GNSS Observations for Remote Sensing in the Arctic

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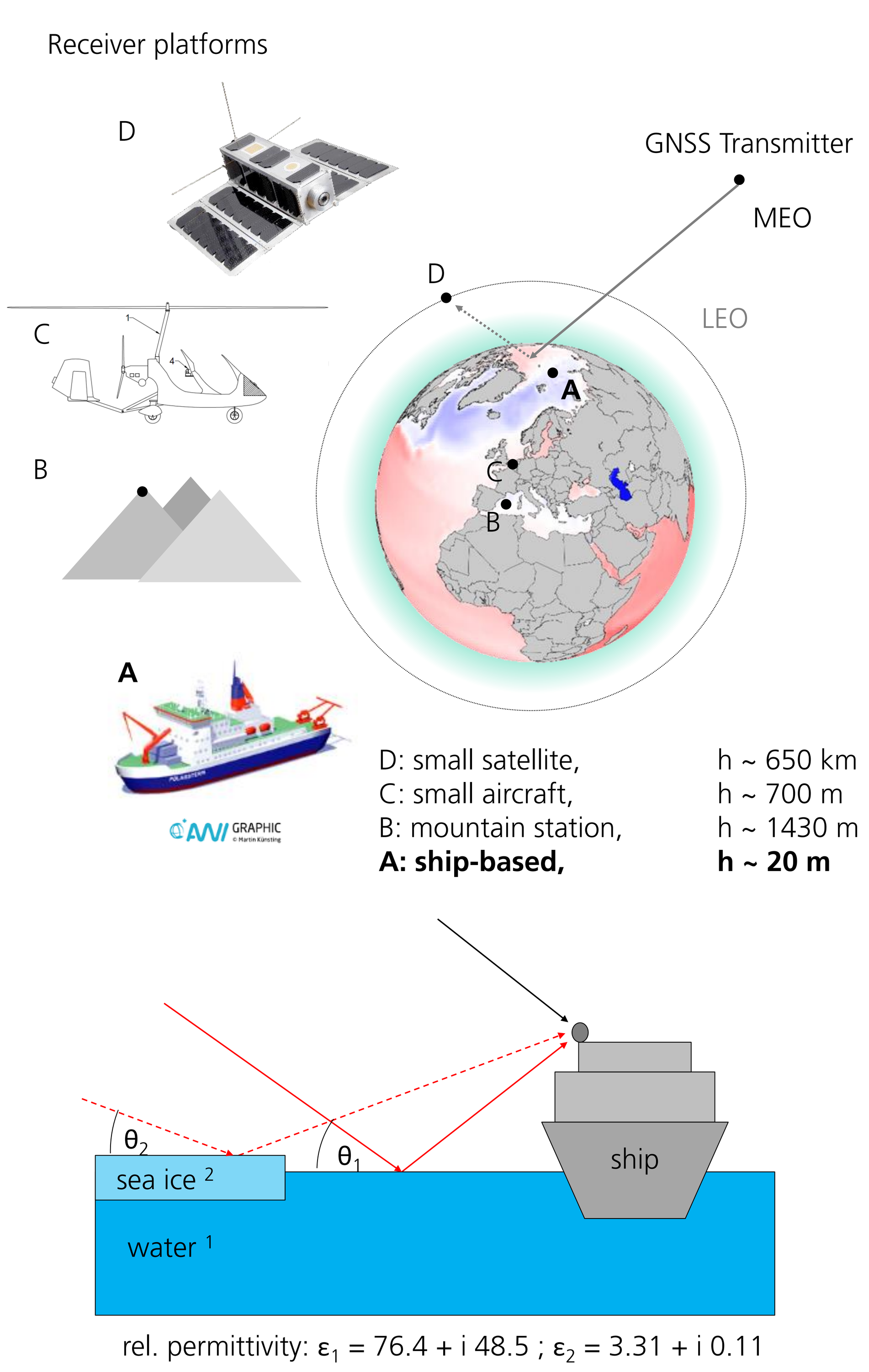
Abstract

In a series of expeditions to the Arctic, high-rate observation data of Global Navigation Satellite Systems (GNSS) have been acquired. These expeditions include the cruises of research vessels *Lance*, *Polarstern* and *Kronprins Haakon* in a period between 2016 and 2020. The remote sensing observations are designated for application in sea-ice reflectometry and ionospheric monitoring. The objective of our ongoing studies is to develop new pathways for these applications with ships operating in the Arctic.

