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# Open-loop GPS signal tracking at low elevation angles from a ground-based observation site

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For more than a decade space-based global navigation satellite system (GNSS) radio occultation (RO) observations are used by meteorological services world-wide for their numerical weather prediction models. In addition, climate studies increasingly rely on validated GNSS-RO data sets of atmospheric parameters. GNSS-RO profiles typically cover an altitude range from the boundary layer up to the upper stratosphere; their highest accuracy and precision, however, are attained at the tropopause level. In the lower troposphere, multipath ray propagation tend to induce signal amplitude and frequency fluctuations which lead to the development and implementation of open-loop signal tracking methods in GNSS-RO receiver firmwares. In open-loop mode the feed-back values for the carrier tracking loop are derived not from measured data, but from a Doppler frequency model which usually is extracted from an atmospheric climatology.

In order to ensure that this receiver-internal parameter set, does not bias the carrier phase path observables, dual-channel open-loop GNSS-RO signal tracking was suggested. Following this proposal the ground-based “GLESER” (GPS low-elevation setting event recorder) campaign was established. Its objective was to disproof the existence of model-induced frequency biases using ground-based GPS observations at very low elevation angles.

Between January and December 2014 about 2600 validated setting events, starting at geometric elevation angles of $+2^\circ$ and extending to $-1^\circ \ldots -1.5^\circ$, were recorded by the single frequency “OpenGPS” GPS receiver at a measurement site located close to Potsdam, Germany (52.3808°N, 13.0642°E). The study is based on the assumption that these ground-based observations may be used as proxies for space-based RO measurements, even if the latter occur on a one order of magnitude faster temporal scale. The “GLESER” data analysis shows that the open-loop Doppler model has negligible influence on the derived frequency profile provided signal-to-noise density ratios remain above about 30 dB Hz. At low signal levels, however, the dual-channel open-loop design, which tracks the same signal using two Doppler models separated by a 10 Hz offset, reveals a notable bias. A significant fraction of this bias is caused by frequency aliasing. The receiver’s dual-channel setup, however, allows for unambiguous identification of the affected observation samples. Finally, the repeat patterns in terms of azimuth angle of the GPS orbit traces reveals characteristic signatures in both, signal amplitude and Doppler frequency with respect to the topography close to the observation site. On the other hand, mean vertical refractivity gradients extracted from ECMWF meteorological fields exhibit moderate correlations with observed signal amplitude fluctuations at negative elevation angles emphasizing the information content of low-elevation GPS signals with respect to the atmospheric state in the boundary layer.