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The impact of GNSS multipath errors on ZTD estimates based on PPP

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1. Motivation

- Multipath is a large systematic GNSS error source which can bias ZTD estimation, e.g. within PPP.
- Since it usually occurs at low elevation angles, where the mapping function values become large and thus significantly contribute to troposphere estimation, one can not simply exclude those observations.
- Given that the multipath environment needs to be carefully modelled at every site, it is difficult to develop a general mitigation approach. This is even more challenging as more and more low-cost stations are currently being installed.
- With the progress of ZTD estimation from high-precision/low-cost/real-time stations, the research on multipath errors becomes particularly important.
- With the help of a commercial GNSS simulator, it is possible to study the impact of multipath effects on ZTD estimates and try to develop the mitigation strategies of general nature.

2. Method

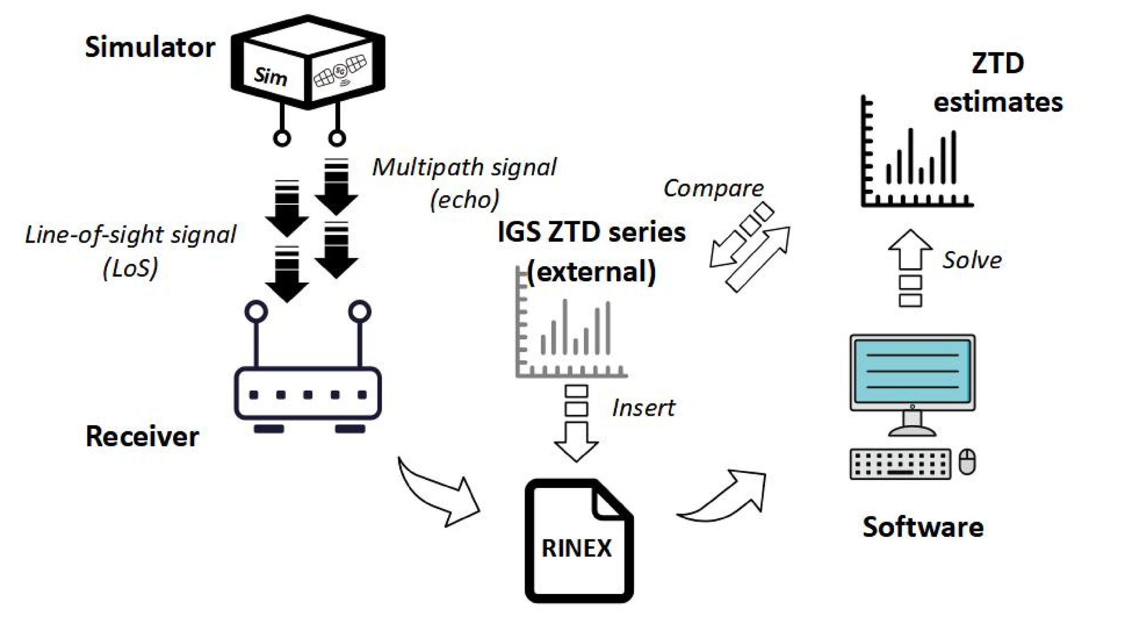

Fig. 1: Flowchart of the simulation chain which allows to study multipath effects on ZTD estimates.

Hardware	Simulator	Spirent GSS9000
	Receiver	Septentrio PolaRx5TR
	Mode	Static
	Data rate and duration	1Hz, 24h June 7-8, 2022
	Error sources	Multipath, receiver clock, thermal noise
Software	Solution type	PPP-AR, post processing
	Signal	GPS L1+L2
	El. mask	5°
	Algorithm	UDUC EKF solution
	Troposphere parameterization	• ZWD modelled as RW • VMF • IGS zpd providing reference ZTD

Tab.1: Hardware and tools used in this study, together with their parametrization .

