Scintillation Index Analysis of ship-borne GNSS Data recorded during the MOSAiC Expedition in the Arctic

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URSI AT-RASC, Gran Canaria, May 2024

Photo Polarstern: Peter Lemke, AWI

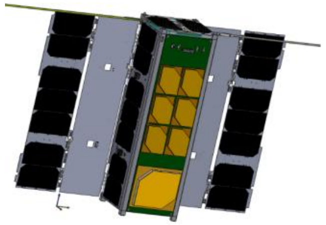
Outline

- GNSS Remote Sensing for Ionospheric Monitoring
- 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

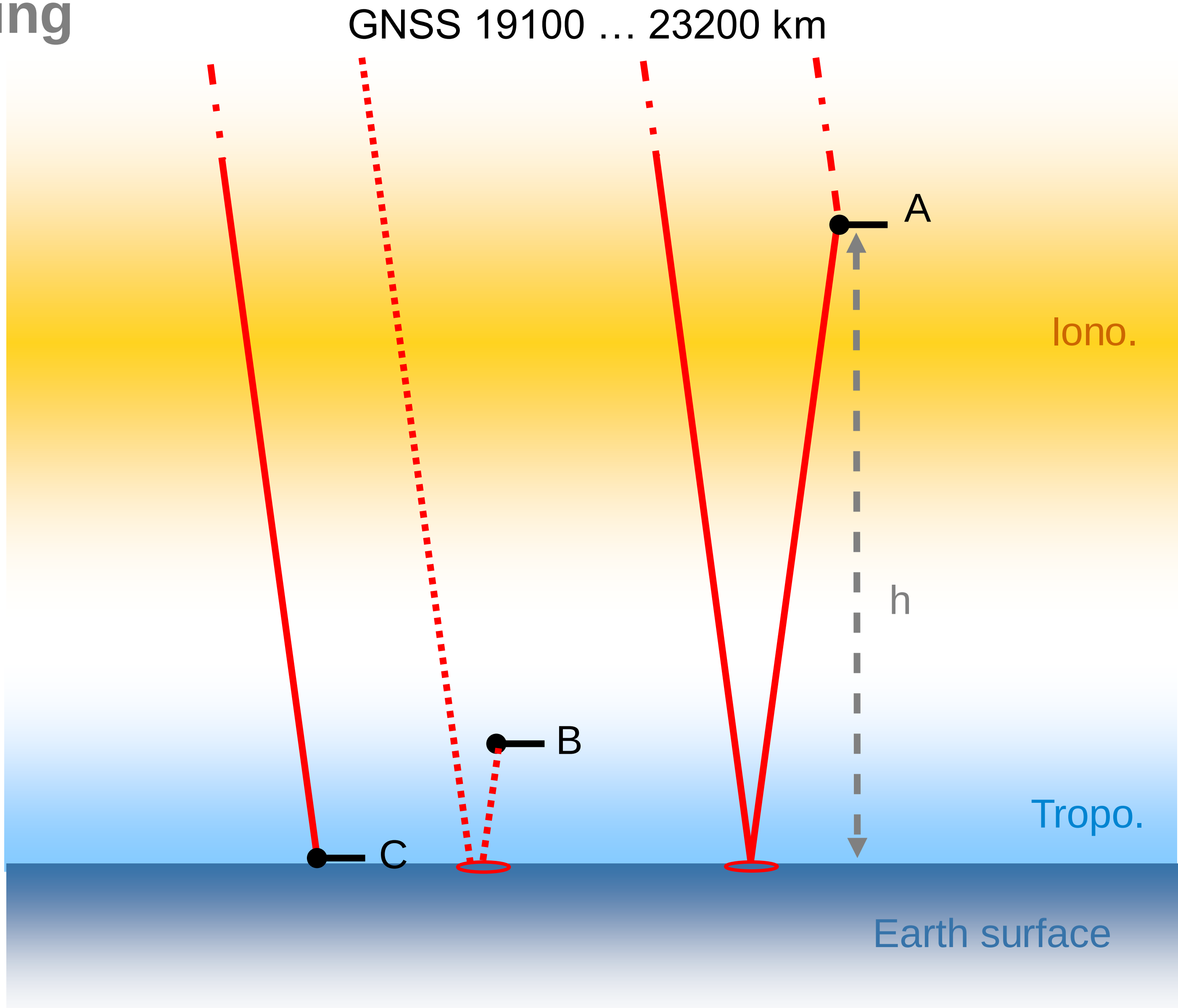
- C: Research Vessels

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

- Application

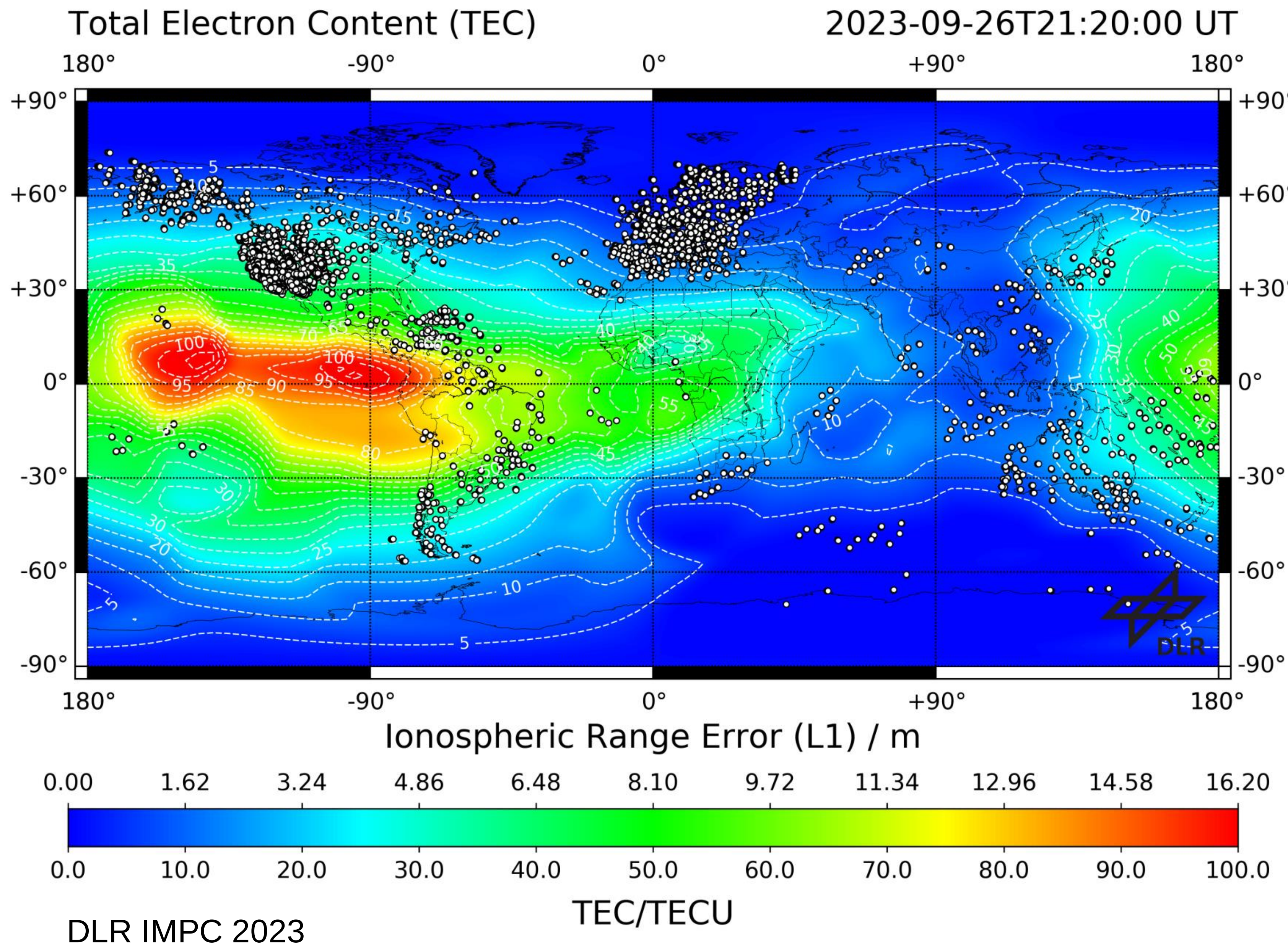
sea surface altimetry
sea state estimation
sea-ice detection

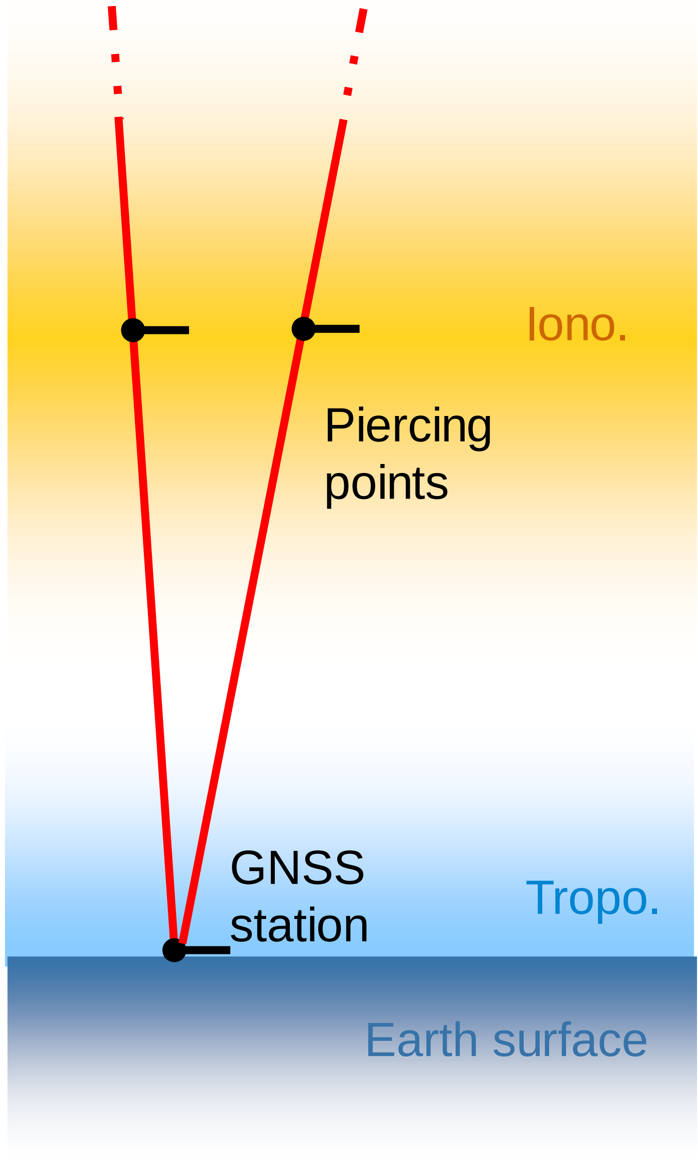
water vapor estimation
iono. scintillation detection



