

**Journal:** Remote Sensing

**Title:** Unmanned Aerial Geophysical Remote Sensing: A Survey

**Manuscript Number:** remotesensing-3272803

**Responses to the comments**

**Reviewer #1**

| No. | Issue                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | Authors' responses                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | References |
|-----|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------|
| 1   | <p>This research paper comprehensively reviews the state-of-the-art UAV-based geophysical methods, encompassing magnetometry, gravimetry, and gamma-ray spectrometer radiometry. The authors provide a detailed account of modern technology applications in geophysics, which are crucial for contemporary research and relevant to current technological advancements.</p> <p>However, there are some observations that I believe the authors should address. The authors need to revise the structure of the research paper. The methodology and results sections should be separated. As it stands, the sections are somewhat cluttered, making the paper unclear and disrupting its flow.</p> <p>The authors should also separate the discussion and conclusion sections for improved clarity.</p> | <p><i>Explained/Revised:</i></p> <p>Thank you very much for taking the time and effort to review our work. We have carefully addressed all your comments, which are detailed in this table. To help you track the changes made to the manuscript, we used the Track Changes feature. This allows you to view both the original text and the revised version.</p> <p>a) <i>However, there are some observations that I believe the authors should address.</i></p> <p>The observations you provided have been carefully addressed. Please refer to the subsequent rows of this table to find our responses to your comments.</p> <p>b) <i>The authors need to revise the structure of the research paper. The methodology and results sections should be separated. As it stands, the sections are somewhat cluttered, making the paper unclear and disrupting its flow.</i></p> <p>Thank you for this comment. The methodology and results sections of our study are separated in their current form. Drawing from various systematic review papers, we explained in the methodology section how we accessed the literature and refined and categorized it based on the PRISMA guidelines. Additionally, we included explanations about the research criteria, parameters, and variables used in our method (see our response to comment #4).</p> <p>It is also worth mentioning that the results section, previously titled "3. UAV-borne Geophysical Survey Methods", has been revised to "3. Review Results: UAV-borne Geophysical Survey Methods." In this section, we present the findings from the full-text review of the literature. To better summarize each result, we added a general overview using figures and tables and then referred readers to the detailed information provided in the tables. Furthermore, several lengthy tables have been relocated to a newly added Appendix section.</p> | -          |

| No. | Issue                                                                                                                                                                                                                                                                                                                            | Authors' responses                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | References        |
|-----|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------|
|     |                                                                                                                                                                                                                                                                                                                                  | <p>These are some of the main changes made to the manuscript. For further details, please refer to the subsequent parts of this table.</p> <p><i>c) The authors should also separate the discussion and conclusion sections for improved clarity.</i></p> <p>Thank you for this comment. We separated the discussion and conclusion sections to improve the clarity.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                   |
| 2   | <p><b>Abstract</b></p> <p>In the abstract, the authors need to review lines 11–12 and rephrase the research objective. In lines 16–20, the results section should be quantified as percentages against the parameters used in the study. These parameters or variables should be clearly defined in the methodology section.</p> | <p><i>Revised/Added:</i></p> <p>Thank you for this comment. The revisions related to the abstract section have been addressed as follows:</p> <p><i>a) In the abstract, the authors need to review lines 11–12 and rephrase the research objective.</i></p> <p>The sentence has been revised to: “The objective of this study is to comprehensively review the state-of-the-art UAV-based geophysical methods ...”</p> <p><i>b) In lines 16–20, the results section should be quantified as percentages against the parameters used in the study. These parameters or variables should be clearly defined in the methodology section.</i></p> <p>The following summary inputs have been added to the abstract:</p> <p>Among the UAV platforms, rotary-wing multirotors were the most commonly used (64%), followed by fixed-wing UAVs (27%), with unmanned helicopters and airships comprising the remaining 9%. In terms of sensors and methods, imaging-based methods and magnetometry were the most prevalent, accounting for 35% and 27% of the research, respectively, while other methods had a more balanced representation (6-11%). From an application perspective, the primary uses of UAVs in geoscience included soil mapping (19.6%), landslide/subsidence mapping (17.2%), and near-surface object detection (13.5%).</p> | Please see page 1 |
| 3   | <p><b>Introduction</b></p> <p>In the introduction, lines 69–76 require attention. The research gaps are not clearly defined, and rephrasing is necessary to clarify them.</p>                                                                                                                                                    | <p><i>Revised/Added/Removed:</i></p> <p>Thank you for this comment. To define the research gap more clearly, the paragraph has been revised as follows:</p> <p>The growing trend of UAV-based geophysical surveys in recent years, and the increasing volume of research published annually highlight a need for a comprehensive review of UAV-based</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | Please see page 2 |

