

Is Satellite Data Right for Your Needs?

HUMANITARIAN DECISION-MAKING GUIDE



CONFLICT-RELATED BUILDING DAMAGE ASSESSMENT

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Acknowledgements

We are grateful to the individuals who participated in our working group for their contributions to this work (listed in alphabetical order): Brady Africk, Carolina Jordá Álvarez, Daniel Andersen, Sheila Baber, Gauri Bahuguna, Cameron Birge, Courtney Bliler, Lars Bromley, Rebecca Chausse, Rowena De Silva, Olivier Dietrich, Erik Christopher Duncan, Eric Fielding, Thomas Gazel-Anthoine, Will Goodhind, Erika Gutierrez, Rohini Haar, Andrew Hassanali, Caitlin Howarth, Clara Ivanescu, Andro Kortis, Judit Lakatos, Tomaz Logar, Josh Lyons, Emnet Negash, Jessie Pechmann, Birke Pfeifle, Nathaniel Raymond, Caleb Robinson, Benjamin P. Stewart, Valerie Sticher, Giulia Tessari, Guillén Torres Sepulveda, Marie Urban, Riccardo Vitale, James Walker, Nick Waters, Rich Weir, Dominik Wielath, Susan Wolfenbarger, and Kyle Woodward.

Thank you to all members of the Decentralized Damage Mapping Group (DDMG) for their support: Eoghan Darbyshire, Raphaela Edler, Lina Eklund, Zhanpei Fang, Jessie Pechmann, Lama Ranjous, David Saah, Marie Schellens, Corey Scher, Jamon Van Den Hoek, He Yin, and Wim Zwijnenburg. Special thanks to Jamon Van Den Hoek, Corey Scher, and Eoghan Darbyshire for providing conceptual and technical guidance for this report; I'm eternally grateful to David Saah for support of my career and belief in the mission. Heartfelt thanks to Josh Lyons for the many years of encouragement and for sharing damage polygon data. Special thanks to Sheila Baber and Valerie Sticher for their valuable feedback during the editing process and for suggesting changes that greatly improved the quality of this report. This report would not have been possible without assistance during the editing, design, and publication process from Seamus Geraty. Thank you to Maia Tarnas, Caroline Crystal, and Sophie Hayes for their invaluable support and teamwork during this fellowship. Thank you to Barira Rashid and Emma Dodd for your valuable contributions to Lifelines. Thank you to Rhiannan Price and Jeff Pituch for your trust and for making this fellowship possible. And thank you to my family for your love and never-ending support of my passion for human rights.

Introduction

Even though civilian infrastructure is protected by the laws of armed conflict (LOAC), also known as International Humanitarian Law (IHL), we are increasingly observing the intentional, strategic targeting of such infrastructure across myriad armed conflict contexts, perpetrated by both state and non-state actors. Civilian objects such as healthcare facilities and water, sanitation, and hygiene (WASH) infrastructure — items deemed “objects indispensable to human survival”^{1,2} — are widely considered off-limits for targeting. Perversely, it is this specific protected status afforded to civilian objects that oftentimes entices armed actors to pursue destruction of such infrastructure if they intend to occupy territory and displace civilians out of contested areas.

During active conflict, a wide array of humanitarian organizations and human rights monitors, as well as governments and intergovernmental organizations like the UN, seek current battlefield intelligence. At the top of the priority list³ is determining where and to what extent civilian infrastructure is damaged so that civilians can be protected and supported during hostilities. But determining where damaged infrastructure exists is extremely challenging for a variety of reasons: satellite imagery may not be available or recent enough; access may be blocked, either voluntarily by commercial satellite companies or via governmental pressure or censorship; spatial resolution may be insufficient; or the physical space over which the armed conflict is playing out is vast, far beyond the capability of very-high resolution satellites to cover fully (as in Ukraine, where damage is observed country-wide or may be present outside of urban areas, which tend to be imaged more frequently), among other challenges.

This case study seeks to help humanitarian decision-makers familiar with geospatial data to understand the strengths and limitations of Earth observation (EO) imagery for the purpose of conflict damage assessment (CDA)⁴ so that they can make informed decisions on how best to use EO data to pursue their missions and objectives, whether it’s the provision of direct humanitarian aid, human rights accountability investigations, or otherwise. This report assumes a baseline level of EO knowledge, although readers will have varying levels of familiarity with EO concepts such as spatial resolution vs. spectral resolution, essential band combinations (e.g., true color vs. false color infrared), and orbital parameters (e.g., off-nadir angle, sensor/sun azimuth angles), among other foundational remote sensing topics.

¹ Article 14 - Protection of objects indispensable to the survival of the civilian population, Protocol Additional to the Geneva Conventions of 12 August 1949, and relating to the Protection of Victims of Non-International Armed Conflicts (Protocol II), 8 June 1977. Available from: <https://ihl-databases.icrc.org/en/ihl-treaties/apii-1977/article-14>

² Dannenbaum et al. Over 100 International Law Experts Warn: U.S. Strikes on Iran Violate UN Charter and May Be War Crimes. Just Security. 2 April 2026. Available from: <https://www.justsecurity.org/135423/professors-letter-international-law-iran-war/>

³ See Common Space Community Demand Report, p. 9, Fig. 3. Available from: https://www.commonspace.world/_files/ugd/25ea80_cf2571ffc4034db49c9a37a2446d1f22.pdf

⁴ CDA is also sometimes referred to as BDA, or battle damage assessment. BDA can also refer to building damage assessment. We use the term CDA throughout this report. While CDA applications can include themes such as agricultural damage, this report focuses on conflict-related damage specifically to buildings. While we encourage emphasis on protected civilian infrastructure, such as healthcare facilities and water infrastructure, the techniques and methods covered in this report can be used to detect damage to most, if not all, types of physical infrastructure. Military infrastructure/materiel is considered out of scope for this report.

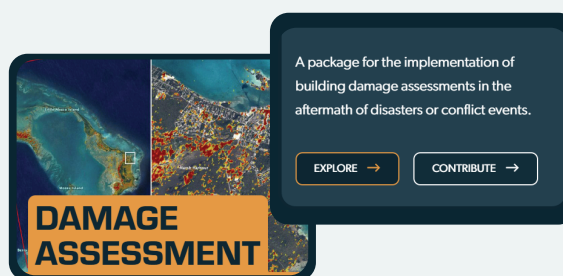
While frameworks exist to help guide the use of open-source information ⁵ for human rights use cases, there is a noticeable dearth of technical guidance on the appropriate usage of EO data and what pitfalls exist for humanitarians who are fluent in GIS and geospatial data but who may lack deep technical understanding of how EO data are created and intended to be used, as well as how to implement workflows for investigative and fact-finding purposes. The goal of this case study is to help close that gap by implementing the NASA Lifelines Suitability Assessment Framework for EO data and by offering applied examples of how EO data may be properly used for damage assessments in armed conflict contexts.

For more in-depth practical workflows, we direct you to the NASA Lifelines Building Damage Assessment Data Studio package.

This case study supplements the **EO Humanitarian Guide**, published by NASA Lifelines in July 2025, and applies the guide's **Suitability Assessment Framework for Satellite Data**. The framework walks through a structured set of questions to help end users determine whether satellite data is fit for purpose, as well as considerations for how to integrate EO data into workflows. This case study is designed for **humanitarian decision makers** who recognize the value of data-driven approaches but may not have deep technical expertise in remote sensing or geospatial analysis.



This case study is accompanied by a companion **Damage Assessment Data Studio Package**, which focuses on disaster and conflict damage. While this report focuses on the analytical and decision-making framework, the Data Studio Package provides hands-on guidance for accessing and working with specific datasets and tools.



⁵ See, for example, Berkeley Protocol on Digital Open Source Investigations. Available from: <https://www.ohchr.org/en/publications/policy-and-methodological-publications/berkeley-protocol-digital-open-source>

Is Satellite Data Right for Me?



This section aims to help decision-makers determine whether Earth observation (EO) data could be a good fit for the damage assessment work they intend to carry out. The questions below walk through what decisions EO could inform, existing precedents, associated ethical and risk considerations, and examples of what specific EO data could support different applications. Working through this section can clarify whether and how EO could add value when conducting remote damage assessments in conflict-affected areas.

What decisions could satellite data support?

Conflict damage assessments (CDAs) are needed throughout all phases of conflict, and satellite-based Earth observation (EO) data is especially well-suited to the task. During active conflict, it is imperative that civilian life is protected. Civilians need to be evacuated from areas of active fighting or accounted for if they choose to remain, and satellite imagery can provide key insights, such as the position and movement of military personnel and materiel, the location of damaged infrastructure and the extent to which it is damaged, and evaluation of optimal safe evacuation routes.

Satellite data can also provide insights regarding the movements of civilian populations themselves, allowing for tracking of displacement camp size changes and vehicle movements out of contested territory. Satellite data can monitor quality of life for civilians caught in conflict scenarios in which they are not able to escape to safety (such as during siege warfare or when civilian movement is restricted).⁶ These scenarios are often access restricted for journalists and humanitarians, so satellite imagery acts as a lifeline data source to help analysts keep an eye on those who might not otherwise have contact with the outside world. Satellite imagery can also be used to monitor how civilians are displaced over long time scales throughout the conflict — either internally (as internally displaced people or IDPs) or externally across international borders (as refugees) — granting a deeper understanding of how the evolution of the conflict is directly affecting survivability of landscapes for civilian populations over time.

Moreover, during periods of active conflict, humanitarian organizations use satellite data to inform decisions around the provision of humanitarian aid based on need arising from conflict-related damage. Understanding the scope of damage to objects indispensable for human survival can help aid providers make decisions about optimal allocation and placement of resources. For example, if satellite data reveals that many pieces of WASH infrastructure are damaged⁷ in and around a certain area where civilians are sheltering, resources can be marshaled to fill the gap.

⁶ Andersen D, Chausse R, Howarth CN, Ismail O, Mooney O, Poole DN, Raymond NA et al. RSF Systematic Mass Killings and Body Disposal in El-Fasher, North Darfur 26 October – 28 November 2025. Humanitarian Research Lab at Yale School of Public Health: New Haven. Available from: <https://medicine.yale.edu/lab/khoshnood/publications/reports>

⁷ Perlman B, Collins SM, Van Den Hoek J. Public health implications of satellite-detected widespread damage to WASH infrastructure in the Gaza Strip. PLOS Global Public Health. 2025 Feb 10;5(2):e0004221. doi:10.1371/journal.pgph.0004221.

Human rights investigators, whether at formal investigative bodies like the ICC or at NGOs such as Human Rights Watch, use satellite imagery to corroborate facts based on reporting from the ground. This allows for monitoring of adherence to International Humanitarian Law (IHL) by armed conflict belligerents in near- real-time and enables investigations of alleged violations of IHL (e.g., targeted and strategic attacks on civilians and civilian infrastructure, such as health facilities).⁸

Lastly, post-conflict recovery and development needs can be based on satellite-derived analyses. For example, the World Bank, UN, and EU consistently publish Rapid Damage and Needs Assessments (RDNAs), which offer detailed information on damage to civilian sectors in conflict contexts. Sector-specific destruction is quantified and recovery costs are calculated based on damage data by sector. This allows for a more accurate accounting of what it would cost to rebuild each sector following the end of the conflict.

Are there any precedents for this use case? Are there relevant resources we could use?