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





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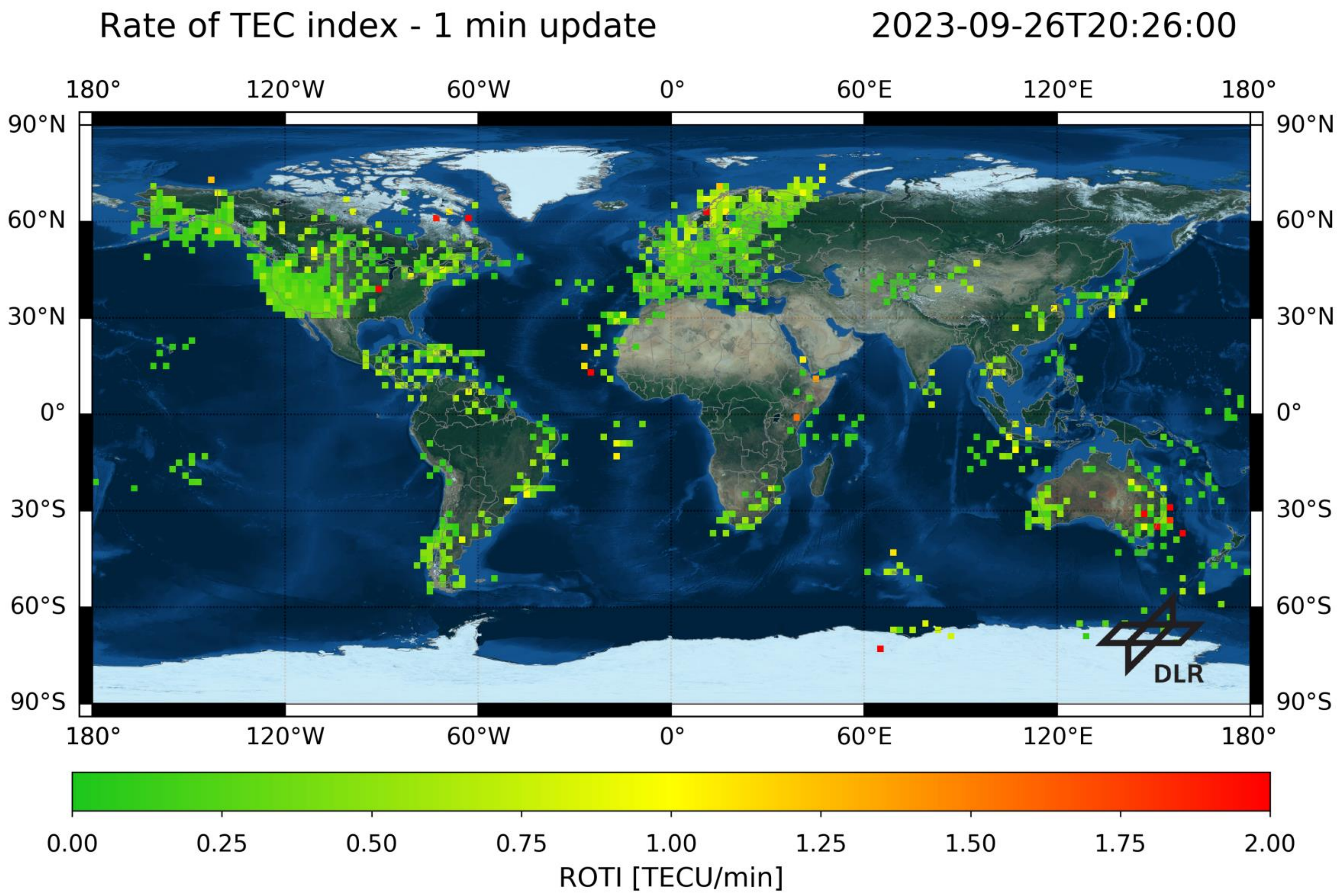
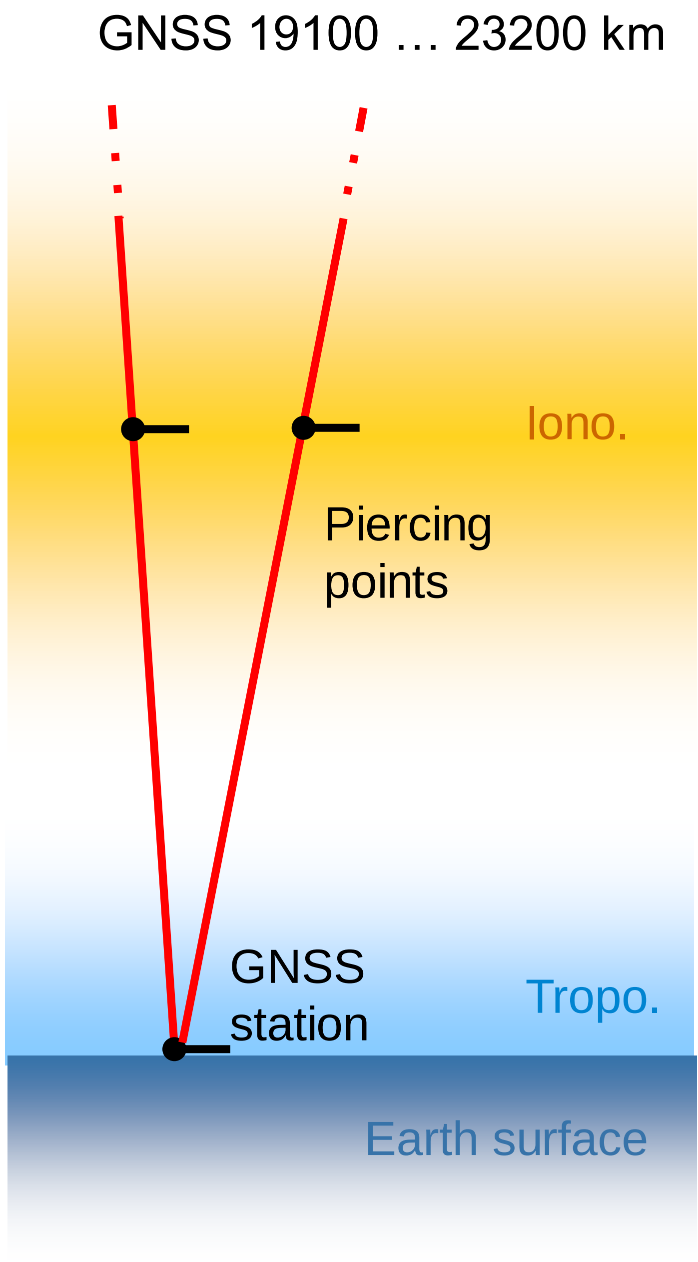
Ionosphere Disturbance Monitoring with GNSS





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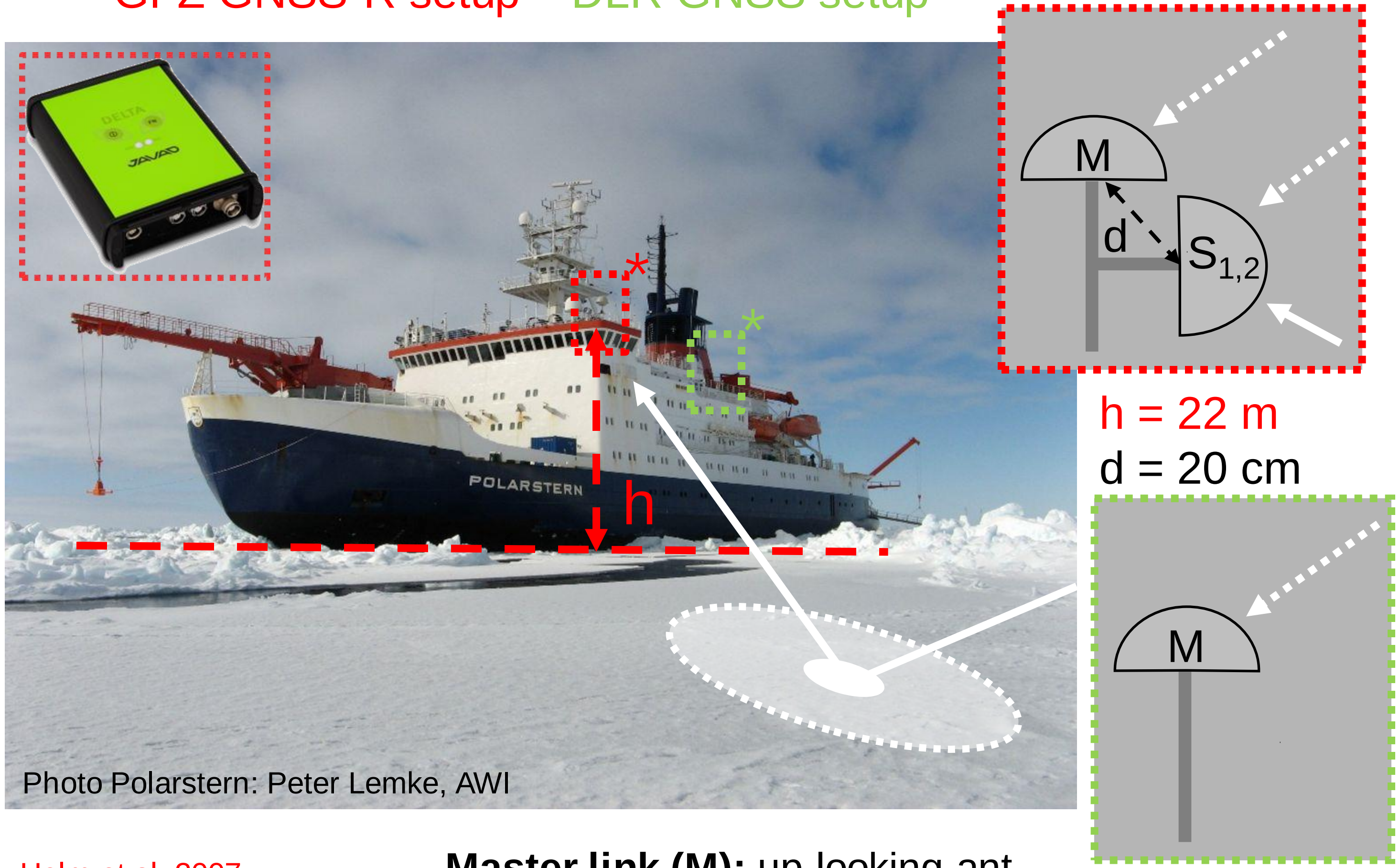
Can we benefit from ship-based data?

