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Quality assessment of GNSS observations from recent low-cost receivers

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Introduction and motivation:

Consequences of technology development are low-cost versions of instruments designed to track Global Navigation Satellite System (GNSS) signals. At the beginning such receivers were used in less demanding applications (for example car navigation) but now they are also tested in a precise positioning.

GNSS mass-market receivers can be divided into:

- the chipsets embedded in smartphone devices
- the low-cost modules integrated with application boards.

Since the first group suffers from low-quality integrated antenna and power management issues, only the second kind of receivers seems to be applicable for more challenging applications.

Prerequisite for any precise positioning is a high quality of GNSS data. Thus, the main goal of our research is evaluation of code and phase measurements recorded by three receivers from the second group.

Data

The GNSS measurements used in the experiment were recorded by three types of low-cost receivers

- UBLOX ZED-F9P,
- SEPTENTRIO MOSAIC-X5,
- SKYTRAQ.

Additionally, as a reference, we used a geodetic receiver – TRIMBLE ALLOY.

In the tests we used pairs of each device working in a zero-baseline mode, i.e., two homogeneous instruments received the signals from the same antenna. The test period covered four days: 27-28 February, 2022, and 2-3 March, 2022. During the first two days, the receivers were connected to a high-grade geodetic antenna TRM59800.00 NONE, whereas in the second two-day long period, a UBLOX ANN-MB antenna was installed.

Code measurements noise - methodology

To evaluate the code noise, we used well-known multipath combinations.

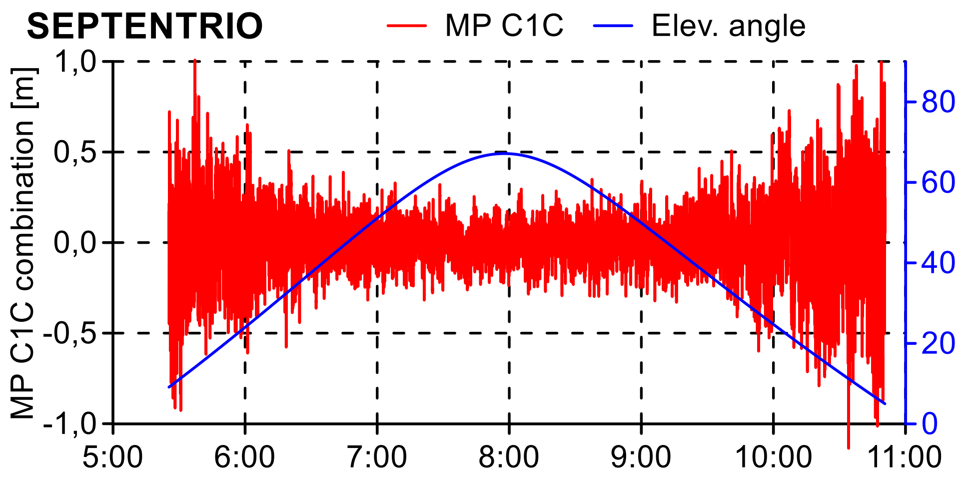
$$MP1 = P_1 - \left(1 + \frac{2}{\propto -1}\right) L_1 + \left(\frac{2}{\propto -1}\right) L_2 \approx \ M_{P1} + \varepsilon_{P1} + B_{MP1}$$

