Reviewers' Comments & the Authors' Responses

Comments from Reviewer A:

Iwasa et al. argue, based on detailed measurements of afterslip along the rupture zone of the 2016 Kumamoto earthquake (Mw 7.0), that afterslip continued for 6–7 years and that the cumulative displacements are comparable to the coseismic displacements. Unlike previous studies and large-scale geodetic estimates of postseismic deformation, the key advantage and novelty of this study lie in its ability to clarify the spatial extent of the afterslip zone and its long-term temporal evolution using in situ total station measurements.

The manuscript is well written, and the authors' findings derived from field measurements provide valuable insights into postseismic deformation associated with onshore active faulting, particularly when considered together with satellite geodetic observations. Below are several comments that should be addressed to further improve the manuscript before it can be considered for publication.

Major comments:

1) I strongly recommend using the term "afterslip" to describe the phenomenon investigated in this study. As widely discussed in the literature, the term "postseismic deformation" is very broad and generally encompasses a combination of processes, including viscoelastic relaxation in the lower crust and upper mantle, poroelastic deformation associated with fluids and porous media in the upper crust, and afterslip along the rupture zone. The relative contributions of these processes naturally vary with time during the postseismic period.

In the present study, the authors focus specifically on afterslip on the ruptured fault itself. However, many of the relevant studies cited by the authors are based on satellite geodetic observations, which analyze deformation over broad areas and may be dominated by viscoelastic deformation, as demonstrated, for example, by Pollitz et al. (2017).

In this regard, in the Introduction (around line 69), the authors may wish to provide a general overview of the mechanisms contributing to postseismic deformation and then clearly state that this study focuses on afterslip as one of these mechanisms.

Response: We appreciate the reviewer's suggestions. Following the reviewer's suggestion, we have changed the term "postseismic surface deformation" to "surface afterslip" throughout the manuscript. Furthermore, in lines 71-74, we have revised the Introduction section to clarify the mechanisms contributing to postseismic deformation.

2) I appreciate the detailed documentation of the temporal variation in the afterslip rate shown in Figure 4, which is rigorously measured using total station observations. However, one could argue that the dashed curves suggest that the fault is currently moving in the opposite sense (left-lateral), rather than simply ceasing dextral motion. Therefore, it is essential to carefully evaluate and clearly present the error bars for each data point. In addition, neither the Methods section nor Figure 3 adequately describes how the fault zone is defined (as shown in Figure 3), nor how the mean offset, and associated measurement uncertainties are estimated. I suggest that the authors provide a more comprehensive and rigorous description of the procedure used to evaluate fault displacement, including, for example, how the fault zone is distinguished from undeformed areas and how the measurement range for the undeformed zone is determined. The estimation of the fault strike, shown as a double-headed arrow, also affects the calculated displacement and its error estimate.

Response: Regarding the argument that Figure 4 could suggest left-lateral displacement, we revised the fitting curve in Figure 4 to a logarithmic function as per other comments. Accordingly, we revised the text description in lines 254–262. These changes resolved the appearance in the previous fitting curve that recent data seemed to show left-lateral displacement. Additionally, regarding how the mean offset and associated measurement uncertainties are determined, we added detailed descriptions to the Methods section in lines 127–139. These include the fault strike, the method for identifying the reference section, the measurement method, and how the error was calculated.

Minor comments:

3) Lines 137–233: While the detailed descriptions are useful and should be retained, I suggest summarizing the key information in a table that includes the location, the time at which each piercing line was fixed, the measurement times, and the corresponding offset values.

Response: As mentioned in Data and code availability, we had already provided the table in the repository. However, since this was not explicitly stated, we added a description in lines 152–154.

4) Lines 133–134: Why is the afterslip observed to be discontinuous, unlike the continuous coseismic surface rupture? Any insight into this difference would be helpful. For example, Toda et al. (2021) discuss the potential importance of subsurface geological heterogeneity.

Response: In lines 149–151, we added sentences regarding the possibility of variations in surface structures or the availability of clear reference markers, and the possibility of heterogeneity in underground structures based on Toda et al. (2021).

