OPEN DATA FOR GREATER CONFLICT ACCOUNTABILITY: DEVELOPING A DAMAGE DETECTION TOOL FOR INVESTIGATING SYRIAN AIRSTRIKES

by

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ABSTRACT

Investigations using social media and open data provide insight into the events of the Syrian Civil War. This project aims to better understand and support these investigations. First, a study was conducted to evaluate the methodologies used by five organizations conducting open source investigations into the Syria conflict. The study identified major methodological shortcomings relating to an overreliance on inconsistent physical data and subjective social media data to substantiate findings. To address these shortcomings, the second part of the project develops an online Google Earth Engine tool that uses publicly available Sentinel-1 imagery to detect damage. The tool successfully detects large building damage and provides useful functionality for open source investigators.

INDEX WORDS: Open Source Investigations, change detection, Google Earth Engine, satellite imagery, airstrikes, social media

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For Amar, Abed, Kos, and Ramih.

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CHAPTER 1: INTRODUCTION

1.1 Project Overview

The world is not just represented in data, it is changed by the processes data enable and the discoveries data bring. The work of producing, preserving, and sharing data shapes the organizational, technological, and cultural frameworks that exist around real-world phenomena (Ribes & Jackson, 2013). Open data, data that are free to use and distribute, reshape these frameworks by allowing more people access to more information than ever before. Open data infrastructures and their related social frameworks do not simply inform new research on phenomena, they fundamentally change the practices and organization of research. Open data have the power to transform the questions asked, how they are answered, and how the answers are deployed (Kitchin, 2014).

The Syrian Civil War provides a timely example of open data's potential. Since devolving from peaceful protests to violent insurgency in 2011, the Syrian Civil War has involved multiple groups competing for ever-changing claims of victorious territory (Gilsinan, 2015). Information from conflict areas, like Syria, has traditionally been limited to the formal sources of journalism and state channels of information. These sources have now been joined by the rise of available open data in the form of publicly accessible satellite imagery, open databases, and user-generated social media. Unlike formal sources of journalism and state-controlled information, social media are emerging informal sources, which are created by individuals and receive little to no review or revision before being published. The Syrian conflict is one of the first to take place in a country with heavy social media use, where videos, images, and text related to the formation of armed groups, bombings, and clashes are regularly uploaded online to create a digital representation of events for the world to see (Ellison, 2016). In addition to this vast user-generated visual content, new crowd-sourced datasets, satellite imagery, and other open sources are all contributing to a robust digital information environment that can be used to better understand the actors and actions of the conflict (Brovelli, 2018).

Open source investigations (OSINVs) refer to a process of examining, combining, and analyzing publicly available data to draw novel conclusions. The term "open source investigation" was established by Eliot Higgins, the founder of the citizen-journalist news site, Bellingcat. Started in 2014, Bellingcat was one of the first organizations to pioneer this form of online inquiry (Beauman, 2018). By creating connections between different open data sources, OSINVs examining the Syrian Civil War can lead to a more complete picture of the conflict for members of the intelligence community, non-governmental organizations (NGOs), human rights analysts, and curious citizens.

OSINVs are particularly valuable for shedding light on the events of Syrian conflict for two reasons. First, Syria is one of the most dangerous countries for journalists; reporters in the country are often jailed or murdered, preventing many from reporting, and thus limiting on-the-ground objective coverage that can inform the world of the war's events (Radio Free Europe Radio Liberty, 2017). Second, ample evidence exists that human rights violations and war crimes have been committed by all sides of the war and obtaining the specifics of these crimes is necessary to hold perpetrators accountable for the atrocities committed (Nebehay, 2018). The location of the violations, their damage, and any evidence connecting those responsible must be uncovered in order to bring awareness of the wrongdoings.

OSINVs on airstrikes in Syria are currently conducted by a small, but diverse group of organizations that are interested in shedding light on the impact of the actions of those involved in the war. These investigations use open data, including social media, satellite data, and publicly available state information, to determine an airstrike's human and infrastructural targets, the damage produced, the strike location, and the actors behind them. This project will conduct an evaluation of the methodologies used by organizations conducting OSINVs on Syrian airstrikes, outlining any gaps in their methods. It will then aim to address the gaps identified by creating a publicly available tool to improve their methodologies.

This thesis is separated into two parts. The first focuses on understanding the OSINV landscape, particularly in relation to investigations focused on Syria. A review of the literature on open data and OSINVs reveals that little research has been conducted towards gaining an understanding of the OSINVs specifically focused on the Syrian conflict. The first part of the project designs and carries out a study of five organizations conducting Syrian OSINVs: an international non-governmental organization (INGO)

(Amnesty International), an independent journalist collective (Bellingcat), a human rights non-governmental organization (NGO) (Physicians for Human Rights), and two independent monitoring groups (Syrian Archive, Airwars). The study analyzes the methods used by these organizations, outlines the social framework of their investigations, and identifies any methodological gaps and other space for improvement.

In the second part of this project, the results of the first study are used to inform the development of a technical tool that can be integrated into the organizations' existing OSINV methodology and address the limitations outlined. Based on the results of the study, the proposed tool is a cloud-based damage detection application that can identify areas of damage across a user-entered spatial and temporal scale. The tool provides novel functionality that can help open source investigators more quickly and effectively geolocate open source media and connect online data to physical phenomena.

1.2 Research Objectives

The goal of this research is to answer the following three questions:

(1) What limitations exist in the current methodologies used to verify and geolocate airstrike damage in the Syrian Civil War?

> To determine what bottlenecks exist in the current procedures of OSINVs into Syrian airstrikes, a study and analysis of the methodologies used in Syrian-focused open source investigations will be conducted. Although the goal of the

method analysis is to uncover operational limitations, the study will also be used to gain a better understanding of the organizations conducting the investigations. Specifically, the analysis will look at information on the organizations' motivations, personnel expertise level, organizational structure, funding mechanisms, potential bias, and how a new tool could be integrated into the existing technical workflow.

(2) *Can publicly available tools (i.e. Google Earth Engine) and publicly available satellite imagery be used to improve the geolocation of airstrike damage in open source investigations of the Syrian Civil War?*

To address the bottlenecks in the geolocation process identified by the first research question, this project will develop an open source tool to detect and map building damage in Syria using open data. The tool will be a script run on Google Earth Engine (GEE) and will conduct change detection using large datasets of satellite imagery that cover both Syria's urban and rural areas. The change detection algorithm and related code will be incorporated into a user mapping interface to create damage detection maps. The process of using the tool will be straightforward and the results produced will be clear and accessible to any non-remote sensing specialists engaged in OSINVs.

(3) What are the implications of the tool created in this project and OSINVs at large for the control of information in authoritarian regimes and for other political and social frameworks?

The primary goal of this project is to contribute to the existing work being done by open source investigators to uncover the events of the Syrian Civil War. To fully understand its contributions, this research establishes the framework of Syria's information environment in terms of its social media landscape and the influence of its authoritarian regime. Then, it will present OSINVs as a new component of that framework and explore the resulting effects of its addition. It will map an understanding of what OSINVs are, what they can be, and how new OSINV technologies, like the tool created, shape and reshape OSINV contributions to broader political and social structures.

