

Earth Surf. Dynam. Discuss., referee comment RC2
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Comment on esurf-2020-108

Manuella Fagundes (Referee)

Referee comment on "Precise water level measurements using low-cost GNSS antenna arrays" by David J. Purnell et al., Earth Surf. Dynam. Discuss.,
<https://doi.org/10.5194/esurf-2020-108-RC2>, 2021

This work is a valid contribution to the GNSS-R research area. With an antenna array used to calculate water level, authors succeeded in decreasing noise and, consequently, obtaining more precise water level data. This work can be accepted after a minor revision. Below I provide corrections about typos and I also offer some comments on aspects that I believe could enrich the text.

In terms of form, the study's aim, methods, and findings are clear. The title is informative and relevant. The references are relevant, recent, and appropriate studies are included. But in most cases, authors need to review and comment about contribution of each work cited. The state of art is clearly described in the introduction. The research question and scope are clearly outlined. The process of subject selection is clear. The variables are defined and measured appropriately. The study methods are valid and reliable. Tables and figures are relevant and clearly presented. Results are statistically significant. Conclusions answer the aims of the study. The limitations of the study are opportunities to inform future research.

Major points in the article which need clarification, refinement, reanalysis, rewrites:

- About the use of different antenna models or types (TOPGNSS GNSS100L and Beitian BN-84U). Even though both are low-cost, it might be interesting to show their SNR. Do you recommend one model over the other or are both comparable?

- You could explain whether the differences found between GNSS-R and tide gauges may be related to the tide gauge technology (pressure or bubbler). There is a difference in the way each of the technologies measure water level. For example, bubblers suffer more influence from the waves.
- You could explain if the difference between the tide gauge sampling intervals has an influence on the comparison with the GNSS-R series. Could the increase in RSME (in the order St. A. Bellevue, Trois-Rivières, and Piermont) be related to the fact that the tide gauge sampling interval increases in the same order (3 min, 6 min, and 15 min)?
- More details are necessary with regard to the parametrization of reflector height. At least the formula for $h(t)=\sum(h_j*B(t))$, with h_j scaling factors and B basis should be given (details about the basis can be left out). An interpretation about the scaling factors or coefficients would also benefit the reader – do h_j represent the instantaneous reflector height at the knots' time? Finally, in the Methodology authors should inform the reader that a discussion about the postulated time spacing between knots and the time window length is given in the Results section.
- Section 6.5 is titled Temporal Resolution, but there are actually two types of temporal resolution that could be defined: of the input SNR or of the output water level. The latter is arguably more relevant for the end user and seems to be considered in section 6.3, under an overly technical title: B-spline knot spacing and time window. I suggest complementing those two section titles and reminding the reader that the spline knot spacing can be considered a measure of temporal resolution in the output water level.
- Authors compare the standard antenna configuration, of one geodetic upright antenna, to an alternative configuration made of multiple low-cost sideways antennas. Therefore, there are three main design factors involved:
 - A) quantity: one vs. multiple
 - B) class: geodetic vs. low-cost
 - C) orientation: upright vs. sideways

While authors focus on factors A and B, factor C should at least be acknowledged, even if it is left for future research. For example, in Fagundes et al. (2021) we have employed a single low-cost zenithal antenna and we are now curious if lateral orientation would have been better.

- I suspect even the largest antenna spacing considered (25 cm) may be too small to avoid mutual near-field electromagnetic interaction among antennas, depending on the satellite elevation angle considered. This can be understood in terms of overlapping direct first Fresnel zones (dFFZ), ellipsoidal volumes with a focus at the antenna and aligned to the satellite line of sight -- not to be confused with reflection first Fresnel zones (rFFZ), planar ellipses on the surface. In radio wave propagation, dFFZ determines the clearance requirement to minimize interference. While a rigorous

treatment may be left for future work, some of the conclusions seem to need caveats. First, the case of an isolated antenna is not really tested, as it is not equivalent to picking an individual antenna in the array, due to the undesirable presence of nearby antennas within the dFFZ. This may partially explain why "the relative performance of each antenna appears to be random". Secondly, the statement that "there is no advantage in using antennas spaced further apart than the short configuration" (5 cm) is only strictly true compared to the tall configuration (25 cm). But the experiments presented do not rule out the possibility that even wider spacings (e.g., 50 cm) could not perform better. Again, the present work is a fine demonstration of the potential of antenna arrays and I recommend it be published, but I am not certain it allows drawing definite conclusions about isolated single antennas and widely spaced antenna arrays.

Moderate points requiring additional information and suggestions for what could be done to improve the article:

- Authors considered two antenna spacing configurations (25 cm and 5 cm), called "tall" and "short", respectively. I suggest reminding the reader these antenna spacings should not be confused with the higher and lower mean reflector heights considered (5.0 m at Trois-Rivières, 2.5 m at Sainte-Anne-de-Bellevue, and 4.0 m at Piermont).
- In the Introduction, only acoustic and pressure tide gauges are considered. Authors should also discuss radar tide gauges, which represent the state-of-art, and bubbler (pneumatic) gauges, which are used for validation.
- The discussion about normalization of the detrended SNR data would benefit from an illustration of the stronger interference pattern found for GLONASS satellites, at least in the supplementary file.
- How much does the mean separation between successive antennas, computed empirically from reflector heights, differ from the expected separation measured manually with a ruler?
- Authors refer to "two different types of low-cost GNSS antennas", TOPGNSS GNSS100L and Beitian BN-84U. I was curious what receivers were used, but it seems those devices are not just antennas. Rather, each device is a combination of antenna and receiver in the same package, also known as "smart antenna" by GNSS industry vendors.

