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CITY-SCALE DAMAGE ASSESSMENT USING VERY-HIGH-RESOLUTION SAR SATELLITE IMAGERY AND BUILDING SURVEY DATA FOR THE 2021 HAITI EARTHQUAKE

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Abstract: *After an earthquake, a rapid identification of the damaged building stock is crucial to prioritise rescue operations, ensure primary services to the most affected regions and support reconstruction. Whilst in-situ reconnaissance missions provide invaluable data on the intensity and distribution of earthquake-induced structural damage, the process of collecting field observations is often dangerous, expensive, and is usually undertaken a few weeks after the disaster. Spaceborne Synthetic Aperture Radar (SAR) can remotely provide imagery data of wide affected areas, enabling to reach locations that are difficult or dangerous to access with traditional survey methods. Furthermore, SAR-based observations are independent from daylight illumination and clear-weather conditions. Thanks to the recent availability of Very-High Resolution (VHR) SAR satellites, post-disaster imagery data with sub-metre resolution are now available within a few hours after a major earthquake, opening unprecedented opportunities for complementing in-situ operations. The textural analysis of post-earthquake VHR SAR images could be used to identify backscattering signatures that are likely associated with building damage. However, application has been limited by the lack of methods that correlate the textural properties of damaged structures in radar images with building survey data. In this paper, we present a method using textural features derived from VHR SAR post-event images in combination with building survey data to classify earthquake-induced building damage at city block-level. We tested the proposed method within the context of a joint Structural Extreme Event Reconnaissance (StEER), GeoHazards International (GHI) and Earthquake Engineering Field Investigation Team (EEFIT) mission that followed the 2021 Haiti Earthquake. The developed method was applied to the city of Les Cayes, Haiti, using a post-event Capella SAR image acquired on the 16th of August 2021. The outcomes can positively impact future earthquake scenarios, with the potential to improve rapid disaster response and remotely aid post-earthquake reconnaissance missions.*

Keywords: post-disaster reconnaissance, remote sensing, texture analysis

Introduction

Major earthquakes can result in substantial loss of life and widespread damage to buildings and infrastructure assets. The number of fatalities can be greatly affected by the effectiveness of relief

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operations, making it critical for decision makers and emergency planners to quickly gain an understanding of the concentration and distribution of damage (Guérin-Marthe et al., 2021).

In recent years, imagery data acquired by Earth observation satellites has increasingly been used to aid in the early stages of the disaster response (Joyce et al., 2009). This data can be available shortly after a disaster event, allowing for a quick and comprehensive overview of large affected areas without the need to send people to the field, which is often risky and logistically challenging (Whitworth et al., 2022). Among the available satellite sensors, spaceborne Synthetic Aperture Radars (SAR) can operate both day and night and in every weather condition (Hanssen, 2001; Moreira et al., 2013), making their usage in post-disaster scenarios appealing. However, it is only thanks to the recent availability of spaceborne SAR sensors with sub-meter resolution, such as Capella (Stringham et al., 2019), that unprecedented opportunities for an operational use of Very High Resolution (VHR) SAR data within post-earthquake scenarios have emerged.