CDAs⁹ have been undertaken by many analysts and researchers across disciplines. There is a strong record of academic literature on the topic of CDA, and humanitarians have also used methods based on those pioneered by academics. For example, academic researchers have used EO analysis methods like moderate-resolution InSAR¹⁰ coherence change detection (CCD) to create polygon datasets that represent likely areas of damage in conflict-affected areas, such as Ukraine.¹¹ Researchers have also created multimodal¹² damage datasets, using a combination of both optical and SAR imagery, which allows for flexibility in all-weather scenarios.¹³ Academics have also published papers focused thematically on specific types of protected civilian infrastructure in wartime, such WASH infrastructure¹⁴ and medical facilities.¹⁵

8 Khoshnood K, Raymond NA et al. Evidence of Widespread and Systematic Bombardment of Ukrainian Healthcare Facilities: Summary. Humanitarian Research Lab at Yale School of Public Health, 17 May 2022. Available from: <https://files-profile.medicine.yale.edu/documents/66d7ed23-f9e1-4974-9d6c-88a673f2c3ef>

9 We will refer to conflict damage assessments as CDAs henceforth. CDA and BDA are generally interchangeable.

10 Interferometric Synthetic Aperture Radar, a remote sensing technique that combines two or more radar images of the same area, taken from a satellite at different times, to measure changes on the ground with very fine precision.

11 Scher C, Van Den Hoek J. Nationwide conflict damage mapping with interferometric synthetic aperture radar: A study of the 2022 Russia–Ukraine conflict. *Sci Remote Sens*. 2025;11:100217. doi:10.1016/j.srs.2025.100217.

12 Multimodal in this context refers to the usage of multiple types of remote sensing sensor types, such as SAR, optical, thermal, and others.

13 Chen, H, Song, J, Dietrich, O, et al. BRIGHT: a globally distributed multimodal building damage assessment dataset with very-high-resolution for all-weather disaster response, *Earth Syst. Sci. Data*, 2025, 17, 6217–6253, doi:10.5194/essd-17-6217-2025.

14 Perlman B, Collins SM, Van Den Hoek J. Public health implications of satellite-detected widespread damage to WASH infrastructure in the Gaza Strip. *PLOS Global Public Health*. 2025 Feb 10;5(2):e0004221. doi:10.1371/journal.pgph.0004221.

15 Poole DN, Andersen D, Raymond NA, Grace R, Smith T, Khoshnood K, et al. Damage to medical complexes in the Gaza Strip during the Israel–Hammas war: a geospatial analysis. *BMJ Global Health*. 2024;9:e014768. doi:10.1136/bmjgh-2023-014768.

BRIGHT: Using VHR optical and VHR SAR together for CDA

BRIGHT is a globally distributed multimodal very-high resolution (VHR) dataset for all-weather disaster response. The authors of BRIGHT, which is a static dataset intended for model development and benchmarking, primarily focused on natural disaster contexts, but the methods used can be applied in a CDA context, given the promising results from the authors' Ukraine case study and NASA Lifelines' work to employ the BRIGHT method over a new conflict context (i.e., Gaza). The authors focused on post-event VHR synthetic aperture radar (SAR) imagery, which allows analysts to rapidly map damage in areas that may still be cloud covered because SAR data can be captured at all hours of the day and in all-weather conditions. The authors used several different combinations of EO modalities; they used pre-event optical imagery and various permutations of post-event imagery, including VHR SAR only, VHR optical only, and a fusion of both SAR and optical. Using available off-the-shelf data processing and visualization tools, such as Google Colab Pro, humanitarians can deploy the BRIGHT method over new conflict contexts, adapting the methods to suit their needs, according to the imagery available.



Likewise, humanitarians, often considered the end users for CDA, have made use of academic research by operationalizing it in the field and in conflict contexts. For example, The United Nations Office for Project Services has a tool, in which CDA data features prominently, called **Compass** that combines various geospatial data into a single dashboard for use by humanitarians deployed in the field. The Humanitarian OpenStreetMap Team (HOTOSM) published a **whitepaper** comparing various types of SAR-based methods for quantifying damage in Lebanon. And the United Nations Satellite Center (UNOSAT) has a **large catalogue** of many CDAs that are based on manual observation of VHR¹⁶ optical satellite imagery.¹⁷ These analyses can not only inform civilian protection efforts in near-real-time but also serve as foundational knowledge on which short- and long-term recovery efforts are based.

There exist several high-quality training options and resources, should those less familiar with EO approaches be interested in learning how to use these methods appropriately. For example, NASA's **ARSET program** routinely posts public training sessions online, available to anyone, such as a course on how to use **InSAR for**

¹⁶ For the purposes of this report, we refer to very-high resolution (VHR) imagery as that which has a spatial resolution of 1m Ground Sample Distance (GSD) or better.

¹⁷ Manual observation of VHR optical satellite imagery is carried out by expert analysts at UNOSAT, who analyze multiple satellite images captured at various time steps throughout a given conflict to assess and update the damage status of individual buildings. A vector database contains individual points which each represent a building, and UNOSAT publishes a .gdb file with these updated damage statuses. The .gdb file is public and available to anyone.

monitoring urban damage in conflict-affected areas. An open-source training manual for Google Earth Engine (GEE) exists as the EEFA book, formally “Cloud-Based Remote Sensing with Google Earth Engine: Fundamentals and Applications,”¹⁸ which walks readers through dozens of applied examples with JavaScript code. For those who want to build more foundational knowledge of automated methods for CDA before diving into technical techniques, ETH Zurich published a report entitled “An Interdisciplinary Approach to Conflict-Related Building Damage: Building Bridges Between Remote Sensing, Machine Learning, and the Social Sciences.”¹⁹ And, NASA Lifelines offers a **building damage assessment data studio package**, which offers workflows, tools, datasets, and more. It is a living repository, as updates are made iteratively based on contributions from the Lifelines community of experts.

What are the ethics and risk considerations of introducing the use of satellite data?

There are myriad risks associated with using EO imagery for CDA — and in armed conflict contexts in general — but we will highlight the most salient and pressing issues concerning humanitarianism here. Satellite data can be misused by bad actors, such as the usage of EO imagery for targeting purposes (e.g., targeting military infrastructure that has newly arrived in a region or targeting civilian infrastructure that is vulnerable or has not yet been attacked, or if attacked, not yet completely destroyed). Dual use satellite constellations²⁰ are currently unavoidable, as a humanitarian-only satellite constellation does not yet exist — though efforts, for example by **Common Space**, are underway to launch such a constellation.

There are also myriad privacy and surveillance concerns with respect to imaging conflict-affected areas.²¹ Civilians caught up in conflict do not necessarily consent to being imaged from space, although commercial satellite imagery companies highly prioritize armed conflict areas of interest (AOIs) in their tasking collection plans. Moreover, tasking priorities are often commercially or politically driven, meaning some conflict zones receive far more coverage than others. Additionally, within conflict zones, urban areas tend to be better covered than rural or remote conflict zones, potentially creating a sampling bias, skewing the overall damage picture.

There are also methodological concerns that make satellite imagery a risky data source if used in an inappropriate manner by those who lack sufficient training and experience. Humanitarians should be mindful of the

¹⁸ Cardille JA, Clinton N, Crowley MA, Saah D, editors. Cloud-based remote sensing with Google Earth Engine: Fundamentals and Applications. 2023. Available from: <https://www.eefabook.org/>

¹⁹ Pfeifle B. An Interdisciplinary Approach to Conflict-Related Building Damage: Building Bridges Between Remote Sensing, Machine Learning, and the Social Sciences. Zürich: Center for Security Studies (CSS), ETH Zürich; 2025 Oct. doi:10.3929/ethz-c-000784694.

²⁰ The term “dual use” refers to satellites that are used for both commercial and military/intelligence purposes.

²¹ Humanitarians routinely annotate VHR imagery for CDA tasks. If there are case-specific privacy/surveillance concerns with respect to the imagery, humanitarians who provide CDA results could publish only the annotation data layers, as opposed to the underlying images on which the annotations are based, thereby ameliorating, at least in part, privacy/surveillance concerns. Humanitarians should communicate directly with conflict-affected communities, where possible, to discuss and validate their concerns and mutually come to an agreement on plans to mitigate such concerns.

of the risk of inaccurate interpretation by non-experts who lack sufficient understanding of the intended usage and limitations of different types of EO modalities. Each choice in the analysis cycle has the potential to alter results of the analysis and the conclusions drawn therefrom. These choices include not only selecting the appropriate sensor modality (e.g., SAR vs. optical) but also choices made during data pre-processing. Analytical misinterpretations are also common, especially given the increasing ease of access to EO data and tools and the complex and technical nature of both EO imagery and armed conflict. Inaccurate maps resulting from poor satellite imagery analysis could have real-world consequences for those who receive protection from IGOs/NGOs, humanitarian aid, or development assistance. Therefore, humanitarians should seek to minimize risk of inaccurate results by, in cases where internal capacity is insufficient, consulting experts who are trained in the proper use of EO data in armed conflict contexts and by not relying on a single EO modality or analytical method. Consulting arms and munitions experts, lawyers specialized in the application of IHL, as well as analysts with specialized knowledge of specific armed forces may also reduce errors, even if those analysts are not specifically trained in EO analysis. Interdisciplinarity reduces the likelihood of errors easily caught by those with thematic expertise.

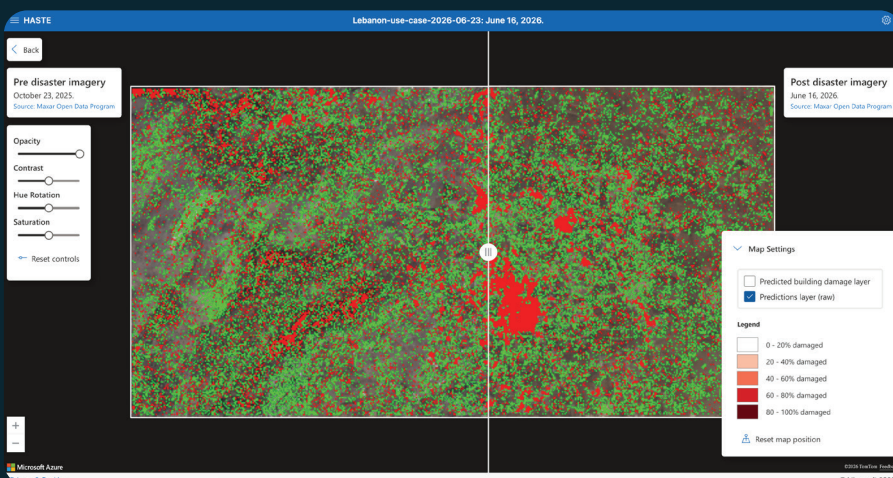
Humanitarians should also be wary of relying too much on Artificial Intelligence/Machine Learning (AI/ML), which could produce false positives (FPs) or false negatives (FNs), and which also at present are not able to replace human expert analysts, given the complexity of the subject matter. Although ML models are good at repetitive tasks that a satellite imagery analyst might be assigned, such as counting aircraft (i.e., feature extraction) over a long time period at a specific airfield, ML models cannot at present easily distinguish between different types of specialized military equipment, nor can they make a judgment call about what is observed in EO imagery where many previous examples do not exist (e.g., **suspected piles of bodies that Yale HRL analysts found in El Fasher, Sudan**). Moreover, ML models for building damage assessment are oftentimes not specifically developed with armed conflict contexts in mind; some models may be trained with data from a few conflict contexts, but it is common for damage assessment models to include training data primarily from natural disaster contexts, with armed conflict contexts included secondarily or not at all.

ML models will continue to improve over time and will assist analysts in working more quickly and efficiently, but at present, humans are still very much needed to make complex determinations using data that can be difficult for machines to decipher. Humanitarians can use off-the-shelf ML models to serve as a baseline for initial results which should then be refined, correcting for FPs and FNs. For more details on how GeoAI (geospatial artificial intelligence) can aid humanitarian decision-makers, we refer you to the March 2026 NASA Lifelines **GeoAI for Humanitarian Action report**.