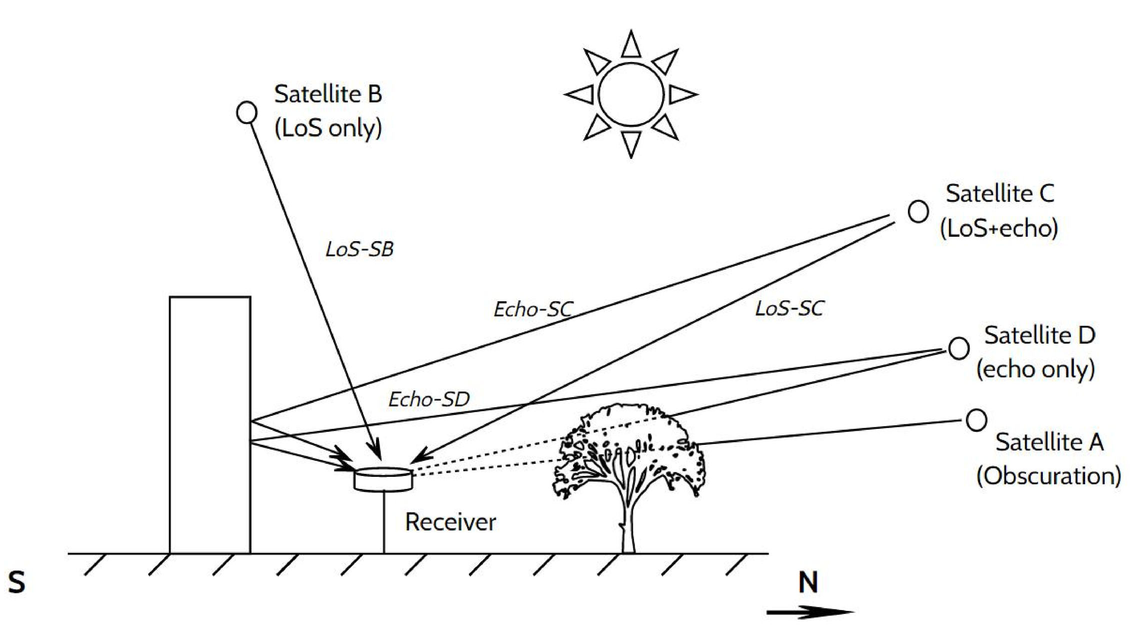

Fig. 2: Illustration of possible scenarios which relate to GNSS multipath.