MOSAiC Expedition and GNSS Data in the Arctic

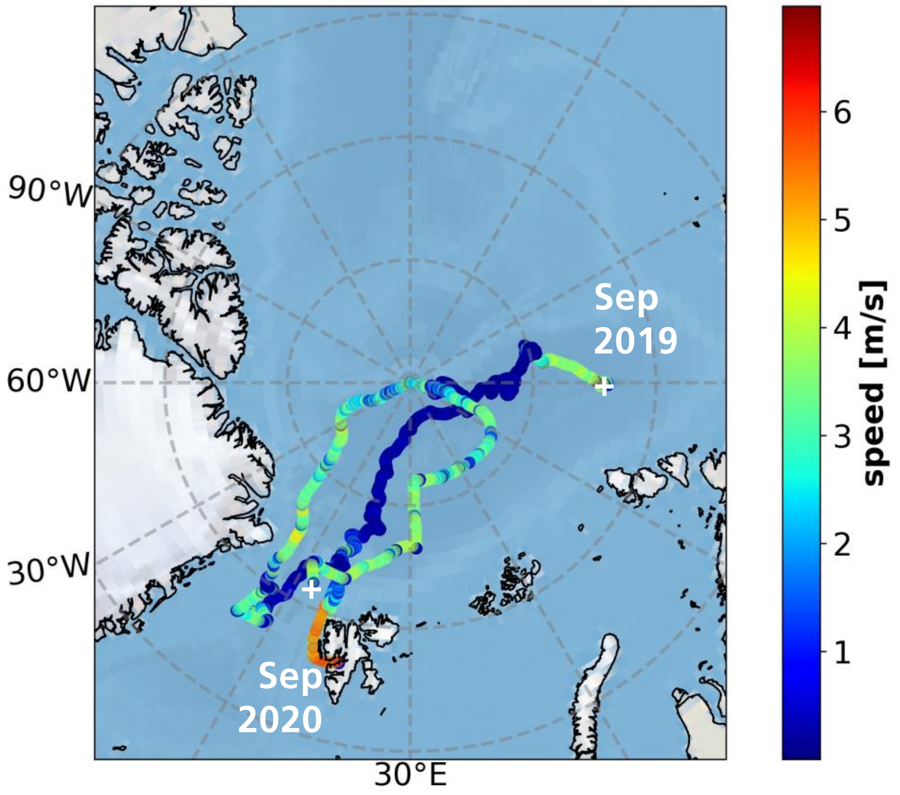
MOSAiC Expedition and Polarstern Setup

* GFZ GNSS-R setup * DLR GNSS setup



h = 22 m
d = 20 cm

MOSAiC expedition: Sep 2019 - Sep 2020

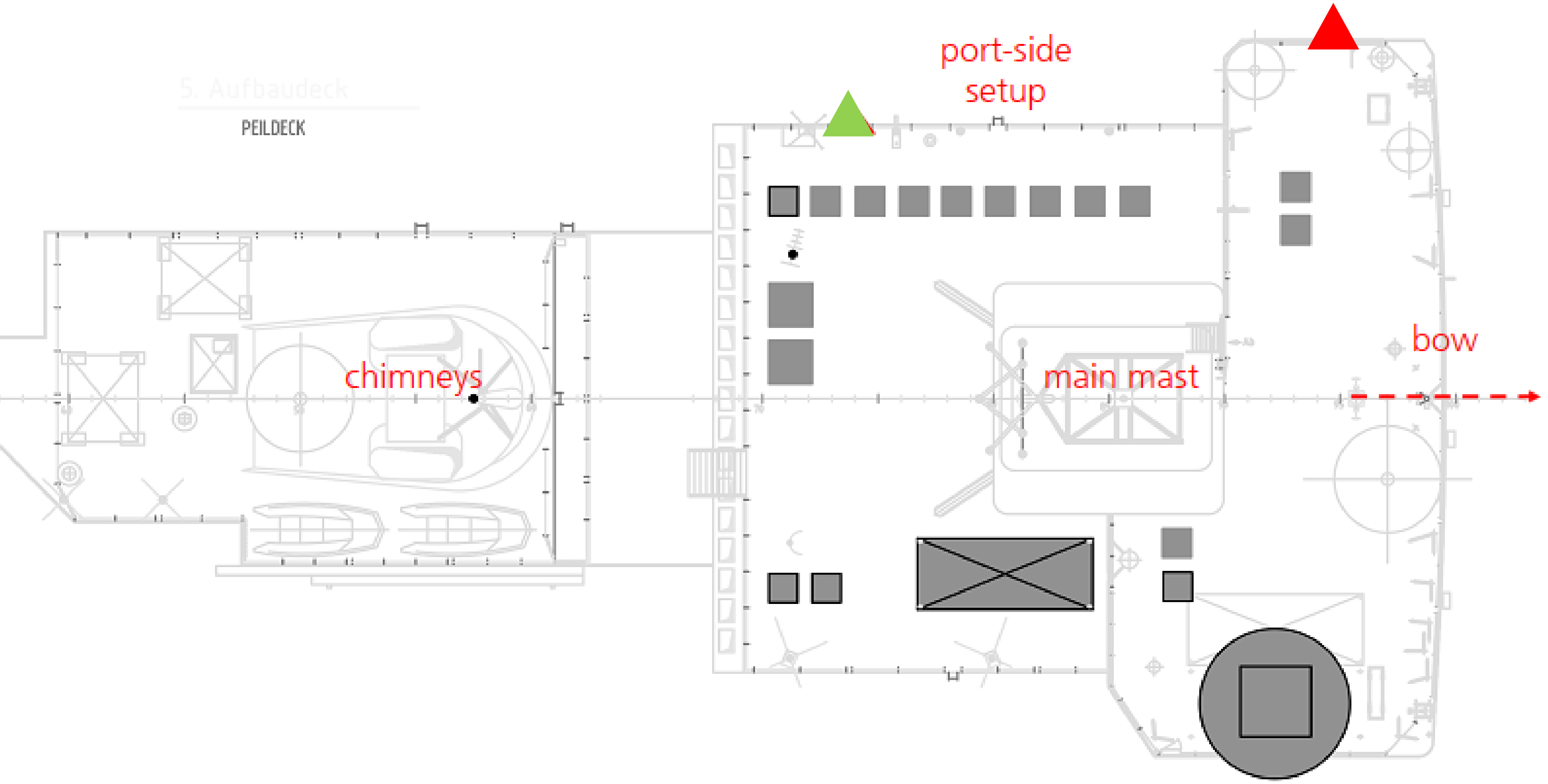


Helm et al. 2007
Semmling et al. 2013
Kriegel et al. 2017

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

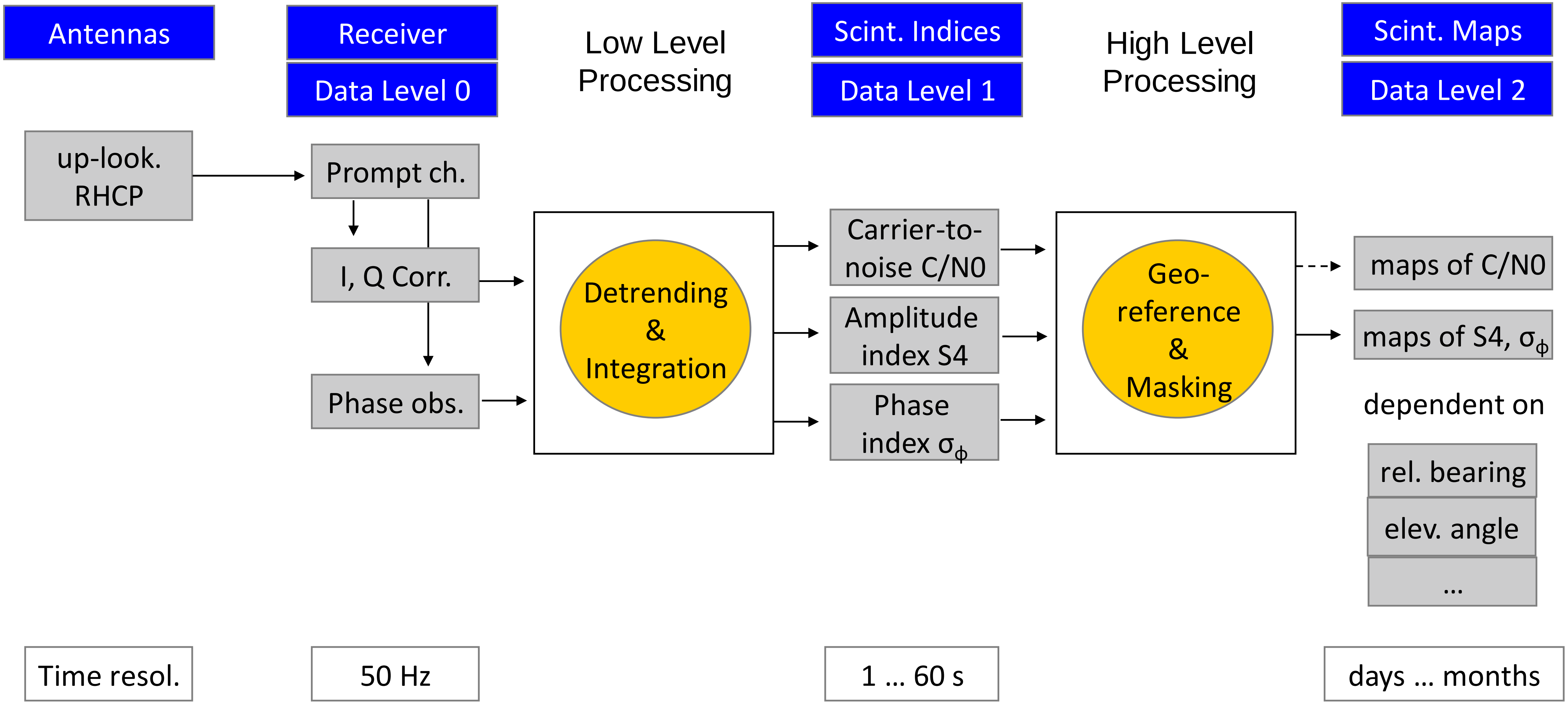
Cruising Periods: speed > 1 m/s
Drifting Period: speed < 1 m/s

