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# Scintillation Index Analysis of ship-borne GNSS Data recorded during Cruises of Research Vessels in the Arctic

M. Semmling(1), H. Sato(1), M. Kriegel(1), F. Fohlmeister(2), Y. Jin(3), C. Nguyen(4), S. Gerland(5), G. Spreen(6), J. Berdermann(1), M. Hoque(1), and J. Wickert(4)(7)
(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
(4) German Centre for Geosciences GFZ, Potsdam, Germany
(5) Norwegian Polar Institute NPI, Tromsø, Norway
(6) University of Bremen, Bremen, Germany
(7) Technische Universität Berlin, Berlin, Germany

## Abstract

We report in this paper on a study of scintillation index data acquired with Global Navigation Satellite System (GNSS) receivers. The GNSS receiver were installed on research vessels for cruises in the Arctic. The focus lies on a one-year data set recorded during the MOSAiC expedition (Multidisciplinary Drifting Observatory for the Study of Arctic Climate) between autumn 2019 and late summer 2020. In general, the level of phase and amplitude indices, retrieved for this expedition period, was in the weak scintillation regime. We found anomalies of the amplitude index (S4) that reach slightly increased level, when higher sea state was reported that varies the ship's vertical displacement (heave). The consideration of sea state and changing multipath conditions is an important aspect of the ship-based scenario. The results indicate that, if these conditions are considered, the GNSS data sets can contribute to the monitoring of scintillation in remote areas, like the Arctic Ocean. Further data records on ships under more disturbed ionosphere conditions are anticipated.

## 1 Introduction

GNSS signals have a wide range of applications. Apart from the user navigation services (providing position, velocity and time), remote sensing applications in geosciences have gained importance over the last three decades. Ground-based networks of GNSS receiver stations contribute today to atmosphere and earth surface monitoring for retrieval of: integrated water vapor, total electron content (TEC), scintillation indices, soil moisture or height level of adjacent water bodies (among others).

Corresponding monitoring products became important to establish weather models or TEC maps on a global scale. The coverage of GNSS data is not equally distributed, gaps remain over oceans and remote land areas (e.g. the polar regions), where only few observations are available. We present here a study on GNSS data recorded on research vessels in the Arctic: on the German *Polarstern* during its MOSAiC expedition 2019/20 [1] and the Norwegian *Kronprins Haakon* during its Fram Strait cruise 2020. Our objective is to investigate the ship-based data for ionosphere monitoring over the Arctic and to identify respective challenges of the ship-based case. Several studies already demonstrated the use of ship-based GNSS data for remote sensing, specifically studies on water vapor [2], sea-ice concentration [3] and sea state [4]. An important aspect, compared to the ground-based case, is the impact of the ship's motion on the signal tracking results, in phase and amplitude.

## 2 Methodology and Preliminary Results

Here, the signal tracking analysis is based on scintillation indices, S4 and $\sigma_\phi$, derived from high-rate (50 Hz) data of JAVAD Delta receivers. The data processing includes a scheme of detrending and integration to obtain S4 and $\sigma_\phi$ with $60\,s$ resolution. An additional processing step is required for the ship-based case to account for the changing visibility mask (in azimuth and elevation) due to the ship's variable position and heading, cf. [5]. Furthermore, measurements of the ship's velocity (horizontal motion) and heave (vertical motion) are considered. Especially, the heave is an indicator for sea-state conditions. It indicates how the ocean wave spectrum affects the ship's motion.

Figure 1 summarizes the distribution of S4 results during the four quarters of the MOSAiC expedition (autumn 2019 to late summer 2020).

In general, the ionosphere conditions were calm in this period, that was close to the solar minimum. During the first quarters (Q4/2019 and Q1/2020) the S4 results are almost entirely ($> 97\%$) in the weak scintillation range. During the later quarters (Q2/2020 and Q3/2020) the majority is still in the weak range. The part in the moderate range,

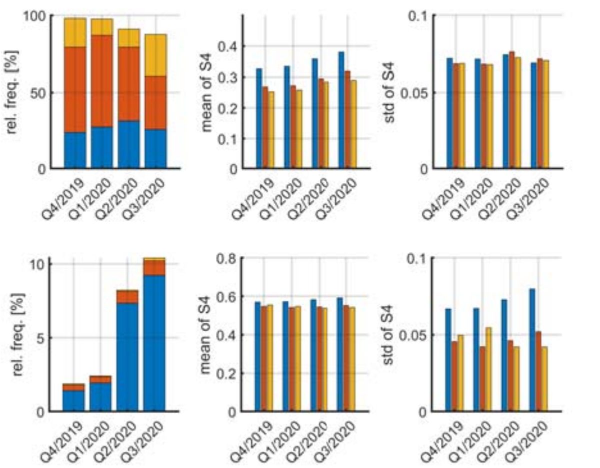


**Figure 1.** Distribution of S4 index retrievals from the MOSAiC expedition data. Upper panels: part at weak a scintillation range (S4 $< 0.5$), lower panels: part at moderate scintillation range ($0.5 \leq$ S4 $< 0.8$). The time bins correspond to the four quarter (Q) of the one-year expedition. Different elevation ranges are color-coded: $10° \ldots 30°$ (blue), $30° \ldots 45°$ (red), $> 45°$ (yellow).

however, increased (to about 8 and 10%). For comparison, we analyzed ancillary ground-based data of the Ny-Alesund GNSS scintillation station operated by the University of Oslo. In the essential period, June 2020, when *Polarstern* was near the station, an increased (moderate range) S4 scintillation level was not confirmed by the station data. The Ny-Alesund results (not shown here) stay permanently at the weak level with $S4 < 0.1$ on average.

## 3 Discussion and Conclusion

A deeper analysis of the *Polarstern* data for typical example events was conducted applying variational mode decomposition. These results show that coherent multipath patterns and a noise-level increase during higher sea state conditions (heave reaching the 1-meter range) play a role in the occurrence of moderate scintillation level for ship-based S4. Values in the strong scintillation range (S4 $> 0.8$) or even loss-of-lock due to multipath or sea state conditions were not detected. In conclusion, we did not find critical disturbance of signal intensity or phase, neither due to ionospheric scintillation nor due to sea-state conditions in the considered data. The given results are based on the *Polarstern* data set. In an on-going step, the analysis is extended to the *Kronprins Haakon* data, still under the calm ionospheric conditions of 2020. Further studies of ship-based GNSS data, under more disturbed ionosphere conditions, are anticipated.

## 4 Acknowledgements

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