Author responses

We thank the reviewer for their additional comments. Below are our responses to the reviewer's comments, with their initial comments in black, our responses in red and quotes from the manuscript indented.

Main points:

1. The authors have added the following text to Section 7:

" The RMSE values obtained are likely upper limits on the precision because they also contain error from the tide gauge measurements. The amount of error from the tide gauge measurements is also likely to differ between sites because there are different types of instruments at the sites in Québec (pressure transducers) and Piermont (bubbler gauge)."

Reviewer: Maybe you could be clearer about the magnitude of the errors resulting from the tide gauge. For example, bubblers suffer more influence from waves, so in places where there are higher waves, you have a higher error in tide gauge measurements.

We have added the following text to section 7:

> "While pressure transducers are more susceptible to errors over long timescales due to instrument drift (Miguez et al., 2005, Pytharouli et al., 2018), bubbler gauges are more susceptible to errors during wavy conditions (Woodworth and Smith, 2003)."

2. As noted in Section 3, we attach the antennas to a ground plane facing outwards from the coastline in order to reduce unwanted interference from the coast. If the antennas are omnidirectional, then the orientation should not make any difference. We have added the following text to Section 3:

" The antennas used here are assumed to be omnidirectional hence the orientation of the antennas should not matter, but the orientation may be important for other antennas."

Reviewer: Commercial GPS/GNSS antennas cannot be assumed omnidirectional. If they were so, one could turn them upside down and they would work equally as well, which is not the case. Actually, they are approximately hemispherical, designed for good reception within +/- 90 degrees from boresight direction. That is the main reason for tipping the antenna sideways in GNSS-R. But there is a tradeoff, as a tipped orientation will have more restricted azimuthal coverage. This may well be left for future work, but it is an important issue.

We removed the quoted text from Section 3. We have added the following text:

> "It should be noted that this configuration would likely reduce the azimuthal range of measurements at a site where there is an azimuthal view of the water surface greater than 180 degrees."

3. Our understanding is that the first Fresnel zone is a concept that is used to determine the radius that needs to be cleared along the path from the satellite to the antenna to avoid interference. It is not clear how this applies to the situation of co-located antennas possibly interfering with each other. As stated above, the first Fresnel zone is focused at the antenna, hence the radius is 0 at the antenna. First Fresnel zones for co-located antennas will overlap

at some point moving outwards from the antennas along the LOS unless they are hundreds of meters apart. A more rigorous investigation of possible interference between antennas would be welcome. We have added the following text to Section 3:
"We note that the distance of 25 cm may not be large enough to avoid interference between antennas."

And in Section 7:
" Whilst our results suggest that the spacing apart of antennas is not important, we cannot rule out the possibility of interference between antennas at the separation distances used in this study. A rigorous investigation of the clearance distance required to ensure that antennas are not interfering should guide a future study."

Reviewer: The antenna is at the ellipsoid focus, which lies inside the ellipsoid volume, and should not be confused with the ellipsoid vertex, that lies at the tip of the ellipsoid surface. Thus, the first Fresnel zone surrounds the antenna instead of being entirely in front of it. The extreme case of a satellite at zenith is clearest: for an array, the direct FFZ will be stacked, with the top antennas obstructing the bottom ones. For a satellite at the horizon, the clearance requirement near the antenna would be least. In general, for satellites at an arbitrary elevation angle, the clearance in the direction perpendicular to the line of sight would be converted to the vertical clearance, with the secant of elevation angle. So, higher elevation angles will be compromised more than lower elevations.

We thank the review for the additional information. We do not feel that this comment requires a change in the manuscript.

Moderate points:

4. We have added the following text to the introduction:
" Radar and bubbler gauges are also commonly used to monitor water levels but these instruments are more expensive than pressure transducers or acoustic gauges."

Reviewer: I think you could write a little bit more about the vantages and advantages of those techniques.

We do not feel that it is important to discuss in detail the advantages and disadvantages of different tide gauge sensors as this is not the focus of this study. We have added the following text to Section 1:

> "Radar and bubbler gauges are also commonly used to monitor water levels (see Woodworth and Smith (2003) for a comparison) but these instruments are more expensive than pressure transducers or acoustic gauges."

5. Instead of adding a figure, we have added the following text to Section 2:

"This step is taken because the amplitude of the interference in the SNR data varies greatly between different satellite constellations; it is generally stronger for GLONASS satellites. The mean variance of the detrended SNR data for GLONASS satellite arcs is approximately 3 times larger than that of GPS satellites or 6 times larger than that of Galileo satellites."

Reviewer: I believe the figure could be a good contribution to complement the text.

We considered adding a figure, but (as the reviewer will know), SNR data is very variable for different satellite arcs. We therefore chose to remain with the quantitative information we provided as we feel it is more useful.

6. We do not feel that an additional table is necessary because this information is already clearly stated in Section 4, aside from information about the distance between the tide gauge and antenna arrays at Trois-Rivières, which we have now added: " The antenna arrays at this site were installed approximately 5 -- 10 meters away from the tide gauges.

Reviewer: I think it could be better to insert a table summarizing the information than the reader searches it in the text.

We have added some additional information to Table 1.