MOSAiC Expedition and Polarstern Setup

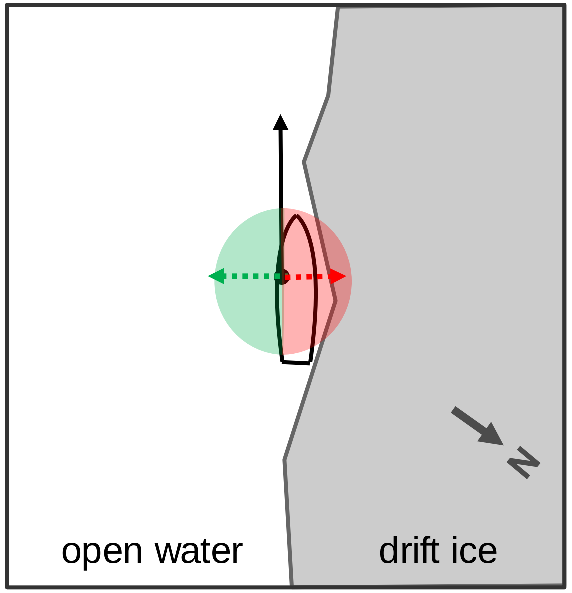


Processing and Masking of Ship-based Data

High-rate GNSS Data Processing



Limits of Visibility from the Ship

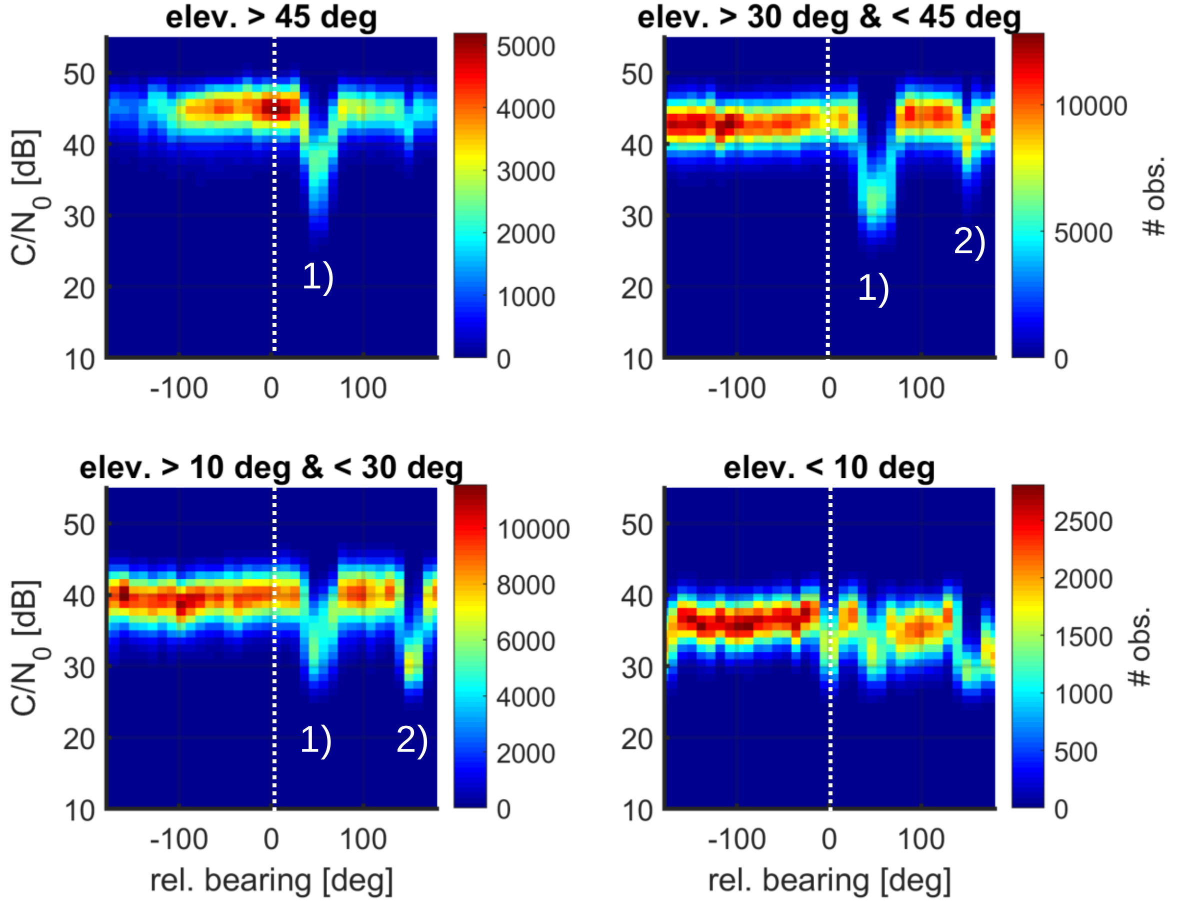


clear view
to port-side

left rel. Bearing:
-180° to 0°

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

C/N0 over rel. bearing

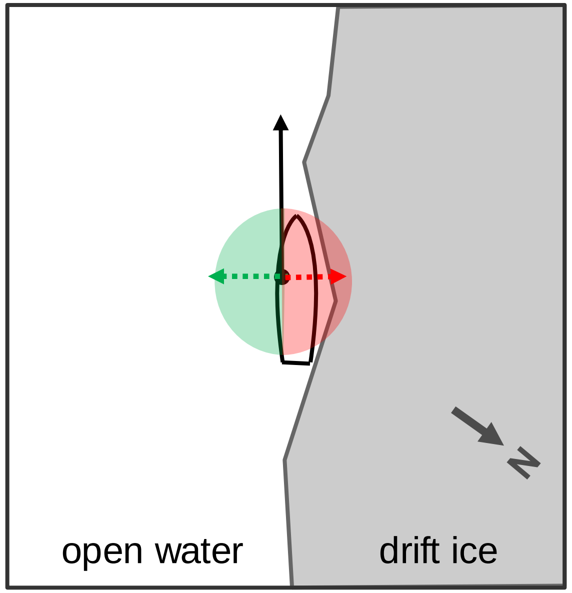


1) ship‘s main mast
2) ship‘s chimney

Sep 2019 … Sep 2020

Semmling et al. 2023

Limits of Visibility from the Ship

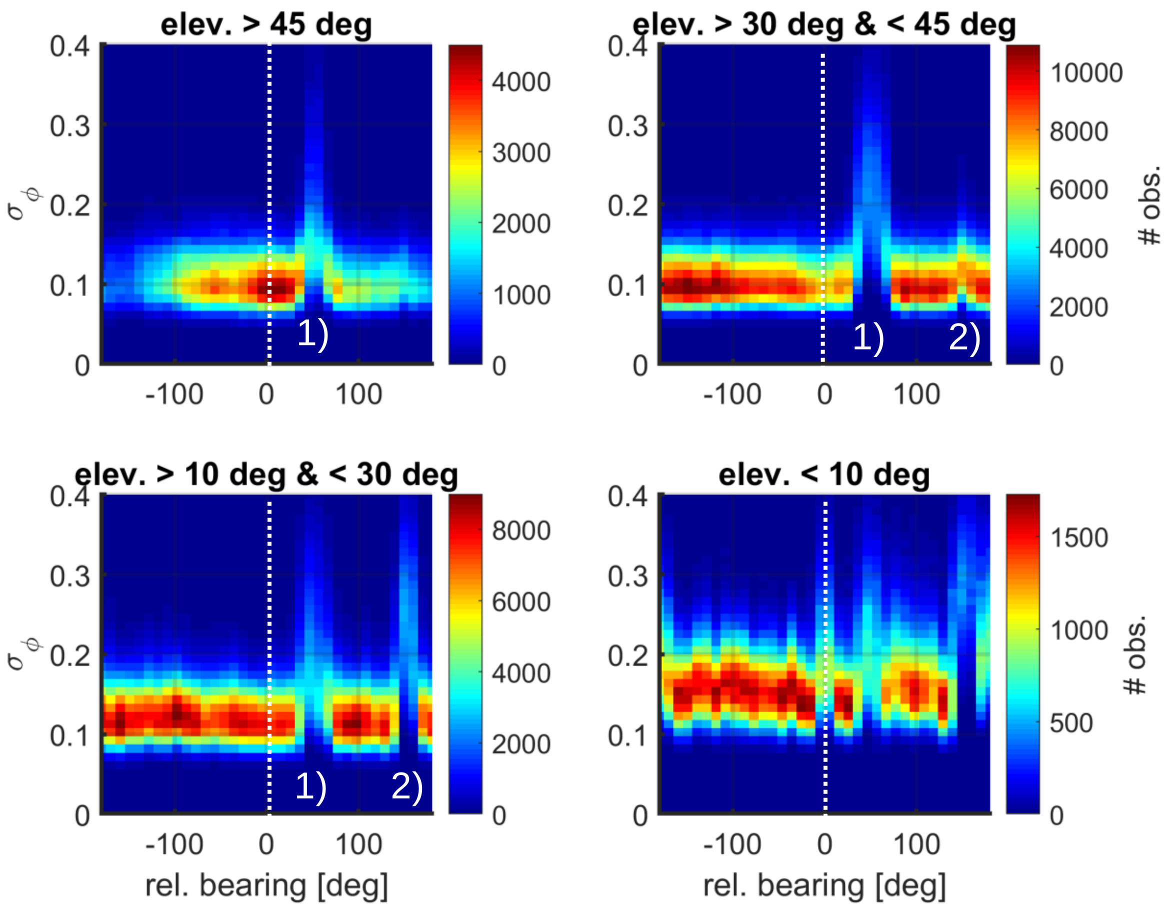


clear view
to port-side

left rel. Bearing:
-180° to 0°