CHAPTER 2: LITERATURE REVIEW

While this project consists of two distinct components (a qualitative study and a technical application), both are situated within the larger context of a shifting nature of data availability and the effects of that shift on understanding conflict. To examine that context in relation to this project, Chapter 2 reviews the literature on information control in authoritarian regimes and traces the evolution of open data and open source investigations.

Section one of the literature review examines the structures of control that authoritarian regimes have over internal information networks and how that leads to manipulated information flows in times of conflict. The next section gives a background on open data and provides a taxonomy to situate its use in this project. The final section of the literature review introduces open source investigations and compiles an overview of methodologies, social frameworks, and limitations faced by OSINVs. This initial, broad exploration of OSINVs constructs a framework that will be used in Chapter 3 to more rigorously examine OSINVs focused on Syria. The general OSINV limitations identified in this chapter will help inform the development of the damage detection tool in Chapter 4.

2.1 Information Environment in Authoritarian Regimes

Understanding how authoritarian regimes manipulate information and their motivations to do so provide a precursor to why OSINVs emerge and why they carry such potential for providing novel insight into conflicts that occur within authoritarian regimes.

2.1.1 Traditional Authoritarian Control

Authoritarian regimes have always used totalitarian control of information to maintain power. For authoritarian regimes to stay in power, they must solve the ‘two fundamental problems of authoritarian rule’—keeping the elite class loyal and preventing the rise of political opposition (Svolik, 2012). Information communication technologies have proven to be useful tools to achieve these goals, particularly the latter goal of controlling the opposition. By controlling the means of mass communication, totalitarian rulers attempt to prevent the circulation of ideas that are at odds with the regime and prevent the formation of ideologically dissenting groups. Traditionally, the means of mass communication have consisted of broadcast media, where central agencies such as newspapers or TV stations relay messages to the broad population. Once a regime controls these central nodes, it has the power to shape the information environment and public opinion. For example, in China’s tightly controlled media environment, research finds that exposure to mass media makes citizens less critical of the political system. (Stockmann & Gallagher, 2011). In Venezuela, President Hugo Chavez limited the public’s exposure to dissenting voices by banning news reports of violent protests. He also further consolidated control by suspending the licenses of media outlets that violated any regulations that he determined. This central control is useful for both propaganda dissemination and for preventing the opposition access to tools for mass communication and mobilization (Rod & Wedimann, 2015).

2.1.2 Change Under Globalization and Internet Access

Traditional authoritarian power over the information environment relied on control of a central communication network. However, new paradigms of globalization and increased access to a decentralized Internet have transformed the centralized framework of control into a new shape entirely. The idea that social media and the Internet act solely as 'liberation technology' and only function as a tool toward democracy is false (Rod & Wedimann, 2015). While emerging media forms do provide new methods of authoritarian subversion, they also enable new forms for authoritarian control. Rod and Wedimann's research finds that regimes aiming to prevent any independent public sphere are more likely to introduce the Internet (2015). Furthermore, it has been shown that the spread of market capitalism at the hands of globalization does not inevitably lead to western style democracies or the free flow of information. Autocratic states are not passive observers of political or social change; they have the power to adapt new structures of capitalism to suit their interests. So, while globalization may result in free market economic growth, it also can result in the expansion of authoritarian control over information (Downs and Mesquita, 2005).

Autocrats have adjusted to the changing shape of the globalized information environment and have looked to the Internet as a useful tool for creating and maintaining a tightly controlled sphere of public opinion. In the early emergence of the Internet, censorship and limiting access was the most effective means of control. In Russia, the Kremlin applied heavy censorship to media outlets and Internet users, pressured domestic communication agencies to filter censored content, and threatened to block the services of international firms, like Google, Facebook, and Twitter, unless they complied with the state's demands (Soldatov, 2016). Before elections in Uzbekistan and Iran in 2007 and 2009, the state governments restricted access to any websites carrying information negative of the regime (BBC, 2007). In China, restrictions on Internet-related activity have included the "Great Firewall," which can block entire sites located abroad and inside China and paying human monitors to manually censor content (Downs & Mesquita, 2005; Shirk, 2011).

However, total control is not possible. Due to the sheer number of Internet users, its decentralized structure, and its necessity for access to the modern economy, authoritarian governments cannot supervise the entirety of the Internet and block all information they deem unworthy. Instead, new means of control in the form of manipulating the online environment are being used to shape public opinion, repress political dissent, and consolidate political power. Every authoritarian regime has social media campaigns targeting their own populations and many employ significant numbers of people and resources to manage and manipulate public opinion online (Bradshaw & Howard, 2017). Governments leverage social media platforms, like Facebook and Twitter, as tools for social control by employing people to generate content, direct opinions, and engage with audiences. For example, China's Fifty-Cent army is a group of individuals who are paid approximately fifty cents for each anonymous message they post that endorses the government's position on controversial issues (Han, 2015). Many countries have similar groups, referred to as cyber troops, that are comprised of government, military, or political teams committed to manipulating public opinion over social media (Bradshaw & Howard, 2017).

Authoritarian media control in the forms of censorship and online manipulation have also been extremely prevalent in Syria. The Syrian government engaged in Internet censorship during the Arab Spring of 2010 by blocking hundreds of websites that provided social networking, news, and other services (Al Saqaf, 2015). Broadly worded laws enable government harassment of Internet users and prompts users to self-censor themselves to avoid the state's ambiguous grounds for arrest (Internet Filtering in Syria, 2009). In addition to censorship, the government actively manipulates the online environment through automated fake accounts that flood social media with spam and fake news and amplify marginal ideas by inflating the number of likes, shares and retweets they receive. Automated Syrian social media accounts have been found to harass individuals relentlessly to silence political dissent (Bradshaw & Howard, 2017). Like many other authoritarian governments, the Syrian government also sponsors their own cyber troops, the Syrian Electronic Army, which actively engage with users by commenting on posts shared on social media platforms. The Syrian Electronic Army may engage in positive messaging that reinforces support for a government position, negative 'trolling' against critics of the government, or neutral comments that distract from the issue being discussed (Bradshaw & Howard, 2017). This online manipulation is effective not only for spreading political propaganda and silencing political dissent, but also for creating an artificial sense of relevance for issues and creating confusion about events as they happen.

This manipulation has continued, and perhaps increased, during the Syrian Civil War. For instance, it has been alleged that the Syrian volunteer rescue workers known as the White Helmets have been targeted by Twitter bots in part of a disinformation campaign to discredit them and position them as an al-Qaida-linked terrorist organization (Solon, 2017). The Syrian regime has also largely banned traditional journalists from reporting in the country. The banning limited the ability for the outside world to witness and record the events of the war and made the manipulated online environment one of the only sources of firsthand information on the war's events (Al Saqaf, 2015).

Social media and the connective power of the Internet provide powerful insight into conflict and can act as alternatives to the journalistic information channels that are restricted by the regime. However, the Internet also provides the opportunity for authoritarian regimes to continue what they have always done–construct and perpetuate information for their own purposes. It is with this knowledge that we consider new open data landscapes both as a source of insight into authoritarian regimes as well as a vessel for further manipulation. Understanding the manipulation used by authoritarian regimes emphasizes the necessity of new approaches to validating and confirming the accuracy of online information.

