Supplementary material: Observing glacier dynamics with low-cost, multi-GNSS positioning in Victoria Land, Antarctica

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PRECISE POINT POSITIONING (PPP) WITH LOW-COST GNSS HARDWARE

Examples of single-receiver PPP solutions for low-cost u-blox ZED-F9P and survey-grade Trimble R10 observations are presented here. PPP solutions are generated with the open-source software RTKLIB (Takasu and Yasuda, 2009) and the online CSRS-PPP service (Banville and others, 2021). RTKLIB configuration settings are included in Table S1. The CSRS-PPP service is described in detail by Banville and others (2021).

Table S1. PPP configuration settings used to process u-blox and Trimble observations with RTKLIB v2.4.3 (Takasu and Yasuda, 2009).

Processing mode	Method
Dynamic model for positions	None (un-linked in time, i.e., treated as white noise). Also referred to as 'kinematic' positioning
Receiver clock error	None (un-linked in time, i.e., treated as white noise)
Carrier-phase bias	Time-constant
Ionosphere	Ionosphere-free linear combination (Takasu, 2013)
Tropospheric delay estimation	Estimate zenith tropospheric delay (ZTD) and horizontal gradient parameters,
	mapping function: Niell (1996)
Constellations	GPS, GLONASS, Galileo
Frequencies	L1+L2
Sampling interval	30 s
Integer ambiguity resolution	None (PPP with ambiguity resolution is experimental in RTKLIB v2.4.3)
Filter type	Combined solution (forward and backward filter).
Elevation mask	10°
Earth tides	Solid earth tidal displacements (IERS1996 conventions)
	Ocean tidal loading, TPXO7.2, (Egbert and Erofeeva, 2002)
Phase wind-up effect	Applied (Takasu, 2013)
Satellite ephemeris/clock	Precise, GFZ0OPSFIN* satellite orbits and clock corrections (Männel and others, 2022)
Receiver/satellite phase centre	Phase centre offset (PCO) and phase centre variation (PCV) values
	from IGS14.atx (Johnston and others, 2017)

PPP solutions for stationary GNSS positioning

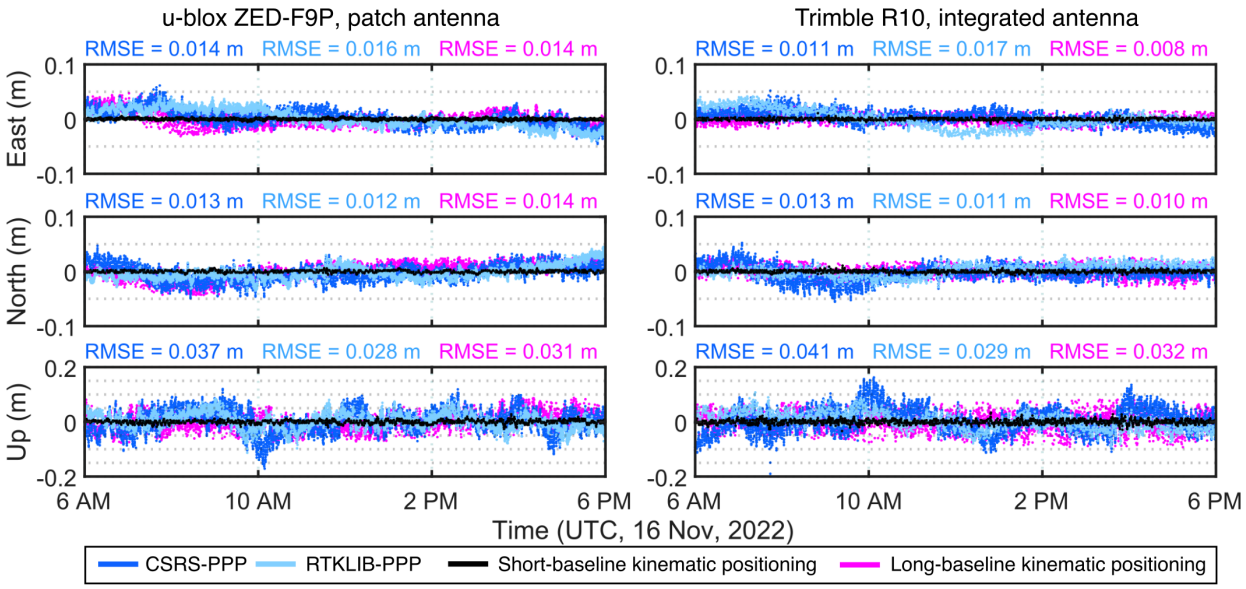

Fig. S1. PPP and single-baseline kinematic positioning solutions for stationary u-blox and Trimble R10 observations from Experiment 1. Root mean square error (RMSE) values describe the difference between the expected position (zero displacement with time) and the observed positions. The short baseline is 3.5 m and the long baseline is 357 km.