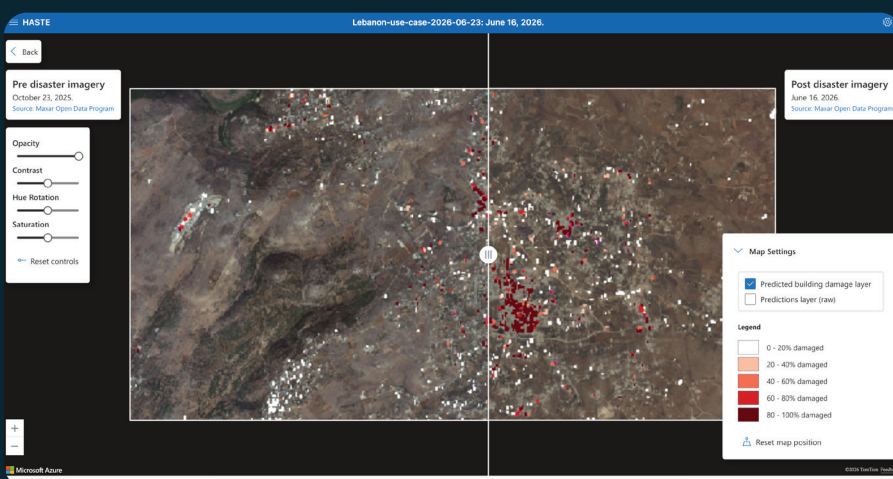
HASTE: a user-friendly tool to label damaged buildings and generate rapid ML-based CDA results

Microsoft AI for Good Lab's HASTE, which stands for High-speed Assessment and Satellite Tracking for Emergencies, is a tool that allows humanitarians to bring in their own pre- and post-event imagery, create a bespoke manually annotated dataset consisting of damaged and non-damaged buildings, train an ML model to detect levels of damage based on those labels, and generate an output, typically a web map showing the model's results. This tool can be adopted by humanitarians to conduct rapid CDA in conflict scenarios where results are needed quickly and absolute accuracy isn't prioritized. If more highly accurate results are needed, analysts can export the results, bring a geojson file into a GIS, and manually review the model results, fixing potential errors of commission, in which the model finds damage where there is none (i.e., false positive), or errors of omission, in which the model does not predict damage in a building that is in actuality damaged

(i.e., false negative). The model has already been **used extensively** in natural disaster contexts, such as the Hawaii wildfires of 2023, Myanmar earthquake of 2025, and Jamaica hurricane of 2025, and there exists an opportunity for humanitarians to employ the tool for conflict-related disasters, as well.



Pixel-level damage predictions using Microsoft AI for Good Lab's HASTE tool on VHR optical satellite imagery



Pixel-level damage predictions mapped to the building level using Microsoft AI for Good Lab's HASTE tool on VHR optical satellite imagery

Image Credit: 2026 © Vantor



Other risks for humanitarians to consider include:

Resolution constraints

Satellite constellations have varying temporal resolutions (i.e., revisit cadence), so events of interest may be missed by not imaging at the right time, resulting in a lack of coverage. Varying spectral resolutions mean that ground indicators can be lost or unobservable if the sensor does not have the sufficient bands necessary to create false color infrared images or NDVI rasters, for example. And spatial resolution is always a concern, as the EO products with the highest spatial resolution tend to be the most expensive.

EO imagery in legal accountability contexts

Evidentiary standards for how satellite-derived CDAs are deemed admissible or credible in international legal proceedings (e.g., ICC, ICJ, tribunals) remain unclear or untested. Domestic

jurisdictions each have their own set of rules for evidence admissibility and evidentiary weight; these rules are not standardized and vary from country to country. Some jurisdictions do not address in sufficient detail, or at all, open source information, which includes satellite imagery, per the Berkeley Protocol on Digital Open Source Investigations.²²

Cost barrier to entry

The high financial cost of VHR imagery access results in a selection bias with respect to who can access the data. Humanitarian organizations lacking the financial resources to access commercial imagery should be supported with financial resources or in-kind contributions (e.g., one-off imagery access agreements). Many commercial EO companies offer open access to a portion of their imagery in natural disaster contexts. However, given political sensitivity concerns around armed conflict, EO companies generally do not make imagery of conflict-affected areas available via open data programs. Or in cases in which they do, imagery is not made evenly available across conflict contexts, which can create situational blindness or biases in the availability of data.

Lack of availability of ground truth data

There can be an over-reliance on satellite imagery-based products, as opposed to ground-truth data, which may be difficult or impossible to collect in conflict-affected areas.²³ For example, UNOSAT damage assessments, while useful in humanitarian contexts requiring CDA results delivered quickly, have both FPs and FNs, and these errors propagate throughout the UN system, humanitarian organizations, academic research, governments, and others. UNOSAT damage assessments are not “ground truth” data but are oftentimes referred to as such in various academic publications and NGO reports. UNOSAT damage assessments can be treated as reference data, but limitations should be enumerated and understood by analysts and end users.²⁴ UNOSAT notes in their products that the data presented has not yet been ground validated. Humanitarians should use EO-only based products with a clear-eyed understanding of not only the limitations of EO data but of rapid damage mapping practices in general, which oftentimes prioritize speed over accuracy for short-term humanitarian use cases.

Disinformation concerns

Deepfake satellite imagery has appeared on social media and can be amplified by social media users or even journalists who unwittingly propagate manipulated imagery. It can be difficult to distinguish real satellite imagery from AI-generated imagery; this requires sufficient training and experience, as well as access to archival imagery as a known image against which to compare unknown (that is, potentially manipulated) imagery.

Analysis replicability

VHR imagery can be difficult to access, which can preclude reproducing results by others who do not have access. Commercial licensing agreements prevent the re-distribution of imagery.

22 OHCHR, UC Berkeley Human Rights Center. Berkeley Protocol on Digital Open Source Investigations: A Practical Guide on the Effective Use of Digital Open Source Information in Investigating Violations of International Criminal, Human Rights and Humanitarian Law. United Nations; 2022. doi:10.18356/9789210053433.

23 It is more common to see ground-truth damage data following natural disasters than it is following anthropogenic disasters such as armed conflict.

24 See Appendix A for a sample of errors observed in UNOSAT’s damage assessment products for the Gaza Strip.

Suboptimal accuracy in CDAs

Lack of local contextual knowledge by satellite imagery analysts can result in inaccurate analytical products. For example, unfamiliarity with building materials or architecture types used in a certain region may contribute to analyst misinterpretation. Moreover, biases in training datasets used for ML-based automated damage detection can reduce accuracy in specific geographic or architectural contexts; ML models may not be generalizable across conflict contexts (e.g., model may perform well for CDA tasks in one conflict context but poorly in another).

Humanitarians beholden to commercial EO companies

There is the unavoidable risk that commercial providers may discontinue services, delete archives, or restrict access to imagery. This hampers journalists reporting on conflict, humanitarian efforts in real time, and long-term justice and accountability efforts. There is also the risk of missing damage or having an incomplete picture of damage across an entire conflict zone if commercial satellite imagery companies “voluntarily” (i.e., pressured by governments) restrict access to VHR imagery.

Risks of open data

Humanitarians should be cognizant of the ever-present and unavoidable tension between open data principles (maximizing accountability and democratizing accessibility) and restricted access (minimizing operational risk to personnel and assets).

Do No Harm principle

Humanitarians should not publish any EO-derived products (or any data, in general) if publication could result in harm to civilian populations. A risk evaluation should be conducted on a case-by-case basis and include details pertaining to the specific situation. For example, EO-derived damage maps containing detailed information on the physical condition and location of civilian infrastructure during periods of active conflict could unintentionally be used for targeting purposes by armed conflict actors. Humanitarian decision-makers will have to weigh such risks according to organizational protocols, risk tolerances, the potential for misuse, and a number of other factors.

“Shutter control” over conflict-affected areas

In the context of Earth observation, the term “shutter control” refers to efforts by governments, EO companies, or both to restrict which areas are imaged or what imagery is released to the public. Humanitarians are vulnerable to shutter control and may lack access to mission-critical imagery necessary to protect civilian life. For example, in the 2026 U.S.-Iran conflict, the U.S. government pressured ²⁵ Planet Labs to “voluntarily” ²⁶ restrict commercial customers’ access to a very large area covering not only Iran and the countries involved in the conflict but also practically the entire region and beyond, including some countries or parts of countries completely outside the conflict-affected area, such as Azerbaijan and Turkmenistan. These strict policies limited crucial access to not only humanitarian and intergovernmental organizations like the UN and Amnesty International but also to journalists seeking to report on the conflict and provide a level of transparency and accountability that only civil society can provide. The stated reason given for the restriction was force protection (i.e., protecting U.S. and allied forces in the region from being targeted with the imagery), but many areas covered under the restriction had no active, overt U.S. presence on the ground.

Moreover, the utility for EO imagery for targeting purposes diminishes with time; a four-day or two-week holdback, as was initially implemented by Planet, would have been acceptable to many humanitarians, but withholding imagery indefinitely, which is the policy that Planet ultimately landed on, hampers humanitarians from doing their jobs and runs contrary to **humanitarian principles**. Those lucky enough to have the financial resources to access non-U.S.-based companies' imagery (e.g., Airbus Defence and Space)²⁷ were able to circumvent these restrictions. However, many humanitarians simply do not have the resources to purchase such imagery and were left blinded. Depending on the use case, open access imagery sources, such as ESA's Copernicus program, may be used as a stopgap during periods of commercial imagery black-outs, but such open access sensors lack the spatial resolution required for many EO analysis tasks that humanitarians undertake. Future efforts, such as the independent humanitarian satellite mission currently in development at Common Space, could alleviate some of these humanitarians' shutter control concerns.

25 Karra K. Where Did the Middle East Go? Satellite Imaging in the Fog of War. Bloomberg. 2026 April 23 [cited 2026 May 15]. Available from: <https://www.bloomberg.com/graphics/2026-satellite-imagery-restrictions-iran/>

26 Bloomberg News reported that "On April 5, Planet announced to customers that the US government had requested that all satellite imagery providers 'voluntarily implement an indefinite withhold' of imagery retroactive to March 9 across a broad swath of the Middle East, including Iran, Iraq, Israel, Lebanon and the Persian Gulf States. The company stopped releasing war imagery to its library and said it was moving to a 'managed access model,' evaluating requests on a case-by-case basis."

27 Toler A, Lum D, Koettl C, Reneau N, Byrd A, Caldwell Z. What satellite images reveal about Iran's attacks on U.S. bases. The New York Times. 2026 May 08 [cited 2026 May 15]. Available from: <https://www.nytimes.com/video/world/middleeast/100000010868609/iran-war-us-military-base-damage.html>



What data could support these decisions? What are 'must have' requirements for the data for these use cases? Is commercial imagery or tasking needed? What are our alternatives?

Must-haves for humanitarian CDA include open access EO products (e.g., Copernicus Sentinel program; Landsat; FIRMS); GIS tools (e.g., QGIS); Jupyter Notebooks (either cloud-hosted such as Colab or local Python implementations); and cloud-based open geospatial processing platforms (e.g., Google Earth Engine). Commercial data and tools are also available but have a financial barrier to entry; these include commercial GIS software (e.g., ArcGIS Pro, Felt) and commercial VHR optical imagery (e.g., Airbus, Vantor formerly Maxar, Planet, Blacksky, Satellogic).