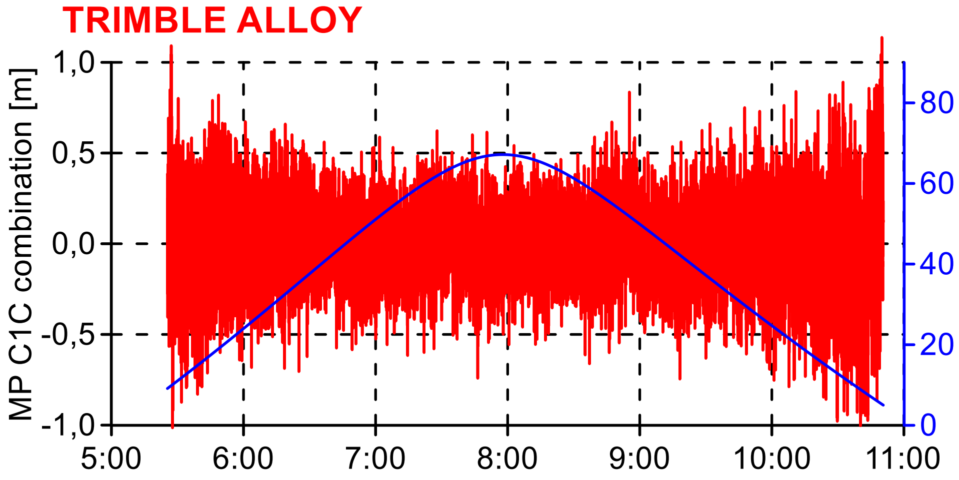
$$MP2 = P_2 - \left(\frac{2\alpha}{\propto -1}\right) L_1 + \left(\frac{2\alpha}{\propto -1} - 1\right) L_2 \approx \ M_{P2} + \varepsilon_{P2} + B_{MP1}$$

where P_1, P_2 and L_1, L_2 correspond to dual-frequency code/phase data α is a frequency factor equal to $\alpha = f_1^2 / f_2^2$.

Since ambiguity terms B_{MP1}, B_{MP2} are constant, the standard deviation of such combinations can be considered as indicator of code data noise. On the other hand, it should be remarked that such characteristic represent a combined impact of noise and multipath.