3. Test cases

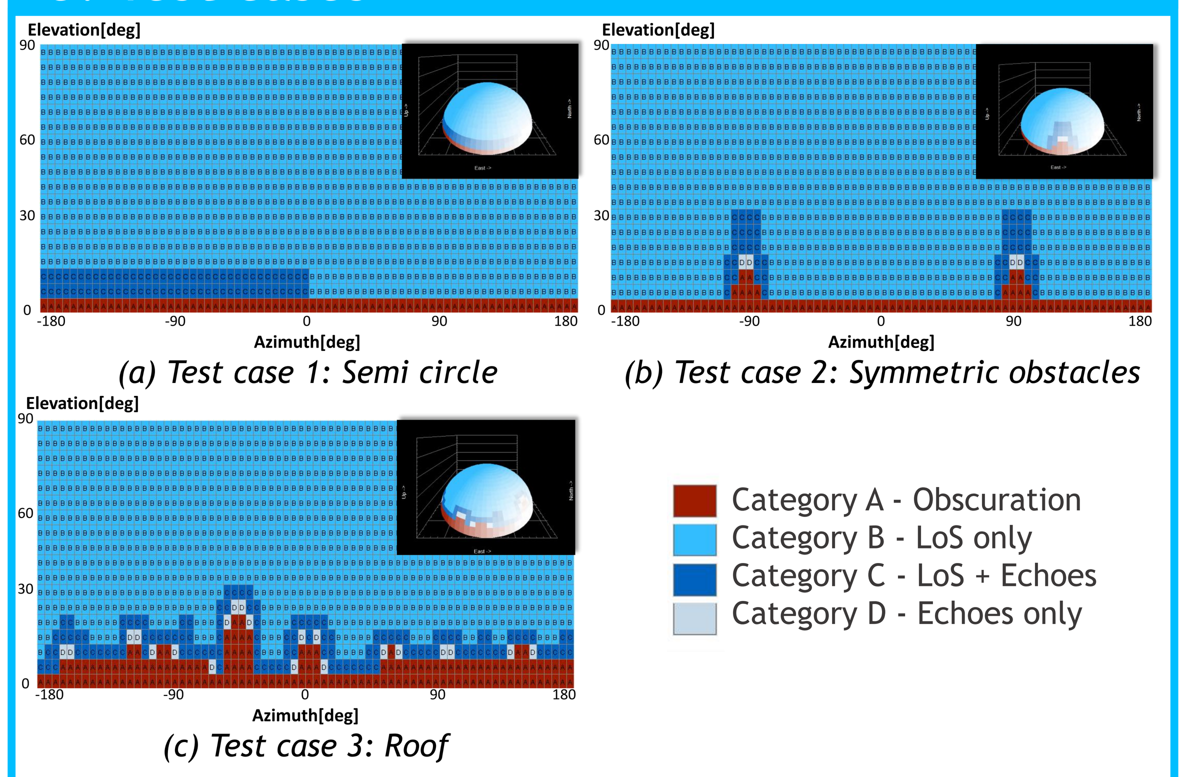

Fig. 3: Spirent's category masks for the three different test cases. (a)Test case 1: a semi-circular reflection area surrounding the receiver. (b)Test case 2: open sky with two symmetrical obstacles in opposite directions. (c)Test case 3: roof-top environment of a building in an urban area.

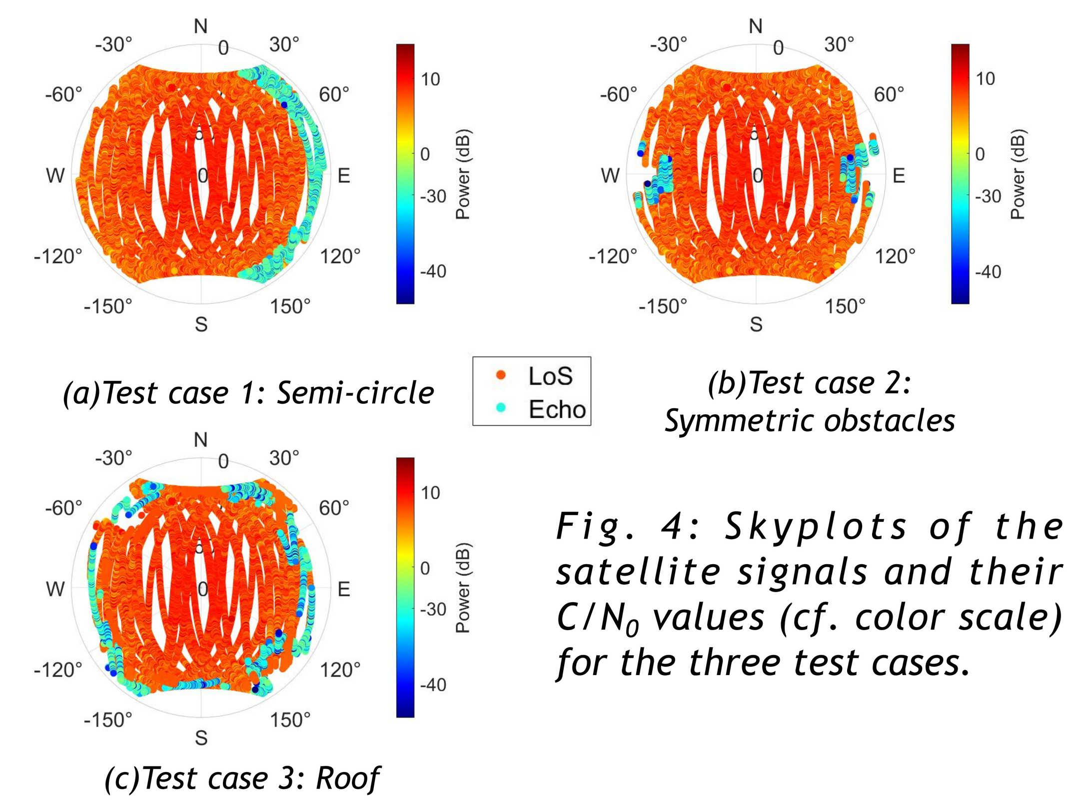

Fig. 4: Skyplots of the satellite signals and their C/N_0 values (cf. color scale) for the three test cases.

