Response to Referee Comment (RC2)

Submission ID: egusphere-2026-1545

Submission Title: Application of radar remote sensing for cyclone damage mapping in Bangladesh: A coherence-based approach

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Dear Sir,

Thank you for the constructive and detailed feedback on our manuscript and for the time taken to evaluate our work. The comments were extremely helpful in identifying areas where the methodology, validation, and discussion needed to be clarified and strengthened, and we believe the manuscript has improved considerably as a result. We have carefully considered and addressed all comments, and the manuscript has been revised accordingly. Below, we provide point-by-point responses (C and R denote comment and reply, respectively) to each of the reviewer's comments –

C0:

The manuscript entitled *"Application of radar remote sensing for cyclone damage mapping in Bangladesh: A coherence-based approach"* presents an important application of multi-temporal Sentinel-1 SAR coherence analysis for cyclone damage assessment in coastal Bangladesh. The study is timely, scientifically relevant, and operationally significant for disaster risk reduction in data-constrained coastal environments. The integration of coherence-based change detection with inundation mapping and field validation is commendable, and the manuscript demonstrates strong potential for publication after revision.

R0:

Thank you for the constructive comments. This manuscript focuses on multi-temporal Sentinel-1 SAR coherence change analysis for cyclone damage assessment across affected coastal districts in Bangladesh, validated against inundation and field data. We have carried out a thorough revision on a point-by-point basis, addressing every major and minor point. Please see our detailed reply to the comments below.

Major Comments

C1:

The novelty of the study should be articulated more clearly in the Introduction section. Although the manuscript discusses coherence-based approaches, the specific advancement over previous SAR-based cyclone damage studies remains somewhat unclear. A dedicated paragraph highlighting methodological novelty and operational contribution would strengthen the paper.

R1:

Thank you for this comment. We agree that the novelty of the study was not sufficiently articulated in the original submission; therefore, we have added a dedicated paragraph at the end of the Introduction that explicitly contrasts our approach with previous single-event and single-pair coherence studies:

"Despite the growing application of SAR-based coherence analysis for disaster assessment, most SAR-based damage assessment has generally relied on a single pre- and post-event image pair, or on differencing two such pairs to isolate event-related change, applied to one disaster and one location at a time (Meneses & Blanco, 2022; Malmgren-Hansen et al., 2020; Alexandre et al., 2020; Fielding & Jung, 2024). It limited their ability to distinguish hazard-induced changes from natural temporal variability, which makes it difficult to distinguish cyclone-induced changes from seasonal or environmental fluctuations (Olen and Bookhagen, 2018). Plank (2014) identified the resulting difficulty of separating true disaster-induced decorrelation from seasonal vegetation growth, soil moisture changes, and other natural variability as a persistent limitation of pair-based designs, calling for more standardized, transferable procedures. Washaya et al. (2018) advanced this by stacking multiple coherence pairs and computing per-block standard deviation, yet still applied a fixed threshold to a single earthquake case and a single hurricane case rather than a statistically derived baseline. This study followed these approaches by constructing multi-temporal Sentinel-1 coherence time series by characterizing baseline surface dynamics that capture how much coherence naturally varies before a cyclone, then testing whether post-event coherence reductions exceeded the range of natural temporal variability observed during the pre-event period."

C2:

The coherence threshold selection procedure requires additional explanation. The manuscript mentions threshold calibration using a small sample dataset, but the exact criteria, statistical basis, and sensitivity analysis should be described more explicitly to improve reproducibility.

R2:

We thank the reviewer for this valuable comment. We agree that the threshold selection procedure was not described with sufficient clarity in the original manuscript. We have revised the manuscript to provide a more detailed explanation of the coherence-based classification procedure.

The proposed method does not employ a fixed or universally predefined coherence threshold. Instead, an adaptive scene-specific approach was adopted to account for natural spatial and temporal variations in Sentinel-1 coherence. Four pre-event Sentinel-1 images were used to generate three consecutive pre-event coherence layers, which were normalized and averaged on a pixel-by-pixel basis to establish the normal pre-event coherence condition. This baseline was then compared with the coherence derived from the image pair spanning the cyclone period to calculate the coherence reduction associated with the event. The average coherence reduction across the valid analysis area was subsequently used as an adaptive decision threshold. Pixels exhibiting coherence reductions greater than the scene-average reduction were classified as potential cyclone-induced disturbance, whereas pixels with smaller reductions were considered relatively stable. This approach avoids the use of an arbitrary universal threshold and instead identifies locations exhibiting coherence loss that is anomalously greater than the overall background response within each cyclone event. To assess the reliability of the resulting classification, the detected disturbance areas were evaluated using field observations and independent secondary damage datasets. The revised manuscript has been expanded to clarify this workflow and improve its reproducibility.