| No. | Issue                                                                                                                                                                                                                                        | Authors' responses                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | References                                                 |
|-----|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------|
|     |                                                                                                                                                                                                                                              | <p>geophysical surveys. Existing review articles tend to focus on specific aspects of UAV-based geophysical surveys, as exemplified by the works of [23,25], which review UAV-based magnetometry or GPR, respectively. While these studies provide valuable insights into specific methods, no previous work has provided an overview of feasible UAV-based geophysical RS methods and comprehensively analyzed them. To address this gap, we aim to thoroughly review all methods feasibly developed for geophysical (or other geoscientific) surveys using UAVs.</p> <p>Moreover, the following sentence from the next paragraph has been removed, as it has already been included in the preceding paragraph:<br/>To the best of our knowledge, no prior work has comprehensively compiled and reviewed all the methods mentioned.</p>                                                                                                                                                                               |                                                            |
| 4   | <p><b>Methodology</b></p> <p>Research parameters and variables are not specified, which affects the presentation and interpretation of results. The authors should indicate whether qualitative or quantitative techniques were applied.</p> | <p><i>Added:</i></p> <p>Thank you for this comment. The following paragraph has been added to the manuscript:<br/>Our systematic review employed both qualitative and quantitative approaches to analyze the literature. The qualitative analysis examined the technical aspects, methodological approaches, and applications of UAV-based geophysical methods. We tracked several key variables for quantitative assessment, including publication year, geographic distribution, platform specifications, sensor characteristics, and application domains. Papers were selected based on four main criteria: primary focus on UAV-based geophysical or relevant RS methods, peer-reviewed publication status, sufficient technical detail, and English language. For each study, we systematically extracted information about platform specifications (UAV type, payload capacity, endurance), sensor characteristics (type, resolution, accuracy), and operational parameters (survey height, speed, coverage).</p> | Please see page 3                                          |
| 5   | <p><b>Results</b></p> <p>The results are not well presented because the research parameters and variables were not clearly defined. This makes it difficult to interpret the results. The results section</p>                                | <p><i>Added:</i></p> <p><i>a) The results are not well presented because the research parameters and variables were not clearly defined. This makes it difficult to interpret the results.</i></p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | Please see pages 6, 7, 12, 16, 18, 21, 22, 25, 27, 28, 30, |

| No. | Issue                                            | Authors' responses                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | References                 |
|-----|--------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------|
|     | should be distinct from the methodology section. | <p>Thank you for this comment. To effectively present the results, we went beyond merely collecting and categorizing the research in table format. Specifically, we provided an overview of the information contained in each table (with the main details included in the tables) and described key research parameters such as the types of platforms, sensor types and their specifications, and the applications from both a general perspective and a higher level of detail. The added inputs are as follows:</p> <ul style="list-style-type: none"> <li>• Current UAV-compatible magnetometers utilize potassium, caesium, or rubidium vapor technologies, with the GemSystems GSMP-35U/25U offering highest sensitivity (0.0002 nT) but greater weight (1 kg), while newer systems like MFAM and QTFM provide reduced sensitivity but significantly lighter packages (0.15-0.23 kg). These systems generally operate in temperature ranges of -30°C to +60°C with sampling rates from 1-5,000 Hz, suitable for diverse aerial survey requirements [23,42]. Detailed specifications are provided in Table 1.</li> <li>• UAV-borne magnetometry systems have been implemented across various platforms: multi-rotors [36,41,42,46-66], fixed-wings [23,37,48,67-83], and helicopters [40,57,84-93]. While DJI-based multi-rotor platforms are most common due to accessibility and stability, each platform type offers distinct advantages. Sensor integration primarily utilizes fluxgate, cesium vapor, and potassium magnetometers, with payload capacities from 2 kg to over 40 kg. System endurance varies significantly: multi-rotors (15-30 minutes), fixed-wings (8-15 hours), and helicopters (1.5-4 hours). Most systems operate at speeds of 7-20 m/s and altitudes of 50-200 m, incorporating GPS, IMU, and laser altimeters for enhanced accuracy. This diversity enables tailored solutions for both detailed local surveys and extensive regional mapping. Detailed specifications are provided in Table 2.</li> <li>• UAV-borne magnetometry has found successful applications across diverse domains: mineral exploration and deposit</li> </ul> | 32, 33, 38, 42, 43, and 45 |