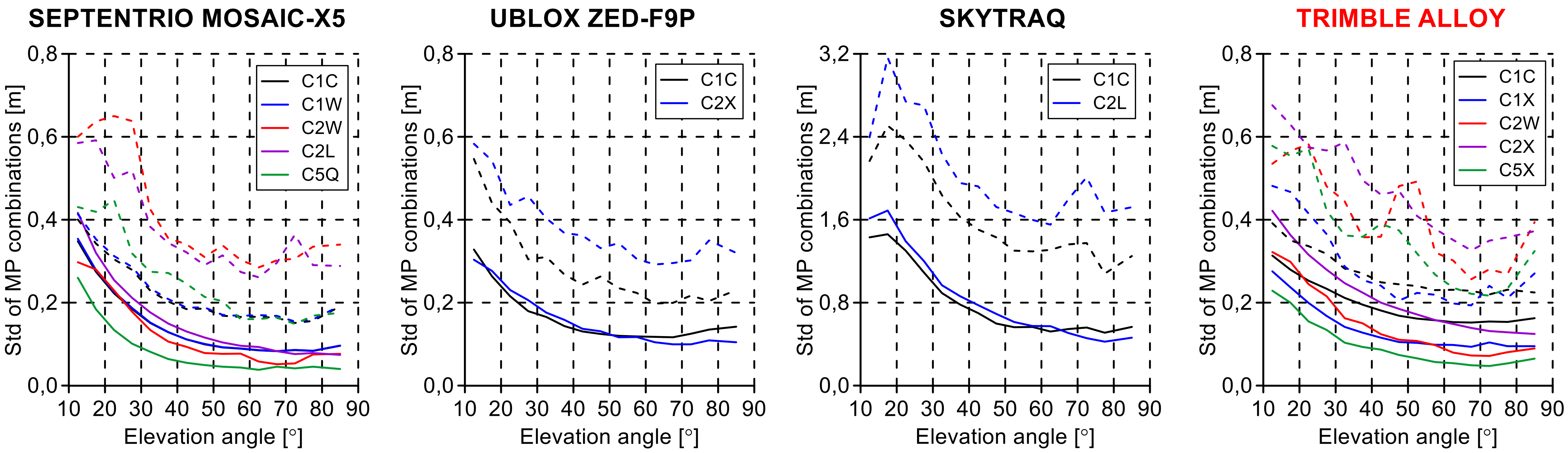
Multipath combination – example





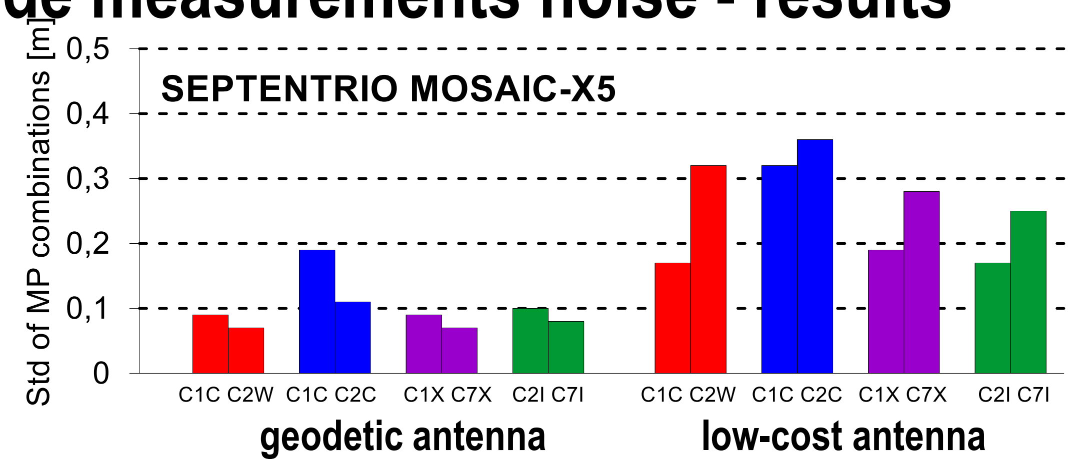
Time series of MP1 combination for satellite GPS 14