"In contrast to conventional coherence change detection methods that employ a numerical coherence threshold, this study adopted a rule-based threshold derived from multi-temporal coherence relationships. To establish the pre-event coherence condition, four Sentinel-1 pre-event acquisitions were used to generate three consecutive coherence layers. These coherence layers were averaged on a pixel-by-pixel basis to represent the normal temporal coherence behavior before cyclone occurrence. The normalized averaged pre-event coherence was subsequently compared with the coherence derived from the image pair spanning the cyclone period to quantify coherence reduction associated with the event.

Rather than applying a fixed numerical coherence threshold, an adaptive scene-specific threshold was adopted. The mean coherence reduction across the valid analysis area was used as the decision criterion, whereby pixels exhibiting coherence reductions greater than the scene-average reduction were identified as potential cyclone-induced disturbance, while pixels with smaller reductions were considered relatively *stable. This adaptive strategy was selected because Sentinel-1 coherence varies with land-cover characteristics, vegetation, surface moisture, and acquisition conditions, making a single universal threshold unsuitable for all cyclone events. The resulting damage maps were subsequently evaluated using field observation and independent secondary damage datasets to assess the spatial correspondence between detected coherence loss and documented cyclone damage."*

C3:

The validation strategy should be strengthened. Field validation was conducted only for Cyclone Remal, while earlier events relied on secondary information. Please discuss the limitations and uncertainties associated with cross-event validation more critically.

R3:

Thank you for this valuable comment. We agree that the validation framework and its associated limitations should be discussed more explicitly. Because the five cyclone events occurred in different years, a uniform field-based validation strategy was not feasible. Field validation was conducted only for Cyclone Remal (2024), while validation for Cyclones Sitrang, Amphan, Mocha, and Hamoon relied on secondary datasets. In the revised manuscript, we have expanded Section 3.5 to explicitly describe this mixed validation framework and its associated uncertainties. We also clarify that, although these secondary sources provide independent evidence supporting the spatial distribution of cyclone impacts, they cannot fully replace direct field observations. Accordingly, the reported accuracy values should be interpreted in the context of the available reference data for each event. We believe these revisions provide a more transparent description of the validation strategy and clearly communicate its strengths and limitations:

Validation was conducted to evaluate the reliability of the coherence-based cyclone damage detection. Owing to the different acquisition years of the five cyclone events, a uniform field-based validation strategy was not feasible. Field verification was carried out only for Cyclone Remal (2024), as it was the only event for which post-disaster site visits could be conducted within a reasonable timeframe. For Cyclones Sitrang, Amphan, Mocha, and Hamoon, validation was performed using secondary datasets. Although these secondary sources provide independent evidence for evaluating the spatial distribution of cyclone impacts, they introduce additional sources of uncertainty, including differences in spatial resolution, reporting bias, and temporal mismatch with the satellite acquisition dates. The field observations collected for Cyclone Remal provide direct verification of the coherence-based damage detection, whereas the validation for earlier cyclones represents an indirect assessment based on independent reference information. This limitation has been considered when interpreting the accuracy results and is acknowledged as an inherent constraint of multi-event retrospective disaster studies. For Cyclone Remal, representative validation points were selected from the coherence-based damage map to include both damaged and stable areas. The locations were georeferenced and verified in the field using GPS-enabled devices, where photographs and observations were collected to document structural damage and impacts."

C4:

The manuscript would benefit from additional quantitative comparison between coherence loss and inundation extent. Including overlap statistics or percentage agreement between inundation- and coherence-based damage zones could improve interpretation.

R4:

We thank the reviewer for this valuable suggestion. In response, we conducted an additional quantitative spatial comparison between the coherence-derived damage maps and independently derived inundation extent maps for the corresponding cyclone events. A pixel-based cross-tabulation was performed to quantify the spatial relationship between the two datasets in the case of Remal. The analysis showed that 78.85% of pixels within the mapped inundation areas were classified as coherence-derived disturbance, whereas 44.90% of pixels outside the inundation extent were classified as disturbed. The occurrence of coherence loss outside mapped inundation areas indicates that the coherence-based approach is not only sensitive to flood inundation. It is also capable of detecting other cyclone-induced surface disturbances, including vegetation damage, structural change, erosion, sediment redistribution, etc. Conversely, not all inundated areas exhibited pronounced coherence loss, reflecting differences in land-cover characteristics, acquisition timing, and the temporal behavior of SAR coherence following cyclone impacts:

> *"To further evaluate the relationship between coherence-derived disturbance and cyclone-induced flooding, a quantitative spatial comparison was conducted between the coherence-based damage maps and independently derived inundation extent maps for the corresponding cyclone events. The analysis showed that 78.85% of pixels located within mapped inundation areas were classified as coherence-derived disturbance, whereas 44.90% of pixels outside the inundation extent were similarly classified. The nearly 34 percentage point difference demonstrates a strong spatial association between inundation and coherence loss, indicating that cyclone-induced flooding is a major contributor to coherence reduction. Nevertheless, the substantial occurrence of coherence-derived disturbance outside the mapped inundation areas indicates that the coherence-based method is not limited to detecting flood impacts alone. Instead, it also responds to other cyclone-related surface disturbances, including vegetation damage, structural damage, erosion, sediment redistribution, and changes in the surface. Conversely, some inundated areas exhibited relatively limited coherence reduction, which may reflect differences in land-cover characteristics, flood duration, acquisition timing, and post-event surface recovery. These findings demonstrate that coherence-derived disturbance mapping and inundation mapping provide complementary rather than equivalent representations of cyclone impacts, highlighting the value of integrating multiple sources of information for comprehensive post-disaster assessment."*

C5:

Several sections of the Discussion contain repetitive explanations regarding coherence decline and recovery. Consider condensing these parts and emphasizing broader scientific implications and transferability of the framework.

R5:

Thank you for the kind suggestion.

We agree that Section 5.1 previously restated event-by-event coherence behavior that had already been presented in the Results, without sufficiently engaging with the broader literature. We have condensed the repetitive material and restructured the subsection so that each key finding is now paired with a comparison to previously published SAR coherence studies, clarifying how our results agree with, extend, or differ from prior work. The revised subsection:

> *"The results establish interferometric coherence as an effective and useful indicator of cyclone-induced surface change and disturbance. The observed temporal decline and gradual recovery after the landfall indicate the short-term destabilization caused by cyclone winds, while the spatial distribution of coherence loss broadly corresponds with reported patterns of cyclone impact from the secondary literature reviews. Partial overlap with inundation layers confirms that coherence captures flooding and inundation, wind-caused damage, and land surface changes within a single radar-derived measure. Thus, CCD as a method offers key advantages such as cloud independence, sensitivity to both flooded and wind-damaged surfaces, and scalability for temporal monitoring, proving to be complementary and a potential alternative approach to other optical or field-based damage monitoring and assessment methods.*
>
> ***5.1 Comparison of Cyclone Damage Scenario and Inundation Scenario***
>
> *Coherence-based damage maps showed clear variation in the spatial extent and distribution of affected areas, reflecting both threshold selection and underlying cyclone dynamics. Cyclone Remal produced a broad low-coherence zone around Kalapara and Amtali subdistricts, consistent with reported inundation and embankment failure; Hamoon showed a more localized footprint around Kutubdia; and Mocha generated a widespread, relatively uniform decorrelation pattern across southern Cox's Bazar, consistent with its extensive wind field. These differences indicate that coherence response varies with cyclone*

characteristics and the spatial distribution of surface disturbance. This event-dependent variation in the magnitude of decorrelation is consistent with Washaya et al. (2018), who reported marked differences in overall coherence losses for a hurricane (75%) and an earthquake (65%) using comparable Sentinel-1 coherence change detection (CCD), indicating that the degree of decorrelation is closely tied to influenced by hazard characteristics and surface conditions rather than being a fixed property of the method itself.

Compared with inundation maps, although 78.85% of pixels within mapped inundation areas were classified as coherence-derived disturbance, a substantial proportion of all coherence-disturbed pixels occurred outside the mapped inundation extent. Substantial decorrelation was frequently detected in inland areas with little or no inundation, where field observations documented structural damage and vegetation loss that were consistent with wind-related impacts. For example, Remal showed notable coherence loss in Nilganj, Baliatali, and Lalua unions despite limited flooding, and Hamoon produced strong inland damage signals in Barabakia and Lemshikhali unions; Mocha and Sitrang showed similar wind-driven decorrelation, while Amphan showed both overlapping and distinct zones of flood- and wind-related damage. This partial overlap with inundation extent is broadly consistent with the SAR-based cyclone flood-mapping literature: Alexandre et al. (2020) applied a Sentinel-1 normalized difference ratio (NDR) chain specifically to delineate flood extent after cyclones AVA and DIANE in Madagascar, and reported strong agreement with Copernicus EMS flood products, but their approach was designed to isolate inundated area rather than the wider set of surface changes considered here. The present results suggest that a coherence-based formulation detects flood-related changes together with additional forms of surface disturbance, including wind-related structural and vegetation changes that a flood-focused change-detection method may not be expected to identify. A similar distinction between water-related and non-water-related surface change was noted by Malmgren-Hansen et al. (2020), who used Sentinel-1 intensity-based Wishart change detection for Cyclone Idai in Beira and found that filtering changes by building footprints was necessary to separate impacts on houses from changes in the surrounding natural environment; their analysis likewise showed that a substantial share of detected change could not be attributed to inundation alone. The methodological logic of isolating hazard-related decorrelation from other sources of surface change also parallels Fielding & Jung (2024), who used correlation-difference mapping between pre- and co-event image pairs to separate earthquake-induced building damage from vegetation-driven decorrelation at Bam, Iran; although the hazard type differs, this supports the broader principle that a single coherence or correlation measurement conflates multiple surface processes unless compared against a reference state, as done here through the pre-event coherence baseline.