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

σ_φ over rel. bearing



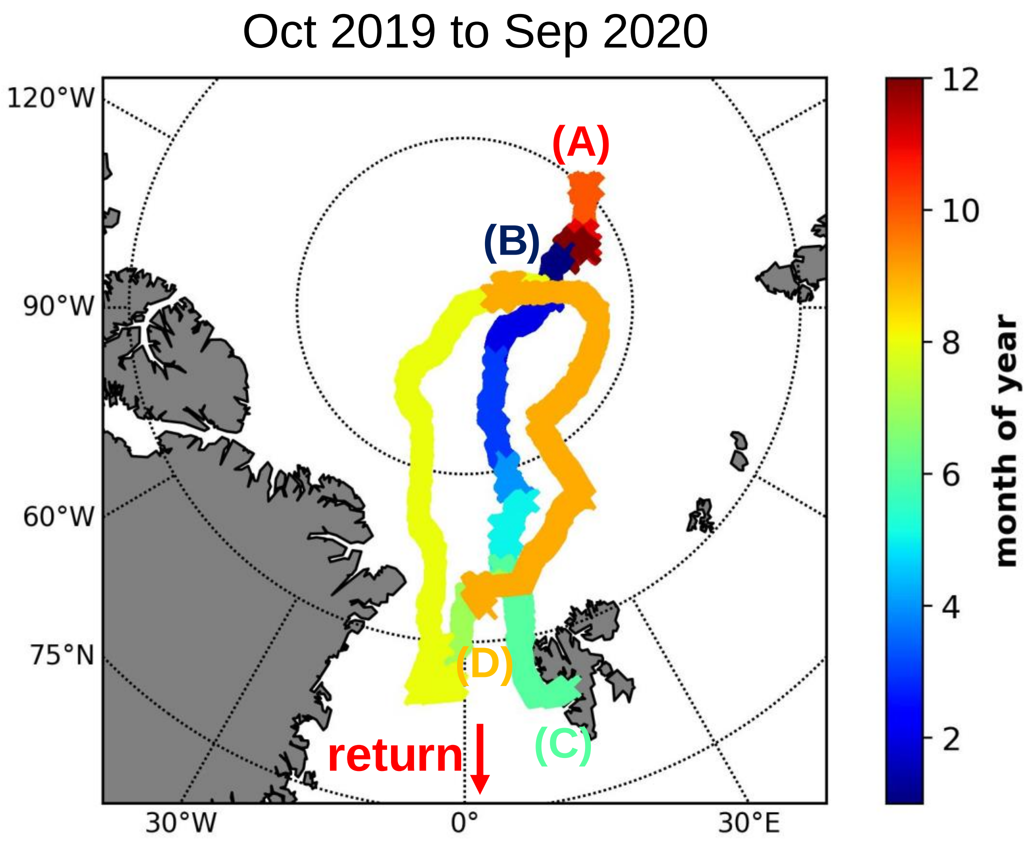
1) ship‘s main mast
2) ship‘s chimney

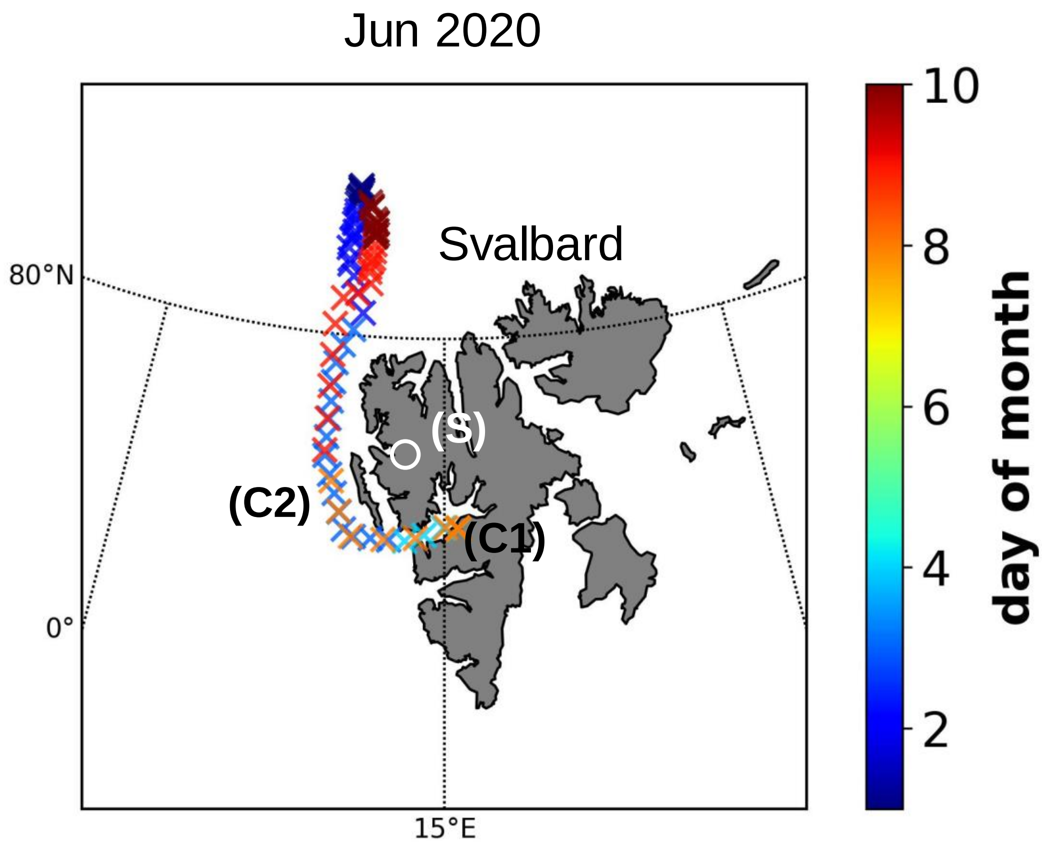
Sep 2019 … Sep 2020

Results of Scintillation Index Analysis

How does a ship-based setup perform compared to a station setup?

Track of R/V Polarstern (PS)





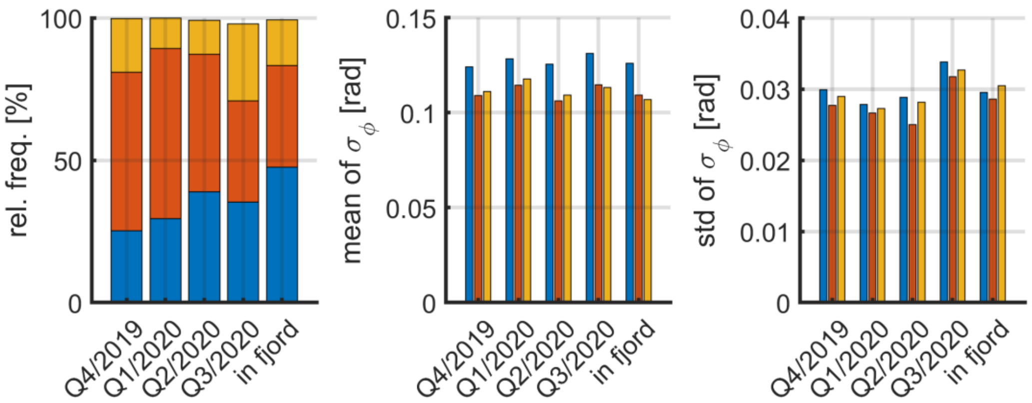
(A) Oct 1, 2019 before drift
(B) Jan 15, 2020 in ice
(C) Jun 5-8, 2020 near Svalbard
(D) Sep 30, 2020 before return

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

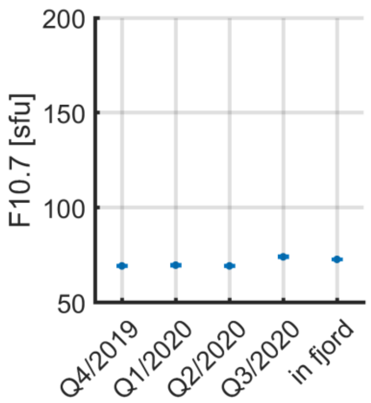
(S) Ny-Alesund station operated by Univ. of Oslo