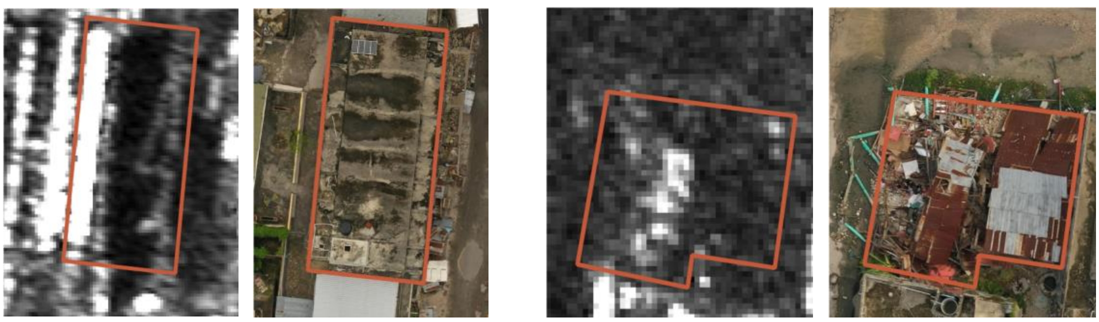
In most studies, the identification of damaged buildings in SAR imagery data involves comparing the backscatter intensity or phase information between pre- and post-seismic images using change detection methods (Ge et al., 2020). However, since VHR satellite acquisitions, such as those in Spotlight mode, are typically tasked only after a disaster has occurred, change detection methods usually cannot be applied to VHR SAR data. To overcome such limitation, a few studies have explored using post-event images only (Dell'Acqua and Polli, 2011; Kuny et al., 2015; Wu et al., 2016). In these studies, differences in texture, which refers to the spatial patterns of pixel values, were used to identify the backscattering signatures of likely damaged buildings. However, research in this area is still limited and lacks integration with field observations, such as building survey data.

In this paper, we present a method that combines textural features extracted from VHR SAR postevent imagery and building survey data to map the concentration of earthquake-induced damage at city scale. We used the developed method to assess the building damage caused by the 2021 Haiti earthquake in the urban area of Les Cayes, Haiti, by combining a post-event Capella-5 VHR X-band imagery acquired two days after the mainshock with building survey data collected during a joint Structural Extreme Event Reconnaissance (StEER), GeoHazards International (GHI) and Earthquake Engineering Field Investigation Team (EEFIT) mission following the 14th of August Haiti earthquake.

Background

Appearance of buildings in SAR images

Space-borne SAR is an active remote sensing technology that uses microwave pulses to scan vast regions of the Earth surface and capture backscattered signals (Moreira et al., 2013). In SAR images, each pixel is defined by amplitude and phase. The amplitude represents the intensity of the reflected signal received by the SAR sensor and is influenced by various physical characteristics of the imaged targets, including size, shape, roughness, orientation, and dielectric properties. The phase refers to the distance between the SAR sensor and the target and is measured as an angle ranging from 0 to 2π. In this work, we used the amplitude information of SAR imagery data to map earthquake-induced building damage.



(a) (b)

Figure 1: Examples of (a) an intact building in VHR SAR data and drone orthophoto and (b) a collapsed building in VHR SAR data and drone orthophoto. The VHR SAR data is Capella imagery acquired over Les Cayes, Haiti (© 2021 Capella Space All Rights Reserved).

SAR satellites use a side-looking imaging geometry, which means that the sensor is oriented sideways with respect to the flight direction. Due to this side-looking geometry, the appearance of urban structures in SAR images is affected by some geometric distortions including shadowing, foreshortening, layover, and multi-bounce reflections (Hanssen, 2001). For an idealised flat-roof building, four types of reflections can be typically recognised (Balz and Liao, 2010; Brunner et al., 2010): (i) layover area, (i) corner reflection, (iii) roof area and (iv) shadow area. The first structural element interacting with the radar signal is the dihedral corner reflector created at the intersection of the building wall facing the SAR sensor and the surrounding ground. The dihedral corner reflector typically produces a very strong reflection called double bounce, which appears as a very bright linear region in the SAR image. The second contribution is the reflection produced by the building roof. This reflection is usually weaker than the dihedral corner reflection and results in lower intensity pixels in the SAR image. Depending on the height of the building, the reflection produced by the building roof could be recorded before the double bounce generated at the intersection of wall and ground. If this happens, a layover effect can be observed before the dihedral corner reflection, resulting in relatively high intensity pixels in the SAR image. Finally, the last contribution is associated with the part of the building hidden from radar illumination, i.e., shadowing effect. Since for such an area no backscattering signal is recorded, part of the building will appear as dark in the radar image.