Together with the temporal coherence behavior and field validation described above, these patterns indicate that coherence loss may reflect multiple interacting hazard processes- including flooding, wind damage, and surface disturbance rather than a single component, and that coherence-based change detection provides a more comprehensive representation of cyclone impacts than flood mapping alone. This integrated sensitivity, combined with independence from cloud cover and daylight, makes the approach potentially useful for rapid post-event assessment in data-constrained environments such as Bangladesh, consistent with the rationale for SAR-based rapid damage assessment established by Plank (2014). The consistency of these patterns with findings from other cyclone and hurricane studies further supports the physical basis and potential applicability in other geographic and hazard contexts of coherence-based change detection. Meneses & Blanco (2022) similarly used Sentinel-1 complex coherence to map typhoon damage across multiple islands of the Philippines, reporting up to 93% correspondence with UNITAR/UNOSAT damage tags when classification was simplified to a binary damaged/not-damaged scheme, demonstrating the potential value of binary coherence-based classification, although their validation framework is not directly comparable with the inundation-overlap analysis used in the present study. Together with the cross-hazard consistency reported by Washaya & Balz (2018) across an earthquake and a hurricane using the same coherence framework, these findings indicate that the approach has potential for application beyond the present study area, subject to local calibration and validation."

Minor Comments:

C6:

Improve grammatical consistency throughout the manuscript, particularly article usage and sentence structure in the Introduction and Discussion sections.

R6:

We thank the reviewer for this kind observation. In response, a thorough grammatical revision has been carried out across all sections of the manuscript, with particular attention to the Introduction, Methodology, Results, and Discussion sections.

C7:

Figure labels and legends should be enlarged for better readability, especially in Figures 4 and 5.

R7:

Thank you for pointing this out. We have increased the font size of the axis labels, legend text, and titles in Figures 4 and 5 to improve readability and have regenerated both figures at a higher resolution accordingly.

C8:

The manuscript should maintain consistency in terminology such as “coherence loss,” “decorrelation,” and “surface disturbance.”

R8:

Thank you for the critical observation. We have reviewed the manuscript and standardized the use of these terms: "coherence loss" and "decorrelation" are now used interchangeably to refer to the reduction in interferometric coherence, while "surface disturbance" is used as the broader term describing the underlying physical cause (e.g., structural damage, vegetation loss, flooding) responsible for that reduction. We have checked their usage throughout the manuscript for consistency.

C9:

Add a brief explanation of why VV polarization was selected instead of VH or dual polarization combinations.

R9:

We thank the reviewer for this suggestion. We have added a clarification in Section 3.2 explaining the selection of VV polarization. VV was used because the co-polarized channel generally provides a stronger and more stable interferometric signal over many terrestrial surfaces than the cross-polarized VH channel, which is more strongly influenced by volume scattering and temporal changes in vegetation. This made VV more appropriate for maintaining a consistent multi-temporal coherence baseline and detecting event-related decorrelation across the coastal study areas:

> *“VV-polarized imagery was selected because it generally provides a stronger and more stable interferometric signal over land surfaces than VH, supporting more consistent coherence estimation across events. Although VH may provide complementary information on vegetation disturbance, VV was used to maintain methodological consistency.”*

C10:

Some references require formatting consistency according to the journal style

R10:

We have formatted the full reference list according to the journal's citation style (author format, journal abbreviations, volume/page/DOI formatting), and cross-checked each entry against the corresponding in-text citation in the reference section.

"Al Shafian, S. and Hu, D.: Integrating Machine Learning and Remote Sensing in Disaster Management: A Decadal Review of Post-Disaster Building Damage Assessment, Buildings, 14(8), 2344, https://doi.org/10.3390/buildings14082344, 2024. Bürgmann, R., Rosen, P. A., and Fielding, E. J.: Synthetic Aperture Radar Interferometry to Measure Earth's Surface Topography and Its Deformation, Annu. Rev. Earth Planet. Sci., 28, 169-209, https://doi.org/10.1146/annurev.earth.28.1.169, 2000.

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We appreciate your guidance and look forward to the next steps in the review process.