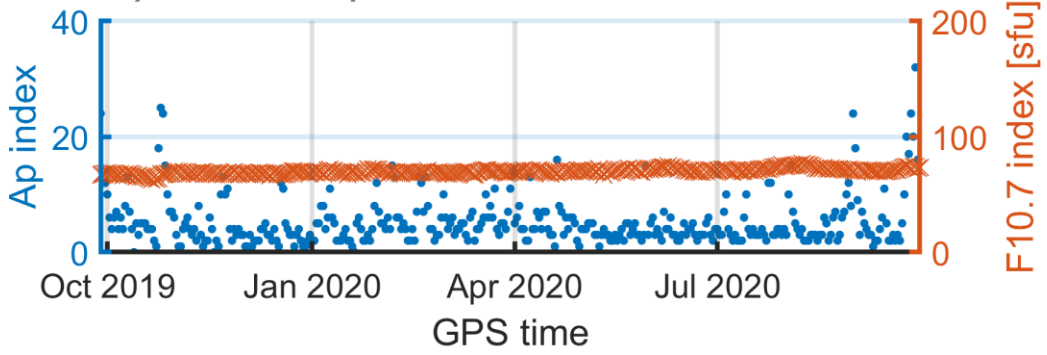
S4 < 0.5 (weak)



S4 higher (moderate)



3) Global Space Weather Indices



Remarks:

- weak scint. overall at high elev. (> 45°)
- increased multipath effect at low elev. (< 15°)
- calm space weather cond. no geomagn. storms constant low solar act.

High Medium Low elev.

Conclusions

- GNSS remote sensing from a ship requires adapted processing (mask out ship structure disturbance)
- MOSAiC data set allow retrievals of amplitude and phase scint. index (S4 and σ_φ) up to the central Arctic
- Scint. index values are mainly in the weak regime under calm space weather conditions in agreement with data of closest station (Ny-Alesund)
- Particularly S4 index is sensitive to ship‘s movement (heave, heading) and to multipath conditions (sea ice concentration nearby)

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

Data used here were produced as part of MOSAiC project.

Thank you for your attention.

References

- Helm et al. 2007: GORS - A GNSS Occultation, Reflectometry and Scatterometry Space Receiver.
  ION GNSS
- Semmling et al. 2013: A zeppelin experiment to study airborne altimetry using specular Global Navigation Satellite System reflections.
  Radio Science
- Semmling et al. 2016: A phase-altimetric simulator: studying the sensitivity of Earth-reflected GNSS signals to ocean topography.
  IEEE Transactions on Geoscience and Remote Sensing
- Wickert et al. 2016: GEROS-ISS: GNSS REflectometry, Radio Occultation and Scatterometry onboard the International Space Station.
  IEEE Selected Topics in Applied Earth Observations and Remote Sensing
- Kriegel et al. 2017: Scintillation measurements at Bahir Dar during the high solar activity phase of solar cycle 24.
  Ann. Geophys.
- Semmling et al. 2019: Sea Ice concentration derived from GNSS reflection measurements in Fram Strait.
  IEEE Transaction on Geoscience and Remote Sensing
- Wang et al. 2019: Retrieving Precipitable Water Vapor from Shipborne Multi-GNSS Observations.
  Geophys. Res. Lett.
- Semmling et al. 2022: Sea-ice permittivity derived from GNSS reflection profiles: Results of the MOSAiC expedition.
  IEEE Transaction on Geoscience and Remote Sensing
- Semmling et al. 2023: Ionosphere Sounding in the Central Arctic: Preliminary Results of the MOSAiC Expedition.
  URSI Radio Science Letters
- DLR IMPC 2023: Ionosphere Monitoring and Prediction Center
  https://impc.dlr.de/products/
- Semmling et al. (under review): Scintillation Index Monitoring over the Arctic Ocean: studying GNSS data of the MOSAiC Expedition.
  GPS Solutions