

Introduction and theoretical background

To obtain highly precise positions with Global Navigation Satellite Systems (GNSS), it is mandatory to take all error sources, including phase center corrections (PCC), adequately into account.

- PCC are composed of a phase center offset (PCO), corresponding azimuthal and elevation-dependent phase center variations (PCV) and a constant part r .
- PCC have to be applied to the measurements since the pattern of GNSS receiver antennas deviate from an ideal omnidirectional radiation pattern.
- Corrections reach up to decimeter level for carrier phase measurements and are either determined by anechoic chamber measurements or calibrations in the field using a robot.

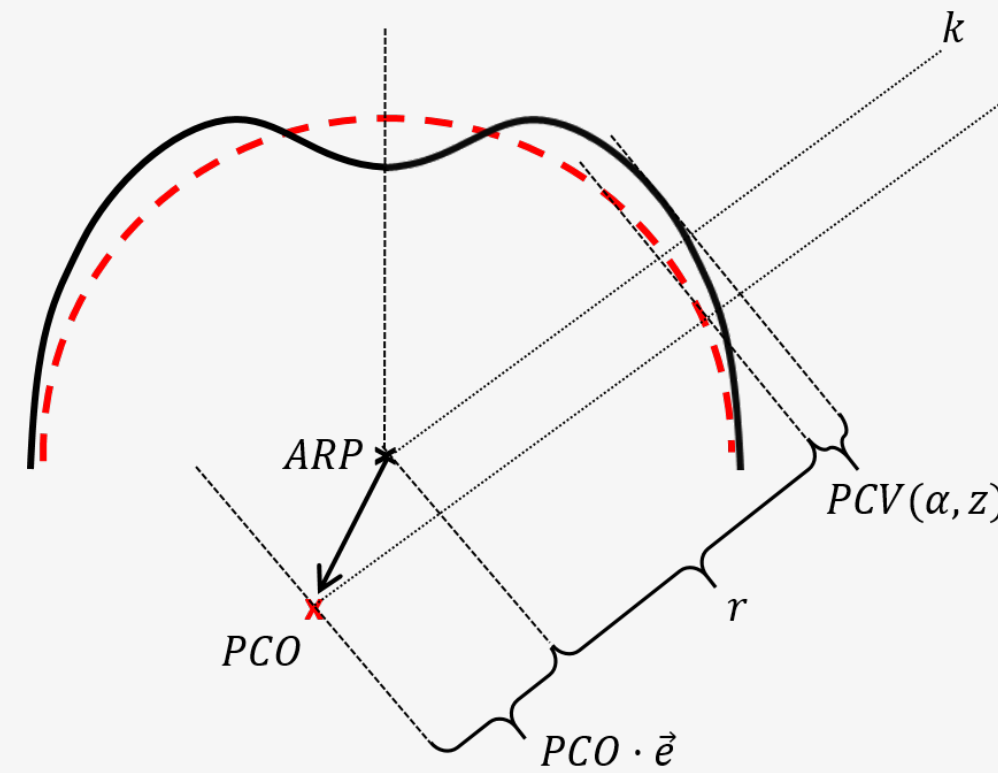


Figure 1: Sketch of the geometric interpretation of PCC, including PCV, PCO and constant part r . The red, dashed line represents the ideal radiation pattern of a GNSS antenna, whereas the black, solid line indicates the real phase front.

In this contribution, the receiver's impact on robot-based calibrations of multi-GNSS antennas is assessed. To this end, PCC estimated with different receivers are analysed (i) at the pattern level and (ii) in the coordinate domain by a well controlled short baseline and common clock setup.

Calibration methodology

- Robot tilts and rotates antenna under test (AUT) in short time intervals ($\Delta \approx 1$ s) around a fixed point in space.
- Same type of geodetic receiver logs GNSS raw data at robot and reference station. For these analyses, a zero baseline at each station (reference, robot) is setup to assess the receiver's impact.
- Together with logged robot movements and timestamps, time-differenced receiver-to-receiver single differences (dSD) are calculated in a post processing approach.
- PCC are parametrised by spherical harmonic functions and estimated in a least-squares adjustment with dSD as observations. Details of the calibration methodology are described in [1]. However, a slightly different algorithm to stabilize the normal equation system has been used here.