Whilst intact buildings are usually characterised by well-defined shapes with sharp edges and strong backscattering, in presence of collapsed or heavily damaged buildings, the four regions of reflections will no longer be recognisable (Brunner et al., 2010). For example, the bright layover area and strong double-bounce line might disappear partially or completely (Wu et al., 2016; Gong et al., 2016). The building shape will lose regularity, with debris behaving like corner reflectors and producing very localised strong reflections (Kuny et al., 2015). Examples of intact and collapsed buildings are shown in Figure 1. This suggests that texture properties of VHR SAR imagery could be used to distinguish between damaged and not damaged buildings.

Texture analysis

Texture analysis refers to a set of image processing techniques designed to quantify spatial relationships between intensity pixel values, also called Grey Levels (GL), in terms of their spatial location in the image. Typically, lower GL values correspond to darker images.

The Grey Level Co-occurrence Matrix (GLCM), originally proposed by Haralick (1973), is one of the most common texture analysis methods. It can measure how often different combinations of pixel brightness values occur in an image. GLCM generates a 2D matrix of N x N dimensions, where each cell represents the frequency of occurrence of a particular combination of pixels values at a given offset. Such matrix is created by comparing each intensity in the input area with its immediate neighbor. The matrix is then converted into probabilities.

Different statistics, or textural features, can be used to examine pixel-to-pixel relationships in different parts of the image. The textural features computed from the GLCM can be grouped into three categories: contrast, orderliness, and statistics. Contrast includes measurements such as contrast, dissimilarity, and homogeneity. Orderliness includes Angular Second Moment (ASM), energy and entropy, which measures how regular the pixel values are within the window. Finally, statistic includes mean, variance, and correlation, derived from the GLCM. Features within each group are highly correlated.

Case study: the 2021 Haiti earthquake

On the 14th of August 2021, a 7.2 magnitude earthquake struck the Tiburon Peninsula in Haiti. The hypocentre was approximately 150 km west of the capital Port-au-Prince, at about 19 km depth (Calais et al., 2022), with over 2000 aftershocks recorded (Douilly et al., 2023).

The earthquake mostly affected the South Department of Haiti, causing significant damage and loss of life. At least 2,248 people were confirmed dead, with over 15,000 others injured and more than 137,500 buildings destroyed or damaged (UN OCHA, 2021). This earthquake was the deadliest of 2021, and the most severe disaster to strike Haiti since the 2010 Mw 7.0 earthquake. Les Cayes, which is the third-largest city in Haiti, was among the most affected areas. The city suffered extensive damage, including several collapsed homes, religious buildings, and commercial structures. For this reason, the urban area of Les Cayes was chosen as a case study for this work.

Material and method

Data

Two datasets are used as inputs in this work: (i) a building survey data with assigned damage levels, and (ii) a post-earthquake VHR SAR image. Both datasets are shown in Figure 2.

