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Interactive comment on "Simulations of direct and reflected waves trajectories for ground-based GNSS-R experiments" by N. Roussel et al.

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Authors are to be commended for their diligent work over the past revision cycles. I find that no major issues remain outstanding in the latest version. I do take the time to indicate a few issues for their consideration. I do not need to see the final version prior to acceptance. Congratulations!

- ⇨ We thank the reviewer for his careful reading and comments.

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Authors state that "[the ellipsoid] has been expanded..." The osculating sphere needs to be modified as a consequence of this ellipsoidal expansion. More specifically, the ellipsoid radius of curvature shall be calculated based on the modified ellipsoidal semi-major axes values. This should improve the agreement with the ellipsoidal results slightly.

- ⇨ The ellipsoid radius of curvature was already calculated based on the modified ellipsoidal semi-major and minor axes values, but the formula presented in the paper was actually not correct. The formula page 4, line 343:

$$r_E = \frac{a^2 b}{a^2 \cos^2(\varphi) + b^2 \sin^2(\varphi)}$$

with φ the latitude of the receiver, a and b the semi-major and semi-minor axis of the WGS84 ellipsoid.

… was replaced by:

$$r_E = \frac{a'^2 b'}{a'^2 \cos^2(\varphi) + b'^2 \sin^2(\varphi)}$$

With φ the latitude of the receiver, a' and b' the semi-major and semi-minor axis of the modified ellipsoid (see subsection 3.3).

As a separate issue, and for improved reproducibility, please further clarify how this expansion is achieved. Authors state that "[the ellipsoid] has been expanded until the ellipsoid height of the receiver equals the height of the receiver above the reflecting surface". This is equivalent to expanding the ellipsoid until its surface coincides with the reflecting surface (at nadir of the receiver), which might be called the surface base point. Yet no equations are given. I assume the ellipsoid remains geocentric and its axes are scaled. It'd seem that the modified axes (say, a' and b') cannot be found simply by summation of the original axes (a, b) and the ellipsoidal height (h) of the base point (not of the receiver itself). Rather, there exists a condition to satisfy, that the Cartesian coordinates of the base point (X,Y,Z) remain unchanged, when computed either from the original geodetic coordinates (lamba,phi,h) and ellipsoid constants (a,b) on the one hand, or their modified values (lambda',phi',h';a',b') on the other hand, where lambda'=lambda is the longitude, phi'=phi is the latitude, and h'=0. The modified ellipsoid constants are, then:

a' = (a^2 + h^2 + h*c + a^2*h/c)^0.5 = a*(1 + h^2/a^2 + h*c/a^2 + h/c)^0.5
b' = (b^2 + h^2 + h*c + b^2*h/c)^0.5 = b*(1 + h^2/b^2 + h*c/b^2 + h/c)^0.5
where c = (a^2*cos(phi)^2 + b^2*sin(phi)^2)^0.5

As a check, if h=0, then a'=a and b'=b for any latitude phi.

- ⇨ You are right, the ellipsoid remains geocentric and its axes are scaled. We used the initial condition you suggest, namely the Cartesian coordinates of the base point remain unchanged, but we proceeded with an iterative method to find a' and b' satisfying this condition. Yet it is faster and better to use the analytical formulas you suggest.
  Results obtained between this analytical method and the previous iterative method we used are the same.
  Based on your suggestion, the following paragraph was added at the beginning of the subsection *3.3 Ellipsoid reflection approximation* (page 5, line 417):