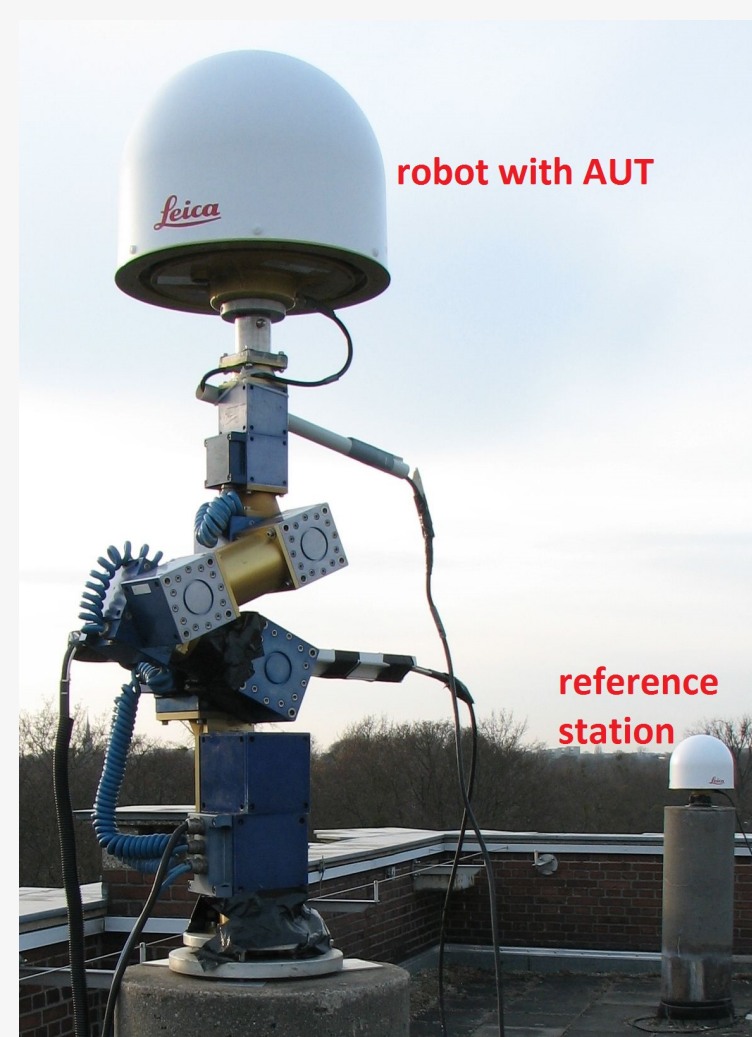


Figure 2: Calibration setup at the IFE.

Repeatability of individual calibrations

- Repeatability of individual calibrations is shown as individual PCC differences (ΔPCC) to the mean pattern calculated from the individual calibrations.
- Repeatability of a NOV703GGG.R2 rover antenna with a Javad Delta receiver (PCC_{JVD} , Fig. 3) and a Septentrio PolaRx5TR receiver (PCC_{SPT} , Fig. 4) is below 0.8 mm for shown GPS (GL1C, GL5X), Galileo (EL1C/X) and Beidou (CL2I) frequencies.