The global coverage of GNSS observations gives us the opportunity to add to the Arctic observing systems with rather small hardware investment for a better understanding of the exceptional Arctic environment in terms of space weather and sea-ice evolution. Current investigations aim to validate GNSS-based sea-ice monitoring for different seasonal conditions, and to examine the space weather impact on GNSS reflection power estimates for long-term monitoring in the Arctic. Different GNSS receiver types, designated for reflectometry, scintillation detection and atmosphere sounding, were used. Here, we concentrate on reflectometry data analysis of cruises to Fram Strait (FS) in 2016 and 2020 and to the Central Arctic in 2019/20 during the one-year MOSAiC expedition (Multidisciplinary drifting Observatory for the Study of Arctic Climate). Currently, the data processing is extended to investigate the space weather impact on ship-based GNSS observations in the Arctic, with further data sets available from the Nansen legacy cruises.

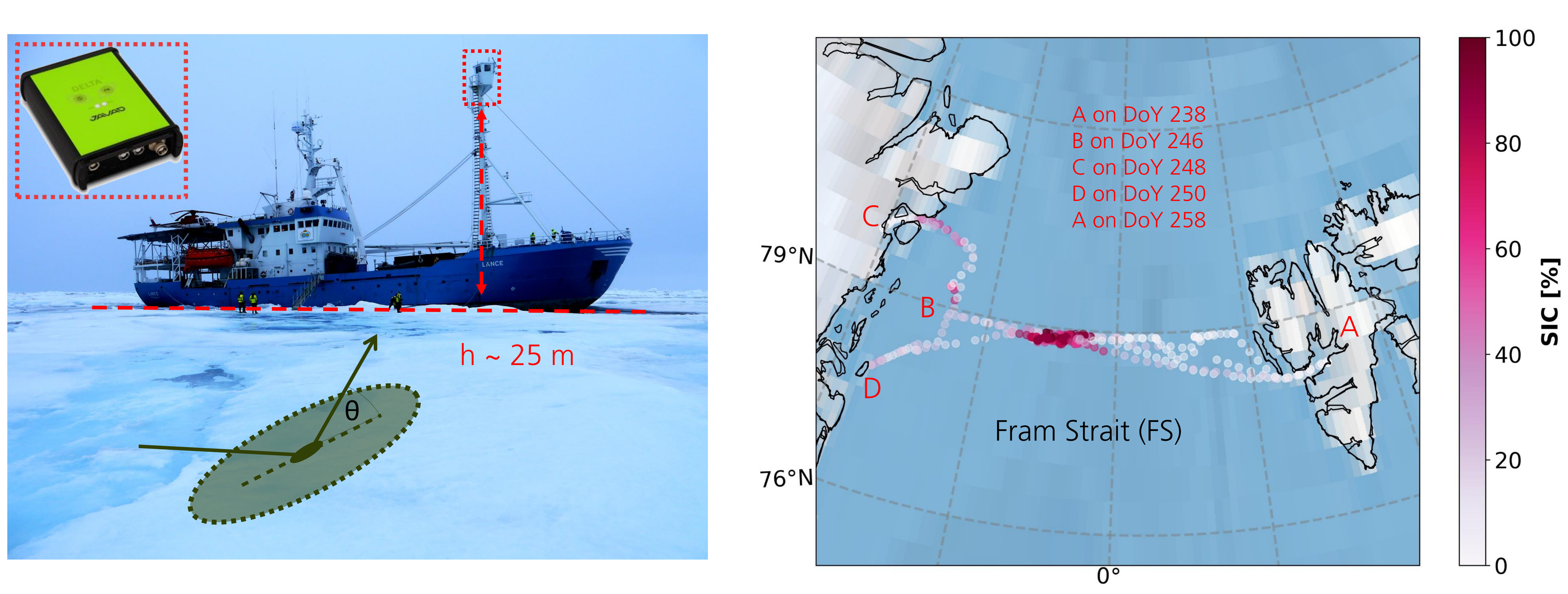
Scenarios for Remote Sensing



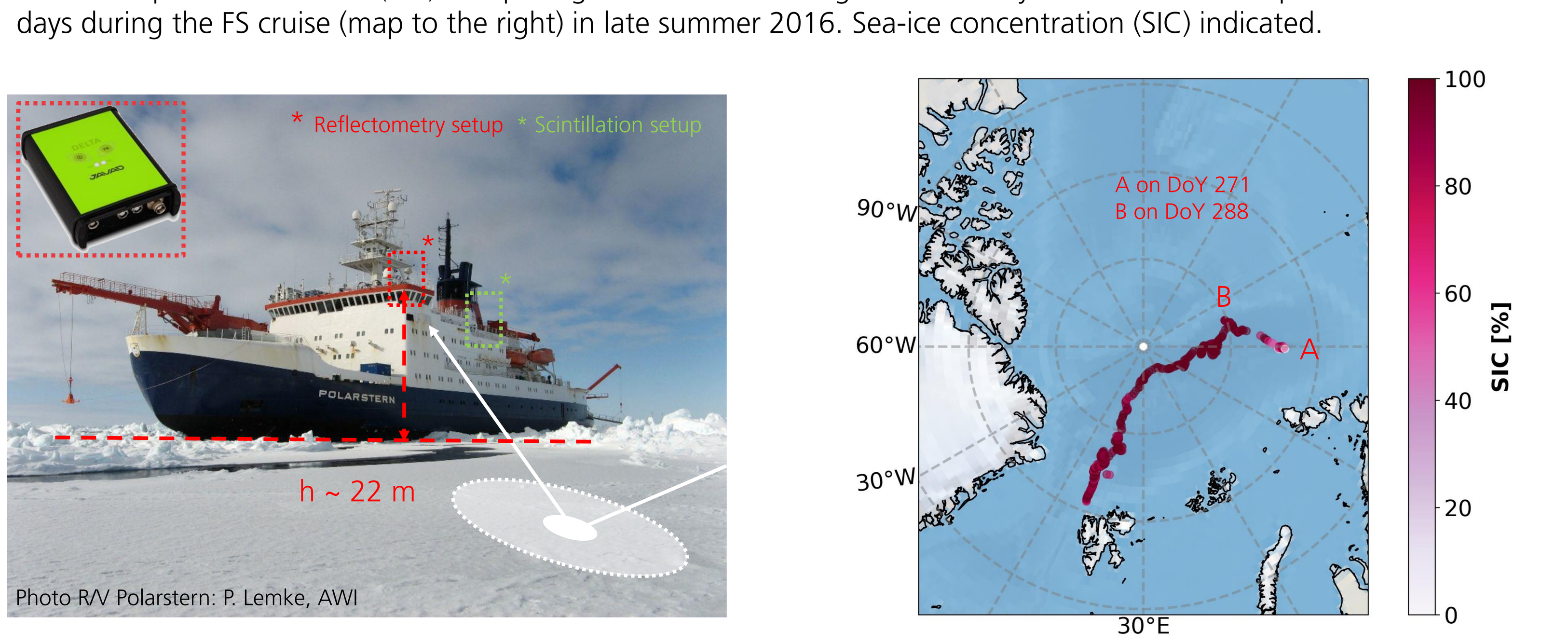
GNSS remote sensing techniques rely on the globally available L-band signals transmitted by Medium Earth Orbit (MEO) satellites. Most common techniques analyze the signal's propagation in the Earth's atmosphere (atmospheric sounding techniques) and the Earth-reflected signal (reflectometry techniques). Several scenarios for reflectometry are currently under research including receivers on ground/mountains, airborne, on satellite and also on ships. Examples are shown to the left: based on ships in the Arctic (A), from a mountain station on Mallorca island (B), from a small aircraft at the French coast (C) and from a small satellite in the PRETTY mission for global observations (D). The over-arching goal of all these studies is a better understanding of the GNSS signal's interaction with the sea surface and atmosphere as well as a respective exploitation of GNSS observations for remote sensing.

The concept of sea-ice monitoring with ship-based observation is indicated here to the lower left. Signals reach the ship-based receiver on the direct path (black ray) and on specular reflection paths (red rays). The power of the reflected signal depends (among other properties) on the permittivity of the reflecting surface. Water and sea ice are significantly different in L-band relative permittivity and contrast in GNSS reflectivity estimates. Another important parameter of the reflection is the elevation angle θ. Characteristic reflectivity profiles over elevation can be found in model and observations.