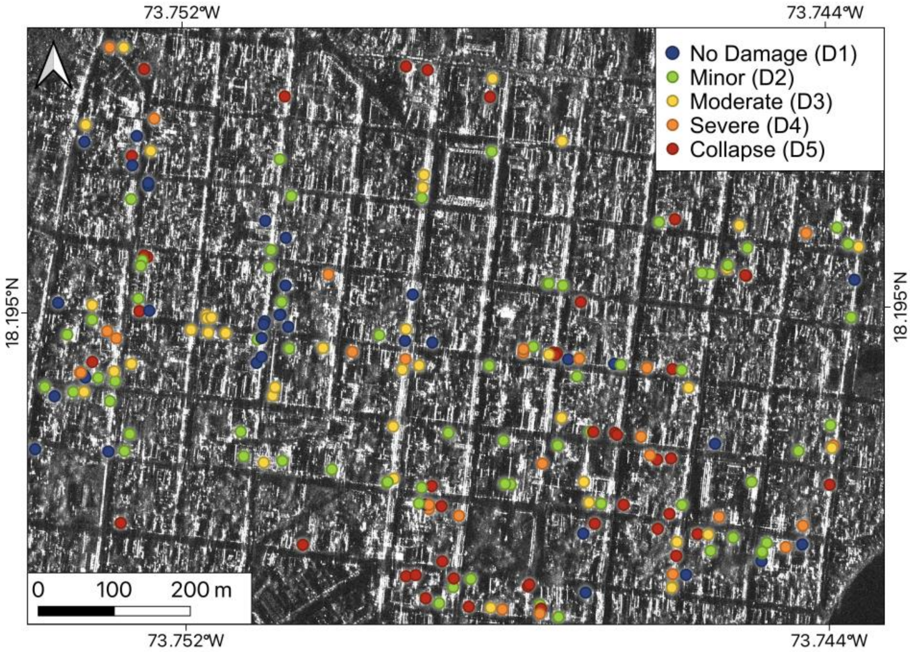


Figure 2. StEER/GHI Fulcrum building survey data with assigned damage levels over the study area in central Les Cayes, Haiti. Background data is the Capella VHR SAR image acquired on the 16th of August 2021 (© 2021 Capella Space All Rights Reserved).

The building survey data used in this work was provided by the StEER/GHI team, who mobilised local field data collectors (mostly non-engineers) to rapidly gather damage descriptors and geotagged photographs after the 2021 Haiti earthquake (Kijewski-Correa et al., 2022). The collected data was made available through a rapid seismic assessment App in Fulcrum, i.e., the StEER Rapid Response (M7.2 Haiti EQ – Aug 2021) App. In the Fulcrum App, teams of experts, such as the EEFIT team, were able to remotely complete the assessment by inspecting photographic material and any additional available information (Whitworth et al., 2022). Each Fulcrum record required the experts to classify the building structural typology and assign a damage rating. Seven classes were used for the building structural typology, which included 'Reinforced Concrete with infill masonry shear walls' (RC), 'Confined Masonry' (CM), 'Unreinforced Masonry bearing walls' (URM), 'Reinforced Masonry bearing walls' (RM), 'Wood Light frames' (WL), 'Wood with Stone infills' (WS), and 'Unknown' (UN). The damage classification utilised a rating system comparable to the European Macroseismic Scale (EMS-98), as defined in the StEER assessment manual (Miranda, 2021). Specifically, the following five damage levels were used: 'No Damage' (D1), 'Minor Damage' (D2), 'Moderate Damage' (D3), 'Severe Damage' (D4) and 'Total or Partial Collapse' (D5). Among the 11,669 assessed buildings, a total of 215 records were included in the study area in central Les Cayes (Figure 2).

The post-event VHR SAR image used in this study was acquired by the Capella satellite constellation, which was recently launched (Stringham et al, 2019). Each Capella satellite is equipped with an X-band radar that can collect VHR data in Spotlight mode. The post-event VHR SAR image was captured on the 16th of August 2021, with an incidence angle of 48.8°. The data covers a 25-km^2-area over Les Cayes and has range and azimuth resolutions of 0.59 m and 0.63 m, respectively. The data is publicly available through the Capella Space Open Data catalogue for disaster response. The image contains amplitude information only and was delivered as a Geocoded Terrain Corrected (GEO) product (Capella Space, 2022). This means that the data has undergone several pre-processing steps, such as range-compression, detection, focusing, and multi-looking, and has been geocoded and terrain-height corrected using a high-resolution Digital Elevation Model (DEM). This is essential for accurate integration with imagery base maps and other geospatial data. Furthermore, as the image was multi-looked by a factor of 1 x 9 (range x azimuth), we were able to work with data at an improved radiometric resolution. The delivered image was characterised by less noise and greater sensitivity to changes in brightness.

Workflow

The proposed method is based on the integration of textural features extracted from a post-event VHR SAR image and building survey data with assigned damage levels to map the concentration of earthquake-induced damage in urban areas. The workflow of the proposed method is shown in Figure 3.