4. Results

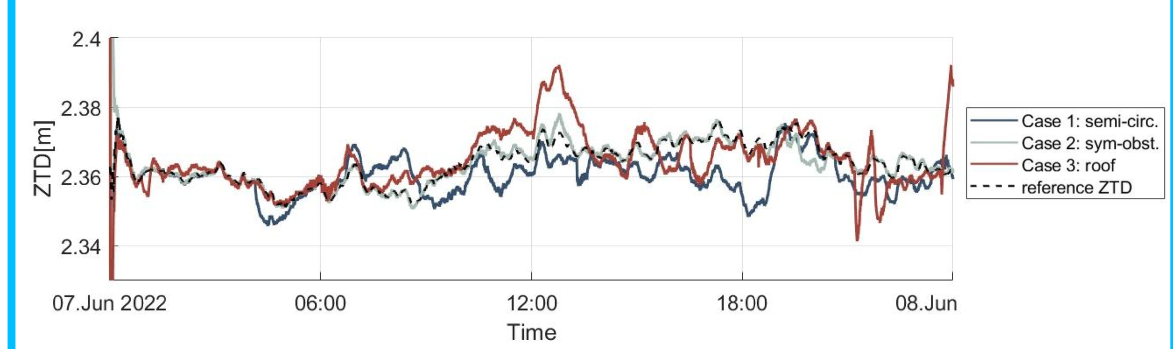

Fig. 5: Estimated ZTD time series for the three test cases together with the simulated ZTD series (IGS combined ZTD products used as reference, cf.Tab.1.

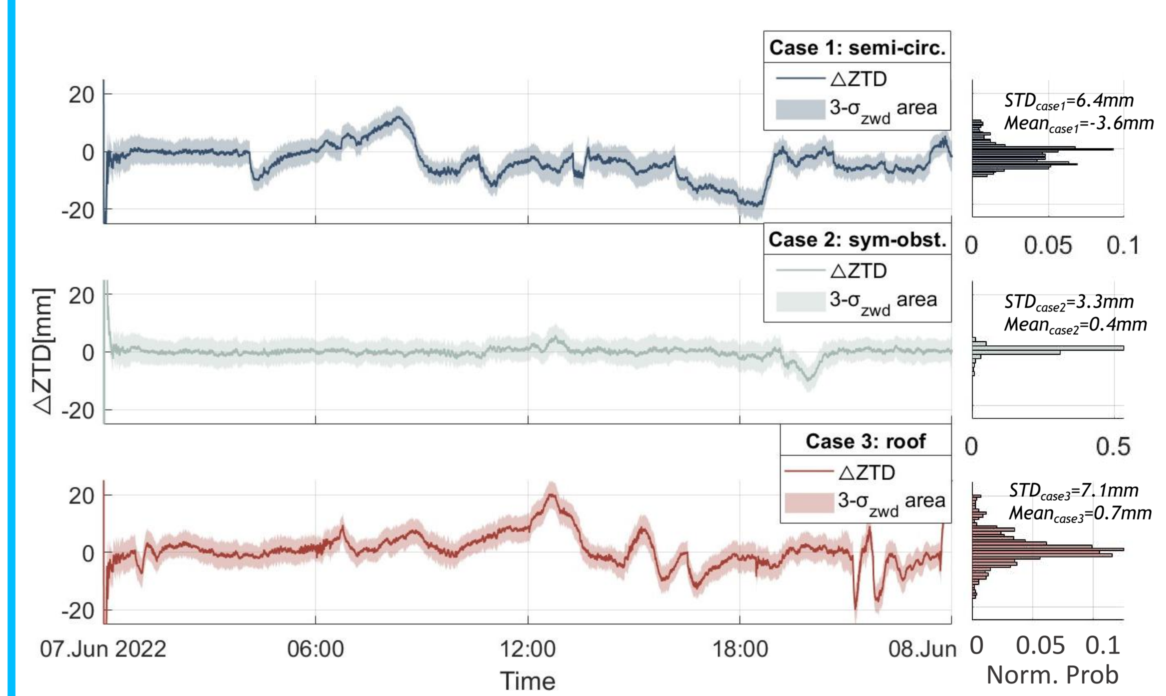

Fig. 6: ΔZTD (= estimated minus simulated ZTD) time series together with their formal errors (3σ level) from EKF runs for the three test cases.