2.2 Open Data

This project applies the concept of open data using its broadest definition; open data are data that anyone is free to use, reuse, and distribute (Pollock, 2006). Open data can take many forms and be created and shared in many ways. To organize an understanding of open data that is relevant to this project, a taxonomy (Figure 1) that organizes them by source has been created.

To begin, it is worth noting how the term ‘open source data’ is related to and can be confused with the term ‘open source software’. While ‘open source’ can be used to describe data that are publicly available, it is also commonly used in a software development context to refers to publicly accessible and editable software source code (Ambrose & Burns, 2018). This distinction between open source data and open source software is visualized in Figure 1. For both data and software contexts, ‘open source’ and just ‘open’ are used interchangeably, so ‘open data’ and ‘open source data’ both refer to the same concept.

To explain how open data are used in this project, I will organize the many types of open data into two main categories based on how they are created, compiled, and shared. The first category is ‘Formal Sources’ and it refers to data created by individuals or organizations that go through an established creation or collection process. The institutionalized creation process is often published online or made widely available and the veracity of the contents of the data are often checked internally or by outside sources. Examples of open data that qualify as formal sources include, but are not limited to: government datasets, news reports from official news bodies, datasets provided by large organizations, businesses, or corporations, and datasets of satellite imagery, which are often provided by private companies or governmental scientific bodies. Although these formal sources are widely considered to be accurate and verified, they can contain inaccuracies, misleading information, and inherent biases. For example, a report from the US Coalition that documents the number of civilian casualties resulting from their airstrike campaign in Syria and Iraq would be considered a formal source although the accuracy of the numbers has been proven incorrect (Khan, 2017).

The second category of open data is ‘Informal Sources’. Data from informal sources do not go through a verified or established creation process. Informal sources are often an individual or a smaller group not affiliated with a large institution. Informal data are constructed and collected through many different methods and are not often stringently verified before being shared. Examples of informal sourced open data include user generated content (UGC), crowd-sourced data, volunteered geographic information (VGI), and news from independent and unverified organizations.

The first three examples (UGC, VGI, and crowd-sourced data) are closely related and their applications often overlap. User-generated content (UGC) refers to online content published by users in a digital form (i.e. data, videos, blogs, discussion forum postings, images and photos, maps, audio files, public art, etc.) (See et al., 2016). Developments in information technology have led to rapid growth in UGC, as Internet users can generate content anywhere, all the time. UGC includes social media, as well as two of the other examples mentioned as informal sources: volunteered geographic information and crowd-sourced information. Social media data are a unique type of user-generated open data that are varied and transcends a simple classification. While an individual's public social media posts meet the definition of open data (i.e. data that anyone is free to use, reuse, and distribute), social media posts that are private do not. In this project, open social data will refer to social media posts, comments, text, videos, photos, and links that have been made *public* by social media users.

Of the other examples of UGC, volunteered geographic information (VGI) is characterized by the spatial nature of the data, while crowd-sourced data are characterized by the data collection process itself. VGI was first used by Goodchild (2007) where he defines it as "the harnessing of tools to create, assemble, and disseminate geographic data provided voluntarily by individuals". Crowdsourcing first appeared in Howe (2006) where it was defined as a practice in which an activity is outsourced to a large network of people. In the context of data collection, crowdsourcing has proven to be an efficient approach to quickly generate huge amounts of data by leveraging a large number of people to support data collection activities (Ortman, 2011). An example that qualifies as user-generated, VGI, and crowd-sourced is the data platform OpenStreetMap (OSM). OSM is an editable, user-generated map of the world where a global network of users can contribute and validate spatial data on building, roads, and points of interest (Haklay & Weber, 2008).

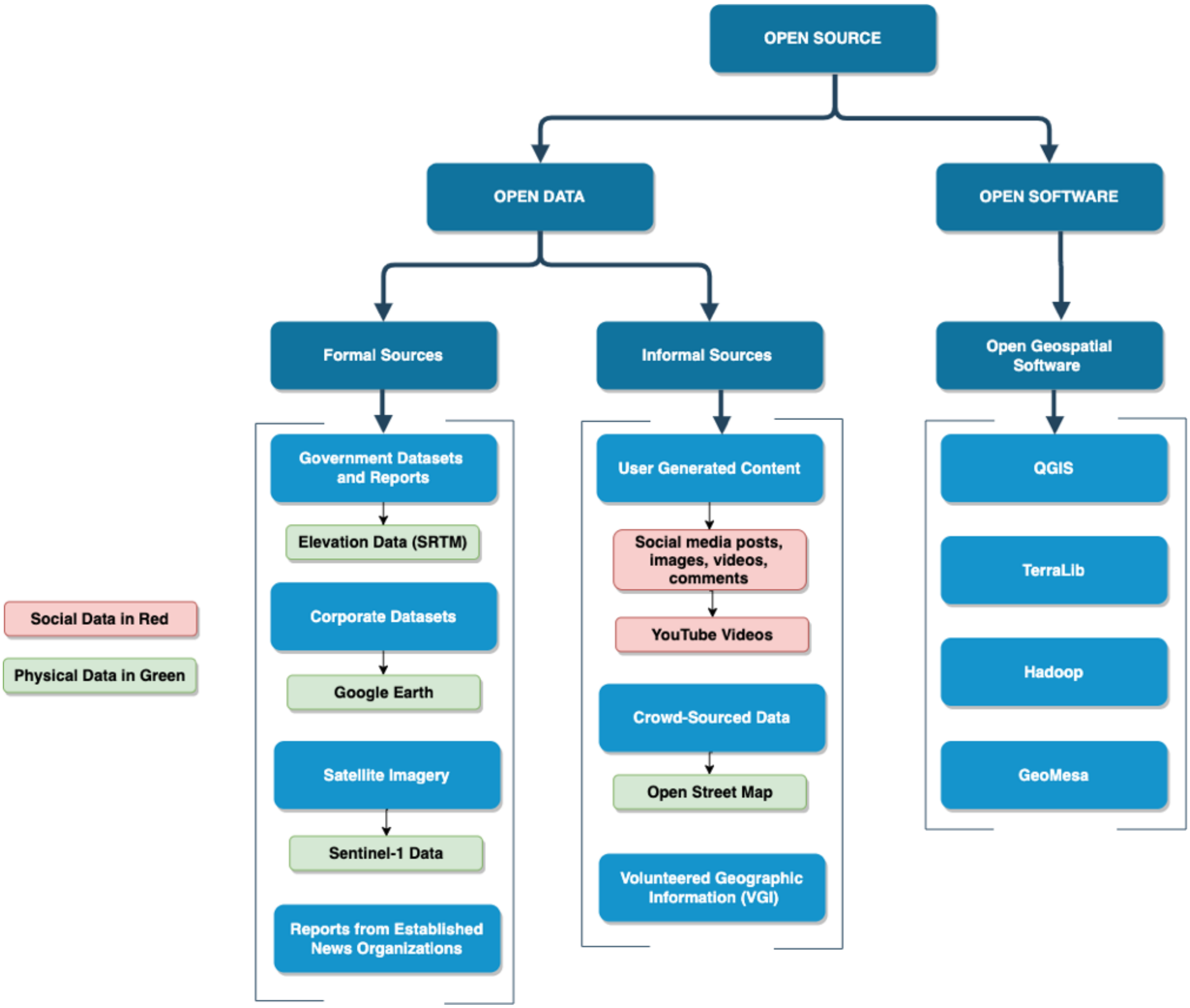

Figure 1. A taxonomy of open data relevant to this project (Source: Sam Tingle)