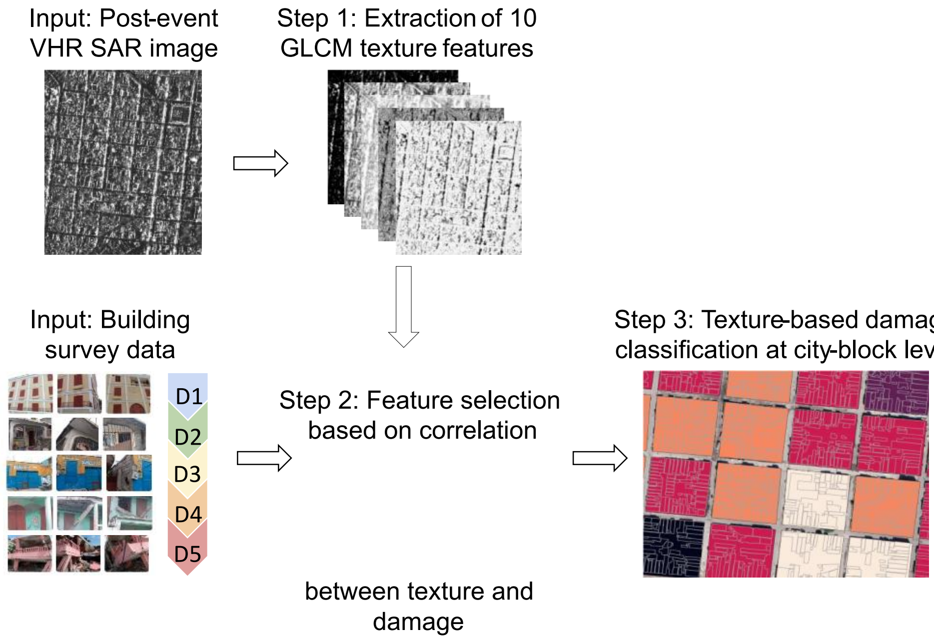


Figure 3. Workflow of the proposed method.

The developed method can be summarised in the following 3 steps:

1. The first step was to process the post-event VHR SAR image through texture analysis techniques to extract SAR-based textural features. Specifically, we used the GLCM texture analysis technique to extract 10 distinct features, including contrast, dissimilarity, homogeneity, ASM, energy, maximum probability (MAX), entropy, mean, variance, and correlation. Because of the high resolution of the data (approximately 50 cm x 50 cm in range and azimuth), we utilised a window size of 15x15m^2, which matched the average size of buildings in the study area and previous research (Zhao et al., 2013; Kuny et al., 2015). The GLCM features were calculated along several directions, including 0°, 45°, 90° and 135°. We then averaged the results from different directions since we were not interested in the directionality of the textures. The SNAP Sentinel-1 toolbox (SNAP, 2022) was used to process the data. Outputs of this step were 10 digital images associated with the different textures.

2. The second step of the method was (i) to select the textural feature that more closely relates to damage and (ii) to assess whether such a textural feature could be used to separate different damage levels. For such a purpose, each of the 10 textural features derived from step 1 was analysed in combination with the Fulcrum StEER/GHI building survey data within the study area (see *Data* section). In a Geospatial Information System (GIS) environment, we first digitised manually building footprints within our study area from a post-event drone orthophoto acquired at a 2-cm resolution, four days after the earthquake. We also made use of an 8-cm-resolution drone orthophoto from October 2016 to deal with the shape of buildings that had collapsed. The aerial images used for this step can be found in the HaitiData web-platform (HaitiData, 2021). A total of 4,116 building footprints were generated. We then matched each damage record in the Fulcrum dataset to the corresponding building footprint. Then, for each texture, we classified pixels that belonged to the Fulcrum StEER/GHI building survey data according to their corresponding damage levels. The textural feature that showed the strongest correlation with damage was chosen to be used in the next step of the method.

3. The third and final step was to produce the final damage classification based on the textural feature selected in step 2. To classify the damage caused by the event, we first divided our area of interest into 75 city blocks, each containing an average of 48 buildings.