σ_φ statistics comparing PS with station data

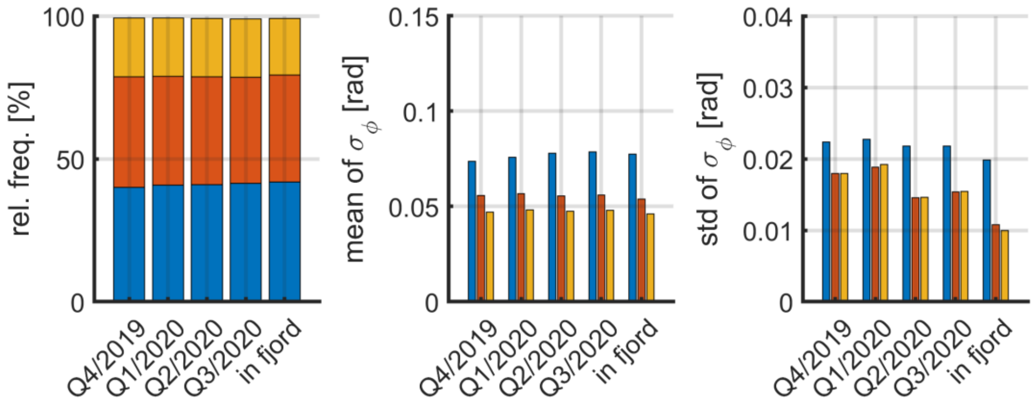
σ_φ on PS during MOSAiC – all weak (< 0.3 rad)



Solar radio flux – permanently low



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

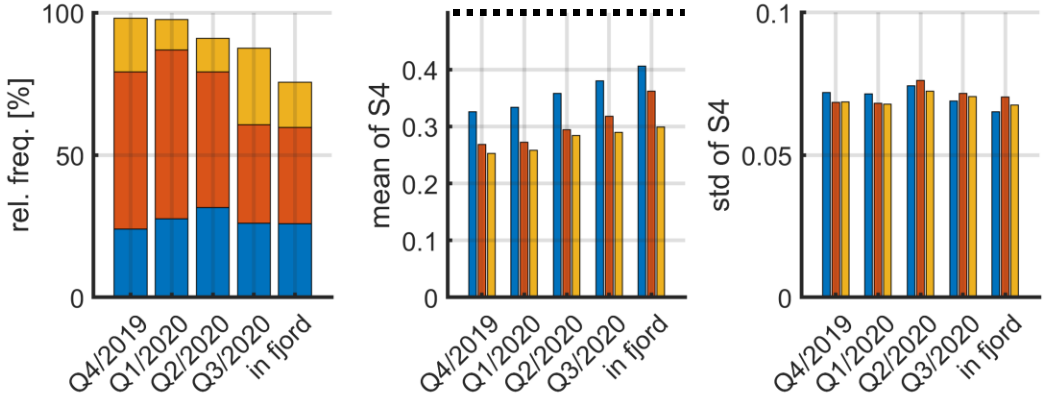


Remarks:

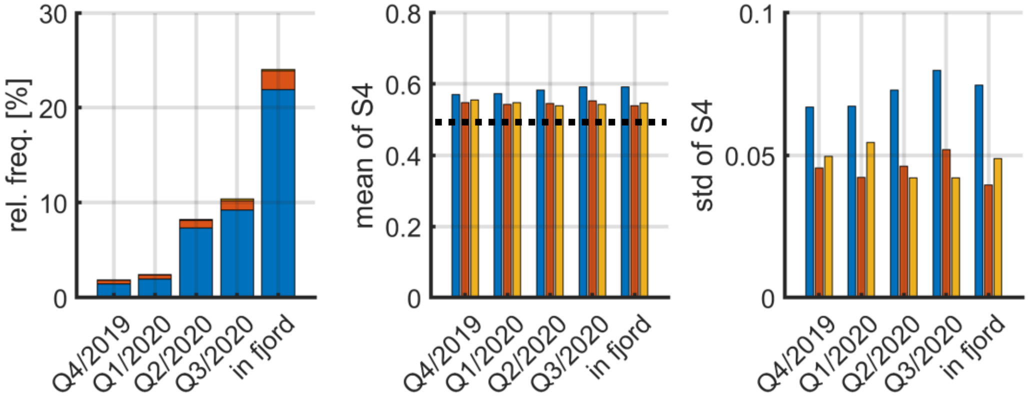
- In general, all σ_φ on PS and at the station are classified weak scint.
- σ_φ on average significantly higher on PS than at the station (0.05 rad to 0.1 rad)
- almost no changes over the year

S4 statistics comparing PS with station data

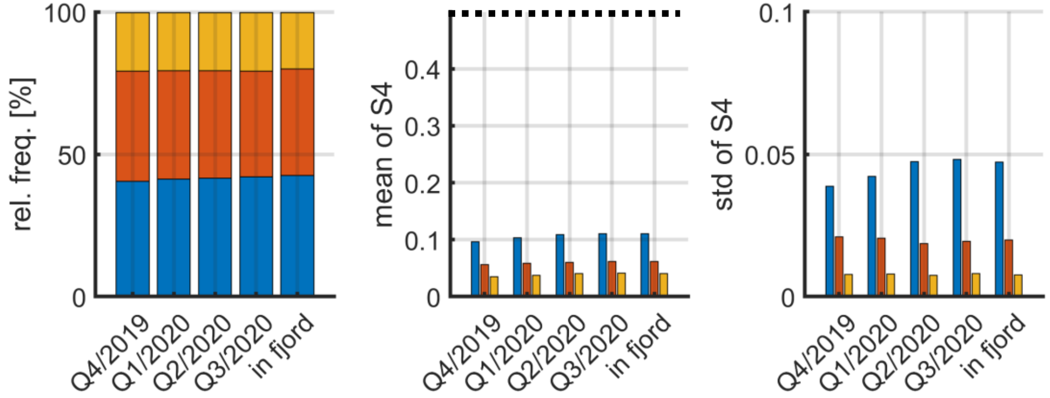
S4 on PS during MOSAiC – weak regime (< 0.5)



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



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

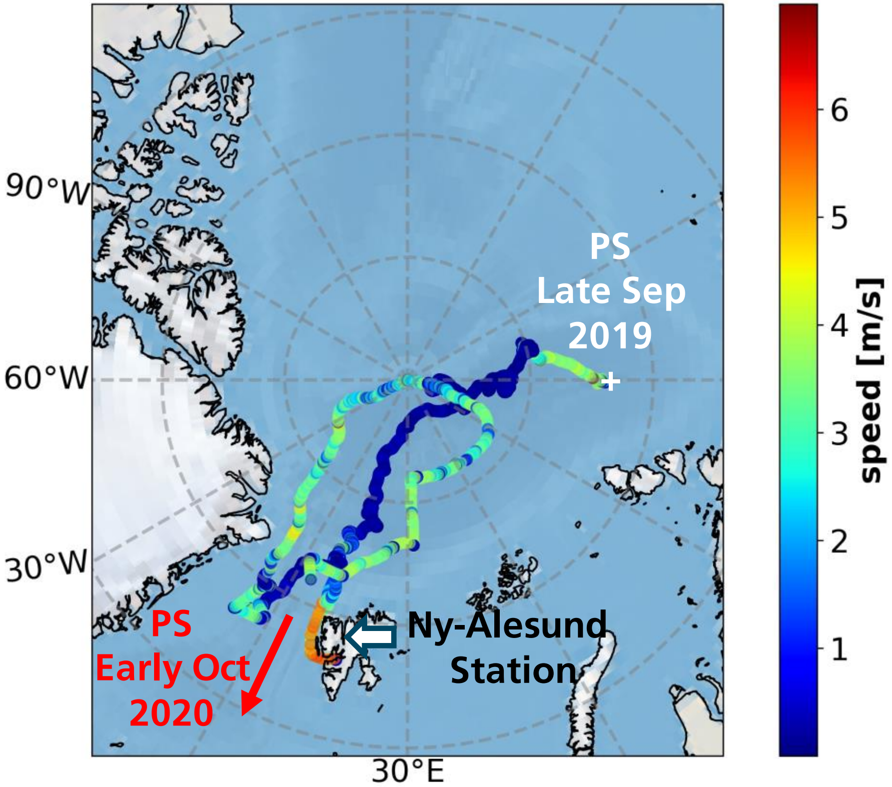


Remarks:

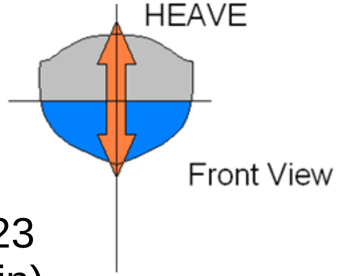
- weak part dominating (> 75%) of S4 for PS
- moderate part for PS mainly at low elev. (10°-30°), later in 2020 (Q2, Q3) and in fjord period
- S4 on average significantly higher for PS (0.25 … 0.55 rad) than for station (0.05)
- reason for increased S4 at PS ?