- Concerning Figure 4, consider showing the differences between GNSS-R and tide gauges in a separate figure, at least as supplementary material. This should provide more insights about the performance, for example: the difficulty in following the sharp sawtooth variations at Trois-Rivières; the outliers near 31-May-2020 at Sainte-Anne-de-Bellevue that may have to be discarded; and an apparent underestimation during low tides at Piermont.
- Consider offering a new table summarizing information about the conventional tide gauges at each site: technology (pressure vs. bubbler), temporal resolution, nominal precision, horizontal distance to GNSS, etc.
- Suggestion for future work: the analysis in section 6.1, Elevation angle limits, could be complemented by considering the spectral analysis retrievals, shown over time in Figure 5, and checking a possible dependence of water level residuals on the satellite elevation angle.
- Consider discussing Yamawaki et al. (2021), "High-rate altimetry in SNR-based GNSS-R: Proof-of-concept of a synthetic vertical array", IEEE GRSL (accepted), DOI:10.36227/techrxiv.14186930
- Consider discussing Williams et al. (2020), "Demonstrating the potential of low-cost GPS units for the remote measurement of tides and water levels using Interferometric Reflectometry", JOAT, DOI:10.1175/JTECH-D-20-0063.1
- Consider providing a sample of the input SNR as open data as authors state that "A description of the data from the low-cost GNSS antennas and how it is processed for GNSS-R analysis is given in the Supplement. Codes written in MATLAB for processing the raw GNSS data and retrieving water level measurements are provided along with this article."
- RMSE values are given in units of cm, sometimes with one decimal place, other times with two decimal places (e.g., 0.12 cm and 3.4 cm); I suggest adopting units of mm with one decimal place throughout (e.g., 1.2 mm and 34.0 mm).

Minor points like figures/tables not being mentioned in the text, a missing reference, typos, and other inconsistencies:

In line 38 revise "Tabibi et al. (2020)" to "(Tabibi et al., 2020)"

In the Abstract: Signal-to-Noise ratio -> signal-to-noise ratio [or Signal-to-Noise Ratio]

In the Abstract: "The low-cost antennas are advantageous over geodetic-standard antennas because they are much less expensive ... and they can be used for" -> The low-cost antennas are advantageous over geodetic-standard antennas not only because they are much less expensive ... but also because they can be used for

Line 24: "vary from 0 to 1.7 m" -> may reach up to 1.7 m

Line 38: "the precision ... was found to be greater than 1 cm" -> the precision ... was found to be lower than 1 cm" [or worse than 1 cm]

Line 41: maybe "interesting".

Line 55: typo in "tropospheric"

Line 55: "According to Nikolaidou et al. (2019), the tropospheric delay bias tends to 0 for an antenna that is 1 – 10 m above a reflecting surface when using elevation angles larger than 20 degrees." -> According to Nikolaidou et al. (2019), the tropospheric altimetry bias varies from 5 cm to 3 mm for an antenna that is 10 m above a reflecting surface when using elevation angles larger than 20 degrees."

Phrase in line 105: revise the sentence. "it" is a reference to the explanation in lines 102, 103 and 104? "As per Strandberg..."? In this case I think you could insert that explanation together the lines 105, 106 and 107. If it is not true, please reformulate the sentence.

Line 111: about "above", you could specify the equations numbers.

Line 130: 0 and 1 are a default number? Why do you choose those numbers?

Phrase in line 152: Be careful with the punctuation in this phrase. "If the source...".

Figure 1: Unit: Does it convert from dB-Hz to volts/volts and detrended?

Line 136: additive inverse -> negative

Line 144: "the antennas are attached to a ground plane facing outwards from the coast" -> the antennas are attached to a ground plane and oriented sideways, facing outwards from the coast

Line 157: "antennas" are duplicated.

Lines 157 and 158: about "25 cm" and "5 cm", is 25 cm the difference obtained from level average? Or, is it measured manually? If measured, you considered the boards or antenna center?

Lines 167: typo in "geodeti"

Line 160: a different frequency region -> a different multipath frequency band

Table 2: Does the fact that Piermont has a different antenna influence this result?

Line 250: typo in "antennna"

Line 314: typo in "GLONASSS"

Lines 383, 386, 389, 398, 407, 409, 415, 417, 424, 427, 432, 435, 440, 444, 452, 455, 457: References having a DOI should not include URLs to the publisher's website.

Many references have duplicated DOI.

Line 393: additional publication details about Geremia-Nievinski et al. (2019): Journal

of Geodesy (2020) 94:70, DOI:10.1007/s00190-020-01387-3

Line 402: Please check this citation.

Line 421: additional publication details about Nikolaidou et al. (2019): Journal of Geodesy (2020) 94:68, DOI:10.1007/s00190-020-01390-8

Line 430: DOI?

Line 445: DOI?

Line 392: additional publication details about Fagundes et al. (2020): GPS Solutions (2021), in press, DOI: 10.1007/s10291-021-01087-1

Line 394: DOI?

Please also note the supplement to this comment:

<https://esurf.copernicus.org/preprints/esurf-2020-108/esurf-2020-108-RC2-supplement.pdf>