5) Figure 1: Could the authors clarify why only foreshocks are plotted in this figure? Please indicate the magnitude threshold and the observation period for the foreshocks. Including moderate-sized aftershocks could also help to better illustrate the fault dip of the Hinagu, Futagawa, and Idenokuchi faults.

Response: In the caption for Figure 1, we revised it to explicitly state that we plotted the largest foreshock. Additionally, we added the aftershock distribution (M>2) to Figure 1.

6) I believe that an important study on postseismic deformation following the Kumamoto earthquake that should be cited is Nakao et al. (2019). One of their key results was later reproduced as Figure 9 in Toda et al. (2021). Numerous GNSS stations

documented an exponential decay of displacement, which may reflect the influence of afterslip along the northern Hinagu fault. This behavior appears comparable to the in situ–measured displacements shown in Figure 9 of Toda et al. (2021). I therefore suggest that the authors consider Nakao et al. (2019) and incorporate their results into the Discussion.

Response: Thank you for providing papers that support the arguments in this paper. In lines 291–300, we have revised the text to discuss, from a geodetic perspective, the persistence and gradual decay of surface afterslip, citing Nakao et al. (2019) and Toda et al. (2021).

Comments from Reviewer B:

I have reviewed the manuscript entitled "Temporal changes in postseismic surface deformation along the 2016 Kumamoto earthquake rupture revealed by repeated field surveys," submitted to Seismica.

The authors present repeated field measurements of surface offsets along the southern part of ruptures associated with the 2016 Kumamoto earthquake and discuss temporal changes that they interpret as postseismic deformation. While the topic is potentially of interest, I have several concerns regarding the measurement strategy, the definition of the reference frame, and the logic used to support the main interpretations. In particular, I am not fully convinced that the reported displacements are robust as presented. The manuscript relies on photographs and qualitative descriptions, but in several places—especially in Section 3.1—it is difficult to verify that the descriptions are consistent with the photographs. My concerns are listed below:

<Major>

1. It is not sufficiently clear which points (and which parts of each linear feature) were used for repeated measurements. While I understand the practical difficulty of installing permanent benchmarks, readers need to know exactly what was measured and how the same reference was maintained across epochs. Please annotate representative photographs (e.g., in Figs. S1–S2) to indicate (i) measurement points/lines and (ii) the "undeformed" reference sections used for defining the offset.

Response: We appreciate the reviewer's suggestions. We added details of the measurement methodology in lines 127–139 to clarify how we maintained the same reference for each measurement. We added a measurement line to Figure S1.

For the identification method of the undeformed reference section, as we added in lines 133-135, it was determined by considering both field observations and the plot of survey results. We considered showing which section was the undeformed reference section in Figure 3. However, we believed that drawing artificial frames here would obscure the actual raw data points and make the figure overly cluttered. We believe readers can visually determine where straight lines were considered by examining the sequence of plotted distant data points, and thus we did not show the undeformed reference section in Figure 3.

2. You should combine Section 3.1 and 3.2, and summarise the survey result at each location in a single paragraph. You did not mention the displacement at Loc 6 and 7 in Section 3.1, but readers would like to know the amount of offset there. Furthermore, the data at these points would be referred for the discussion later.

Response: Following the comments, we combined sections 3.1 and 3.1 and revised the text to describe each location in a single paragraph.

3. You mentioned "measured at four times" but Figure 4 shows a bunch of plots showing displacement from the reference point. Does this mean an iterative number of measurements at the same points? If so, please revise the sentence and clarify which values did you plot in Figure 3 (median or mean?).

Response: We did not intend to imply that four measurements were taken during a single campaign; rather, we intended to state that four measurements were taken between 2020 and 2022. Due to the ambiguity of the original wording, we have revised lines 171–172.

4. I'm just wondering why the displacement magnitude decreased between 2022 and 2023 at Loc 6 and 7 as shown in Figure 3 and 4. Is that caused by any physical phenomena, or is the variation of displacements within the measurement error? If the decreased displacement during 2022-2023 was plausible, do you have any interpretations for the temporal characteristics?