Movement of Polarstern

MOSAiC expedition: Sep 2019 - Sep 2020

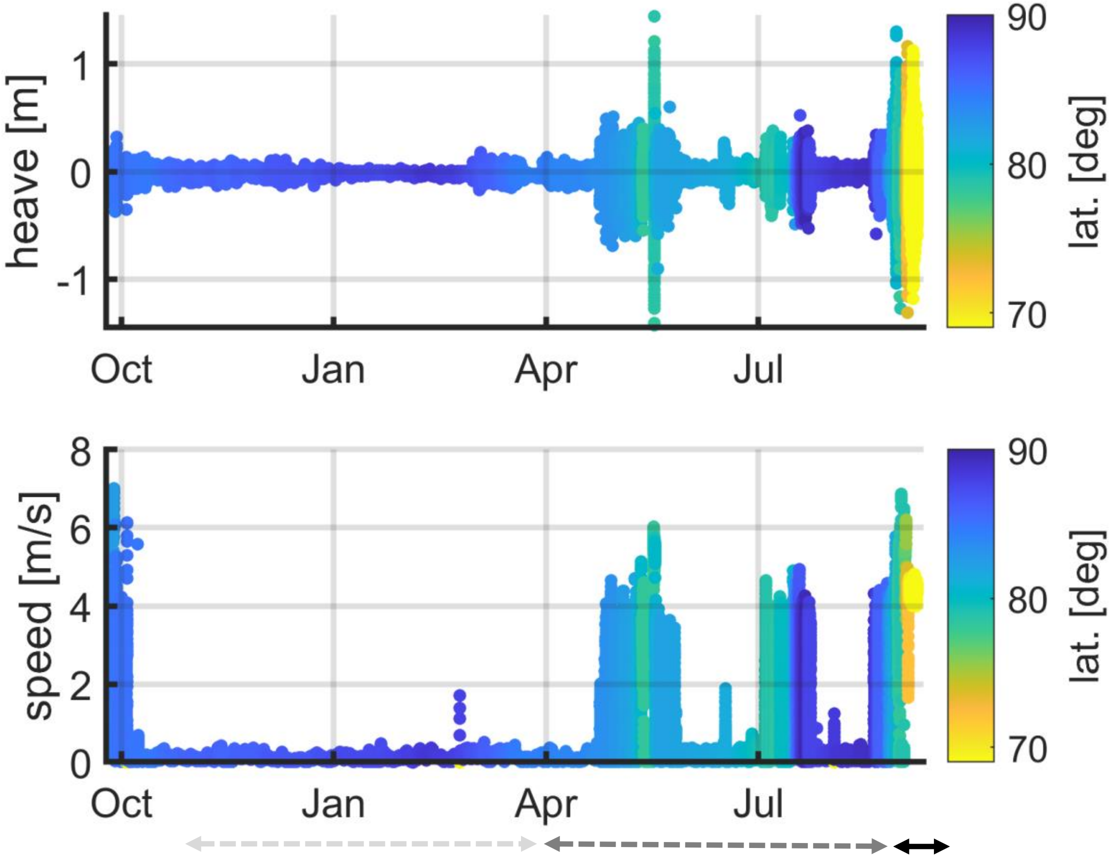


Cruising Periods: speed > 1 m/s
Drifting Period: speed < 1 m/s



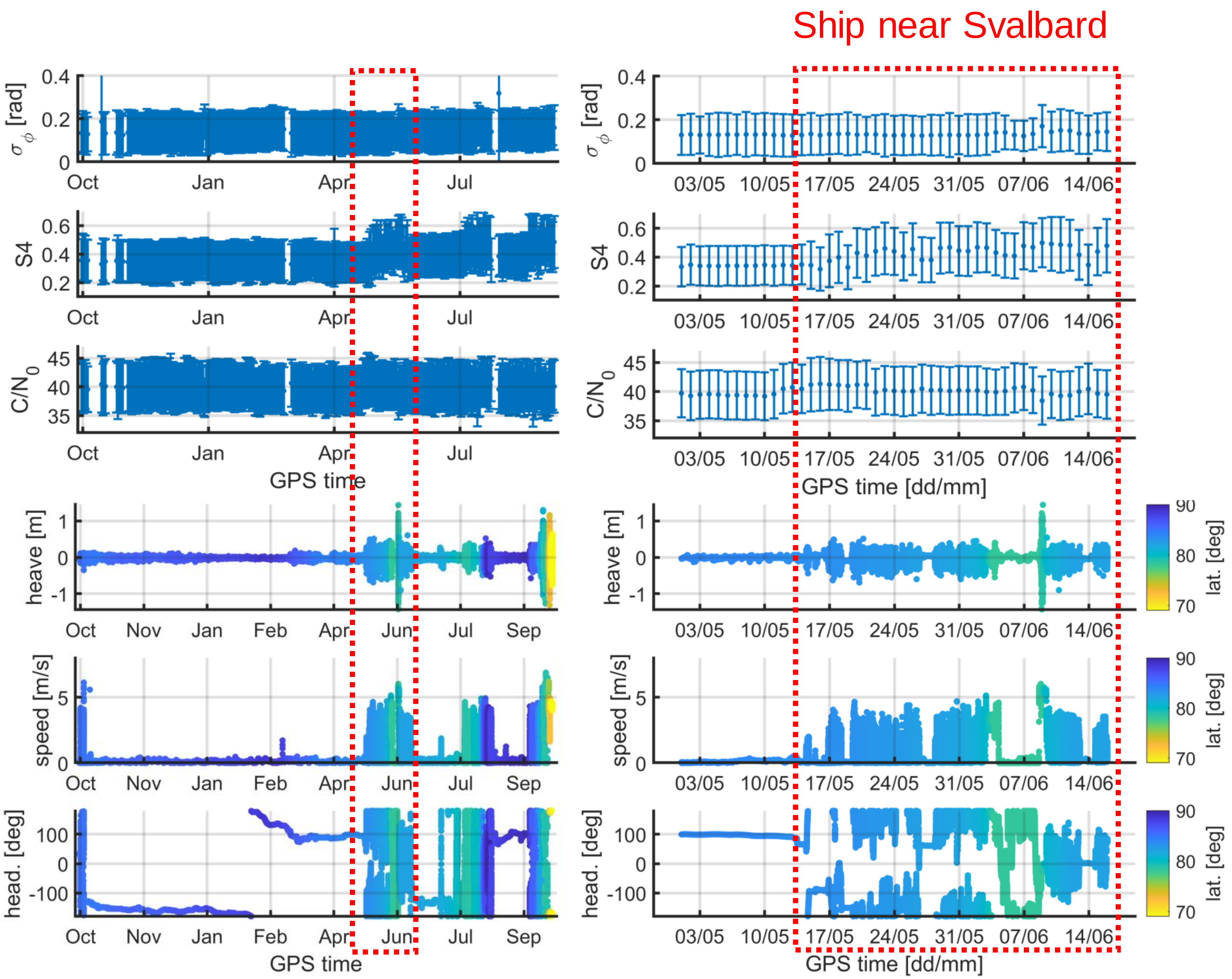
Wikipedia 2023
(Public Domain)

MOSAiC expedition: Polarstern 2019/2020



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

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 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 (Feb 2020 – Oct 2020)

Ny-Alesund Station on Svalbard (Mar 2020 – Jun 2020)

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 (mask out ship structure disturbance)
- Baseline phase noise (σ_φ) and amplitude fluct. (S4) are increased compared to station obs., however, not to severe level
- Carrier-to-noise ratio (C/N0) is decreased (by 6 … 7 dB) compared to station obs., it means reference signal intensity is lower on a ship than at the station
- S4 increased (by ~20%) in periods of increased heave (std 0.5 … 2m), σ_φ is not
- 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

Data used here were produced as part of MOSAiC project.

Thank you for your attention.

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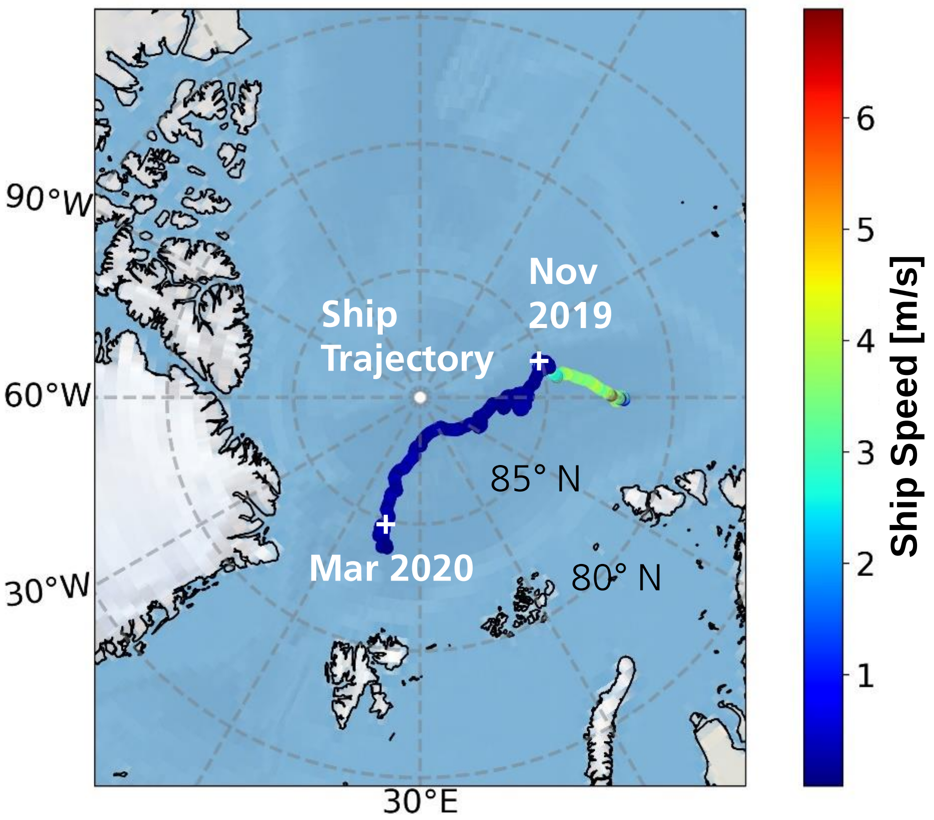
  URSI Radio Science Letters
- DLR IMPC 2023: Ionosphere Monitoring and Prediction Center
  https://impc.dlr.de/products/