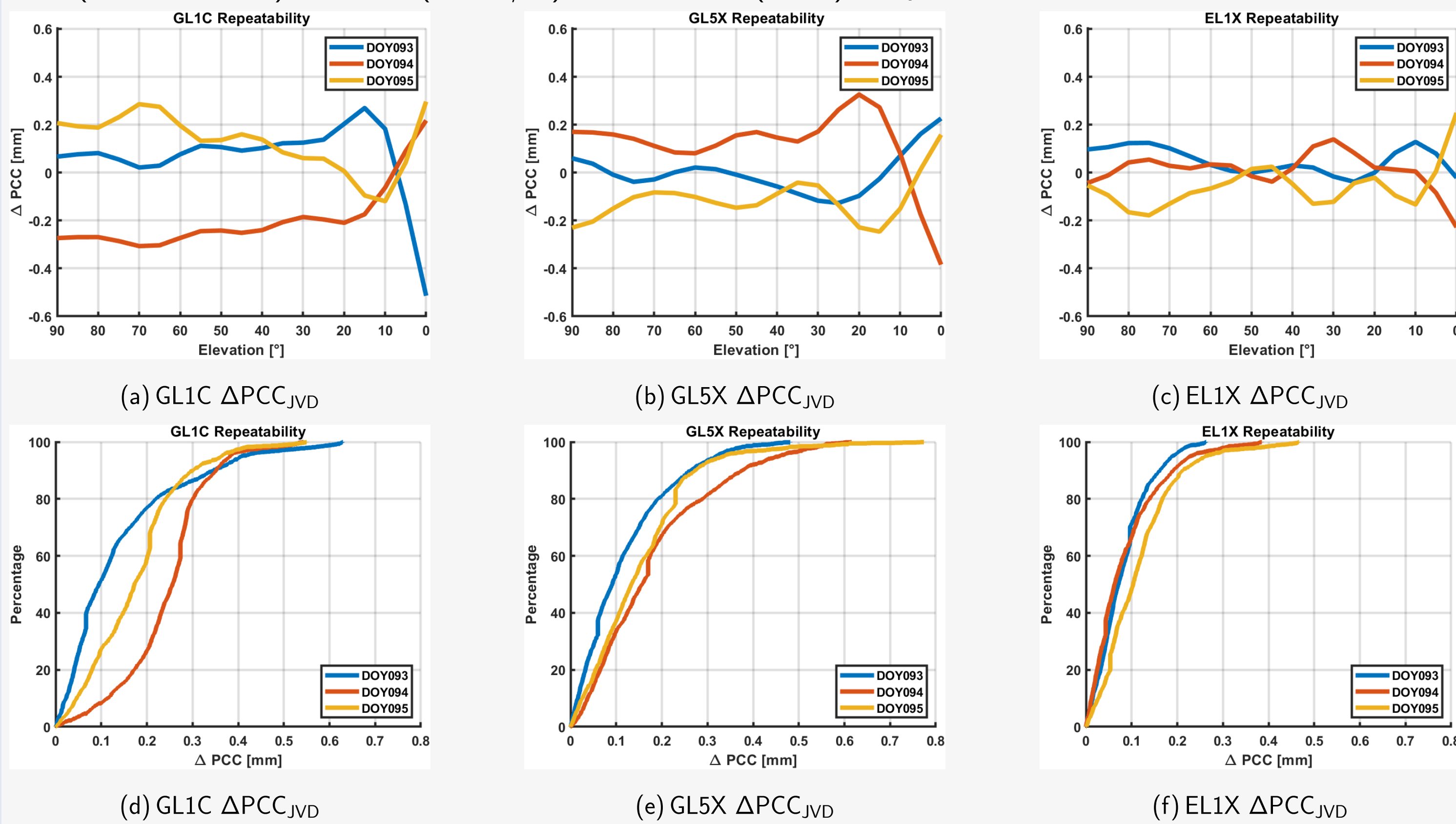


Figure 3: Repeatability of NOV703GGG.R2 PCC estimated with a Javad Delta receiver in 2021 in terms of only elevation-dependent ΔPCC (a – c) and absolute differences shown in cumulative histograms (d – f).