Nice-to-haves include commercial VHR SAR imagery (e.g., ICEYE, Capella Space, Umbra); VHR thermal data (e.g., EarthDaily, constellr, Aistech Space, Ororatech, SatVu); hyperspectral imagery (e.g., Kuva Space, Wyvern, OSK, Pixxel); cloud storage buckets (e.g., AWS S3; Google Cloud Storage; Azure Blob Storage); and cloud compute capacity (e.g., AWS EC2; Google Cloud Platform; Microsoft Azure). Google Colab Pro also offers very affordable and attractive options for Python-based processing of EO data in a cloud-hosted notebook, including access to high RAM GPUs.

Using texture features in post-event VHR SAR imagery for CDA

Similar to HASTE in that it has historically been employed over natural disaster contexts, the VHR SAR GLCM (Gray-Level Co-Occurrence Matrix) method developed by academic researchers offers an opportunity for humanitarians to employ new, cutting-edge methods for CDA purposes. Using open-source software, the authors of [the paper](#) extracted texture features from post-event VHR SAR imagery following earthquakes and trained a machine learning model to detect damage on a per-building basis. The results were promising and can be employed in a conflict context. If humanitarians can get access to VHR SAR imagery from a commercial provider such as Capella Space, Umbra, ICEYE, or DLR/Airbus, they can relatively simply follow the same methods that the paper authors used by using freely available software, such as ESA SNAP and Google Colab.



Building-level damage results based on analysis of VHR SAR imagery using the GLCM method published by Macchiarulo V, Giardina G, Milillo P, Aktas Y, and Whitworth MRZ (2024). Red denotes True Positives; green denotes True Negatives; blue denotes False Positives; and purple denotes False Negatives.



There is a whole host of ancillary data ²⁸ that may be useful to humanitarians conducting EO-based analyses. For example, georeferenced conflict events (e.g., ACLED, UCDP); building footprints (e.g., OSM/HOTOSM, Overture, VIDA, Microsoft AI building footprints, GlobalBuildingAtlas); verified OSINT-derived user-generated content (UGC); location databases (e.g., OSM, Wikimapia); street-level imagery (e.g., Google StreetView, Mapillary); and population and population movement databases (e.g., WorldPop, GHSL, GRID3) may assist in providing additional insights that augment EO-based analyses.

When determining whether tasked or archive data ²⁹ from VHR commercial providers is more appropriate, humanitarians should consider costs, recency requirements, and imagery/orbital parameters required.

²⁸ For the purposes of this case study, ancillary data includes data that is tangentially related to CDA or that which can assist in the analysis process or be helpful to put the analysis in context. For example, building footprints may be useful data to help the analyst understand how many buildings existed in an area pre-conflict. If accurate and up-to-date, these pre-conflict building footprints can be useful in that they can be compared against CDA results to gain a more holistic understanding of how many buildings were damaged or destroyed due to the conflict.

²⁹ “Tasked data” is imagery that is ordered from a commercial EO provider that does not yet exist in the company’s archive. “Archive data” is imagery that already exists in a commercial EO provider’s archive. The former is forward-looking (i.e., image acquisition has not yet occurred), while the latter is backward-looking (i.e., image acquisition has already occurred).

Oftentimes, for humanitarian purposes, imagery acquired by other commercial customers, so long as it is not embargoed, will be fit for purpose. In rare instances, humanitarians may need to task imagery either because AOIs have not been recently imaged by others or the available imagery in the archives may not be fit for purpose. Some commercial providers will task their satellites to support humanitarian work on a case-by-case basis. In sum, access to historical commercial EO archives — as long as data is recent and surfaceable, i.e., not artificially restricted by the companies — is, generally speaking, sufficient. Tasking is not a must-have, although it is a nice-to-have for areas that are missed, deprioritized, or whose image rights have been sold to a third-party, making the imagery non-surfaceable to humanitarian users.

Finally, damage mapping informs other work under other humanitarian action priorities, such as food security and public health. We refer you to the concurrently published case studies on these two topics — specifically, food security and disease risk mapping — as well as the [Lifelines data studio packages](#).

What's our Approach?



This section helps decision-makers design an approach to incorporating EO data into their organization's specific context and constraints. The sections below cover organizational capacity, required resources, and fit with existing solutions. Before working through these questions, organizations may benefit from conducting a structured assessment of their current programs, capabilities, and infrastructure. This kind of assessment can clarify what spatial data is already being collected or used, as well as any organizational gaps in expertise or guidance.

Do any existing solutions meet our requirements? If not, what gaps exist?

There are many existing solutions for EO-based CDA, and while it is beyond the scope of this case study to enumerate all available methods and their advantages and drawbacks, we will highlight a few notable tools and methods that humanitarians can presently use, pulling from standout academic research. There are various “flavors” of CDA: take for example the automated vs. manual decision. Oftentimes, manual analysis of VHR optical imagery may suit a humanitarian CDA use case, especially if the AOI is confined to a relatively small area and the study period is short. If larger AOIs (e.g., wall-to-wall country coverage) are needed, automated methods should be considered.

The automated methods that do exist at present are oftentimes somewhat inaccessible to humanitarians, given the high technical and knowledge requirements to implement them. Academics who pioneered these methods do not necessarily have the capacity to support the many NGOs that may benefit from using these methods, and staff at these NGOs do not necessarily have sufficient technical understanding of the EO analysis methods and tools developed in academia.

Balancing speed and accuracy is another tradeoff that should be considered: is it important to have as accurate as possible data, getting as close to ground-truth that one can get using EO methods? And can these results be delivered in several months, as opposed to hours or a few days? Or is some amount of error acceptable in our results, as long as we produce them rapidly? Humanitarian decision-makers should take these and other factors into account before launching into EO-based CDA.

Other considerations include but are not limited to:

Optical imagery vs. SAR

- Are there enough cloud-free images of my AOI? If not, perhaps SAR imagery may be substituted.
- What kind of damage can I see with optical vs. SAR? Am I concerned with damage to sides or facades of buildings? Or do I only care about rooftop damage or complete destruction of buildings?
- Do I care about trying to determine the munition used and the range and azimuth (i.e., distance and direction, respectively) of fire so I can investigate who would have likely caused this damage?

VHR vs. moderate spatial resolution

- How large is the damage we are trying to detect? For example, are we concerned with fine scale damage to buildings that may have been damaged due to indirect fire, such as artillery or mortars? Or can we accept coarser spatial resolution to detect only fully razed buildings, and will that meet our case requirements?

Tasked vs. archive

- Is there VHR imagery available in commercial archives that already exists that I can repurpose for humanitarian use? Or do I need to task bespoke imagery according to specific parameters (e.g., off-nadir angle, sensor azimuth angle, time of day)?

Commercial vs. open source imagery

- Data access tends to be the most common issue for humanitarians with respect to commercial EO companies. There are of course cost considerations and challenges, but recent holdbacks of imagery by commercial companies have blinded humanitarians in many cases or made data validation more difficult.³⁰ Humanitarians may be relegated to relying solely on open access imagery in these cases and may not be able to produce building-level CDA with such data, especially if high confidence on a building-to-building damage status basis is needed. However, open source data can still be used for CDA to map general areas of damage and to corroborate damage derived from other sources (e.g., UGC video/photo, news reports).

Raw data vs. derived data

- Before beginning a new EO analysis from scratch, analysts should consider whether existing solutions meet operational needs. For example, derived data that has already been processed and published may be sufficient for end users, negating the need to conduct original analysis, thereby saving time and resources. However, for sensitive situations where data integrity, provenance, and accuracy are prioritized highly, such as in legal contexts, analysts should consider conducting their own analyses using raw data processed with methods that can be replicated.

³⁰ In the current U.S.-Iran war context, researchers are running into the issue in which damage data derived from moderate spatial resolution EO imagery is available, but validating and assigning levels of confidence to the results is made more difficult for researchers because of the lack of access to recent VHR imagery due to the imposition of holdbacks by the commercial providers.

Sentinel-1 InSAR Coherence Change Detection (CCD)

Researchers at Oregon State University have pioneered a way to use open source Sentinel-1 InSAR data to generate CDA datasets that represent areas of likely damage, based on a marked decrease in coherence values in areas that were stably coherent for a long temporal baseline pre-conflict. This method³¹ has been employed over Ukraine, Gaza, Iran, and Lebanon, and damage polygon datasets are accessible to humanitarians on a per-request basis.³²

³¹ Scher C, Van Den Hoek J. Nationwide conflict damage mapping with interferometric synthetic aperture radar: A study of the 2022 Russia–Ukraine conflict. *Sci Remote Sens.* 2025;11:100217. doi:10.1016/j.srs.2025.100217.

³² Humanitarians may contact data@conflict-ecology.org for access.



Labeling Conflict-Related Building Damage

When labeling conflict-related damage to structures, there are a few different reasons why you would want to label damage differently in various use case scenarios. Perhaps you want to train an ML model or use an off-the-shelf model for your conflict context; what kind of damage labeling schema does each model use? What if you're doing manual-only CDA? How should you ideally label damage? Should you only rely on building footprints and classify damage to each footprint? What about craters and areas of damage that don't necessarily correspond to pre-conflict building footprint datasets? Because there are so many ways to label damage (e.g., per-building basis, per-detonated area basis, per-crater basis) and different organizations have different output requirements, humanitarians should consider how to best label damage in EO imagery for their use case, based on a number of criteria, including:

- What is the required output? (e.g., Number of buildings damaged? Number of craters visible? Total area of agricultural land damaged?)
- Is the approach solely manual, is it an ML-only approach, or a combination of manual and automated? If ML is involved, which labeling schema is the most appropriate to train your model?
- What kind of damage and level of damage am I concerned with for my use case? Do I only want to highlight completely destroyed or razed buildings, or do I want to include portions of buildings that may be partially or moderately damaged?

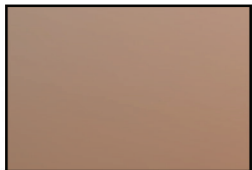
There are many ways to label conflict-related building damage. We have identified nine labeling schemas that may be useful for humanitarian conflict damage assessment (CDA), although additional approaches certainly exist. No single schema is appropriate for every use case. The optimal approach depends on factors such as the available Earth observation data (including spatial resolution and remote sensing modality), whether the assessment will be conducted manually or using machine learning, the required level of detail,

the geographic extent of the analysis, and the urgency of the response. In most humanitarian applications, the primary objective is to determine the damage status of an entire building rather than individual structural elements. For example, if one portion of a building is destroyed while another is only lightly damaged, the building would typically be classified according to the most severe observed damage (i.e., destroyed). Detailed structural engineering assessments of individual building components fall outside the scope of this guide. While many machine learning studies use complete building footprints (Labeling Schema S3), this approach may not always be the most appropriate for humanitarian applications. Before beginning a CDA workflow, humanitarians should carefully consider these tradeoffs and, where possible, consult experts with experience in the relevant Earth observation data and analytical methods. **Table 1** below summarizes each labeling schema, and Appendix B provides additional guidance on selecting an appropriate schema based on the available imagery and intended application.

To Consider...

Spatial Resolution

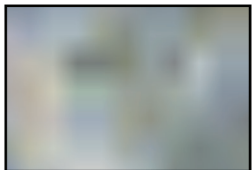
The level of detail that can be observed is fundamentally limited by the spatial resolution of the imagery. While coarse- and moderate-resolution sensors (e.g., VIIRS, MODIS, Landsat, and Sentinel-2) are well suited for identifying broad patterns of damage or areas requiring further investigation, they generally cannot resolve individual buildings or small damage features. Very high-resolution (VHR) imagery (e.g., Planet SkySat, VANTOR, or other commercial imagery) is often required to reliably identify damaged structures, craters, or debris and to support detailed manual or machine learning-based conflict damage assessments.