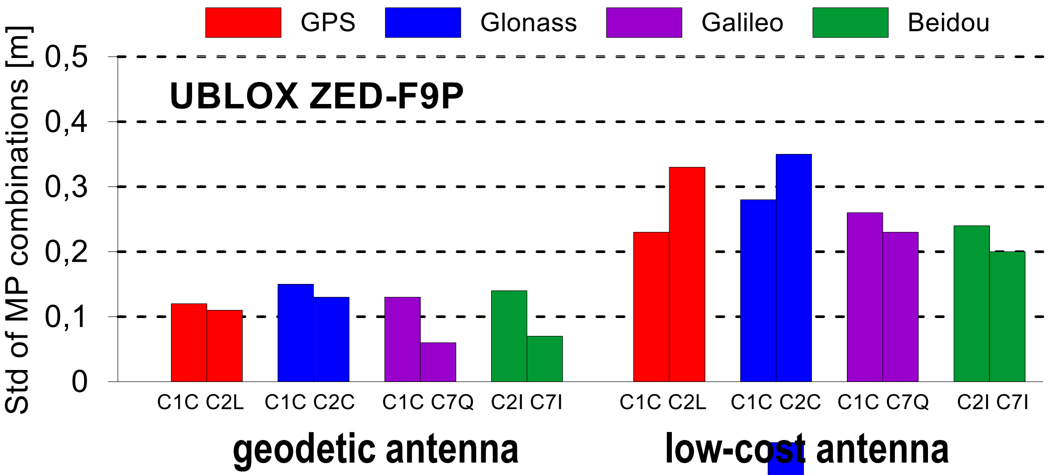
Code measurements noise - results

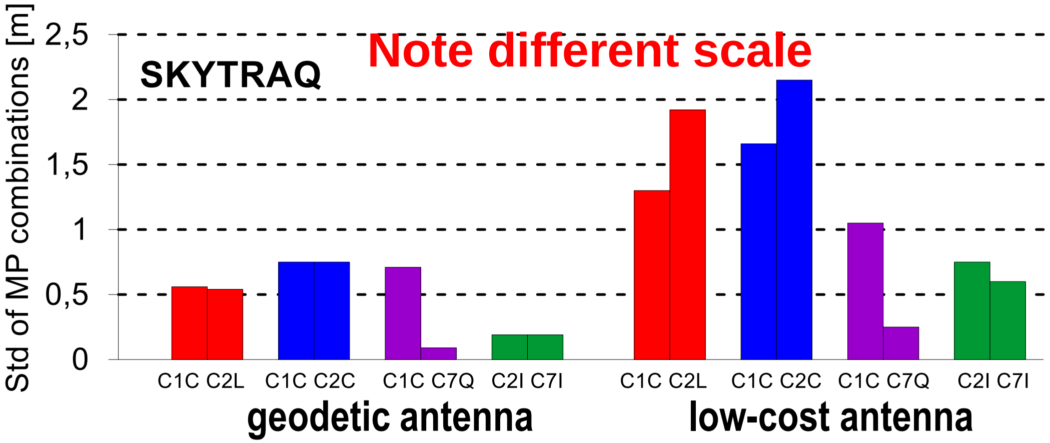


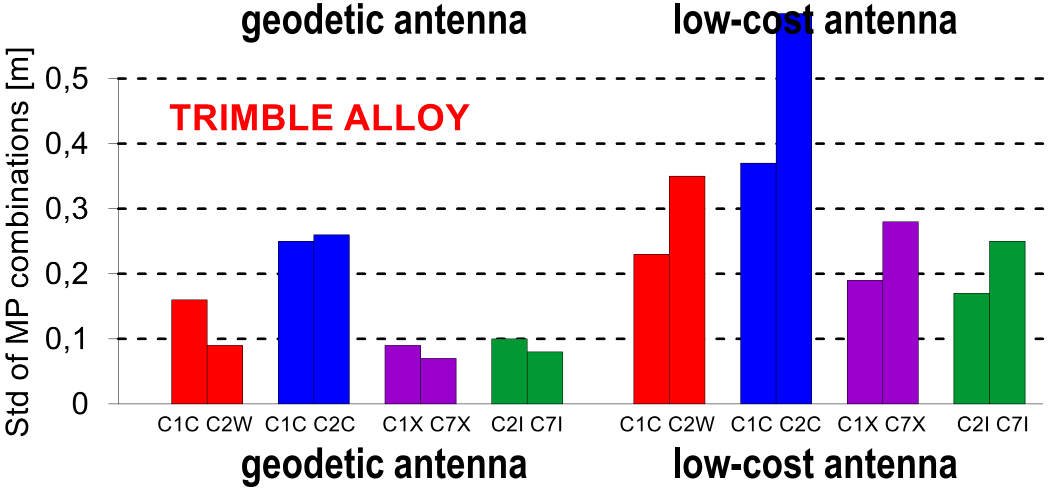
Dependence of code measurements noise on elevation angle for all GPS data (solid lines – geodetic antenna TRM59800.00, dashed lines – low-cost antenna UBLOX ANN-MB)