As in this paper we refer to a city block as the smallest group of buildings that is surrounded by streets, we derived city blocks from the OpenStreetMap-road network (OSM, 2021). It is important to note that bare ground, car parks and vegetation can create reflections that significantly affect the average texture within a block (Dell'Acqua and Polli, 2011). For instance, debris and high vegetation can have similar textural signatures (Kuny et al, 2015). To ensure that the final damage classification was not affected by such effects, we only used pixels within building footprints to estimate the average texture within each block. After computing the average texture values, the blocks were classified into 5 damage levels based on their average texture value, ranging from "very low" to "very high".

Results

Figure 4a shows final classification outcomes based on the SAR-based entropy, which was the texture correlating better with the partial or total collapsed buildings. The map shows the distribution of average entropy values within each block, with low entropy values indicating a low density of damaged buildings and high entropy indicating a high concentration of damage structures. Figures 4b and 4c show examples of a city block with a very low level of average entropy in overlap with the building survey data and a city block with a very high entropy level analysed in combination with a 2-cm-resolution drone orthophoto acquired after the earthquake. Both cases show good agreement between the respective entropy classes and the presence of actual damage.

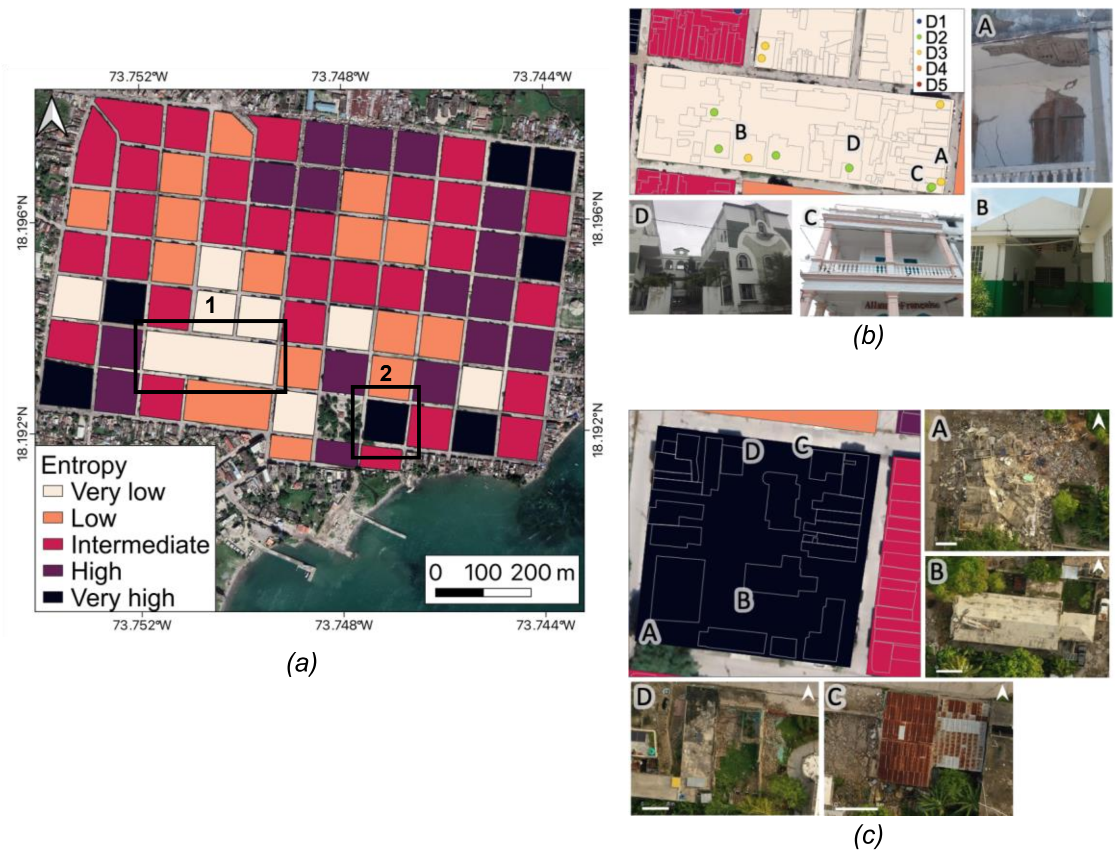


Figure 4: Final classification results: (a) damage map at the city block level in central Les Cayes, Haiti based on the entropy texture derived from the post-event Capella VHR SAR image; (b) close up of city block 1 in (a) and comparison with the damage assessment records from the StEER/GHI Fulcrum building survey data; (c) close up of city block 2 in (a) and comparison with buildings visually inspected in a 2-cm-resolution drone orthophoto acquired on the 18th of August 2021.

Conclusion

In this paper, we presented a method that uses radar remote sensing data for the rapid assessment of building damage after an earthquake. The method involves combining textural features derived from a post-earthquake VHR SAR image with building survey data collected during a reconnaissance mission. The output of the method is a map that classifies damage at the level of city blocks.