Another useful delineation between the types of open data used in this project is between physical data and social data (also shown in Figure 1 in green and red respectively). Physical data refers to data that represent the physical phenomenon of the world. They include satellite images, online maps, and elevation data, and can come from both formal and informal sources. Social data are online data created within the digital society of a social media platform. They consist of shared text posts, images, videos, comments, and any interactions that occur on social media platforms. Some sources can provide both physical and social data, such as Google Maps, which provides maps, satellite imagery, and building footprints, as well as user comments.

The delineation between physical and social data is important because both types of data are used in open source investigations, but in different ways. Social data heavily filter the reality they represents through individual motivations and online interactions. Physical data, on the other hand, are much less affected by human biases in their creation and distribution, although they are not completely free from bias (i.e. a government's motivation to deploy satellites determines what data are collected and how). Because physical data are less biased, they are predominately used in OSINVs to confirm the validity of events discovered through social data.

Global developments in information and communication technologies have resulted in the constant production of timely, varied data that are increasingly becoming more open and accessible to the public. Whether it be with formal or informal data, physical or social, investigating the intersections and relationships between these data establishes new ways of asking questions about the world and new ways of coming up with answers.

2.3 Open Source Investigations (OSINVs)

Building upon the open data taxonomies established, this section introduces open source investigations (OSINVs) as a tool to leverage open data, address the information gaps resulting from the control of authoritarian regimes, and support efforts to document human rights abuses. OSINVs can be executed using a variety of methodologies and serve a variety of purposes. This literature review examines the available literature on their general methodologies, their limitations, and the motivations behind them.

2.3.1 OSINV Methodologies

Open source investigations (OSINVs) are a process of examining, combining, and analyzing publicly available data to draw novel conclusions. The central pursuit of an OSINV is to find publicly accessible data on an incident or subject, verify the authenticity of the data, use that data to confirm the temporal and spatial dimensions of the incident, and then cross-reference the data with other digital records. As shown in Figure 2, these steps can occur in a cyclical pattern. Steps 2, 3, and 4 cycle back on each other in a reoccurring process of cross-referencing data to verify and confirm the information of other data. This process continues as more data become available and can be used for further validation.

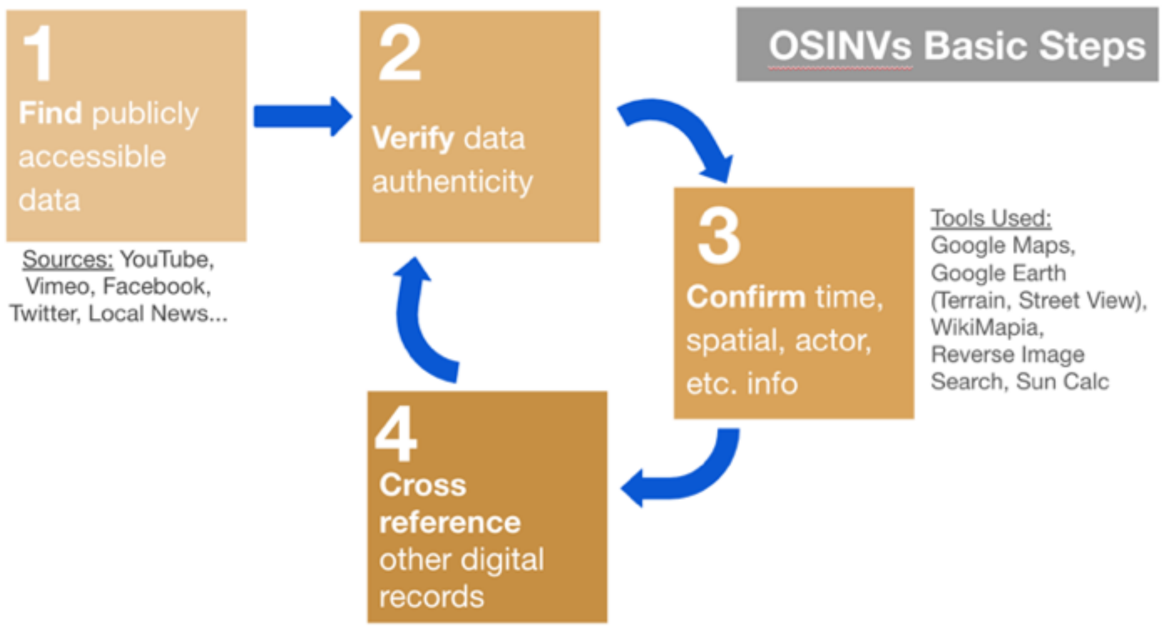

Figure 2. The four main basic steps of the OSINV process (Source: Sam Tingle)

The term 'open source investigation' can be traced back to Eliot Higgins, founder of the citizen journalist news blog, Bellingcat. Bellingcat pioneered this form of online open source and social media inquiry and dubbed it 'open-source investigations' (Beauman, 2018; Keefe, 2013). The term has then since been used by many relevant organizations, including Amnesty International and Human Rights Watch. It is worth noting that open source investigations could also be referred to as open source intelligence (OSINT) investigations, a term also present in the literature. OSINT is commonly used in a national security context and is defined by the National Defense Authorization Act (2006) as 'intelligence that is produced from publicly available information'. While semantically different, investigations that use OSINT are the same as investigations that use open sources. For clarity purposes, within this project only the term open source investigations (OSINVs) will be used.

Open source investigations come in many forms and are conducted by a variety of investigators ranging from professional intelligence agents to curious citizens (Higgins, 2016). Their diversity stems from the breadth of open data that exist. Although, no single methodology for OSINVs is codified, a review of related literature uncovers recurring themes and practices that can be used to better understand OSINV knowledge production and to help structure this study's evaluation of Syrian specific OSINVs.

The literature on open source investigations is divided into three main applications: journalism, human rights monitoring, and national security, with most of the literature focusing on OSINVs for journalism. Across the three divisions, social media data, also referred to as citizen media, are the most prominent source of open data used (Brandtzaeg et al., 2015; Akhgar et al., 2016; Koettl, 2016). Regardless of the open data used, the methodologies discussed in the literature emphasize data verification as the core of OSINVs. Verification refers to the process of establishing the accuracy and validity of both the source of the data and the data content itself (Posetti, 2014). Verification is often the most time-consuming part of the investigation and a rigorous verification process is required for the investigation's findings to be considered legitimate.