Response: Based on another comment, we revised the fitting curve in Figure 4 to a logarithmic function and modified the text accordingly. Specifically, we described the possibility that surface afterslip gradually decays and is nearly terminated.

5. Definition of fitting function in Fig 4. Given that postseismic deformation commonly follows decaying functions, I strongly recommend fitting the temporal characteristics of post-seismic deformation using exponential or logarithmic functions instead of linear functions. This will provide a basis for assessing whether/when the deformation terminated and for comparison with geodetic studies.

Response: Following the comments, we revised the fitting curve in the figure to a logarithmic function and modified the main text in lines 254–256. Furthermore, based on observations from recent field surveys, we mentioned the possibility that it is likely nearly terminated.

6. Loc 6: The explanations about Loc 6 in Section 3.1 and 3.2 would be inconsistent. You mentioned less than 10 cm of offset was observed in Section 3.1 and Figures 3-4, but you summarized that greater than 40 cm of offset was observed in Section 3.2 and Figure 5. Could you clarify this discrepancy and explain the significant spatial variation in offsets (ranging from less than 10 cm to approximately 40 cm) observed within 140 meters at this site?

Response: Regarding the discrepancy in displacement amounts between Loc. 6 and the point 140 meters away, we added the following explanation on lines 225–236: The discrepancy is likely due to a combination of spatial variations, the timing of repairs (missed initial rapid afterslip), and differences in measurement methods.

7. Figure 5: I hope you plot co-seismic and post-seismic deformations at all available, not solely Loc 2, 6, 7. The expanded view enhances the readers' understanding of the spatial variation of post/coseismic deformation ratio. I think even incomplete information is enough for the comparison. Furthermore, the meaning of plotting zero at the plot termination is unclear and requires clarification.

Response: We have added information from other locations regarding the coseismic deformation shown in Figure 5 and revised the caption accordingly. Regarding afterslip, we could not use displacement data from 2017 to 2020 for locations other than Loc 2, 6, and 7. Consequently, we are unable to calculate the cumulative displacement since the mainshock and have therefore not plotted it.

8. Could you provide interpretations about the greater ratio of post-seismic deformation and the post-seismic deformation at Loc 6? Readers would benefit from a discussion of the physical mechanisms that might explain why the greater contribution of post-seismic deformation was in this case.

Response: In lines 272–277, we added our interpretation that in the northern part of the Hinagu fault, where coseismic displacement was small, the proportion of surface afterslip may have been large because stress release during the earthquake was insufficient.

<Minor>

1. Line 117: which "three sites" do you indicate?

Response: At line 125, we added "(Locs. 2, 6, and 7)" to clarify the target indicated by "three sites".

2. Line 160: How much displacement did Toda et al (2021) report at Loc 3?

Response: In lines 201–202, we added the displacement values reported by Toda et al. (2021).

3. Line 167: How much displacement did Toda et al (2021) report at Loc 4?

Response: At this location, Toda et al. (2021) did not report displacement values, so we did not describe the strike-slip displacement in the main text.

4. Line 173: It is hard to find the pavement joint from the picture (Figure 2c).

Response: We added the text "Pavement joint" to Figure 2c to enable identification of the pavement joint.

5. Line 190: According to Figure S3c, "concrete block wall" would be appropriate rather than "house wall". I expected that "house wall " means the wall of the house.

Response: Following the comment, we revised "house wall" to "concrete block wall."

6. Loc 5: It is hard to identify displacements from the pictures (Figure 2h).

Response: We added an enlarged photograph as Figure 2i.

7. Line 225: How large do you consider the observation error? If you mention, Could you clarify the magnitude of the observation error?

Response: Regarding observation error, we added detailed descriptions concerning the fault strike, the method for identifying the reference section, the measurement method, and how the error was calculated in lines 127–139.

8. Line 236: You concluded "the post-seismic deformation had likely terminated.", but I think it is better to discuss carefully. Could you expand the

discussion about the detection limit of your observation strategy, observation uncertainties, and reference instabilities?