| No. | Issue | Authors' responses                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | References |
|-----|-------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------|
|     |       | <p>characterization [36,40,48,50,52,55,59,60,66,67,73,94,104-108], archaeological surveys [65,109], near-surface object detection and identification, specifically mines and unexploded ordnance (UXO) [41,49,57,68,90,110,111], geological structure and fault mapping [112], volcanology [64,84,85,113], and oil/gas infrastructure identification [53,61,114-116]. Several studies have been conducted for general purposes rather than specific applications [37,51,54,87,91-93,102,117-120]. The applications extend beyond terrestrial environments to marine domains, including offshore geophysical surveying, beach-shallow sea transition area magnetic surveying, and anti-submarine warfare system detection [81,86,121]. These systems have proven particularly valuable in remote or hazardous environments where traditional ground surveys are impractical or highly challenging [71,72]. Detailed specifications for each application are provided in Table 3.</p> <ul style="list-style-type: none"> <li>• Notable implementations of strapdown systems include lightweight iCorus [133-135] and iMAR iNAV-RQH [136]. The MEMS-based solutions are represented by systems such as Wee-g [126,137-139], Imperial College's devices [140], HUST's MEMS device [141], Silicon Micro Gravity [142,143], FG5-L [144,145], and Scintrex RG1 [126,146]. For visual presentation of these sensors, refer to Table 4.</li> <li>• The development of UAV-borne gravimetry systems has been led by various organizations, including military institutions (Portuguese Ministry of Defence [146]), universities (University of Glasgow [138,147], Technical University of Denmark [135], National University of Defense Technology [24]), and government agencies (National Oceanic and Atmospheric Administration (NOAA) [148], Geological Survey of Japan [149]). Additionally, several self-developed systems have been successfully implemented for regional studies [136,150-154]. While both rotary-wing [136,149,150,152,155,156] and</li> </ul> |            |

| No. | Issue | Authors' responses                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | References |
|-----|-------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------|
|     |       | <p>fixed-wing [24,135,151,153,157-161] platforms have been employed, long-endurance fixed-wing drones dominate national and international projects. Strapdown gravimeters are the most commonly used sensors [24,151,154,157], with some systems incorporating additional geophysical sensors for integrated surveys [159-161]. Table 5 presents detailed specifications of these systems.</p> <ul style="list-style-type: none"> <li>• UAV-borne gravimetry applications primarily span three domains: system re-search and development (R&amp;D), geological studies, and exploration [24,126,135,136,138,147,149,152,153,155-157]. Most research focuses on system development, including INS/GNSS integration [136,157] and miniature system refinement [138,149]. Applied studies demonstrate successful implementation in earthquake research [150], Arctic exploration [155,156], mineral prospecting [126], and datum definition [148]. International projects like DroneSOM [159-161] showcase the technology's potential for integrated geophysical surveys. Table 6 provides more details of these applications.</li> <li>• Several ready-to-use gamma-ray spectrometers have been tested and validated for UAV deployment. These include the Medusa MS Spectrometer Series [164,170,183], Georadis D230A Spectrometer [176,184], CeBr<sub>3</sub> (and Twin NaI-CeBr<sub>3</sub>) Scintillation Detector [181], CsI(Tl) detector [172,194,195], Cadmium Zinc Telluride (CdZnTe or CZT) Semiconductor Detector, GR1/-A Kromek Spectrometer [169,173,195-197], Cs<sub>2</sub>LiYCl<sub>6</sub>:Ce<sup>3+</sup> (CLYC) Elpasolite scintillation sensor [173,198,199], and Geiger-Müller Tube Particle Counter [200]. Among these, the Medusa MS Spectrometer series has gained widespread commercial adoption, while other sensors are primarily research-oriented developments with limited commercial availability. Table 7 provides detailed specifications of these UAV-compatible radiation sensors.</li> </ul> |            |