While no single open source verification process is established, multiple verification frameworks have been presented. Brandtzaeg et al. (2015) interviewed twenty-four journalists working with social media in news organizations in Europe and documented the verification practices they used, including their tools, processes, and limitations. Each of the organizations the journalists worked with had their own verification strategies, of which Brandtzaeg et al. summarized into five main categories (Table 1). The verification of social media data fell under strategy four, Multimodal Verification, and the specific verification methods Brandtzaeg et al. uncovered are shown in Table 2. The journalists interviewed revealed that videos and photos were the most challenging modalities for them to verify. The study also found that a fair number of the journalists did not have the necessary skills or knowledge of online tools to conduct an independent and timely assessment of photos and videos posted on social media (Brandtzaeg et al., 2015).

Another journalism-focused open source verification study is the Verification Handbook, which aims to provide journalists with guidelines for using user-generated open source content (Silverman, 2016). The book presents four elements necessary for verification (Provence, Source, Date, Location) (Table 1) and introduces verification techniques through case studies (Table 2) (Wardle, 2016; Browne, 2016; Barot, 2016). Similar to the Verification Handbook, Kohler's work also focuses on OSINVs in a journalism context. She conducted interviews with five journalists that had expertise in social media verification and asked them about the tools and processes they use. The results of her survey highlight the time-consuming nature of the geolocation process, the varying motivations of the reporters, and a strong consistency in the geolocation procedural framework used (Kohler, 2017). Details of the methodologies Kholer identifies are shown in Table 2. The OSINV literature related to national security relies on a verification paradigm established in NATO's Open Source Intelligence Handbook (2002) (shown in Table 1) that is very similar to the checklist put forth in the Silverman's Verification Handbook (Gibson et al., 2017).

Differing from journalistic or national security approaches, Koettl (2016) and Kazanksky et al.'s (2019) work looks at OSINVs in the context of human rights and activist applications. Koettl, a senior analyst at Amnesty International, develops an analytic framework for reviewing and assessing open source content specific to human rights fact-finding research. His framework has seven general steps (as shown in Table 1). Within the general steps a detailed verification and geolocation methodology is provided (Table 2). It is the most comprehensive methodology provided in the literature. Kazanksly et al. surveys data activist research projects that mobilize open datasets for social causes. He posits that OSINVs qualify as a type of data activism and surveys three projects that rely on open data. His research highlights how new information environments that subvert traditional corporate and state control are emerging from open data applications, but is vague on the actual methodologies used to leverage open data (Kazanksly et al., 2019). Finally, a working paper by Ambrose and Burns (2018) evaluates the organizations using open data to conduct human rights research, comparing how they conduct investigations. The paper does not go into detail on the methods each organization use, but it does shed some light in the literature on the social systems of the organizations themselves – what communities they emerge from, what their motivations are, and how their organizations are set up (Table 3).

Table 1: Verification strategies and guidelines identified in the OSINV literature

	1	**2**	**3**	**4**	**5**	**6**	**7**
Brandtzaeg et al. Verification Strategy Categories (2015)	*Strategy 1:* Trusted sources	*Strategy 2:* Access to eyewitness and authenticating sources	*Strategy 3:* Traditional journalist methods	*Strategy 4:* Multimodal verification and verification tools	*Strategy 5:* Workaround methods		
Koettl Analytical Framework Steps (2016)	*Step 1:* Material collection and preservation	*Step 2:* Metadata review	*Step 3:* Verification of provenance and source	*Step 4:* Content analysis	*Step 5:* Optional: Expert Analysis	*Step 6:* Integration with other research	*Step 7:* Professional standard consideration
Wardle Verification Checklist (Verification Handbook, 2016)	Item 1: Provenance: Is this the original piece of content?	*Item 2:* Source: Who uploaded the content?	*Item 3:* Date: When was the content created?	*Item 4:* Location: Where was the content created?			
NATO Open Source Intelligence Handbook – Verification Checklist (2002)	*Item 1:* Authority of the Source	*Item 2:* Accuracy (by validating it against other sources)	*Item 3:* Objectivity of the source (possibly with sentiment analysis)	*Item 5:* Currency (provision of a timestamp and the presence of an author)	*Item 6:* Coverage (degree of relevancy)		

Table 2: Verification and geolocation methodologies identified in the OSINV literature

Techniques	Brandtzaeg et al. (2015)	Koettl (2016)	Verification Handbook (2016)	Kohler (2017) – Geolocation Focus
Source Verification	- Check what other videos user has uploaded -Check if trusted news organizations have already republished	- Review account history and activity - Review links to other social media accounts - Reverse image search on account profile - Search Internet for unique video/account ID - Investigate file names of downloaded content - Check cached websites for removed content	- Investigate social profiles - Use website who.is - Research upload history - Online search profile name - Check the profile information: logo, bio, when account was created, location, interests, likes, related accounts, etc. - Check uploader's friends, network, and affiliations - Check theme of uploaded content -Search for earlier content matching keywords - Search Twitter/Facebook for unique video code	
Location Verification	- Cross check location with street view of Google Map	- Check language and dialect (written and spoken) - Match features shown in media to satellite imagery/street-view	- Listen to audio for languages, dialects, slang, background noise, etc. - Check if clothing is regional	- Narrow down geographic region of search iteratively - Look for clues in the media that point to the location (terrain,

		imagery/ open source geo-referenced picture libraries - Features to check include: traffic signs, license plates, names of shops, landmarks, vegetation/ terrain, graffiti, street lamps, conditions of roads	- Is the light artificial or natural? - Cross refence visual evidence with other sources - Clues include: license plate numbers, weather conditions, clothing, signage/lettering, shops, terrain, geological formations, streetscapes, bridges, churches, distinctive streetscapes, advertising billboards	landmarks, distinct buildings) - Compare to aerial and satellite sources, use pen and paper to reorient content to satellite imagery bird's eye perspective
Date/Time Verification		- Shadow analysis - Determine weather by clothing shown and historical weather data - Corroborate time with other open source materials	- Use weather information (use Wolfram Alpha, other uploads from the same day) - Use sunlight and shadow information	
Actor Verification		- Extract uniforms, flags, insignia, weapons, inventory or serial numbers, munitions, license plates or clothing information - Check with publicly available images	- Check clothing	

Other Verification Techniques	- Extract and check thumbnails	- Review metadata for upload time, media timestamps, date, location/ geo-tagging, type of recording device - Watch videos in slow motion - Note if other recording devices are shown, indicating other documenting materials - Consult with experts (weapons specialists, digital forensic experts, etc.)	- Check if the information reported is found anywhere else - Check EXIF/ meta data - Check captions or related labels - Check file extensions in video title to indicate a direct upload from device	- Seek help from Twitter community (locals, specialists, etc.)
Sources Motioned	YouTube, Twitter	YouTube, Twitter, Facebook, WhatsApp,	YouTube, Vimeo, YouKu, Twitter, Google Plus	
Photo Verification Tools	Google Image Search, TinEye, Exif Viewers, Topsy, Tungstene		Google Reverse Image Search, TinEye	
Geolocation Tools	Google Maps	Google Earth, Google Maps Street view, WikiMapia, Open Street Map	Google Maps, Google Earth, Google Earth Terrain View, WikiMapia, BingMaps, Geofedia, Ban.jo (image upload location)	Google Earth, Digital Globe, Google Street View, Panaramio