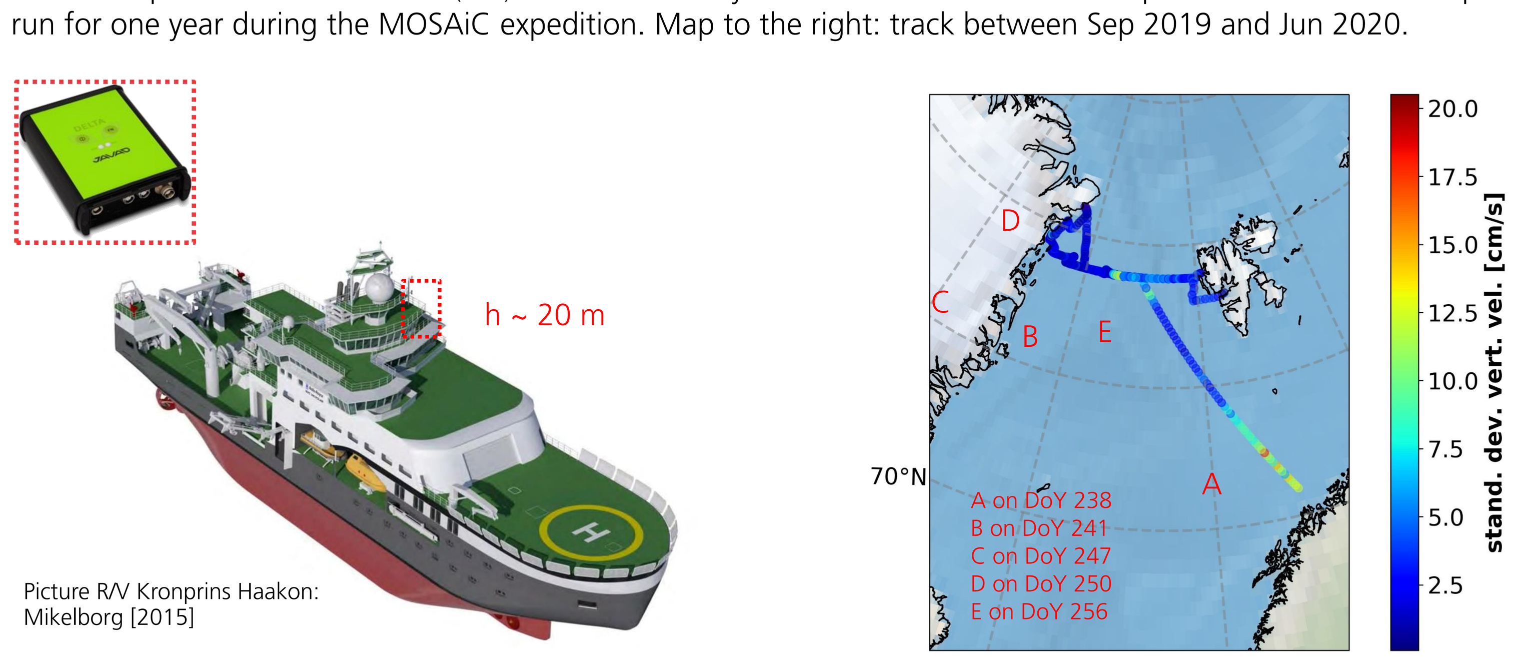
Ship-based Scenarios in the Arctic



GNSS setup on **R/V Lance** (left) comprising a starboard-looking reflectometry antenna. The setup run for 20 days during the FS cruise (map to the right) in late summer 2016. Sea-ice concentration (SIC) indicated.

