**Title**

State estimation and validation of currents using Delft GNSS single-frequency precise point positioning algorithm: With emphasis on the variance model

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**Abstract**

The Delft real-time GNSS single-frequency precise point positioning (RT-SF-PPP) algorithm is extended to include velocity and receiver clock drift as unknown states to be estimated from Global Navigation Satellite Systems (GNSS) measurements. Carrier-phase ambiguities are assumed constant over time. Two different variance models are used, one obtains variance as a function of satellite elevation, and the other obtains variance as a function of carrier-to-noise density ratio as estimated by the receiver. The elevation based variance model was used in the original RT-SF-PPP algorithm, and adapted to include Doppler measurements. The carrier-to-noise density ratio based variance model components are estimated from double difference (DD) observation combinations using measurements obtained from a shortbaseline experiment with two receivers setup over multiple days. Two velocity observables are used and related to velocity and clock drift through the extended functional model of the original algorithm: the receiver generated Doppler and a time-derivative of the carrier-phase observable: the time-differenced carrier-phase (TDCP). Algorithmic performance is evaluated by the horizontal RMSE, which represents accuracy as the variance plus bias squared, precision and reliability. This was validated using three different experiments: a stationary receiver on top of a roof, a buoy freely adrift in the North Sea, and a receiver mounted on a car driving a regional road. It was found that in terms of position in the static experiment and under calm water conditions during the drifting buoy experiment the horizontal RMSE was between 0.429 and 0.530 [m], and under rough water conditions and a road partly flanked by fences and trees between 0.682 and 0.812 [m]. Furthermore in terms of velocity it was found that the TDCP observable in combination with the carrier-to-noise density based variance model has a horizontal RMSE between 0.014 and 0.068 [m/s] over all experiments, and using the Doppler observable with either variance model a RMSE between 0.033 and 0.122 [m/s]. The algorithm was even found by means of external reliability to be capable of detecting faults at the boundary of 0.5 [m] for position and 0.1 [m/s] for velocity in the TDCP observable case.