We consider an ellipsoid corresponding to the WGS84 one extended such as the ellipsoid height of the receiver is equal to the receiver height above the reflecting surface. In other words, the WGS84 ellipsoid is expanded until its surface coincides with the reflecting surface, at nadir of the receiver (surface base point). The cartesian coordinates of this surface base point must remain unchanged, when computed either from the original geodetic coordinates $(\lambda, \varphi, h)_{WGS84}$ and ellipsoid constant $(a,b)_{WGS84}$ on the one hand, or their modified values $(\lambda', \varphi', h', a', b')$ on the other hand, where $\lambda = \lambda'$ is the longitude, $\varphi = \varphi'$ is the latitude, and $h' = 0$.
The ellipsoid thus remains geocentric and its axes are scaled as follows:

$$a' = \sqrt{a^2 + h^2 + hc + \frac{a^2 h}{c}} = a\sqrt{1 + \frac{h^2}{a^2} + \frac{hc}{a^2} + \frac{h}{c}} \qquad (19)$$

$$b' = \sqrt{b^2 + h^2 + hc + \frac{b^2 h}{c}} = b * \sqrt{1 + \frac{h^2}{b^2} + \frac{hc}{b^2} + \frac{h}{c}} \qquad (20)$$

where $c = \sqrt{a^2 \cos(\phi)^2 + b^2 \sin(\phi)^2}$

This ellipsoidal extension is only done once as long as the receiver position remains unchanged with respect to the reflecting surface; it is redone if the reflecting surface changes (e.g., tidal waters) but is not with changes in the satellite direction.

It wouldn't hurt to stress in the text that this ellipsoidal expansion is only done once as long as the receiver position remains unchanged w.r.t. the reflecting surface; it is redone if the reflecting surface changes (e.g., tidal waters) but it is not redone with changes in the satellite direction.

- ⇨ You are right. We added the following sentence at the beginning of the subsection *3.3 Ellipsoid reflection approximation* (page 6, line 438):

  > *This ellipsoidal extension is only done once as long as the receiver position remains unchanged with respect to the reflecting surface; it is redone if the reflecting surface changes (e.g., tidal waters) but is not with changes in the satellite direction*

I find it unnecessary to include ellipsoid vs. plane results in the table and figures, as they are essentially the combination of other already reported results (sphere vs. plane and sphere vs. ellipsoid, dominated by the former).

- ⇨ Ellipsoid VS Plane results were deleted from figures 11, 12, 13 and 14 and table 2.

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  MINOR

  The abstract speaks of "mean deviations" but I suspect the values are maximum absolute deviation, which is what is given in the tables. Please correct. Otherwise, clarify the mean depends on how the satellite elevation angle is sampled (more densely near zenith or near the horizon).

- ⇨ The results presented in the abstract are means of the differences obtained during a 24h simulation with a complete GPS and GLONASS constellation. You are right that it thus depends on how the satellite elevation angle is sampled. We added this sentence in the abstract, page 1, line 44:

  > *These results are means of the differences obtained during a 24h simulation with a complete GPS and GLONASS constellation, and thus depends on how the satellite elevation angle is sampled over the day of simulation.*

Fig 10: please explain why the mean of differences sometimes is correlated with the tide and other times it is anti-correlated (their arithmetic signs are not always the same).

- ⇨ The differences are always positive because they correspond to the distance between two sets of points: the first obtained with a static reflecting surface, and the second obtained with a moving reflecting surface (a moving receiver height above the reflecting surface, to be more exact). The differences are thus correlated with the absolute amplitude of the tide (and not with the sign of the tide variation).

Fig 11-14: why there is dispersion within results for a fixed elevation angle and fixed pair of algorithms (e.g., multiple green dots intersecting a given vertical line)? Is it a consequence of what source: azimuthal variability in the ellipsoidal radius of curvature (Euler's formula); time-variable ellipsoidal expansion (tidal waters); troposphere correction (I'd recommend disabling it in these plots and keep it enabled only in Fig 16).

- ⇨ The following sentence was added to the legend of figures 11, 12, 13 and 14:

  Note the dispersion within results for a fixed elevation angle which is a consequence of the azimuth variability in the ellipsoidal radius of curvature.

Results for the planar Earth model could be mentioned in the abstract.

- ⇨ Results for the planar Earth model are already mentioned in the abstract, page 1, line 40:

  The altimetric and planimetric differences beween the plane and sphere approximations are on average below 1.4 cm (resp < 1 mm) for satellites elevation angle greater than 10° and below 6.2 cm (resp. 2.4 mm) for satellite elevation angle between 5° and 10°.