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Are ship-based GNSS measurements precise enough to detect ionospheric phase scintillation at solar minimum?

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A GNSS data set was recorded for ionosphere sounding on the German research icebreaker *Polarstern* during the expedition of MOSAiC (Multidisciplinary Observatory for the Study of the Arctic Climate). The GNSS setup comprised a multi-GNSS high-rate (50 Hz) receiver and a multiband GNSS antenna at right-handed polarization. During the one-year expedition (Sep. 2019 to Oct. 2020) the ship drifted with ice floes over the Arctic Ocean for studying the Arctic climate. In addition, the drift gave an excellent opportunity to collect GNSS data for ionosphere sounding over the central Arctic (at lat. > 85° N). More than five months the ship was drifting in the central part of the Arctic where data from permanent GNSS stations are not available. Nearest stations are all located further south. These measurements aboard *Polarstern* provide ideal conditions to study scintillations induced by disturbances in the Arctic ionosphere (e.g. by polar patches). The coincidence of the expedition period (2019/20) and solar minimum is a small drawback for the study. It limits the probability of strong scintillations in the observations. So, the question arises whether the precision of GNSS phase measurements on a ship is high enough to detect phase scintillations at solar minimum.

The standard deviation of detrended phase samples (phase scintillation index) is derived with 30 s resolution for each GNSS link to quantify disturbance. The study focuses in a first approach on GPS data and high elevation angles (> 30°) as these rays propagate rather vertically and stay in the central Arctic with ionospheric piercing points (assumed at 350 km) not far from the ship location (roughly: horizontal distance < 600 km). Three categories of disturbance are identified in this elevation range:

- Phase index baseline of about 0.1 +/- 0.05 rad, that is the lower limit for this ship-based setup
- Phase index anomalies from 0.15 to 0.4 rad (and more) that are found in constant directions on the ship (constant relative bearing) and can be attributed to disturbance of ship multipath/shadowing (by mast and chimney) affecting the field-of-view in these directions
- Phase index anomalies between 0.15 and 0.2 rad, that occur around local noon at the given high latitudes and can be identified as weak scintillations due to ionospheric disturbance in the cusp region (at the convergence of geomagnetic field lines)

Compared to a typical ground-based station operating in the Arctic, the ship-based measurements present a rather high baseline index level that is already in the weak scintillation range. The difference between baseline and the cusp-related scintillations is rather small. Parameters (latitude, elevation angle and local time of the observation) are considered to identify the ionospheric scintillations. Furthermore, anomalies induced by ship multipath disturb the scintillation detection and need to be identified and masked out based on relative bearing limits. We conclude that ship-based GNSS is precise enough to detect Arctic phase scintillations even at the minimum of the solar cycle if proper analysis is conducted.