VIIRS
SPATIAL RESOLUTION
Approx. 1km (926m)
ACQUISITION DATE
2025-10-11



MODIS
SPATIAL RESOLUTION
500M
ACQUISITION DATE
2025-10-11



LANDSAT 9
SPATIAL RESOLUTION
30M
ACQUISITION DATE
2025-10-08



VANTOR WV03
SPATIAL RESOLUTION
0.40M
ACQUISITION DATE
2025-10-11



SENTINEL-2
SPATIAL RESOLUTION
10M
ACQUISITION DATE
2025-10-11



PLANETSCOPE
SPATIAL RESOLUTION
3.6M
ACQUISITION DATE
2025-10-11



PLANET SKYSAT
SPATIAL RESOLUTION
0.83M
ACQUISITION DATE
2025-10-14

Table 1: Building Damage Labeling Schema

ID	Schema Name	Geometry	Description	Use case / Notes
S1	Per-Damage Polygons	Polygon or Multipolygon	Draw a separate polygon around each individual area of visible damage on a single building (e.g., each hole, collapse zone, or scorch mark).	Highest spatial precision and accuracy. Best for VHR optical imagery where individual damage features are resolvable.
S2	Grouped-Damage Polygons	Polygon	Draw one polygon (a convex hull) to represent all damage on a building (e.g., one polygon covering a damaged wing or façade section).	Balances granularity with labeling efficiency. Suitable where damage clusters are distinct.
S3	Whole-Footprint Polygon	Polygon	Draw a single polygon encompassing the entire building footprint, precisely shaped according to the actual building footprint; assign one damage label to the whole footprint.	Baseline approach consistent with many existing benchmarking damage assessment datasets.
S4	Axis-Aligned Bounding Boxes	Polygon or MultiPolygon	Place axis-aligned (upright, aligned in Cartesian space) bounding boxes around each area of damage rather than tracing precise polygon boundaries.	Faster annotation. Useful for rapid labeling campaigns or modalities with lower spatial resolution.
S5	Oriented Bounding Boxes	Polygon or MultiPolygon	Place rotated (non-axis-aligned) bounding boxes around each damage area, oriented to minimize enclosed non-damaged area. Defined by center, width, height, and rotation angle.	Tighter fit than axis-aligned boxes for elongated or angled damage features (e.g., linear collapse along a roofline). Moderate annotation effort.

S6	Point Annotations	Point	Place a single point at the centroid of each visible damage feature on a building. Similar to UNOSAT method or StEER method (used, e.g., following the 2021 Haiti earthquake) ³³	Lower annotation effort. May introduce accuracy errors because placing points at exact building centroids is difficult with satellite imagery, given off-nadir angles and positional accuracy issues.
S7	Grouped Buildings Polygon	Polygon	Place a polygon around a group of damaged buildings that are geographically located close to one another. Undamaged buildings can be similarly labeled in this way.	Could be a faster way of generating large amounts of labels in a crisis rapid mapping context. Can be used in crowdsourced contexts, where volunteers selected “damaged” or “not damaged” for a group of buildings located within a bounding box. ³⁴
S8	Per-Damage Brush Painting	Polygon	Use a crowd-sourced damage mapping platform where volunteers can paint with a brush tool areas of damage they see in VHR optical imagery.	Not yet a widely used schema. Could be used to generate a training dataset of suspected damaged areas, based on crowdsourced labels.
S9	Per-Detonated Areas Circle Annotations	Polygon	Use with moderate-resolution optical imagery (e.g., Sentinel-2) to manually annotate areas of detonation using circle polygons in a GIS.	This method has successfully been implemented for the Lebanon and Gaza contexts. Could be used to train a ML model to detect detonated areas.

For more detailed information on which remote sensing modalities work best with each of the listed labeling schema, please refer to **Appendix B**.

³³ Kijewski-Correa, T., B. Alhawamdeh, C. Arteta, et al. "StEER: M7.2 Nippes, Haiti Earthquake Preliminary Virtual Reconnaissance Report (PVRR)." 2024. StEER - 14 August 2021, M7.2 Nippes Earthquake, Haiti. Available from: <https://doi.org/10.17603/h7vg-5691>

³⁴ See, for example, WISEN WATCH by CEOBS on Zooniverse: <https://www.zooniverse.org/projects/ceobs/wisen-watch>

What types of skills and expertise are needed? Based on our internal capacity and bandwidth, can our teams take on this work? What kinds of partnerships are needed?

Original EO-based CDA done responsibly requires a combination of education, specialized training, and experience. The technical barrier to entry can be high but not insurmountable: users should be fluent in GIS and associated software, as well as basic remote sensing concepts. It is also helpful to be intimately familiar with advanced remote sensing processing and machine learning (ML) methods. Over time, we will see the democratization and commercialization of low-code or no-code automated environments, but those options are currently few.

The skill sets necessary to do manual analysis/visual interpretation of EO imagery are quite different from the skill sets needed to do remote sensing science. It's important to keep this in mind when forming a team: interdisciplinarity is the best approach. Ideally, you would have multiple subject matter experts from a variety of backgrounds working together on the same analytical task, either simultaneously or in sequence, but constraints in the humanitarian field may preclude this.

When the necessary skill sets are lacking internally, humanitarian organizations may need to partner with academics to conduct automated EO analysis. While currently quite common, this is akin to “giving a person a fish, not the fishing rod” and may result in necessitating long-term partnerships to conduct iterative analyses in the future, including the potential for sustaining funding to continue partnered work — funding which may be hard to come by for humanitarians wishing to fund work inside academia in the current funding environment. However, opportunities for capacity building exist: the idea of an academic-humanitarian partnership offers a valuable opportunity for skill building and knowledge exchange in both directions, which can help with sustainability.

What data, tools, standards and techniques are already adopted and trusted by humanitarians? What is my team familiar with? How can we know we've covered everything?

There are services that provide derived data products for CDA. “Derived data products” refers to maps or data that are based on analysis or interpretation of raw satellite imagery. This means that humanitarians don't have to do any analysis on EO pixels at all; they can merely download the derived data and rely on the data producers to vouch for the data's accuracy and comprehensiveness. The problem with this approach is that derived data may not always be accurate or comprehensive, or the AOIs are too small and don't include the actual AOIs humanitarians prioritize for a given conflict. Humanitarians should seek to deeply understand how each derived data product is made and use small AOIs as test cases to see if the data on offer will be suitable for their needs.

Examples of derived data products that may be of interest to humanitarians include:

CEMS (Copernicus Emergency Management Service)

- CEMS currently only supports natural disaster response, not conflict-related disasters.

NASA ARIA (Advanced Rapid Imaging and Analysis) Damage Proxy Maps

- Damage Proxy Map (DPM) products from **NASA ARIA** are satellite radar-based damage maps that may be available on a case-by-case basis following natural disasters, most commonly earthquakes, volcanic eruptions, landslides, and other sources of surface deformation. ARIA does not currently support conflict damage mapping.

UNOSAT (United Nations Satellite Centre)

- It is important for humanitarians to note that **UNOSAT's derived data products** are not considered "ground truth" data and should not be treated as such. UNOSAT notes this caveat in their products, using the disclaimer: "This is a preliminary analysis and has not yet been validated in the field." However, many academic studies cite UNOSAT as "ground truth data," when in reality, it should be treated as "reference data." Ground truth data cannot be collected via satellite-based remote sensing alone.
- As mentioned, UNOSAT's products are intended to be used in humanitarian settings as rapid response damage data, not as ground truth data that researchers cite in academic papers, although UNOSAT data may be treated as "reference data" in academic studies. The intent behind creating the UNOSAT datasets is speed (i.e., to support humanitarians in rapid response settings) over 100% accuracy (i.e., for academic research). UNOSAT data can be used in academic research, but it should be placed in context and used with other reference datasets, where available. It is important for those working with UNOSAT data to note its caveats and understand its limitations, a sample of which are enumerated in Appendix A.



UNOSAT Building Damage centroid points in Gaza. In the righthand photo, dark red points signify destroyed buildings, red signifies severely damaged buildings, pink signifies moderately damaged buildings, and yellow indicates buildings that were possibly damaged.

Other tools and data sources beyond EO imagery can assist humanitarians as they conduct EO-based analyses. These include:

- OSM for building footprints and HDX for conflict-related geospatial data
- GIS tools: QGIS and ArcGIS Pro, both of which are common among humanitarians.
- Google Earth Engine (GEE) and its data catalogue are good sources of moderate-resolution EO data; GEE scripts can be easily generated by working with an LLM (e.g., Anthropic Claude, Google Gemini).
- Copernicus Browser is an accessible way to view Copernicus EO imagery (e.g., Sentinel-1, Sentinel-2)

Earth Observation Foundation Models

Earth Observation Foundation Models (EOFMs) or Geospatial Foundation Models (GFM), which are models pre-trained on large amounts of EO data and designed to serve as a general purpose backbone for a wide range of geospatial tasks, are great examples of how academic research can be parlayed into effective humanitarian use cases (e.g., flood and wildfire/burn scar detection and extent mapping). However, EOFMs are oftentimes intended to be used with moderate-resolution EO imagery; building-level CDA requires the use of VHR imagery in many cases, so there may be a mismatch between tool/model availability and imagery access. Future EOFM development could focus on using multiple EO modalities at a variety of spatial resolutions, including VHR imagery, which tends to be the proper resolution for many humanitarian EO use cases. EOFM developers should consider the needs of key stakeholders, such as humanitarian organizations, before designing new models or iterating on existing ones; consultation between computer science and remote sensing technical experts on one side and humanitarian end users on the other could aid in effective design, production, and implementation of new EOFMs for humanitarian use cases, including conflict damage assessment.



Other aspects of CDA for humanitarians to consider beyond how to label damaged infrastructure include damage gradation scales — that is, severity level of damage observed. Damage gradation scales are not standardized, and many different scales for grading damage severity on a building level exist.³⁵ There is not one that emerges as the definitive scale, and humanitarians should choose the scale that best suits their needs. Perhaps different levels of damage are needed (e.g., differentiating between moderate and severe damage); in other cases, a binary classification (i.e., damaged or not damaged) is sufficient.

Other considerations for existing methods include:

- **Rapid Damage and Needs Assessments (RDNAs)** are public reports by the UN, EU, and World Bank that offer detailed information on damage in conflict contexts, focusing largely on the financial implications of conflict-related damage. While very thorough and indeed helpful, they aren't available comprehensively across all conflicts. Moreover, raw data for replicability studies are not available.
- **OGC (Open Geospatial Consortium)** sets the standards for geospatial data formats, making data interoperable across organizations and sectors.
- **SAR challenges:** Working with SAR data is technically challenging, and various ways of working with SAR data exist. These include backscatter intensity (using amplitude data only) analysis methods, InSAR CCD (interferometric SAR coherence change detection), and others. This can be confusing for

³⁵ Examples of damage gradation scales include EMS-98 (European Macroseismic Scale), UNOSAT's standardized gradation scale, and the IWG-SEM (International Working Group on Satellite-based Emergency Mapping) scale. It is beyond the scope of this case study to fully list all available damage gradation scales or assess their validity for humanitarian EO purposes, but humanitarian decision-makers should choose the appropriate scale for their application on a case-by-case basis.

humanitarians because the science is not yet settled but consistently improving, and results can vary by orders of magnitude³⁶ depending on analytical choices (e.g., one SAR processing method over another).