Other Tools	Storyful		Pipl.com (Cross reference names), LinkedIn, Google Translate, Free-OCR (extract text from an image), Snopes (website for debunking online info)	Twitter, Slack, pen and paper

Table 3: Social framework of OSINV organizations identified in the OSINV literature

Organization Name	Type of Organization	Personnel	Organizational Set Up	Purpose/Work Done	Approach to their Work	Funding
Amnesty International – Amnesty Decoders	International NGO Program	Crowdsourced volunteers supporting Amnesty researchers	Online micro-tasking platform	- Image analysis - Oil detection - Other	Mentality of providing aid	*Not covered in the working paper*
Amnesty International Digital Verification Corps	International NGO Program	Student volunteers and interns from universities and human rights centers with a background in law	Train students in OSINV and verification measures to help Amnesty open source research	- Verify citizen evidence - Identify human rights violations and related implications	Mentality of providing aid	*Not covered in the working paper*

UC Berkely's Human Rights Investigation Lab	Academic institution in California	Majority is student run	Partners with Syrian Archive, The Center for Justice & Accountability, ProPublica, Archer, and Meedan	- Use public social media posts to investigate human rights abuses	Mentality of providing aid	*Not covered in the working paper*
Atlantic Council Digital Forensic Research Lab (DRFL)	Part of a think tank based in Washington, DC	Experts, including former adviser to Obama Administration, former National Security Council adviser	Funded and operated by the Atlantic Council, a think tank involved in international affairs	- Debunk disinformation - Investigate war crimes and identify perpetrators	Mentality of exposing wrongdoings for intervention or legal process	- United Arab Emirates, Ministries of Foreign Affiars (Norway, Sweden), NATO, oil companies
WITNESS Media Lab	Online training facilitator	*Not covered in the working paper*	*Not covered in the working paper*	- Training the public to responsibly film human rights violations	Mentality of exposing wrongdoings for intervention or legal process	*Not covered in the working paper*

Bellingcat	UK-based investigation blog	Full time investigators and volunteers	*Not covered in the working paper*	- Open source investigations - Instructional posts on social media verification techniques - Identifying perpetrators of war crimes	Mentality of exposing wrongdoings for intervention or legal process	*Not covered in the working paper*

2.3.2 Limitations and Suggestions Identified

Throughout the literature, many studies point to limitations in the current verification processes and offer suggestions for mitigating the shortcomings identified.

Koettl (2016) argues that most OSINV that analyze social media focus on individual images or videos, but are unable to analyze large amounts of images or videos in a timely manner. While investigating single videos can provide pieces of evidence for atrocities or war crimes, such narrow investigations are unable to reveal larger trends and patterns. Koettl (2016) puts forth the example of the Syrian conflict noting:

> Looking at the massive number of videos related to the Syrian conflict, the human rights community currently has no suitable tools at its disposal to review, analyze and, most importantly, connect all these videos in order to identify patterns and trends (p. 29).

Many researchers suggest developing improved tools and emphasizing cross specialist collaboration to address these challenges. Brandtzaeg et al. (2015) proposes the development of easy-to-use tools that can structure the overwhelming amount of social media content and support the verification process. His suggestions are echoed by calls for better analytical tools from the journalists that he interviewed. Similarly, Koettl (2016) suggests developing accessible technical tools to automate the analytical process and make it less resource intensive. He also recommends that academics and human rights groups work together to tackle large datasets and to develop approaches that automate some of the processes. Kholer (2016) recommends using online and crowdsourced tools to increase the speed and accuracy of the geolocation process. He also suggests that more trainings be developed to make the analysis of social media a standard skill for interested researchers.

2.4 Implications for this Project

Overall, the literature on OSINVs is fragmented by application and is mainly focused on widely applicable verification guidelines (Table 1). It outlines few comprehensive methodologies (Table 2), does not evaluate the merits of those methodologies, and provides little analysis of the organizations themselves that conduct the OSINVs (Table 3). The literature reveals recurring categories for verification, common methods (geolocation), and typical tools (Google mapping products) that can be used to structure this project's study and evaluation of OSINVs focused on Syria. The literature review reveals gaps in available literature on OSINVs into Syrian airstrikes, as well as a lack of literature that evaluates the organizations conducting the OSINVs and that seeks to understand how they are funded, what expertise they have, their relation to the subjects studied, and any biases they may hold. The literature also lacks a comprehensive evaluation of the methodologies used when conducting open source investigations. A comprehensive evaluation that would address this gap would compare prominent methodologies, compile the processes and tools used, and analyze the workflow for bottlenecks and areas of improvement.

The amount of information available online and access to that information are growing rapidly. Authoritarian regimes have adapted to this changing online environment and have devised ways to manipulate what information is available and how it spreads. OSINVs are emerging as a way to counter this manipulation. OSINVs also leverage the online information environment by assembling disparate open data in ways that lead to new insights. While totalitarian governments restrict access to the events transpiring within their borders and even spread misinformation, OSINVs provide new ways to circumvent their restrictions and authenticate what is happening. However, the current methodologies of OSINVs are limited in their ability to verify the vast amount of open data flowing from conflict areas and authoritarian regimes. The literature review indicates that new methods are needed to structure the overwhelming amount of social data content and to make validation less resource intensive by automating parts of the analytical process. For OSINVs to provide more insight into conflicts and authoritarian regimes, they need new tools that enable a more streamlined, systematic process of validating open data and that support the incorporation of all forms of open data—informal, formal, social, and physical. The development of such a tool is what this project sets out to achieve.

The gaps and limitations identified in this literature review will be used to motivate and guide the following two parts of this project. The first part of the project will examine the methods used in Syrian focused OSINVs to identify methodological areas for improvement. The second part of this project will then address the gaps by creating a new tool.

CHAPTER 3: STUDY OF SYRIAN OSINV METHODOLOGIES

3.1 Introduction

Chapter 3 tests the larger contexts of open source investigations and the controlled information environments of authoritarian regimes within a real-world application by focusing on the Syrian Civil War. Syria is the ideal setting for exploring these contexts and how they interact. First, Syria is in the midst of an eight year long Civil War in which human rights violations worth investigating are occurring. Second, Syria has an authoritarian government that is a major actor in the war. Traditional sources of information from Syria are restricted, and the regime has actively engaged in manipulation of the information environment. Third, Syria's developed Internet infrastructure and widespread use of social media provide new ways of obtaining information about the events of the war. And finally, due to the limitation of traditional information channels and the prevalence of social media, many organizations are engaging in OSINVs to leverage these emerging information sources to better understand the conflict.

This chapter will conduct a study of those OSINVs and the organizations conducting them. The study will fill gaps identified in the literature by exploring OSINVs focused on Syria, the organizations conducting them, and how the methodologies used can be improved.