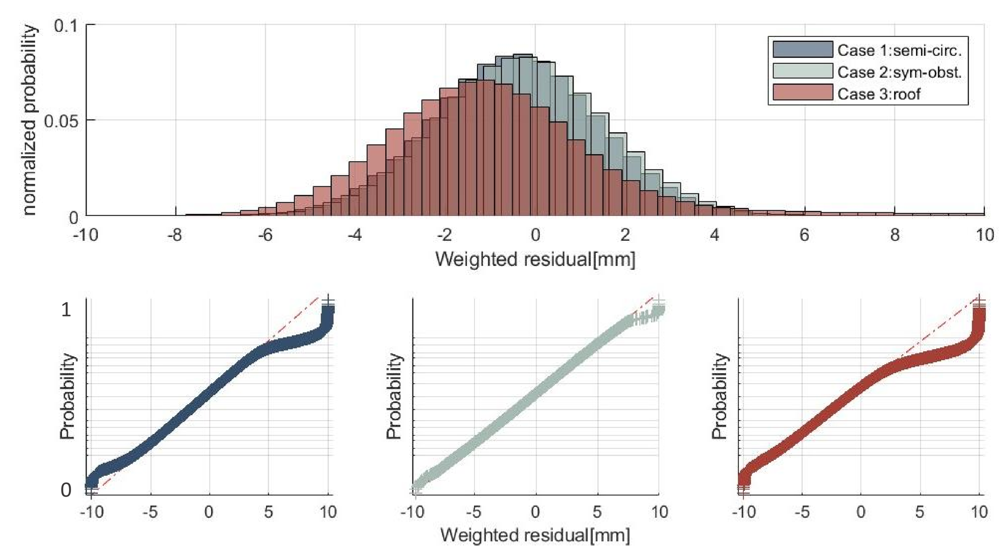

Fig. 7: Histogram of the weighted residuals (top figure) and their normal probability plots (lower part).

4. Results (contd.)

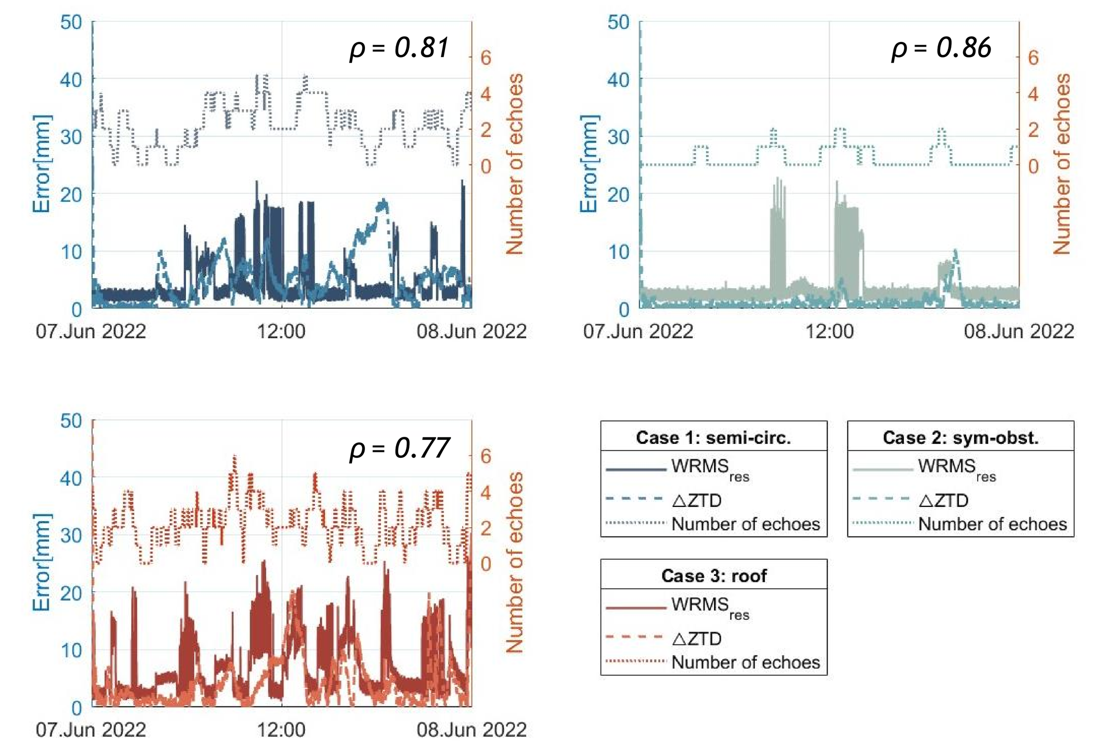

Fig. 8: Plots of ΔZTD and WRMS of residuals (left-axes) and the number of observations which are affected by multipath at every epoch (right-axis). The Pearson correlation coefficient (ρ) between the latter measure and ΔZTD has been added to each figure.