We tested the proposed method in the urban area of Les Cayes, Haiti, which was heavily impacted by the 2021 Haiti earthquake. Our findings show a good correlation between the VHR SAR-based entropy texture and actual observed damage. Using the entropy-based damage classification at city block-level, we can provide a rapid overview of damage concentration in different parts of an urban area. This is confirmed by comparing the damage classification results with the StEER/GHI Fulcrum data and drone-based orthophotos. The proposed method has potential to benefit future post-earthquake scenarios and improve disaster mitigation strategies.

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References

Balz T and Liao M (2010) Building-damage detection using post-seismic high-resolution SAR satellite data, *International Journal of Remote Sensing*, 31:13, 3369-3391. https://doi.org/10.1080/01431161003727671

Brunner D, Lemoine G and Bruzzone L (2010) Earthquake damage assessment of buildings using VHR optical and SAR imagery. *IEEE Transactions on Geoscience and Remote Sensing*, *48*(5), pp.2403-2420. https://doi.org/10.1109/TGRS.2009.2038274

Calais E, Symithe S, Monfret T, Delouis B, Lomax A, Courboulex F, Ampuero JP, Lara PE, Bletery Q, Chèze J and Peix F (2022) Citizen seismology helps decipher the 2021 Haiti earthquake. *Science*, *376*(6590), pp.283-287. https://doi.org/10.1126/science.abn1045 Capella Space (2022) SAR Imagery Products Guide – Version 3.5. Available at: https://support.capellaspace.com/hc/en-us/articles/4626115099796-SAR-ImageryProducts-Guide

Dell'Acqua F and Polli DA (2011) Post-event Only VHR Radar Satellite Data for Automated Damage Assessment: A Study on COSMO/SkyMed and the 2010 Haiti Earthquake. *Photogrammetric Engineering and Remote Sensing,* 77(10):1037–1043. https://doi.org/10.14358/PERS.77.10.1037

Douilly R, Paul S, Monfret T, Deschamps A, Ambrois D, Symithe SJ, St Fleur S, Courboulex F, Calais E, Boisson D and de Lépinay BM (2023). Rupture segmentation of the 14 August 2021 Mw 7.2 Nippes, Haiti, earthquake using aftershock relocation from a local seismic deployment. *Bulletin of the Seismological Society of America*, *113*(1), pp.58-72. https://doi.org./10.1785/0120220128

Ge P, Gokon H and Meguro K (2020) A review on synthetic aperture radar-based building damage assessment in disasters. *Remote Sensing of Environment*, *240*, p.111693. https://doi.org/10.1016/j.rse.2020.111693

Gong L, Wang C, Wu F, Zhang J, Zhang H and Li Q (2016) Earthquake-Induced Building Damage Detection with Post-Event Sub-Meter VHR TerraSAR-X Staring Spotlight Imagery. *Remote Sensing* 8(11). https://doi.org/10.3390/rs8110887