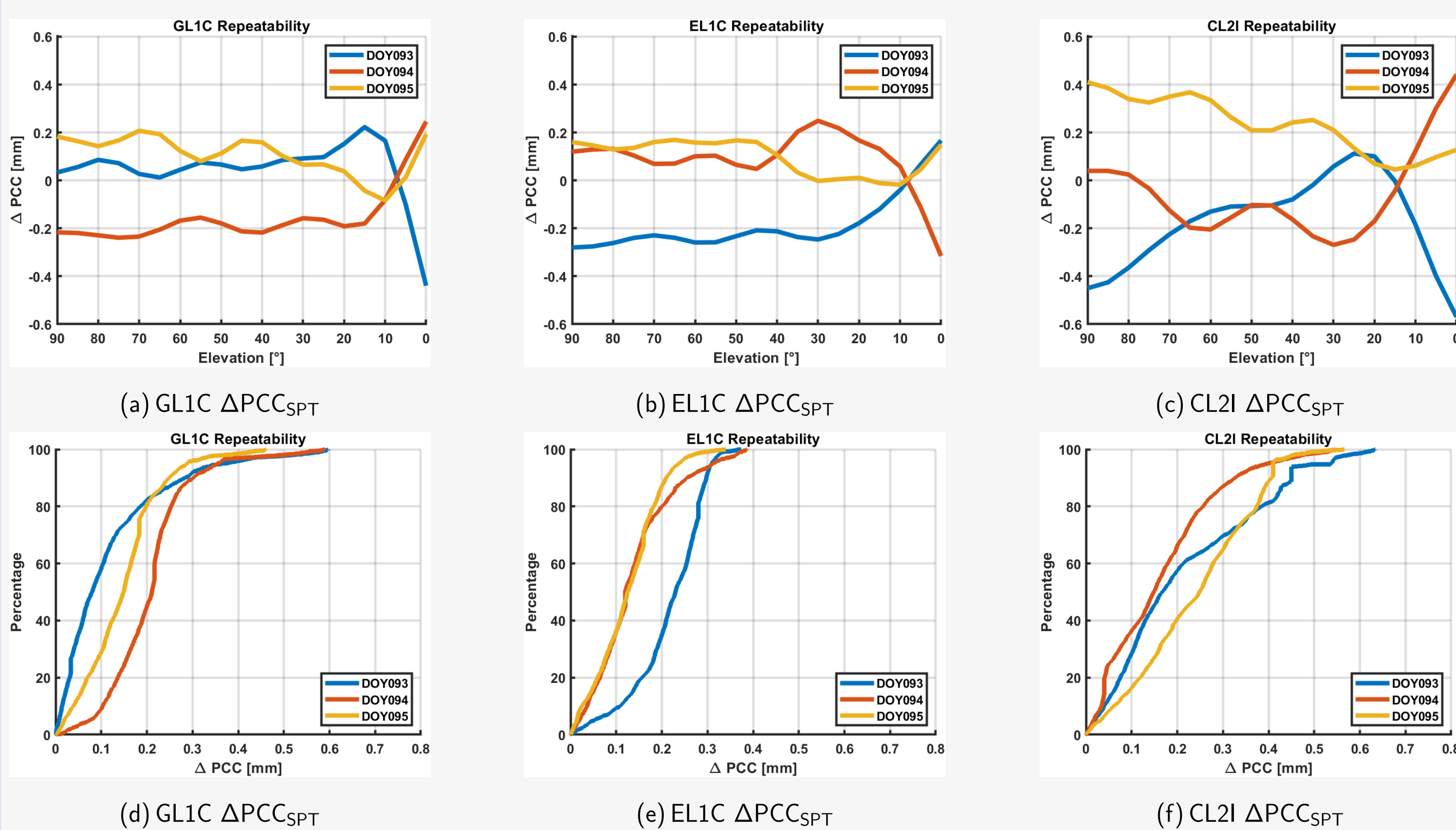


Figure 4: Repeatability of NOV703GGG.R2 PCC estimated with a Septentrio PolaRx5TR receiver in 2021 in terms of only elevation-dependent ΔPCC (a – c) and absolute differences shown in cumulative histograms (d – f).

Differences between different antenna-receiver combinations

- Impact of the receiver on estimated PCC marginal, since absolute PCC differences < 0.25 mm for shown frequencies.
- Slightly higher differences ($\Delta PCC_{Rx} < 1$ mm) observable for Javad GRAnt_G5T antenna.