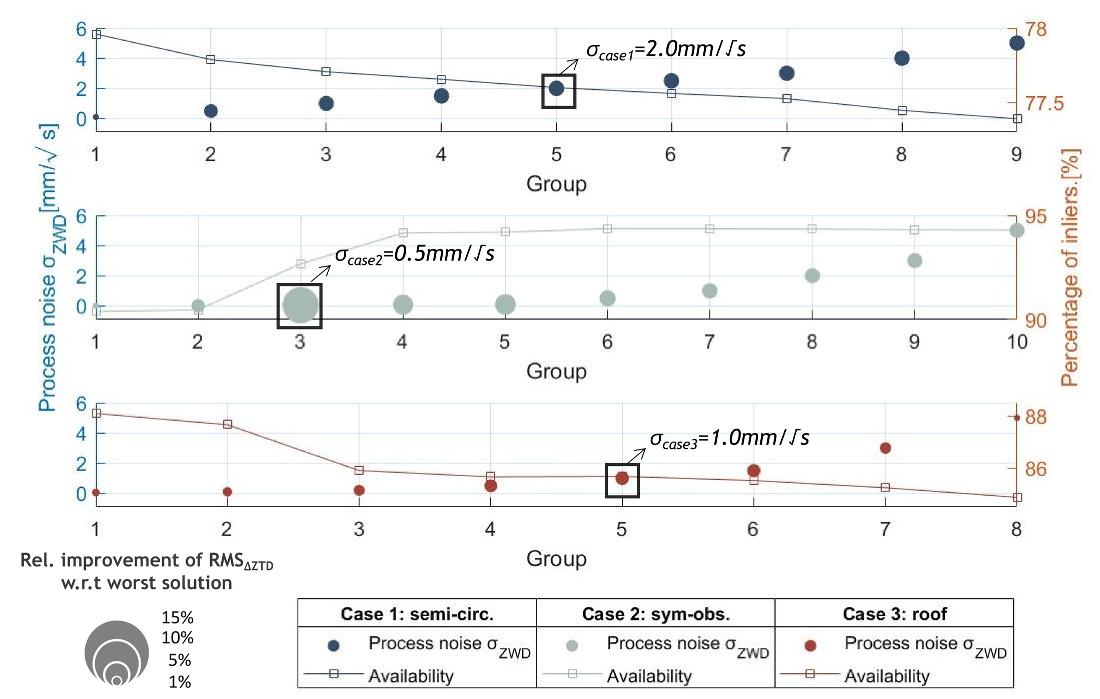

Fig. 9: Plots of $RMS_{\Delta ZTD}$ (the size of each circle represents the relative improvement of $RMS_{\Delta ZTD}$ w.r.t the worst solution in each test case) and percentages of inlier (ΔZTD within 3σ bounds, right-axis) for different choices of ZWD process noise σ_{ZWD}(left-axis). The group located in the black box is the optimal solution for each test case, and the optimal process noise is currently chosen visually.

5. Conclusions

Impact of multipath on ZTD:

- The impact of multipath on the ZTD estimates ranges from millimeter to centimeter, depending on the environment and the choice of ZWD process noise.
- ΔZTD reveals systematical biases by about 4 mm for test case 1 for which the incident directions of the multipath signals are not uniform.
- ZTD errors appear to be linearly correlated(ρ>0.7) with the number of satellites that are affected by multipath at every epoch.

Error mitigation:

Our results indicate that the right choice of process noise σ_{zwd} in the filter could mitigate large fractions of multipath errors on ZTD estimates. The selection of the right process noise level is currently done by visual identification. However, there might be the possibility to automatize the selection of process noise and develop a more general mitigation approach which is applicable to arbitrary GNSS sites.

6. Acknowledgements

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