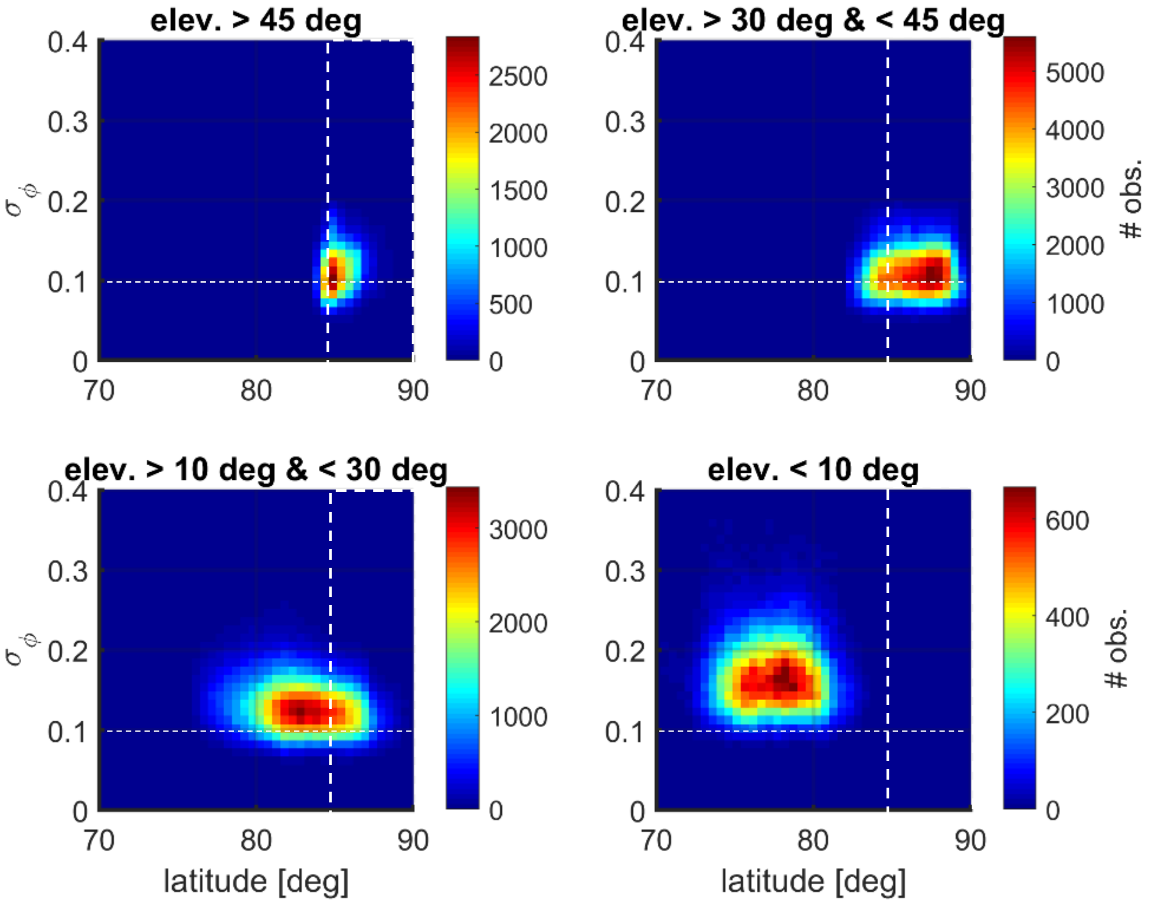
Appendix

Drift - High Arctic - Winter

GNSS obs. in the Central Arctic



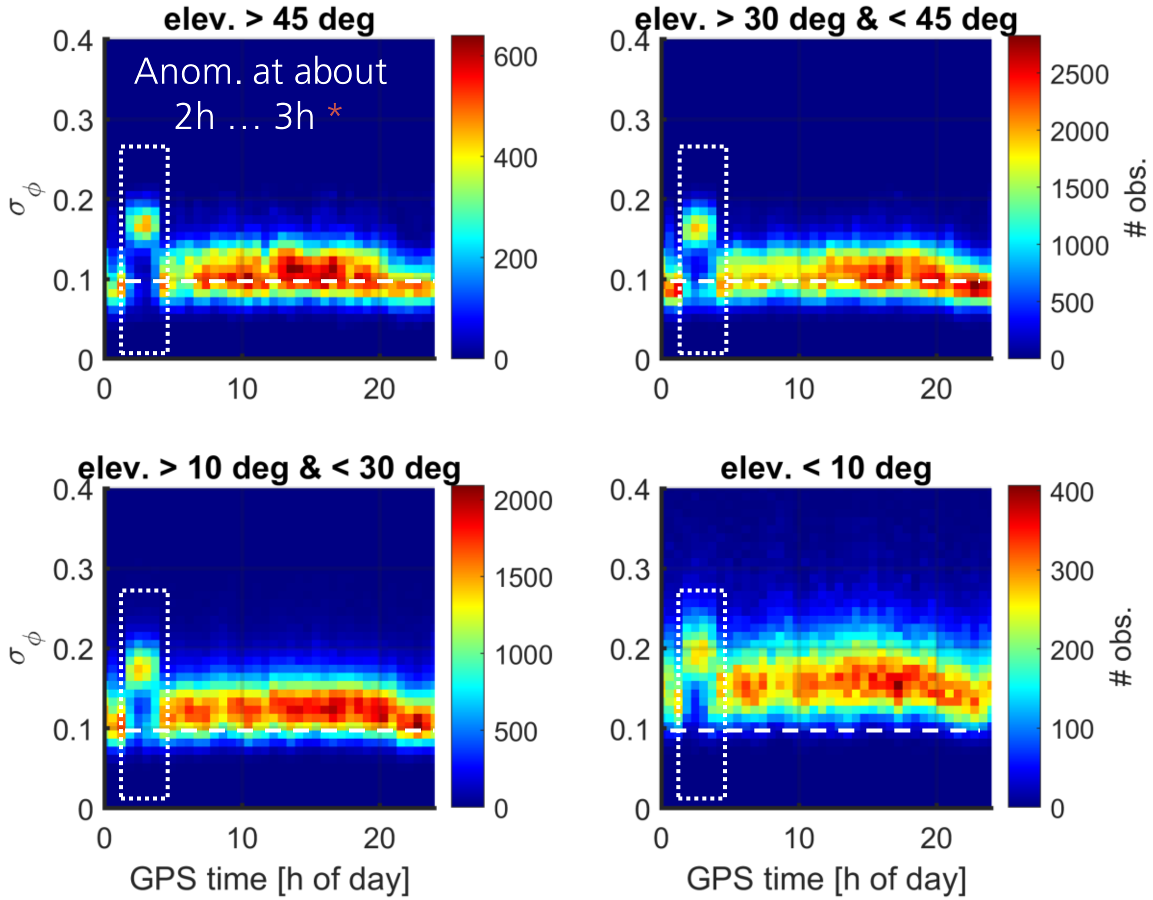
σ_φ over lat. at IPP (height 350 km)



Nov 2019 … Mar 2020

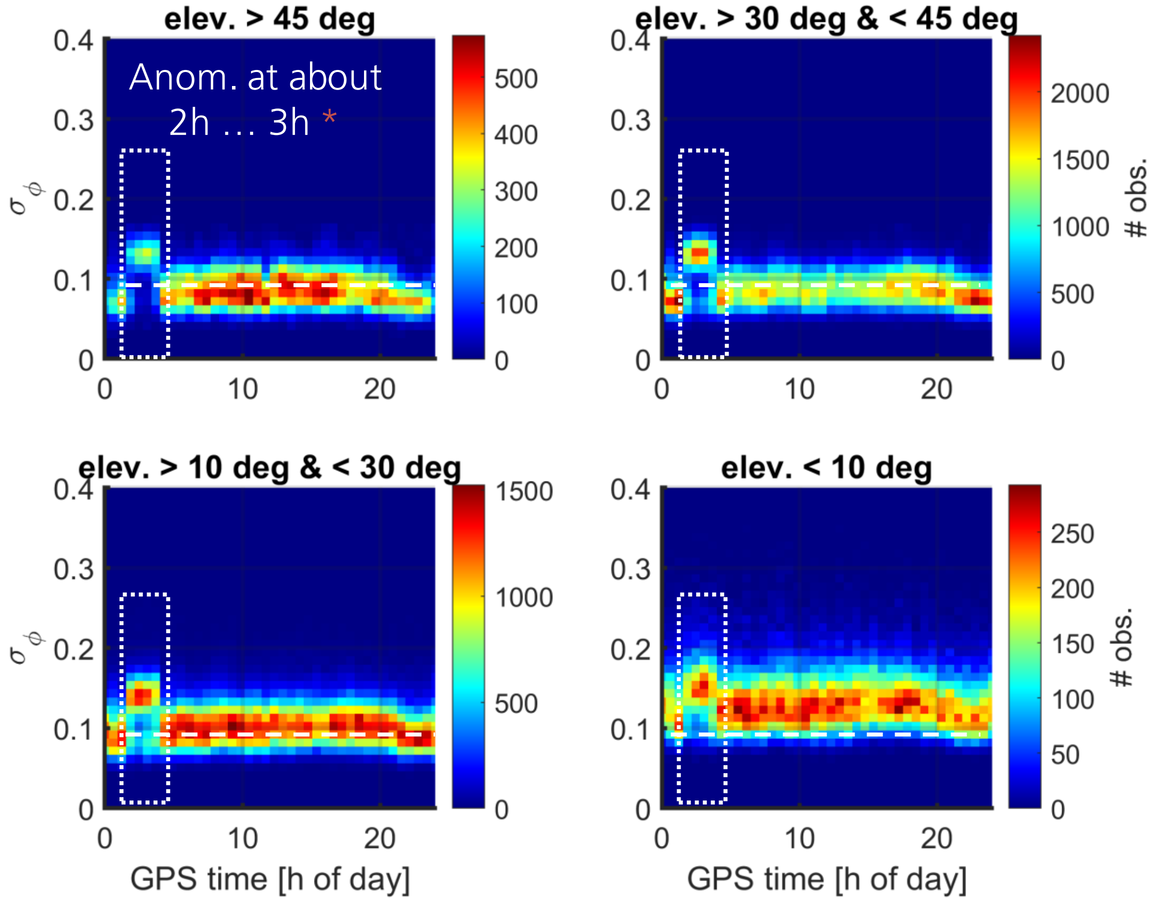
Drift - High Arctic - Winter

σ_φ for GPS L1 C/A over hour of day



Nov 2019 … Mar 2020

σ_φ for GPS L2C over hour of day



Nov 2019 … Mar 2020

* Ship effect?