3.2 Background

3.2.1 Syrian Civil War

In 2011, Syrian civilian protests led to brutal government crackdowns that eventually escalated into country-wide fighting between President Bashar al-Assad's government and rebel groups in 2012. From 2013 to now, government attacks (including illegal gas attacks) have targeted civilians in rebel-held territories. In September of 2014, the presence of ISIS (Islamic State of Iraq and Syria) in the country began to grow and the US became involved by launching limited airstrikes targeted at ISIS militants (Konviser, 2017). The list of various groups involved in the fighting is dynamic, but a majority of reports on the war will group the combatants into four broad categories: the Assad government of Syria, which is backed by Russia and Iran; the Rebels, consisting of a loose group of insurgents, which has been supported by the US, Turkey, and Saudi Arabia; the Kurdish militias, which has also received US support; and extremist groups, largely ISIS (Gilsinan, 2015).

The drivers of involvement for each of these groups varies from maintaining control of one's regime (i.e. Assad), seeking to overthrow an authoritarian regime to replace with a democracy (i.e. some elements of the insurgency), seeking to establish a moderate Sunni caliphate (still other elements of the insurgency), establishing control through extremism (i.e. ISIS), and seeking regional autonomy (i.e. the Kurds). Further, the alliances between various groups shift and change rapidly, exemplified by the US decision in 2019 to no longer support the Kurdish fighters in the northeastern region.

3.2.2 Airstrikes in Syria

The use of unmanned airstrikes has increased worldwide in warfare. Airstrikes are one of the most frequently used tactics of both the American and Russian militaries as they are relatively cheap, precise, and present an ideal alternative to deploying soldiers. In the Syrian Civil War, they are commonplace and are carried out by the major militaries involved.

Since 2011, the Assad government has launched numerous air attacks on civilians and civilian infrastructure in opposition-held areas (Kassab, 2018; HRW World Report, 2018). After providing military aid behind the scenes, Russia actively entered the conflict on September 20, 2015 in support of the Assad regime. Together, the Russian-Syrian military coalition continued to conduct indiscriminate air attacks on civilian infrastructure. Although evidence has been reported connecting multiple Russian-Syria airstrike offensives to the targeting of schools and hospitals, Russia rejects all war crime allegations and claims it did not target such structures (BBC, 2016; HRW World Report, 2018).

The US has been mainly involved in the war through its financial and armed support of a coalition of different actors called the Combined Joint Task Force Operation Inherent Resolve (CJTF-OIR). As part of the CJTF-OIR, numerous countries conduct airstrikes in Syria including the United States, Australia, Bahrain, Canada, Belgium, France, the Netherlands, Jordan, Saudi Arabia, Turkey, the United Arab Emirates, and the United Kingdom.

The United States' participation has led to an increase in numbers of civilian causalities from airstrikes. In the Obama administration, more commanders within the CJTF-OIR were given authority to call in strikes. When Donald Trump took office, he grew that trend, resulting in increased numbers of overall strikes (Watson, 2017). Like Russia, the US coalition members have been less than forthcoming in acknowledging the impacts of their air campaigns and have even been accused of falsifying data to conceal their actual number of civilian deaths (Amnesty International, 2018). The Pentagon reports airstrikes by the American-led coalition fighting the Islamic State killed at least 1,257 civilians in Iraq and Syria as of the end of January 2019 (CJTF- OIR Monthly Civilian Casualty Report, 2019). Airwars, a university-based monitoring group, estimates that those strikes killed at least 7,500 civilians in those countries, more than five times the Pentagon's numbers (Airwars, 2019). See Figure 3.

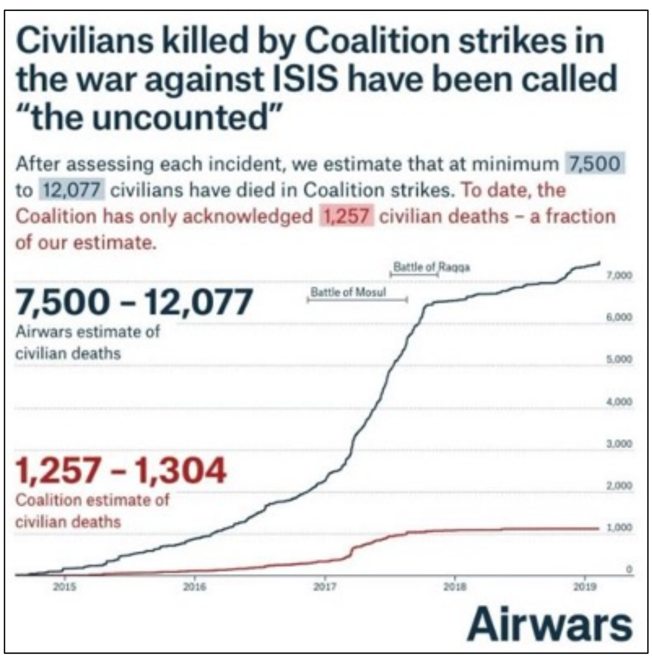

Figure 3. A chart comparing the official number of civilian casualties reported by the US Coalition and the number estimated by monitoring groups (Airwars.com)

The US is not the only state within the coalition denying the full impact of their airstrike campaigns. The United Kingdom's Ministry of Defense, the second most active member of the US coalition force, claims that its airstrike activity during the battles for Raqqa in 2016 and 2017 resulted in no civilians harmed (Imhof, 2018). However, an Airwars report found that to be statistically impossible given the intensity of fighting, the extensive use of explosive weapons, and the significant civilian populations known to have been trapped in the city (Oakford, 2018).

The devastating attacks from both the US coalition and Russian-Syrian forces have been carried out with little accountability and transparency. For example, few specifics exist on the battle for Raqqa which marked the most significant periods of both destruction and civilian harm in the fight against ISIS in the region. According to reports released by a monitoring group, an estimated 2,400 civilians were killed in Raqqa, and almost 70% of Raqqa's urban area was destroyed or rendered uninhabitable (Imhof, 2018). Understanding the human and infrastructural toll caused by the devastation of such an offensive (to prosecute war crimes or to inform the public) requires objective and validated measurement of the destruction. This objective measurement is not provided by the biased interests of state governments. For example, the UK Ministry of Defense's internal review process on civilian harm tends to concede only events which are observable – most often via imagery captured by aircraft that show civilians visibly present at or near the target area (Oakford, 2018). Yet most civilian harm in Raqqa occurred in less visible spaces, such as when buildings collapsed upon those sheltered inside. Other sources of information that challenge the state's narrative are necessary to provide more accurate measurement of the harm caused by the actions of the militaries involved.

Organizations that investigate and document the impact of airstrikes pressure militaries to improve how they track, assess, and report civilian casualties. Without these organizations pushing for accountability, international military forces have little consequences for their airstrikes wrongly targeting noncombatant civilians. Without any consequences for getting it wrong, there are no incentives to try to get it right (Oakford, 2017). The role of pushing state militaries toward accountability has typically been held by journalists. However, Syria's banning of foreign journalists (among other obstacles) limits their ability to document these events. Open source investigators that utilize open data from inside Syria present a potential solution. However, the next section presents evidence that this form of intelligence gathering stemming specifically from social media comes with its own limitations.