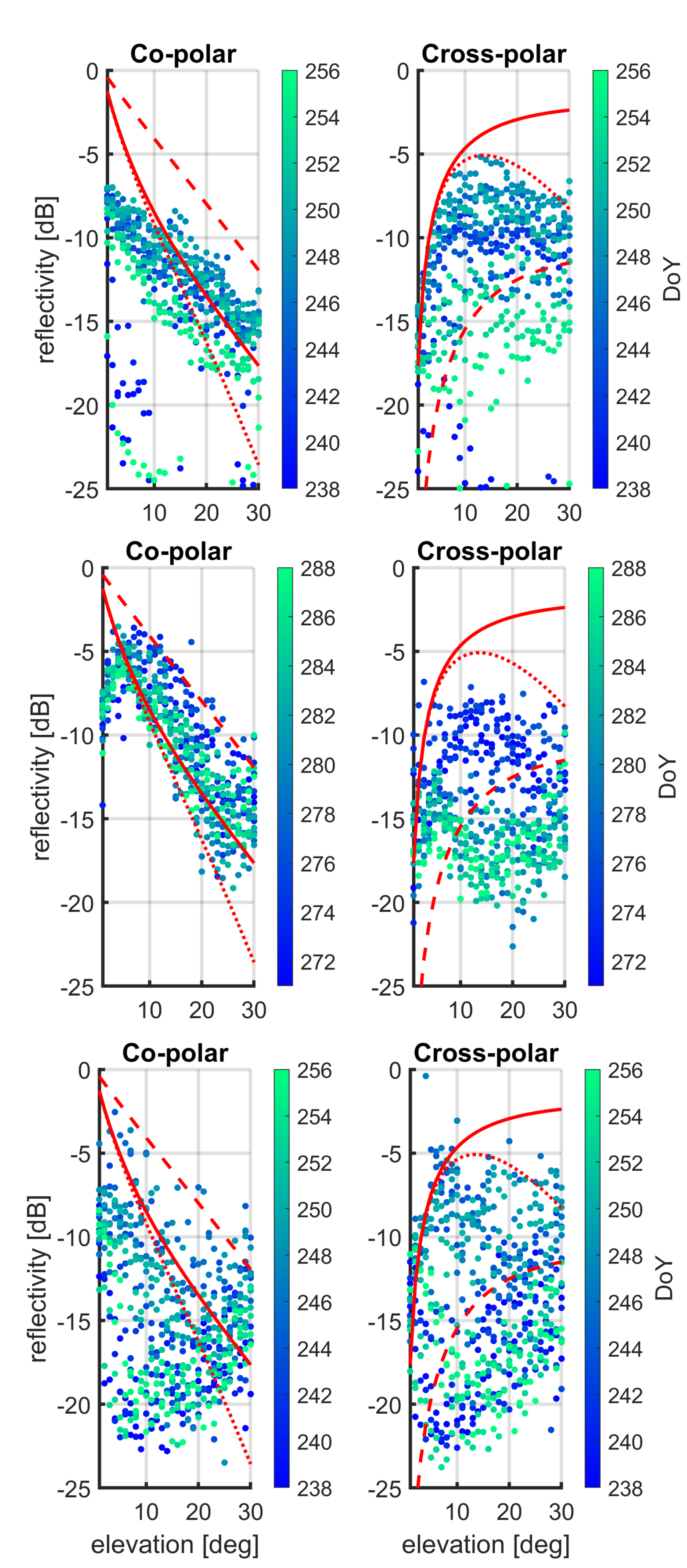


GNSS setups on **R/V Polarstern** (left) for reflectometry and scintillation studies with portside view. Both setups run for one year during the MOSAiC expedition. Map to the right: track between Sep 2019 and Jun 2020.



GNSS setup on **R/V Kronprins Haakon** (left) equipped for reflectometry and scintillation studies with portside view. The setup run during several cruises, the map to the right shows the FS cruise in summer 2020. The standard deviation of the ship's vertical velocity is color-coded as indicator of sea state.

Sea Surface Reflectivity Results



Reflectivity results (to the left) from the respective expeditions: FS 2016, MOSAiC 2019 (first 18 days when entering the ice) and FS 2020, cf. indicated dates with respective maps. Model prediction of reflectivity added as red lines: smooth water (solid), water with moderate roughness (dotted), low-permittivity sea ice (dashed).

In all data sets variations of reflectivity over the plotted period are found. For the FS 2020 data variability of co-polar reflectivity is particularly high. Further analysis of the cross-polar profiles allowed: the retrieval of sea-ice concentration based on FS 2016 data [Semmling et al. 2019] and of sea-ice permittivity using MOSAiC data [Semmling et al. 2022].

Conclusion & Outlook

Reflectivity profiles of the sea surface can be derived from a ship-based GNSS setup. The changing surface permittivity, when sea ice occurs, can be resolved from these (cross-polar) reflectivity results.

The high variability of reflectivity results from *R/V Kronprins Haakon* indicate that the given position of the setup there is insufficient for an unperturbed view and reflectivity retrieval. In general, the vicinity of the antenna to larger ship structures need to be avoided.

A further study is on-going analyzing amplitude and phase fluctuations in the MOSAiC data set to reveal impact of ionospheric irregularities. The ship-based scenario, in general, is more challenging (attitude changes, restricted visibility) than in commonly used ground-based observations. Additional processing can partly overcome these challenges to achieve valuable GNSS remote sensing observations from ships. Such data is relevant to improve sparse coverage over the oceans.

References

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