PPP solutions for stationary u-blox and Trimble positions are presented in Fig. S1. These datasets were obtained as part of Experiment 1 (Section 3), conducted at Mario Zucchelli Station on November 16, 2022. Raw observations are processed in kinematic mode, that is, the same parameter settings applied to dynamic GNSS positions from a glacier. The correct solution for the stationary time series is zero displacement with time, and therefore, any excursions from zero displacement quantify the PPP solution quality. The root mean square error (RMSE) describes the difference between the expected position (zero displacement) and alternative solutions (CSRS-PPP, RTKLIB-PPP and long-baseline kinematic positioning).

PPP solutions for dynamic GNSS positioning

PPP and single-baseline solutions for dynamic observations are compared using data from station Ub1 installed on Priestley Glacier as part of Experiment 3 (Fig. S1b). For this comparison, we take the medium-baseline (34 km) solution as the expected solution. The RMSE is used to compare alternative positioning solutions to the medium-baseline displacement time series. Long-baseline positioning (390 km, GPS+GLONASS+Galileo) provided better horizontal positioning performance in terms of RMS errors than the CSRS-PPP (GPS+GLONASS) and RTKLIB-

PPP (GPS+GLONASS+Galileo) solutions (Exp. 3; Fig. S1b).

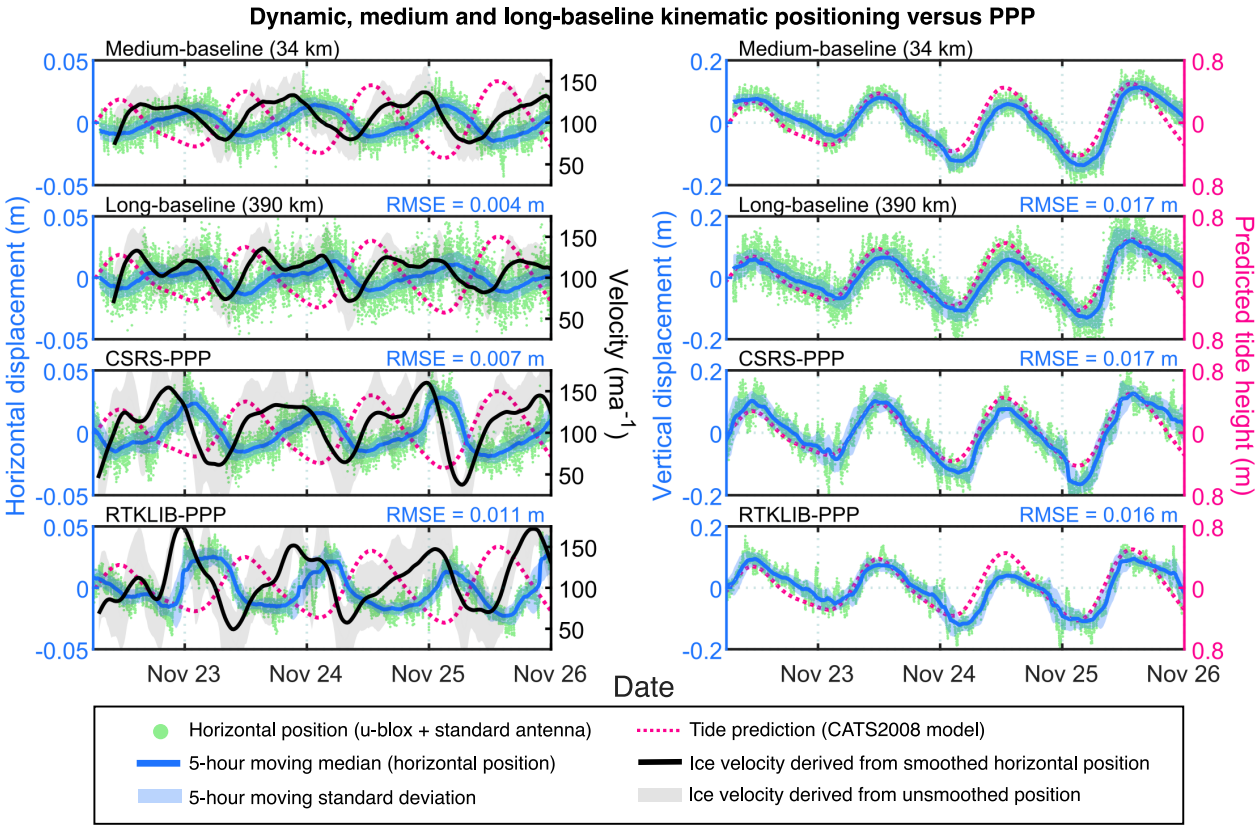

Fig. S2. Horizontal and vertical position time series from low-cost u-box station Ub1 installed on Priestley Glacier (Experiment 3). RMSE values describe the difference between the expected displacement (the medium-baseline solution) and alternative solutions (long-baseline, CSRS-PPP and RTKLIB-PPP solutions). The medium-baseline (34 km) test uses the temporary base station installed at Mario Zucchelli Station and the long-baseline (390 km) test uses IGS reference station SCTB installed near Scott Base, (Johnston and others, 2017). The tide prediction is from the CATS2008 model (Padman and others, 2002; Howard and others, 2019).

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