Response: First, having reexamined the fitting curve in Figure 4, we revised our interpretation to be more cautious in lines 255–256. Furthermore, based on observations from recent field surveys, we mentioned the possibility that it is likely nearly terminated.

9. Loc 6: The displacement on the concrete wall is significantly greater compared with other points. Was the co-seismic deformation at this site also proportionally greater? It is critical to consider whether this substantial displacement could be influenced by localized deformation or tilting of the concrete structure itself, rather than purely surface rupture.

Response: We added lines 227–230 regarding the possibility that deformation or tilt of the structure itself may have contributed.

10. Figure 4: How did you evaluate the measurement uncertainties as you plot the errorbars? Could you plot the similar errorbar in Figure 3? (in horizontal direction?)

Response: We have added a detailed description of how to evaluate the error on lines 137–139. The error bars in Figure 4 represent the statistical uncertainty of the displacement amount, calculated as the difference between the mean values of the two reference intervals. We computed this as the square root of the sum of the squares of the standard errors for both intervals.

Regarding adding error bars to Figure 3, since Figure 3 shows survey points measured by a total station and the errors are small relative to the size of the plotted symbols (points), we cannot draw them as visual error bars. Additionally, Figure 3 displays the error values numerically.

11. Figure 4, 5: If you have data of displacement in 2020 as you showed in Figure 5, you should plot the value in Figure 4. The values of the early post-seismic deformation help improve the fitting curve for temporal evolution of post-seismic deformation.

Response: We have already plotted the values for 2020 in Figure 4. If you are referring to the displacement 12 months after the earthquake in 2017, the values shown in Figure 5 are estimated values derived by calculation, not measured values. Therefore, they cannot be shown in the same column as Figure 4.

12. You mentioned that the post-seismic slip rates inferred in this study are consistent with those from geodetic approaches reported by previous studies, but I think it appears to be overstated. For instance, the ~15 cm of deformation in Loc 2 (Figure 5 and a paragraph from Line 255) can be reached by 2019-2020 under the assumption of 6cm/yr for two years and 2-3 cm/yr for the subsequent two years, as referred to in the manuscript. Please discuss the relevant slip rates and/or cumulative displacements from Hashimoto (2020) and Liu et al. (2024) more explicitly, including time windows and locations.

Response: To avoid exaggeration and clarify our intent, we specified in lines 298–300 that the "consistency" we refer to does not indicate direct agreement in absolute numerical rates, but rather the long-term persistence and gradual reduction of afterslip over a period of 6 to 7 years.

13. Line 269: I hope you show some references.

Response: We added a reference on line 326.

14. You mentioned the amount of displacement along the Hinagu fault, but did you compare it with GNSS data? If there are any papers reporting post-seismic deformation using GNSS, please compare them. Do you check the contribution of aftershocks?

Response: Following this and other comments, we performed a qualitative comparison with GNSS survey results regarding the decay of surface afterslip by citing Nakao et al. (2019) in lines 291–300. On the other hand, we considered that direct comparison is difficult because, while this study targeted the immediate above the fault, the GNSS observation network around the fault is located several kilometers away from it. Regarding the relationship with aftershocks, Toda et al. (2019) examined this.

15. Shirahama et al (2016) is cited in the main text, but Shirahama et al. (2018) is listed in the bibliography.

Response: We revised the citation.

16. I'm curious about the survey point in this study. The coseismic deformation along the Hinagu fault was not so large compared with those along the Futagawa fault as reported in previous studies. It would be helpful to clarify the scientific motivation for emphasizing the Hinagu segment in this paper. Could you briefly explain in the Introduction why postseismic deformation along the Hinagu fault is particularly informative for understanding the physical mechanisms of the 2016 Kumamoto earthquake sequence (e.g., fault junction effects, spatial variability in frictional properties, or differences in shallow structure).

Response: In lines 109–115, we added information explaining why it is beneficial to clarify the temporal changes in surface afterslip in the northern part of the Hinagu fault, which may possess a complex subsurface structure.