- **Multispectral change detection:** Humanitarians can use open access optical data (e.g., Sentinel-2) to find areas of concern using off-the-shelf methods (e.g., comparison of NDVI, false color infrared composites). This was done in Sudan by Yale HRL³⁷ to find burned then abandoned villages using both optical and thermal (i.e., FIRMS) data.
- **ML's high barrier to entry:** There exist automated methods (e.g., BRIGHT³⁸, xBD³⁹, SKAI⁴⁰, HASTE⁴¹) to conduct CDA, but some may be difficult for humanitarians to access due to their high technical requirements — although some are more accessible than others, offering lower technical barriers to entry, such as GUIs (graphical user interfaces) and well-documented public code repositories, such as on GitHub.
- **Crowdsourced damage digitization:** HOTOSM and Missing Maps have coordinated virtual asynchronous mapathons for hundreds of users to map damage using tools like MapSwipe. The Conflict and Environment Observatory (CEOBS) has recently launched a crowdsourced damage labeling initiative via [Zooniverse](#); future versions of the tool could allow humanitarian organizations to submit their AOIs to CEOBS for analysis by the crowd using moderate-resolution sensors, such as Sentinel-2.
- **Ground truth verification:** Academic researchers have used field data to validate EO-based analyses in natural disaster contexts.⁴² This is more difficult in armed conflict contexts, due to safety and physical access concerns, although recent work published by UNDP (United Nations Development Programme) is a rare example of EO-based CDA validated in the field during a period of active armed conflict.⁴³ UNDP's workflow incorporated both deep learning and manual visual interpretation methods that were then field-validated. While safety to personnel should always be top priority for humanitarian decision-makers during active conflict, if it can be safely carried out, field validation provides an additional layer of confidence in CDA results and allows for nuance and detection of damage that may not be visible via satellite-based remote sensing.
- **Drones for CDA:** While beyond the scope of this report, drone-based remote sensing may be useful to humanitarians in that drones can collect extremely high resolution imagery not currently available via commercial satellite-based remote sensing. Limitations with drone-based RS for CDA include security, legal, political, privacy, and other concerns associated with drone flight in conflict-affected areas.

36 HOTOSM. Lebanon — Informing Humanitarian Response: A Guide to Remote Sensing Analyses of Conflict Damage. ReliefWeb, September 2025. Available from: <https://reliefweb.int/report/lebanon/lebanon-informing-humanitarian-response-guide-remote-sensing-analyses-conflict-damage-september-2025>.

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38 Chen, H, Song, J, Dietrich, O, et al. BRIGHT: a globally distributed multimodal building damage assessment dataset with very-high-resolution for all-weather disaster response, Earth Syst. Sci. Data, 2025, 17, 6217–6253. doi:10.5194/essd-17-6217-2025.

39 Gupta R, Hosfelt R, Sajeev S, et al. xBD: A dataset for assessing building damage from satellite imagery. arXiv [Preprint]. 2019 Nov 21 [cited 2026 May 16]; arXiv:1911.09296. Available from: <https://arxiv.org/abs/1911.09296>.

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41 Microsoft AI for Good Lab. High-speed Assessment and Satellite Tracking for Emergencies (HASTE) [Software]. Microsoft AI for Good Lab; 2025 [cited 2026 May 16].

42 Cardiff University. EEFIT mission: September 2023 Morocco earthquake. UKRI; 2024 [cited 2026 May 16]. Available from: https://gtr.ukri.org/projects?ref=NE%2FY006356%2F1#

43 UNDP, UNDSS, Lebanese Armed Forces, and National Council for Scientific Research – Lebanon. Building-Level Damage Assessment: Beirut and Mount Lebanon. 08 June 2026. Available from: <https://www.undp.org/lebanon/publications/building-level-damage-assessment-beirut-and-mount-lebanon>

InSAR? Backscatter intensity? Dihedral corner reflectors? That's a lot of jargon. What gives?!

It's not as complicated as it might seem at first. Taking a step back: There are active and passive remote sensing (RS) modalities. Passive RS modalities, like optical satellite imagery, capture light reflected from the Earth's surface, much like a digital camera would — although with important distinctions. Active RS modalities, like synthetic aperture radar (SAR), send signals — in the case of SAR, radar — from the satellite in orbit down to the Earth and collect the returning signals as data, which get computed into an image. Because SAR satellites collect data from their own radar emissions, they don't rely on the sun's light to image the Earth; radar is also unaffected by clouds. For these reasons, SAR data can be captured day or night and in all-weather conditions.

A couple of different ways to use SAR data emerge as the most helpful for CDA: backscatter intensity-based analyses and InSAR-based analyses. Backscatter intensity-based methods use the intensity (or strength, referred to as amplitude) of the returning signal — or backscatter — to measure surface smoothness/roughness, geometry, and moisture. In the CDA context, urban areas appear particularly "bright" in SAR images because building corners readily reflect these wavelengths. A surface that was bright in one image and then dark in the next image, or vice versa, can indicate change. On the flip side of the coin, InSAR, or interferometric SAR, uses before and after images to measure surface deformation using the "phase" of the returning signal, or how many times the radar wave makes a complete cycle on its way back to the satellite. In the CDA context, both backscatter intensity⁴⁴ and InSAR⁴⁵ have been used to study conflict-related building damage. For a more in-depth explanation of the benefits and drawbacks of each SAR method, as well as a case study comparing the methods deployed for CDA in Lebanon, we refer you to the **2025 HOTOSM publication** entitled "Informing Humanitarian Response: A Guide to Remote Sensing Analyses of Conflict Damage."

44 Ballinger O. Open access battle damage detection via Pixel-Wise T-Test on Sentinel-1 imagery. Remote Sens Environ. 2025;331:115025. doi:10.1016/j.rse.2025.115025

45 Scher C, Van Den Hoek J. Nationwide conflict damage mapping with interferometric synthetic aperture radar: A study of the 2022 Russia-Ukraine conflict. Sci Remote Sens. 2025;11:100217. doi:10.1016/j.srs.2025.100217.



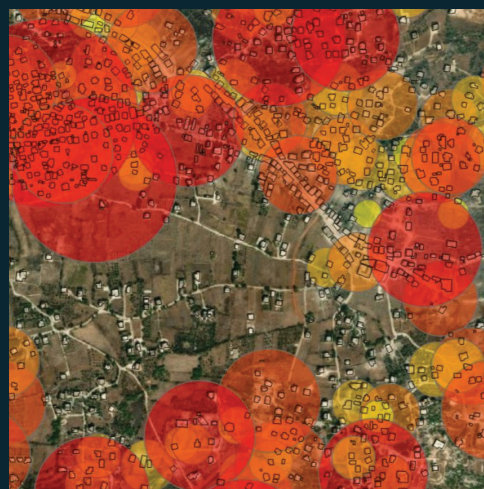
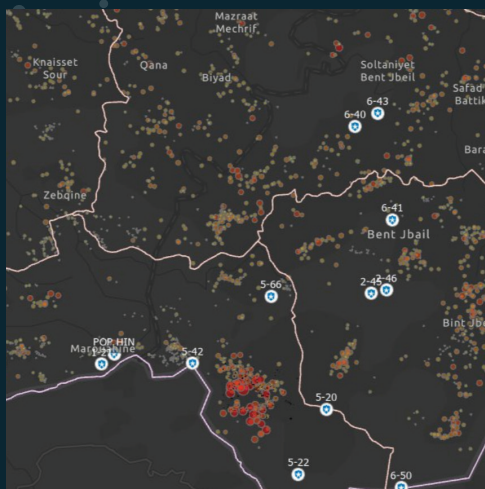
Which data is open and accessible for us and our partners? Who needs access to the data? Any sensitivities on who gets access or when?

Moderate spatial resolution imagery products, such as Copernicus program data (e.g., Sentinel-2) and Landsat program data, are freely available to anyone. There are also free tools available for processing and analysis, such as Google Earth Engine, Google Colab, and QGIS. A number of web mapping platforms, such

as Felt, Tableau, and Flourish, are available for a fee. Many of these companies offer free or discounted subscription models for organizations in the education or humanitarian sectors. Humanitarians are advised to reach out to each individual company to see what pricing options may be presently available, as these programs may change over time and vary from company to company.

Using moderate spatial resolution optical data to detect detonated areas in topographically diverse landscapes

EO analysts frequently rely upon open access moderate resolution imagery, given its global coverage and ease of access. Such imagery, such as from ESA's Sentinel-2 constellation, can be used to detect “detonated” areas — that is, areas that have been damaged due to the use of high explosives in armed conflict contexts. This method can be useful in identifying areas of suspected damage to civilian infrastructure, based on damage signatures consistent with the use of high explosives, whether delivered from the air or detonated from the ground, as was recently observed in southern Lebanon. By manually annotating Sentinel-2 imagery, creating circle polygon datasets of suspected detonated areas, analysts can quickly give humanitarian decision-makers insights into where the most extensive and severe damage may be occurring over a wide area. Given that this process of manual annotation may be time-consuming, automated methods may be employed to detect potentially detonated areas, as long as analysts then manually review the imagery to verify that damage actually occurred where the model predicted it occurred, as well as to annotate potentially damaged areas that the model missed. While no such disaster-ready ML-based tool currently exists, NASA Lifelines co-developed a prototype model with technical guidance from Conflict Ecology at Oregon State University. The results were promising, but much more technical development work will be needed if this method is to be employed for CDA purposes in the future.



Manually annotated circle polygon dataset of suspected detonated areas based on Sentinel-2 imagery.



With respect to VHR imagery, unfortunately much of the relevant imagery over conflict-affected areas is only available on a commercial basis, meaning that humanitarian organizations would need to either purchase subscriptions from the EO companies themselves or purchase one-off access to imagery from third-party resellers, such as UP42, SkyWatch, SkyFi, and others. However, with imagery purchased from resellers, there are often restrictions regarding how the imagery can be used (e.g., can be used for internal analysis but cannot be published externally). In an ideal world, VHR imagery should be available for internal use to all humanitarian organizations; organizations should then be able to obtain permission to publish or share externally. In reality, EO imagery is not available or is difficult to obtain, and sharing or publishing is strictly prohibited. Humanitarian organizations can negotiate with each individual company on a case-by-case basis if certain license terms are needed.⁴⁶

What will this approach cost (in people time, time spent, data purchases, travel, etc.)? Is it worth the investment? Are there free/more affordable alternatives?

In terms of people cost, humanitarian organizations need dedicated staff who primarily focus on EO-based analysis. For humanitarians wanting to conduct complex custom CDAs, having GIS skills alone unfortunately doesn't meet the bar because detailed knowledge of EO sensors and image processing and analysis is completely separate from general GIS knowledge, although that is required, too. However, for more straightforward implementations that use off-the-shelf derived data products, beginner or intermediate-level knowledge may be sufficient. We recommend that analysts wanting to conduct CDA undergo specialized training in EO techniques for damage assessments, conducted by experienced analysts who deeply understand the pitfalls of using satellite imagery incorrectly and how to avoid errors.

In terms of imagery cost when purchased from resellers, it depends on task requirements, for example:

- How large is your AOI? (Smaller AOI = lower cost.)
- How many AOIs do you have? (More AOIs = more imagery needed = higher cost.)
- Do you need building-level information? (If so, it will be more expensive.)
 - If you only need moderate resolution data, that will be cheaper because much of the data is free, but it is harder to interpret and requires higher skills than basic photointerpretation of VHR optical imagery, which humanitarians can easily do or be trained to do.
- How recent do you need the data to be?
 - If you need imagery captured today, for example, it may take several hours or even days or weeks for updated imagery to appear in resellers' catalogues. Delivery latency varies from company to company.

⁴⁶ In the past, some commercial EO companies have offered discounts or special access for humanitarians. We recommend that humanitarians reach out to companies individually to discuss access, pricing, and licensing terms.



How much time do you need to gather data? For analysis?

The time it takes to gather data can vary, depending on a number of factors. Freely available moderate spatial resolution data can be accessed in mere minutes. VHR imagery can be obtained quickly (within minutes to hours) in theory, but it depends on your organization's relationship with the commercial providers. Perhaps you already have an account and access to VHR archived imagery. In this case, imagery can be obtained within minutes of it being posted to the archive (which may take hours to days, depending on a variety of factors, such as data latency, downlink times, processing pipelines, political pressure to withhold data for a specified time period or indefinitely, etc.).