| No. | Issue | Authors' responses                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | References |
|-----|-------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------|
|     |       | <ul style="list-style-type: none"> <li>• A review of developed UAV-borne GRS systems (Table 8) [167,169,170,172,173,176,182-184,195,199,201-208] reveals that their primary objective is RS of radionuclide contamination in radioactive incidents and nuclear emergency monitoring. Some systems integrate additional geophysical capabilities, such as mag-netic and electromagnetic surveys, to enhance survey efficiency and reliability [202]. Helicopters and multi-rotors demonstrate superior applicability for these systems (e.g., RotorRAD [206] and Radiation Monitoring System (RMS) [195]) due to their ability to hover and maintain precise control near radiation sources, although fixed-wing plat-forms have also been employed (e.g., Autonomous Airborne Radiation Mapping (AARM) system [195]).</li> <li>• UAV-borne GRS has found diverse applications, including precise soil (texture) mapping [162-164,168,170], environmental contamination monitoring at critical sites (including mine tailings [163], industrial plant surveillance [197], and lost radioactive source location [206]), characterization of Uranium Legacy Sites (ULSs) [181,195,209], accurate mapping of radiation sources and polluting gases [207], and radiometric measurements for mining applications [184]. Table 9 provides in-depth information of these applications.</li> <li>• In reviewing the geoscientific applications of UAV photogrammetry, fine-scale digital terrain modeling for geomorphological studies emerges as a significant area of implementation. A crucial step in this methodology involves filtering the original point cloud data to isolate the natural terrain points [221]. The subsequent generation of topographical maps, created by integrating orthomosaic imagery with contour lines, enables comprehensive geomorphological analysis and various practical applications. The second major application category focuses on landslide mapping and moni-toring. A review of the literature (Table 1A, Appendix A) demonstrates that this ap-plication requires</li> </ul> |            |

| No. | Issue | Authors' responses                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | References |
|-----|-------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------|
|     |       | <p>multi-temporal surveying and analysis of orthophoto-mosaics and DTMs from pre- and post-landslide events to map horizontal and vertical displacements, respectively [222-237]. The number, distribution, and accuracy of ground control points (GCPs) are critical in this methodology. UAV photogrammetry serves as a complementary approach to ground-based methods, including geodetic surveys, terrestrial laser scanning (TLS), and GNSS-based solutions. However, the co-registration of multi-temporal photogrammetric products remains a significant technical challenge. The third major category of applications focuses on land subsidence and ground failure mapping, where vertical displacement measurements are paramount and precise multi-temporal DTMs play a crucial role (Table 2A, Appendix A) [238-249]. Within this category, subsidence mapping in mining areas has received particular attention in the literature. The methodological considerations previously discussed for landslide monitoring are equally applicable in this context. Research has demonstrated that integrating UAV photogrammetry with other ground-based and remote sensing methods, such as GNSS, LiDAR, and Differential Interferometry Synthetic Aperture Radar (DInSAR), enhances the accuracy and reliability of results [241,242,244,245,248]. In both landslide and subsidence mapping applications, where terrain geometry is the primary concern rather than spectral information, visible-light imaging sensors typically provide sufficient data. A consideration in these applications is the sensor's capacity to deliver fine ground sampling distance (GSD), which serves as an indicator of spatial resolution.</p> <ul style="list-style-type: none"> <li>• The fourth major category of applications addresses geothermal exploration [250-265]. These studies focus on remote measurement of ground-level surface and subsurface temperatures and the detection of geothermal activity in both terrestrial and aquatic environments. Thermal-infrared imaging</li> </ul> |            |

| No. | Issue | Authors' responses                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | References |
|-----|-------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------|
|     |       | <p>sensors and video capture systems serve as the primary data collection tools, yielding thermal orthophotos (with visible orthomosaics as supplementary data), 3D thermal models, and DTMs. In the reviewed literature, multirotor drones have played a predominant role in these applications. For a comprehensive overview of research conducted in this field, refer to Table 3A, Appendix A. The fifth category encompasses mineralogy, mining, and soil mapping applications [266-294], spanning a broad range of activities from mineral detection and soil type classification to mine topographic mapping, volume estimation, and geological structure mapping (detailed information provided in Table 4A, Appendix A). Within this research domain, soil moisture mapping, specifically the remote detection of subsurface water content, has garnered significant attention [263,295-301] (Table 5A, Appendix A). MS and HS imaging sensors have proven particularly effective in these applications. Due to the requirement for precise spectral analysis, robust radiometric and geometric corrections are crucial [268]. Structure from Motion (SfM) and Multi-View Stereo (MVS) processing techniques have been widely employed to generate MS or HS orthomosaics, while artificial neural networks (ANNs) and machine learning (ML) approaches have played significant roles in extracting valuable higher-level spectral features [263,278,279,295,298]. The resulting RS data has been successfully integrated into Geographic Information Systems (GIS) for further analysis [275,299]. Research has demonstrated that combining these imaging results with other ground-based and UAV geophysical data (e.g., magnetic surveys) enables more comprehensive geological analysis of subsurface conditions [270,272,277]. The final category of geoscientific applications focuses on volcanic research [302-304] (Table 6A, Appendix A). Although this category comprises a smaller body of literature compared to other applications, these studies primarily</p> |            |