Code measurements noise - results



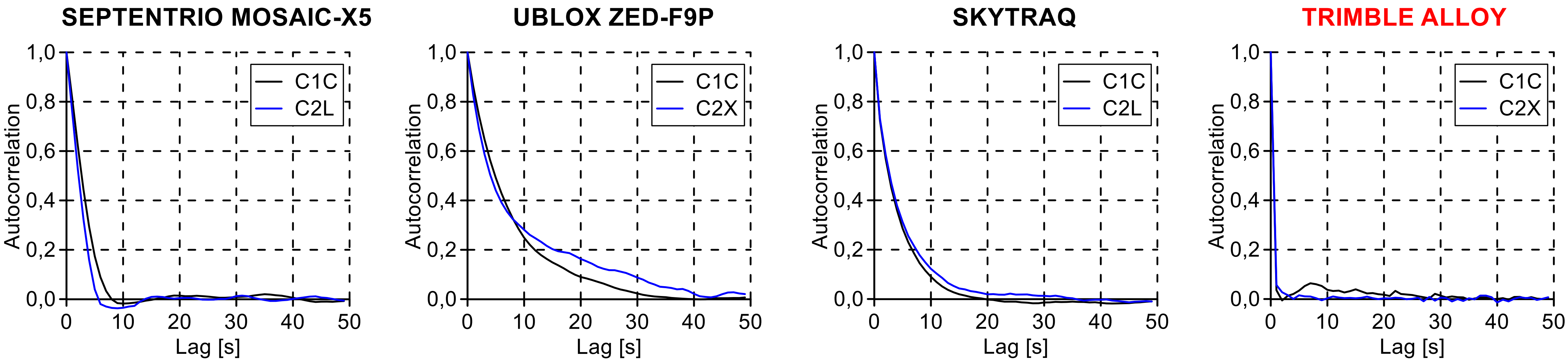






Std of MP combinations for measurements with elevation > 45°

Code measurements noise – temporal correlation



The results of autocorrelation of Double Differenced code data for GPS system

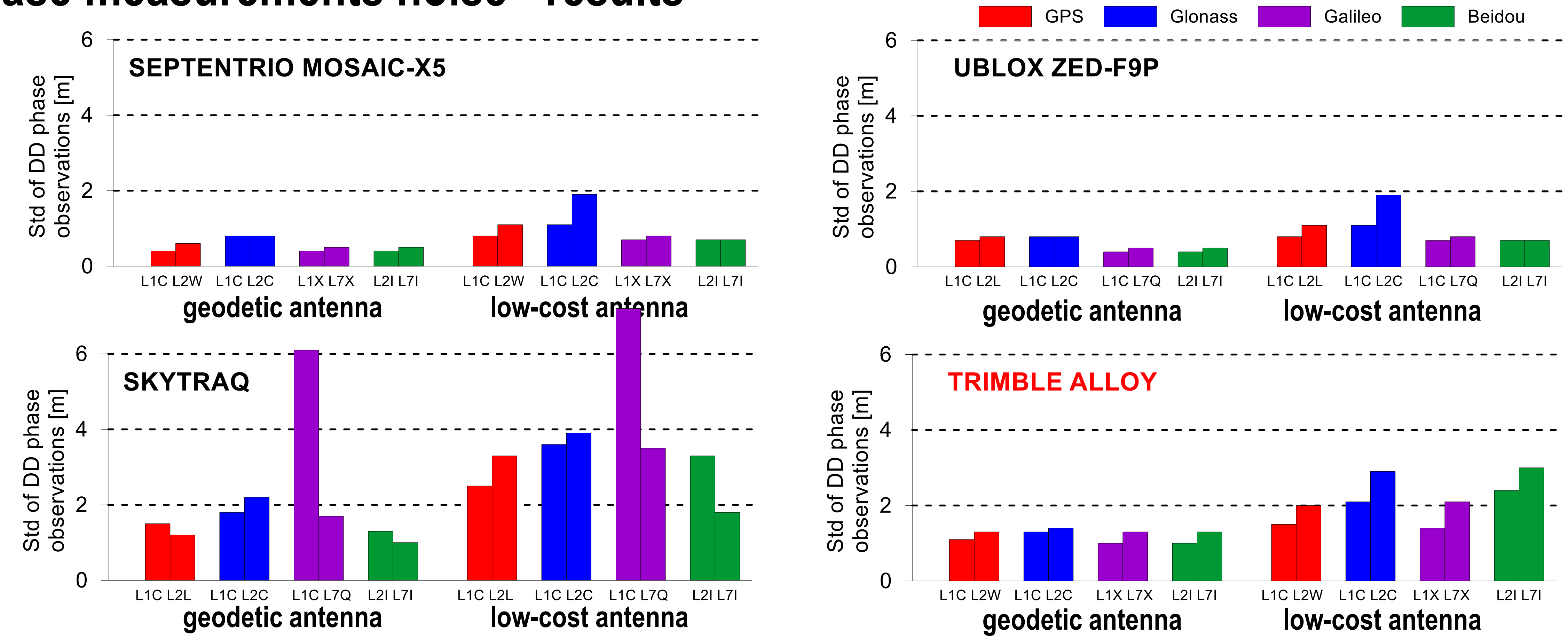
Phase measurements noise – methodology

Noise of phase data has a very small amplitude. Thus, its evaluation requires double differenced phase observations. In our case, we used the most common approach for such analyses, i.e., a so-called zero-baseline. The generation of double-differenced observations at zero-baseline eliminates all factors related to the uncertainty of clocks and delays in atmospheric layers. Consequently, all variations in such prepared time series should be considered as phase noise.

$$L^{kl}_{1,ij} = (L^{k}_{1,i} - L^{k}_{1,j}) - (L^{l}_{1,i} - L^{l}_{1,j}) = \varepsilon_{L1}$$

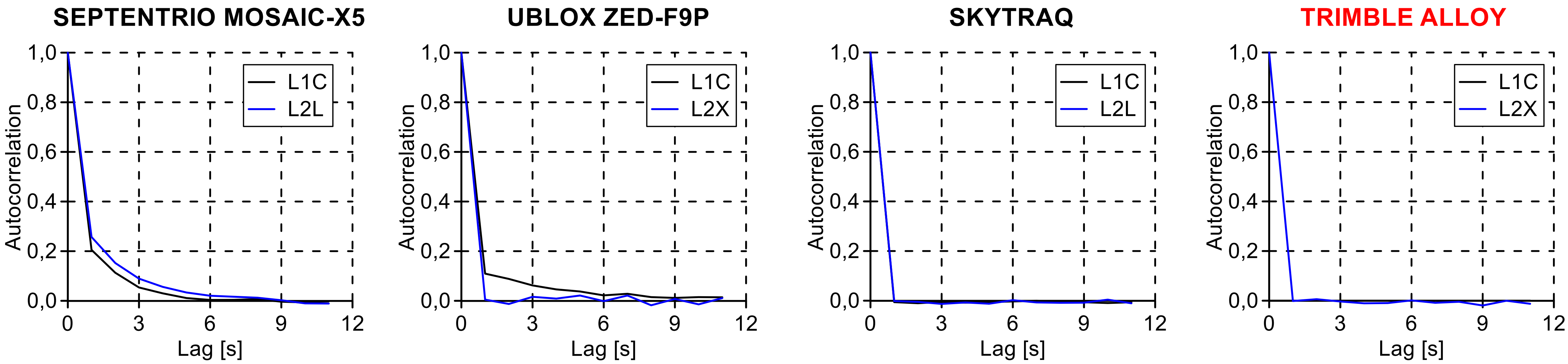
It should be noted that the results from the zero-baseline solution underestimate the phase noise occurring in real conditions. This is related to the mitigation of all antenna impact and phase multipath. Nevertheless, it allows a comparison of different receivers

Phase measurements noise - results



Std of Double Differenced phase measurements with elevation > 45°

Phase measurements noise – temporal correlation



The results of autocorrelation of Double Differenced phase data for GPS system

Conclusions

- The analysis indicated that observations from SEPTENTRIO MOSAIC-X5 and UBLOX ZED-F9P low-cost receivers are of high quality, and there is no doubt they can be used in precise positioning and applications.
- SKYTRAQ GNSS low-cost receiver has a much worse quality of observations.
- Comparing datasets from SEPTENTRIO MOSAIC-X5 and UBLOX ZED-F9P with those provided by TRIMBLE ALLOY, they are even more precise. Such an effect has, however, implications for temporal correlation of low-cost GNSS observations.

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