Analysis timeframes can also depend on a variety of factors. If you just need the damage status of a single building, analysis can be completed in minutes. If you need wall-to-wall country-wide analysis, that can take months to years. For example, based on our experience, if the requirement is to ascertain the damage status of a single water tank and VHR optical imagery is available and readily accessible, this analysis can be completed in a few minutes. However, if the task is collating a comprehensive dataset of all WASH infrastructure in a region or country and then ascertaining the damage status of all WASH sites for a given study period of several months, this analytical task could take over a year. In sum, the time needed to complete a CDA will depend on various factors, such as the scope of the analytical task, the availability of raster (i.e., EO imagery) and vector (i.e., point/polygon locations of interest) data, budgetary constraints, the number of analysts available, and others.



What are your needs for analysis like cloud computing, internet bandwidth, team time, other expertise, and in-country partners?

For storing imagery, it can be more convenient to transfer data directly from EO providers' servers directly into a cloud storage bucket, such as an AWS S3 bucket or a GCS (Google Cloud Storage) bucket. Such cloud-based data transfer pipelines are optimal because EO imagery can take up a lot of hard drive space locally, especially with larger AOIs. With respect to cloud computing needs, this depends on the context. Certain use cases do not require any cloud compute (e.g., small, single AOI CDA), while others solely rely upon it (e.g., ML-based damage detection methods). Humanitarians deployed in field environments should also consider internet bandwidth constraints. Good connectivity and high upload/download speeds are required to work with large amounts of EO imagery, whereas derived data products can be delivered in a vector data format that takes up minimal disk space and can be transferred easily in low bandwidth environments. Finally, in-country partners can be helpful in providing local contextual knowledge, as well as potentially ground-truth data, if it can be obtained with minimal risk to personnel.

Sharing and Communicating Results



This section helps practitioners translate EO analysis accurately and responsibly to inform humanitarian decision-making. The sections below cover considerations for how to characterize the reliability of findings, how to communicate risks and limitations, what elements of an approach are worth sharing externally, and how to evaluate impact. Given the stakes of humanitarian work, clear and honest communication is essential in outlining assumptions and limitations.

How accurate are the data, analysis, and findings? What is our confidence in this data?

There is always a level of uncertainty when it comes to CDA. This can depend on a number of factors, such as image interpretability, clarity, and quality, the number of images available and from which angles (at-nadir vs. off-nadir imagery, as well as various sensor azimuth angles), the size of the buildings/structures under analysis, EO sensor modality and analysis choices, and many others. When using derived data, humanitarians should be aware of the risk of relying too much upon finished analyses that appear to be confident in their results, while in actuality, inaccuracies exist. The amount of methodological transparency varies among derived data producers.

How should we communicate about risks and uncertainty and how to apply data?

Humanitarians should be clear about the limitations of their EO-based analyses. Techniques include using confidence intervals and error bars ⁴⁷ and providing detailed explanations of methods and how confident we are in the results. Moreover, clearly communicating about the temporal aspect of CDA results is crucial. CDAs only reflect damage during a specified study period or until a particular point in time, and analysts should communicate that damage statuses could change at any point — including repeat damage of an individual location over time and repair/reconstruction of damaged or destroyed infrastructure, especially that which is crucial for human survival (e.g., WASH infrastructure, shelters, healthcare facilities).

⁴⁷ In the CDA context, a confidence interval can be a range around the estimated number of damaged buildings that is likely to contain the true count of damaged buildings with a specified level of certainty. For example, a 95% confidence interval (CI 95%) means we can be 95% confident the true number of damaged buildings falls within that range, while a 99% confidence interval (CI 99%) reflects greater certainty across a correspondingly wider range. Error bars graphically represent this concept: lines extending from an estimate on a map, chart, or figure that visually convey this uncertainty, allowing humanitarian users to see the margin of error around each damage estimate at a glance.

Are there elements of our approach that should be shared? (e.g., lessons learned, data, tools)?

Transparency is key. Analysts should clearly and thoroughly document methods and be clear and enumerate completely all known limitations and suggestions for further work to improve accuracy. Consider sharing results widely with key trusted stakeholders for feedback and publishing publicly information that can be shared safely without risk of harm to those on the ground.

What was the impact of our decision-making using this data/analysis?

Remote sensing science is constantly changing and advancing, so humanitarians are encouraged to stay abreast of the most recent research and improving EO methods. In published outputs, whether for internal colleagues or external partners, humanitarians should clearly communicate how their data products should be used — and how they should not be used.

Humanitarians should consider conducting “postmortem” (i.e., once a task or project is complete) meetings to successfully iterate on previous work. Set up meetings with all stakeholders for hot washes or after actions. A hot wash is a concise meeting to address any pressing issues immediately after they occur. After action meetings can take place once periods of activity have concluded; this allows for more retrospective insight with the benefit of time.

In retrospect, would we use satellite data again? What do we want to do differently next time?

After action meetings can highlight areas of improvement, as well as what went right, so that processes can continually improve. Structured checklists of areas to discuss during after action meetings can be created. These checklist areas can include:

- Ethics
 - Safety
 - Security
 - Privacy
- Operational
 - Imagery access
 - Tool access
 - Storage access and capacity
 - Cloud compute access and capacity
- Effectiveness of the analysis
 - Accuracy
 - Discussion of known unknowns and what might be in unknown unknowns

- Did this work substantively influence our understanding of the situation and our humanitarian programming?
- Did this work ultimately benefit affected populations and if so, how?
- Cartographic production
 - Static maps vs. interactive online platforms
- Distribution
 - Permissions to share which materials and hold back which materials
- Iteration
 - What went well and what did not go well?
 - What should we implement or tweak for future similar use cases?
 - What training opportunities exist to teach colleagues moving forward based on this experience?

Checklists are useful to make sure a comprehensive discussion takes place and covers all bases. They are used routinely in airplane cockpits and hospital operating rooms to ensure safety and that all details are addressed. Checklists should be standardized so they can be used over and over again, creating institutional memory, knowledge, and capacity but should be designed to be flexible to allow for non-standard context-specific issues and malleable so that they can be continually improved upon, based on experience and evolving requirements.

Conclusion

Conflict damage assessments can be crucial and life-saving tools if used effectively, accurately, and in a timely manner. There exist many pitfalls for humanitarian users — either in generating CDA analyses or making humanitarian decisions based on the results — so it is vitally important to understand how data is created, what CDA results represent with respect to what is happening on the ground, and how results are both intended and not intended to be used. The remote sensing science underpinning many of the methods described in this case study is constantly evolving and improving, so humanitarians would be served well by keeping up-to-date with the latest analytical methods, as well as new satellite technology that collects EO imagery, as the proliferation of commercial EO satellites grows on an exponential trajectory. Keep in mind that for topics as complex as CDA and humanitarian EO more broadly, experts may disagree, and that is okay. Humanitarians should seek to get as close as possible to ground truth by keeping an open mind to multiple working hypotheses, seeking peer and expert review,⁴⁸ and by communicating clearly not only the limitations and intended interpretation of the results but also how these data can be used to help humanitarians serve the world's most vulnerable.

⁴⁸ OHCHR, UC Berkeley Human Rights Center. Berkeley Protocol on Digital Open Source Investigations: A Practical Guide on the Effective Use of Digital Open Source Information in Investigating Violations of International Criminal, Human Rights and Humanitarian Law. United Nations; 2022. doi:10.18356/9789210053433.

Appendix A: UNOSAT Accuracy Review

Many organizations across the humanitarian sector, academia, and journalism use UNOSAT derived data products in conflict settings to understand where infrastructure is damaged over a certain AOI. UNOSAT conducts these conflict damage assessments with the purpose of serving humanitarians who need a rapid damage assessment to conduct their respective missions. UNOSAT does not intend for these data to be considered error-free or used as ground truth data. While UNOSAT data can be used as reference data in academic studies and elsewhere, users should develop a full understanding of the intended use and limitations of the published datasets.

To understand and quantify these issues on a more granular level, NASA Lifelines conducted an accuracy review of UNOSAT derived data over a small AOI in the Gaza Strip, examining multiple aspects of the UNOSAT output; among these were:

1. point placement (i.e., understanding which points correspond to which buildings), and
2. assessed damage status (i.e., does the damage status assigned by UNOSAT accurately reflect the actual damage status of the building).

The findings concluded that while many inaccuracies exist, UNOSAT data is still useful to humanitarians and may be useful to academics but only if used in a responsible way (e.g., conducting a review of the derived data for their AOI and not blindly accepting the UNOSAT data as ground truth).

An accounting of the accuracy review follows:

UNOSAT product reviewed:	UNOSAT Gaza Strip Comprehensive Damage Assessment
Date of publication:	2025-10-31
Date and sensor of “after” satellite image (for damage assessment statuses):	2025-10-11 WorldView-3
Date and sensor of centroid placement image (first published UNOSAT damage assessment):	2023-10-15 WorldView-2

UNOSAT Accuracy Review Results

Centroid placement issues

- Non-uniform centroid placement
 - Even in buildings that appear to be similar/symmetric, centroids were not placed uniformly between the two.

- Centroids were most likely placed manually by hand using the first post-event damage image, which in the case of UNOSAT's first Gaza damage assessment, was between 23-27° degrees off-nadir across multiple WV-2 images. This off-nadir image results in inaccurate centroid placement, because the centroids would be in a different location if the image used to place the centroids had an off-nadir angle of 0° (i.e., at nadir).
 - This is a structural problem with imagery selection for centroid placement: the taller the building is, the greater the error becomes.
- Upon close inspection of the UNOSAT data, there are many cases in which it is unclear which points belong to which buildings.
 - There was also an instance in which building points were placed in a roadway, as well as an instance in which an empty lot was labeled as "destroyed."

Denominator issues

- There are many instances in the UNOSAT data in which there are multiple points representing one building.
- There were instances of clearly damaged/destroyed buildings that UNOSAT completely missed (i.e., did not include these buildings in their dataset).

Accuracy issues in damage gradation assessed

- There are many instances in the UNOSAT data where the damage gradation was clearly erroneous. For example:
 - There was an instance in which a building was labeled as both "destroyed" and "possibly damaged."
 - There was an instance of a clearly destroyed mosque that was labeled as "severely damaged."
 - There were two buildings flatted (on their sides) that received different damage gradations (i.e., one was labeled "destroyed" and the other was labeled "severely damaged" without any meaningful difference in the level of damage between the two buildings).
 - There was an instance where a building labeled "moderately damaged" was at least severely damaged, if not destroyed.
 - There was an instance in which a building labeled "possibly damaged" was clearly destroyed.
 - There was an instance in which a building was labeled "possible damage from adjacent impact debris" when it was clearly destroyed.

* Images of the accuracy review were not included in this report due to licensing constraints, but for further discussion please reach out to info@nasalifelines.org

Discussion and Conclusion

Humanitarians may use and rely upon UNOSAT data as reference data but should understand the limitations of the dataset and its intended use. Humanitarians should also be wary of adhering strictly to the damage gradation scale used by UNOSAT. In many cases, it was unclear how a determination was made. For example, there were many buildings in our review that were labeled as "moderately damaged" with no apparent signs of visible damage. These should have been labeled as "possibly damaged."