| No. | Issue | Authors' responses                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | References |
|-----|-------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------|
|     |       | <p>concentrate on visual inspection and modeling of active volcanic landforms, conducted through both single-time observations and temporal monitoring campaigns. <b>(Six tables in this section have been transferred to the Appendix section)</b></p> <ul style="list-style-type: none"> <li>• UAV-borne EM Survey Systems: Building on the previously discussed platforms and sensors, 26 distinct UAV-borne EM systems that have been developed [10,73,159,161,202,308,310,346-348,350-352,355,364,365,368-380], with a thorough overview provided in Table 10. Rotary-wing platforms dominate system development compared to unmanned helicopters or fixed-wing drones, with the GEM-2 emerging as the most widely implemented EM instrument.</li> <li>• UAV-borne EM applications span several key domains, including structural discordance and tectonics mapping [346], uranium deposits analysis [372], detection/investigation of subsurface targets (infrastructures) such as buried wires/power cables and pipelines [73,355,386], fence crossings [365], landmine/UXO [364,373], and even buried vehicles [347], underground tunnel investigation [73,387], fresh-saline water mapping [355,365], soil/sub-soil mapping (soil resistivity mapping [347], sand-clay lithology mapping [365]), and deep slope subsurface resistivity structure/distribution investigation [347,374,388]. Table 11 provides detailed information about these applications.</li> <li>• Approximately 40 cutting-edge UAV-based radar and GPR systems have been identified in the literature [389-392,394-407,412-415,417,421-423,425,426,429,439,442,449-466]. Multi-rotors are predominantly used, which is consistent with GPR survey requirements as they allow effective scattering and backscattering reception. The systems operate across diverse frequency ranges (100 MHz to 9.8 GHz, with many systems operating in the 0.5-5 GHz range), utilizing various antenna designs (linear arrays, horn, helix, and Vivaldi). Systems employ Pulsed, FMCW, and SFCW technologies, with penetration</li> </ul> |            |

| No. | Issue | Authors' responses                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | References |
|-----|-------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------|
|     |       | <p>depths ranging from centimeters to several meters depending on application. Flight heights ranging from 0.5 to 7 meters for most applications, though some systems operate at heights up to 10 meters, with systems implementing different radar architectures (DLGPR, FLGPR, SLGPR) and measurement configurations (monostatic, bistatic). Table 13 provides detailed specifications of these systems.</p> <ul style="list-style-type: none"> <li>• Review and categorization of UAV-borne GPR applications reveals several key domains: buried threats object (landmines, IDEs, and UXOs) detection [391,400-402,405,413-415,421,422,426,442,449-451,453,455,458,464], snow and ice studies [392,454,456,457], archaeological mapping [394,465], agricultural applications [467], soil moisture mapping [403], bathymetry [460], and search and rescue (SaR) operations [423,468], with buried threat detection emerging as the predominant application area. Beyond geoscience applications, the technology has demonstrated utility in other disciplines such as agriculture and SaR (for example, victim detection). Table 14 provides a comprehensive review of these applications.</li> <li>• These applications include fine-detailed digital terrain modeling [480-485], fault zone mapping [486], landslide mapping and monitoring [487-495], subsidence and fissure mapping [31,495-500], geological mapping (geological structure measurement [501-505], geological catalogue production [506], characterization of ice morphology evolution [507]), glaciological investigations [507], groundwater level mapping [508], topographic mapping for precision land leveling [509], volcanological studies [510], and soil mapping (e.g., estimation of soil organic carbon (SOC)) [511,512]. Besides the spatial and structural information of LiDAR, some sources of imaging information are sometimes combined for enhanced analysis ability [511,512]. Table 15 provides a detailed explanation of these applications.</li> </ul> |            |