Guérin-Marthe S, Gehl P, Negulescu C, Auclair S and Fayjaloun R, (2021) Rapid earthquake response: The state-of-the art and recommendations with a focus on European systems. *International Journal of Disaster Risk Reduction*, *52*, p.101958. https://doi.org/10.1016/j.ijdrr.2020.101958

HaitiData (2021) HaitiData. URL https://haitidata.org

Hanssen RF (2001) Radar Interferometry: Data Interpretation and Error Analysis. Springer Science + Business Media, Dordrecht, the Netherlands

Haralick RM, Shanmugam KS, and Dinstein I (1973) Textural features for image classification. IEEE Transactions on systems, man, and cybernetics, (6), pp.610-621.

Joyce KE, Belliss SE, Samsonov SV, McNeill SJ and Glassey PJ (2009) A review of the status of satellite remote sensing and image processing techniques for mapping natural hazards and disasters. *Progress in Physical Geography: Earth and Environment* 33(2):183–207. https://doi.org/10.1177/0309133309339563

Kijewski-Correa T, Rodgers J, Presuma L, Dévilmé G, Lochhead M, Canales E et al (2022) Building Performance in the Nippes, Haiti Earthquake: Lessons Learned from a Hybrid Response Model. In: Proceedings of the 12th National Conference in Earthquake Engineering, Earthquake Engineering Research Institute, Salt Lake City, UT

Kuny S, Hammer H and Schulz K (2015) Discriminating between the SAR signatures of debris and high vegetation. In: 2015 IEEE International Geoscience and Remote Sensing Symposium (IGARSS), pp 473–476, https://doi.org/10.1109/IGARSS.2015.7325803

Miranda E (2021) Assessment manual: Rapid Damage Classification for Nippes August 14, 2021 M7.2 earthquake in Haiti. Technical report.

Moreira A, Prats-Iraola P, Younis M, Krieger G, Hajnsek I and Papathanassiou KP (2013) A tutorial on synthetic aperture radar. IEEE Geoscience and remote sensing magazine 1(1): 6–43 https://doi.org/10.1109/MGRS.2013.2248301

OSM (2021) Openstreetmap. URL https://www.openstreetmap.org

SNAP (2022) S1TBX ESA Sentinel Application Platform. URL http://step.esa.int

Stringham C, Farquharson G, Castelletti D, Quist E, Riggi L, Eddy D, Soenen S (2019) The Capella X-band SAR Constellation for Rapid Imaging. In: IGARSS 2019 - 2019 IEEE International Geoscience and Remote Sensing Symposium, pp 9248–9251, https://doi.org/10.1109/IGARSS.2019.8900410

UN OCHA (2021) Global humanitarian overview: Haiti. Tech. rep., United Nations

Whitworth MR, Giardina G, Penney C, Di Sarno L, Adams K, Kijewski-Correa T, Black J, Foroughnia F, Macchiarulo V, Milillo P, Ojaghi M, Orfeo A, Pugliese F, Dönmez K, Aktas YD and Macabuag J 2022. Lessons for remote post-earthquake reconnaissance from the 14 August 2021 Haiti earthquake. *Frontiers in Built Environment*, p.53. https://doi.org/10.3389/fbuil.2022.873212

Wu F, Gong L, Wang C, Zhang H, Zhang B and Xie L (2016) Signature Analysis of Building Damage With TerraSAR-X New Staring SpotLight Mode Data. *IEEE Geoscience and Remote Sensing Letters* 13(11):1696–1700. https://doi.org/10.1109/LGRS.2016.2604841

Zhao L, Yang J, Li P, Zhang L, Shi L and Lang F, (2013) Damage assessment in urban areas using post-earthquake airborne PolSAR imagery. *International Journal of Remote Sensing* 34(24):8952–8966. https://doi.org/10.1080/01431161.2013.860566