The issues enumerated above could be addressed with post-processing UNOSAT data, as opposed to blindly accepting it as 100% accurate reference data. Nevertheless, it can still be useful if treated with appropriate post-processing workflows and the limitations and shortcomings of the data are clearly laid out. Post-processing steps could include taking multiple points assigned to one building and assigning it a

single encompassing damage status; correcting inaccuracies with respect to clearly erroneous damage levels; and fixing centroid placement. It's important to correct errors in the dataset so as to not propagate errors throughout research that relies upon UNOSAT data for reference data. Research should also clearly spell out the reasoning behind labeling building damage with a single point at building centroids. There exist other ways of labeling damage, such as detonated or blast areas. We have listed a total of nine ways to label damage in **Table 1** beginning on page 17 of this guide.

In conclusion, despite the limitations listed above, UNOSAT CDA products can be very useful data for humanitarians, even if not perfect, as long as they are used in the appropriate way (e.g., corrected or, if not, used with caveats and limitations enumerated) and placed in context with other EO methods. This is an argument to **use multiple EO modalities and processing methods** for conflict damage assessments. Humanitarians should not rely on just one modality (e.g., manual analysis of VHR optical imagery) if the goal is to get accurate results out of a CDA. Instead, use multiple modalities and independently triangulate damage signals (e.g., fusing moderate resolution S1 InSAR CCD; VHR SAR automated methods like BRIGHT or GLCM; VHR optical analysis, whether manual or automated). Consult with experts from a variety of disciplines and get multiple opinions, as experts may disagree on intricately complex topics such as CDA.

Appendix B: Remote Sensing Modalities & Labeling Considerations

When choosing the appropriate labeling schema for building damage assessments, humanitarians should consider the level of granularity of their intended output, as well as which remote sensing modality or modalities are available to them. Labeling feasibility and strategy vary by sensor type. The table below summarizes each modality and modality-specific guidance for damage annotations.

Remote Sensing Modality	Resolution/ Examples	What is visible?	Recommended labeling schemas
VHR Optical	Sub-meter GSD (e.g., Vantor, Airbus, Planet SkySat/Pelican)	Individual structural damage: roof collapse, rubble, scorch marks, façade damage (off-nadir). Highest interpretability.	All Schemas applicable (S1-S9).
Moderate-resolution Optical	3-5m GSD (e.g., PlanetScope); 10-30m GSD (e.g., Sentinel-2, Landsat)	Damage visible at block/neighborhood scale. Individual building damage/features are generally not resolvable.	S7, S8, and S9. Building polygons generally not meaningful at this resolution, especially in contexts with smaller or tightly packed buildings.
VHR SAR (Backscatter Intensity)	Sub-meter to ~1 m (e.g., ICEYE, Capella, Umbra, TerraSAR-X Spotlight)	Structural geometry changes: building collapse as bright scattering signatures, rubble piles, shadow changes.	S2, S3, S4, S5, S7. Per-damage polygons (S1) may be feasible for major structural changes.
VHR SAR ⁴⁹ (InSAR Coherence)	Sub-meter to ~1 m; pre-/post-event coherence maps	Coherence loss indicates surface change. At VHR, coherence maps can resolve damage at individual building level. Low coherence over building footprints serves as a damage proxy.	S3 preferred (coherence loss mapped to building footprints).
Moderate-resolution SAR (Backscatter Intensity)	10–20 m (e.g., Sentinel-1, NISAR)	Backscatter changes at block level. Individual buildings rarely distinguishable.	S7. Annotation is block-level rather than per building.
Moderate-resolution InSAR (InSAR Coherence)	30–40 m raster cell (e.g., Sentinel-1 InSAR CCD); pre-/post-event coherence	Coherence-based damage polygons. ⁵⁰ Rapid wide-area assessment.	S7. Annotation is block-level rather than per building.

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- 49 Note that for commercial SAR providers, there may be limited pre-event coverage, negating the ability to conduct InSAR CCD, which requires a long temporal baseline of pre-conflict imagery captured with the same or similar orbital parameters as the intra- or post-conflict collects. Some commercial SAR providers offer imagery captured with ground-track repeat orbits, thus enabling InSAR CCD, while others do not currently have such capacity.
- 50 Scher, C., & Van Den Hoek, J. (2025). Nationwide conflict damage mapping with interferometric synthetic aperture radar: A study of the 2022 Russia-Ukraine conflict. *Science of Remote Sensing*, 11, 100217. <https://doi.org/10.1016/j.srs.2025.100217>

Other considerations include:

- Spatial resolution of the EO data available to humanitarian in a given use case will be an important determining factor of the best labeling schema to use. For example, for VHR optical data, perhaps labeling damage (schema S1) or labeling buildings (schema S3) might be most appropriate, while for moderate-resolution optical data, perhaps labeling large swathes of suspected damaged areas (schema S9) might be more practical given the lack of spatial detail on a per-building basis.
- Moderate-resolution SAR or InSAR results can be paired with VHR data for validation of backscatter intensity- or coherence-derived damage labels. We encourage humanitarians to use multiple remote sensing modalities and analysis methodologies to the fullest extent possible for the most accurate results.
- Pick the appropriate ML methodology, according to sensor modality. For SAR, that could include using a GLCM-based approach, in which GLCM texture features (such as entropy and homogeneity) are extracted from post-event VHR SAR imagery and statistically correlated with damaged areas,⁵¹ or Damage Proxy Maps (DPMs).^{52, 53, 54}
- Humanitarians should take care to decide what is considered “damage” for the purposes of their applied use case. The damage threshold for what is considered damaged will vary by context and humanitarian organization; for example, minor damage may be considered “no damage” by some but may be important to include for others. In the cases in which only major or significant damage is relevant, humanitarians could aggregate damage labels to a binary classification, per the **EMS-98 damage gradation schema**, translating from a multi-class gradation of damage severity to a binary classification as follows:
 - DG1-2 → 0 (no damage)
 - DG3-5 → 1 (damage)
- Several off-the-shelf options exist for annotating EO imagery for CDA. Tool selection may depend on the remote sensing modality and labeling schema being applied. Some options include:
 - **Collect Earth Online (CEO)**: Web-based platform designed for collaborative land-use assessment. Supports point and polygon collection over custom imagery basemaps. Well-suited for schemas S3 and S6, and for moderate-resolution modalities where simple geometry collection is sufficient.

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- 51 Giardina, G., Macchiarulo, V., Foroughnia, F. et al. Combining remote sensing techniques and field surveys for post-earthquake reconnaissance missions. *Bull Earthquake Eng* 22, 3415–3439 (2024). <https://doi.org/10.1007/s10518-023-01716-9>
- 52 Fielding, E. J., & Jung, J. (2024). Damage proxy mapping with SAR interferometric coherence change. *Procedia Computer Science*, 239, 2322–2328. <https://www.sciencedirect.com/science/article/pii/S1877050924016697>
- 53 Ainscoe, E.A., Swaminathan, R., Way, L. et al. Earthquake damage mapped more comprehensively and accurately by radar satellites than optical imagery. *Commun Earth Environ* 6, 631 (2025). <https://doi.org/10.1038/s43247-025-02623-4>
- 54 Singh DK, Hoskere V, Milillo P. Multiclass post-earthquake building assessment integrating high-resolution optical and SAR satellite imagery, ground motion, and soil data with transformers. *Earthquake Spectra*. 2025;41(5):3365–3392. <https://doi.org/10.1177/8755293025137778>

- **QGIS / ArcGIS Pro:** Full-featured desktop GIS with advanced editing tools, support for all vector geometry types, and native raster data handling. Preferred for VHR modalities and complex labeling schemas (S1, S2, S4, S5) requiring precise polygon editing, attribute management, and multi-layer overlay.
- **HASTE (Microsoft AI for Good Lab):** Purpose-built tool for humanitarian damage assessment that integrates human labeling with ML-based damage assessment. Useful for accelerating annotation process by using in-browser labeling tools and for leveraging pre-computed building footprints and damage predictions that can be exported and used within a GIS environment. Use with schema S3.
- **EEFIT (Earthquake Engineering Field Investigation Team) approach:** Portable, in-situ tools for in-field ground truth data collection. Used in Morocco by Riccardo Vitale of the University of Houston.

Glossary

Term	Definition
ACLED	Armed Conflict Location & Event Data
AI	artificial intelligence
AOI	area of interest
ARIA	Advanced Rapid Imaging and Analysis
ARSET	Applied Remote Sensing Training Program
AWS	Amazon Web Services
BDA	building damage assessment or battle damage assessment; see CDA
CCD	coherence change detection
CDA	conflict damage assessment; see BDA
CEMS	Copernicus Emergency Management Service
CEOBS	Conflict and Environment Observatory
CI	confidence interval
CV	computer vision
DL	deep learning
DLR	Deutsches Zentrum für Luft- und Raumfahrt (German Aerospace Center)
DPM	Damage Proxy Map
EC2	Elastic Compute Cloud; see AWS
EEFA	Earth Engine: Fundamentals and Applications; refers to book entitled "Cloud-Based Remote Sensing with Google Earth Engine: Fundamentals and Applications"
EEFIT	Earthquake Engineering Field Investigation Team
EMS	European Macroseismic Scale
EO	Earth observation; in defense and intelligence GEOINT contexts, EO may refer to electro-optical imagery
EOFM	Earth Observation Foundation Model; see GFM
ESA	European Space Agency
EU	European Union
FIRMS	Fire Information for Resource Management System
FN	false negative
FP	false positive
GCP	Google Cloud Platform
GCS	Google Cloud Storage
GEE	Google Earth Engine
GeoAI	geospatial artificial intelligence
GEOINT	geospatial intelligence
GFM	Geospatial Foundation Model; see EOFM
GHSL	Global Human Settlement Layer
GIS	geographic information systems

Term	Definition
GLCM	Gray-Level Co-Occurrence Matrix
GPU	graphics processing unit
GRID3	Geo-Referenced Infrastructure and Demographic Data for Development
GSD	Ground Sample Distance
GUI	graphical user interface
HASTE	High-speed Assessment and Satellite Tracking for Emergencies
HDX	Humanitarian Data Exchange
HOTOSM	Humanitarian OpenStreetMap Team
HRL	Yale Humanitarian Research Lab
HRW	Human Rights Watch
IAC	International armed conflict
IC	intelligence community
ICC	International Criminal Court
ICJ	International Court of Justice
IDP	internally displaced people
IGO	intergovernmental organization
IHL	International Humanitarian Law; see LOAC
IMINT	image intelligence
INGO	international non-governmental organization
InSAR	interferometric synthetic aperture radar
IWG-SEM	International Working Group on Satellite-based Emergency Mapping
LLM	large language model
LOAC	Law of Armed Conflict; see IHL
ML	machine learning
NASA	National Aeronautics and Space Administration
NDVI	Normalized Difference Vegetation Index
NGO	non-governmental organization
NIAC	Non-international armed conflict
OCHA	United Nations Office for the Coordination of Humanitarian Affairs
OGC	Open Geospatial Consortium
OHCHR	Office of the United Nations High Commissioner for Human Rights
OSINT	open-source intelligence
OSK	Orbital Sidekick
OSM	OpenStreetMap
QGIS	Quantum GIS
RAM	random-access memory
RDNA	Rapid Damage and Needs Assessments
RS	Remote sensing
S3	Simple Storage Service; see AWS

Term	Definition
SAR	synthetic aperture radar
SNAP	Sentinel Application Platform
TN	true negative
TP	true positive
UCDP	Uppsala Conflict Data Program
UGC	user-generated content
UN	United Nations
UNDP	United Nations Development Programme
UNOPS	United Nations Office for Project Services
UNOSAT	United Nations Satellite Centre
USG	U.S. government
VHR	very-high resolution; for the purposes of this case study, satellite imagery with a spatial resolution of 1m GSD or better is considered VHR
WASH	water, sanitation, and hygiene; WASH infrastructure includes wastewater treatment plants, water storage infrastructure like tanks and towers, desalination plants, etc.
WV	WorldView