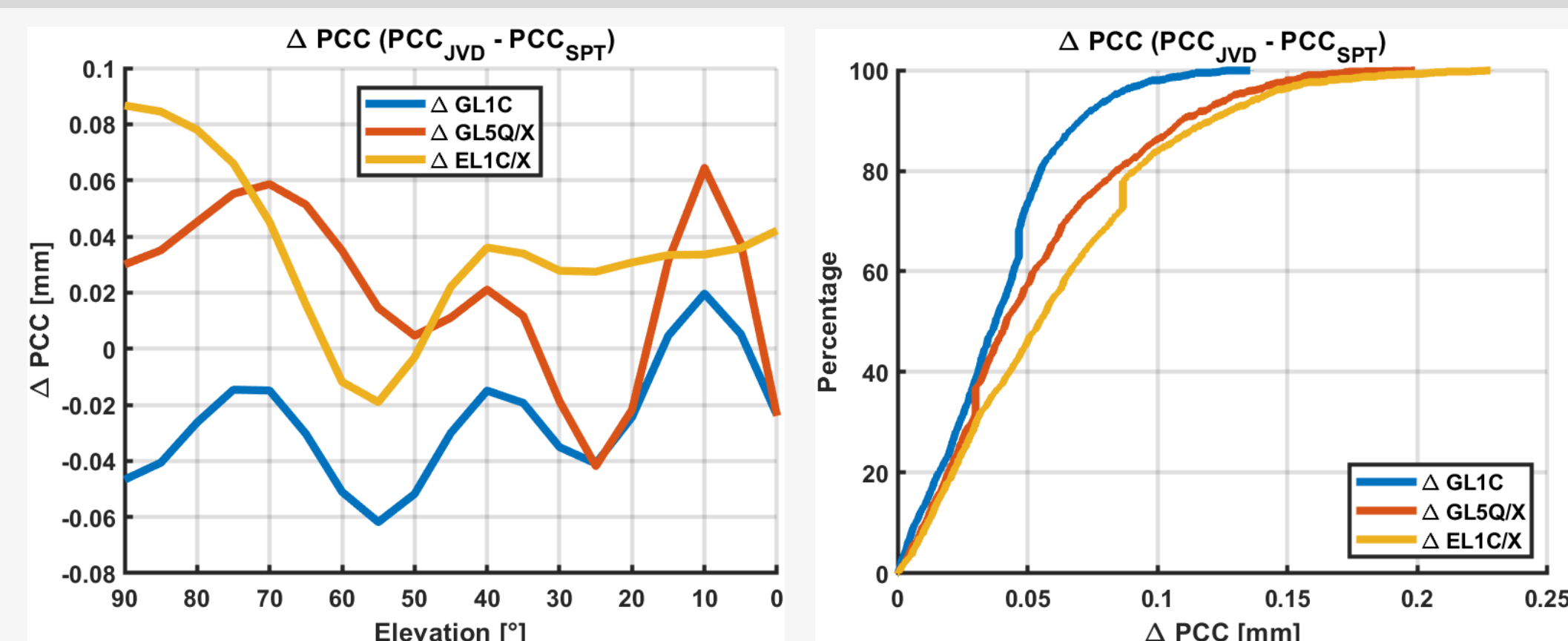


Figure 5: NOV703GGG.R2 pattern estimated with Javad Delta or Septentrio PolaRx5TR receivers.

Controlled validation setup

- Short baseline (20.643 m) common-clock setup to assess the impact of the receiver used during the calibration in the coordinate domain.
- Identical receivers used during the calibration process are used at each station (MSD5, MSD8) as a zero baseline configuration.
- GNSS data with a sampling rate of 15 s recorded for 10 days (DOY 162 to DOY 173 in 2020) with NOV703GGG.R2 rover antenna on MSD5 and LEIAR25.R3 LEIT on reference station MSD8.



Figure 6: Validation setup at IFE.

Evaluation strategy

- PCC impact evaluated for GPS and Galileo L1 observations using Bernese GNSS Software [2].
- Pattern of reference station MSD8 stays the same (estimated with Javad Delta receiver).
- All processing parameters are identical, only PCC (i.e. PCC_{JVD} , PCC_{SPT}) are changed at the rover site.
- Topocentric coordinate differences are calculated and compared for three different receivers (Javad Omega, Javad Delta, Septentrio PolaRx5TR).
- Individually daily batches are combined at the normal equation level.
- For each frequency (GL1, EL1 and GE L1) the whole processing is repeated independently.

Validation in the coordinate domain

- Horizontal topocentric coordinate differences are below 1 mm.
- Height offset for all frequencies and receivers of ≈ -2 mm can be seen:
 - Compared to solution of the reference coordinate, antenna at reference and rover site has changed. Offset introduced by antenna change, especially at rover site (≈ 1.3 mm) [3].
 - Daily baseline solutions vary between 1.2 to 1.5 mm for up-component.
 - Smaller height offset observable for L1 and E1 solution with NAX3G+C antenna [4].
- No clear improvement using antenna-receiver calibration can be seen for shown frequencies and combinations.