| No. | Issue                                                                                                                        | Authors' responses                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | References             |
|-----|------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------|
|     |                                                                                                                              | <ul style="list-style-type: none"> <li>The sensor integration and data fusion solutions in UAV-borne geophysical survey that have been applied include photogrammetry-magnetometry [48,532,533], photo-grammetry-GPR [407,534], magnetometry-GPR [535], photogramme-try-magnetometry-GPR [536], magnetometry-gravimetry [24], magnetome-try-radiometry/spectrometry [172], radiometry/spectrometry-EM [346], magnetome-try-EM [535,536], photogrammetry-LiDAR [507,537-539], photogrammetry-GPR [540], and integrated aerial photogrammetry and spaceborne RS [244,245,248,541-544]. The majority of these sensor integration and data fusion approaches involve UAVs exclusively, though some cases integrate ground-based, aerial, and spaceborne data, resulting in complex multi-platform and multi-sensor data integration systems for geoscientific applications.</li> </ul> <p><i>b) The results section should be distinct from the methodology section.</i></p> <p>Thank you for this comment. In fact, the methodology and results sections of our study are separated in their current form. Following the approach seen in various systematic review papers, the methodology section explains how we accessed the literature and how we refined and categorized it based on the PRISMA guidelines. More importantly, in response to your comment, we have clearly outlined the research parameters that were crucial to our study, both in the research refinement phase and during the full-text review process—specifically the parameters and variables related to platforms, sensors, and applications.</p> <p>In the results section, which was previously titled “3. UAV-borne Geophysical Survey Methods,” we revised it to “3. Review Results: UAV-borne Geophysical Survey Methods.” In this section, we present the results of the full-text review of the literature.</p> |                        |
| 6   | <b>Discussion and Conclusions</b><br>For clarity, the discussion and conclusion sections should be separate from each other. | <i>Revised/Added:</i><br>Thank you for this comment. To enhance clarity, the Discussion and Conclusions sections have been separated from each other.<br>Furthermore, the following first input has been added to the Discussion section, and the last two                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | Please see pages 79-49 |

| No. | Issue | Authors' responses                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | References |
|-----|-------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------|
|     |       | <p>items have been added to the Conclusions section, respectively:</p> <ul style="list-style-type: none"> <li>Given these ongoing requirements for fieldwork and other technical challenges, improving UAV-based RS analysis in geophysics and related fields requires attention to four key aspects: (1) Platform development - enhancing drone endurance and pay-load capacity, (2) Sensor advancement - developing lightweight, energy-efficient sensors with improved resolution, (3) Software optimization - updating processing capabilities to handle increasing data volumes efficiently, and (4) Field validation - implementing more effective ground-truth data collection methods to ensure comprehensive coverage of surveyed areas.</li> <li>This study presents a comprehensive review of cutting-edge geophysical survey techniques applicable via UAVs. To the best of our knowledge, this is the first review to systematically compile and evaluate these methods. The reviewed methods encompass traditional geophysical approaches such as magnetometry, gravimetry, EM survey, GPR, gamma spectrometry, and radiometry, as well as non-geophysical methods like photogrammetry and LiDARgrammetry. The collected papers were categorized based on sensor type (active or passive) and another category explores sensor integration and data fusion concepts in UAV-based geophysical surveys.</li> <li>Looking ahead, research should focus on several advanced areas: developing robust methods for multi-source and multi-modal data fusion from different UAV-based sensors, implementing advanced artificial intelligence (AI) and DL algorithms for automated data analysis, and exploring Internet of Things (IoT) integration for real-time data collection and processing. These technological advances would further enhance the integration capabilities of UAV-based geophysical surveys.</li> </ul> |            |

| No. | Issue                                                                                                                                         | Authors' responses                                                                                                                                                                                                                                                 | References |
|-----|-----------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------|
| 7   | <b>Report recommendation</b><br>I feel the authors should attend to the issues, that I have raised above. Revise the research and resubmit it | <i>Explained:</i><br>At the end, we would like to confirm that all the comments you raised in this table have been carefully addressed. We hope our revisions contribute to improving the quality of the manuscript, and that our responses are convincing to you. | -          |