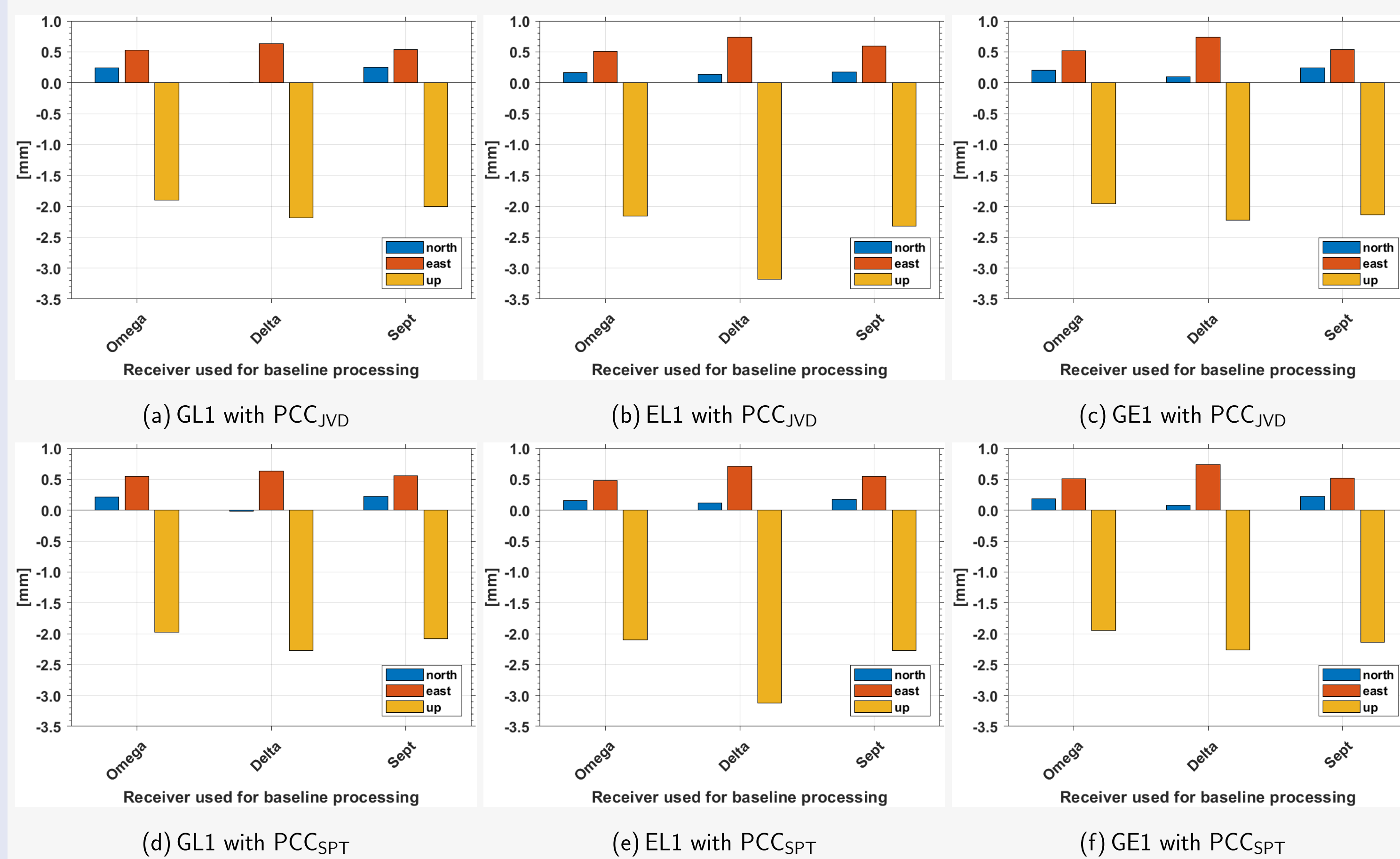


Figure 7: Impact of antenna-receiver calibration in the coordinate domain in terms of topocentric coordinate differences.

Conclusion

- PCC can be estimated with a high repeatability ($\Delta PCC_{max} < 0.8$ mm) for both investigated receivers.
- PCC differences between different antenna-receiver combinations are below 1 mm at the pattern level.
- Horizontal topocentric coordinate differences for all antenna-receiver calibrations are below 1 mm. Height offset should be further investigated.

References & Disclaimer

- [1] Kröger et al. (2021). Multi-frequency multi-GNSS receiver antenna calibration at IFE: Concept - calibration results - validation. *Advances in Space Research*. Doi: 10.1016/j.asr.2021.01.029
- [2] Dach et al. (2015). Bernese GNSS Software Version 5.2. *University of Bern, Bern Open Publishing*. Doi: 10.7892/boris.72297
- [3] Krawinkel et al. (2014). Scheinbare Koordinatenänderungen von GPS-Referenzstationen: Einfluss von Auswertestrategien und Antennenwechseln. *zfv 139(4)*, S. 252-263
- [4] Kersten et al. (2021). On the Role of GNSS Receivers for Antenna Patterns and Parameter Estimations. *EGU General Assembly 2021*. Doi: 10.5194/egusphere-egu21-3029

The authors do not attempt to recommend any of the instruments under test. It is also to be noted that the performance of the equipment presented in this paper depends on the particular environment and the individual instruments in use