3.2.3 Social Media in Syria

On-the-ground journalism coverage of the Syrian Civil War faces many obstacles. Rebel-held areas are extremely dangerous and both foreign and Syrian journalists have been routinely targeted and murdered by rebel groups. The regime of Bashar al-Assad effectively banned the international press in 2013 and repeatedly denies press visas to foreign reporters, leading the Committee to Protect Journalists to declare Syria as one of the most dangerous datelines in the world (Keefe, 2013; Malsin, 2014). Although access for journalists is limited, new alternative information sources are emerging online in a variety of forms that provide details of events as they unfold on the ground.

Syria's Civil War has been deemed the most socially mediated civil conflict in history, with online social media allowing citizens to share information in the absence of a free press. An exceptional amount of what the outside world knows—or thinks it knows—about Syria's conflict has come from videos, analysis, and commentary circulated through social networks (Lynch et al., 2014). The user-generated media has already proven to be valuable in the absence of a strong on-the-ground journalist presence. After Sarin gas was used to attack Damascus in August 2013, individuals in the targeted areas shared hundreds of videos, photographs, and text posts on Twitter, Facebook, and YouTube. Since foreign journalists did not have access to the areas attacked, these social media posts were the only source of first-hand accounts of the attacks (Higgins, 2016).

Although, social media is playing an ever-increasing role in shaping the reality for the rest of the world of what is happening on the ground, questions arise around how credible social media is as a primary source of information. Since few journalists or international observers are located in Syria to check the validity of claimed events, digital verification methods, like OSINVs, are needed to assess the validity of and overcome the systematic limitations inherent to the torrential flow of online information.

Social media is a group of Internet-based applications (i.e. YouTube, Facebook, Twitter, Instagram) that allow users to create and exchange content in the form of images, videos, text, and audio (Kaplan & Haenlein, 2010). While Syria's social media may seem like an unmediated source of information that provides an accurate account of the conflict, that could not be further from the truth. Syria's social media exists within a subjective online geography that diverges along linguistic boundaries, clusters together thematically, and is curated by individuals. Syria's social media is not an unmediated information source, but instead contains constructed narratives and skewed presentations of reality (Lynch et al., 2014).

First, language segments the social media landscape, dictating how information flows and reaches certain audiences. Early in the Arab Spring, English-language social media played a crucial role in transmitting the regional uprisings to a Western audience. However, by June 2011, Arabic had overtaken English to dominate the online discourse and the social media landscape began dividing into local and identity-based communities. Now, the English-language Twitter conversation interacts largely with itself, creating an echo chamber unaware of the broader Arabic discourse (Lynch et al., 2014). This segmentation has resulted in insular regional and linguistic groups that each discuss different topics, circulate different imagery, and impede information from crossing linguistic and cultural boundaries.

Syria's social media landscape is vast, varied, and complex. Linguistic ability, contextual knowledge, and a lot of time is necessary for individuals to make sense of it. That is why general audiences tend to rely on a selected group of online Twitter users and news hubs to sort through, interpret, and synthesize online information into coherent material relevant to their interests. These curators, both media organizations and individuals, often carry their own biases in how they cover a story or in how they privilege one side's narrative while skeptically reporting another's (Lynch et al., 2014).

Syria's social media also perpetuates biases that have long existed in coverage of conflict. News media has customarily been biased toward covering violence and conflict at the expense of showing peaceful protest and diplomacy. For example, an editor at Global Voices Online notes that although most of Syrian society was aiming for peaceful routes to revolution early in the conflict, their rejection of rebel groups' violent strategies did not receive coverage because they did not produce the kind of compelling videos attractive to media outlets (Lynch et al., 2014). This predisposition in the news media for violence creates an incentive for groups in Syria to produce (or manipulate) online videos to highlight such content and advance their cause, thus creating distorted views of the situation on the ground. There have many cases where manipulated photos and untrue stories, spread via social media, are picked up and distributed by news agencies (Schifferes & Newman, 2013). In one instance, a video that claimed to show Syrian soldiers beating detained protesters was aired by several major news networks and ran by Reuters as footage from Syria. However, it turned out to be from Lebanon and was being misrepresented online by a Syrian activist (Shelton, 2012).

Contrasting the excessive sharing of events for biased purposes, some attacks and events may be under-shared and not reach online audiences. Smaller-scale protests or airstrikes that do not have an outsize impact tend to receive less media coverage. Additionally, events occurring in more dangerous or restricted areas (i.e. ISIS-controlled areas or areas under siege), may have even less online presence. For instance, medical facilities targeted in Eastern Ghouta tried not to publicize information about attacks out of fear of retaliation, resulting in minimal presence online.

Videos shared online are also used by militaries to create a skewed narrative of the war. The state actors of Russia and the CJTF-OIR publish videos of the airstrikes they conduct to show the success of their airstrike campaigns. The Russian Ministry of Defense uploads airstrike videos to their official YouTube channel, while the CJTF-OIR publishes videos of their airstrike campaigns on the Defense Visual Information Distribution Service (DVIDS) website. The videos published by both sides of the conflict have been selected to provide a biased presentation of their campaigns as precise and with little civilian impact. Their videos present a narrative that greatly deviates from the reality on the ground (Khan & Gobal, 2017).

The geography of Syria's subjective social media landscape combined with news media's tendency toward sensationalist narratives have the potential to create a lot of misinformation. This does not mean that the rich open data source of social media should be ignored. However, it does point to the need to develop systematic procedures and tools to guard against recognized fallacies. It points to the need for methods that can establish data credibility by rooting online information in physical reality. To leverage social media data as evidence to prosecute war crimes or to uncover human rights violations, rigorous verification of the social media and the events they depict are required (Higgins, 2016). OSINVs are a powerful tool for such verification and can be used to address the subjectivity and manipulation of Syria's social media.

3.3 Methodology

To address the gaps identified in the OSINV literature, an evaluation of five organizations conducting OSINVs into the Syrian conflict was carried out. The information collected from each organization was contrasted with one another in terms of techniques, organizational structure, and procedural limitations. Overarching themes and practices are outlined, and reoccurring gaps highlighted. The findings of the evaluation inform the creation of a technical tool and are vital in ensuring that the created tool can be integrated into existing social and technological structures.

3.3.1 Organizations Studied

The evaluated organizations were selected based on two criteria: their use of predominately open source data to conduct their investigation and a focus on the Syrian Civil War. Led by these two criteria, five organizations were chosen: the civilian journalism blog, (1) Bellingcat; the independent conflict monitoring groups, (2) Airwars and (3) the Syrian Archive; an NGO, (4) Physicians for Human Rights (PHR); and a large international organization, (5) Amnesty International. The group of organizations is diverse in their motivations for conducting OSINVs, the resources and expertise they have available, and the audiences they target with their work.

3.3.2 Evaluation Criteria

As previously stated, the categories used to evaluate the organizations and the OSINVs they conduct are modeled from Table 2 and Table 3 developed in the literature review. Table 4 is used to examine the various verification and geolocation techniques used. It includes more comprehensive criteria than the table developed in the literature review. Table 4 outlines the following categories:

- Source verification techniques: how the identity of the source is confirmed
- Sources used: where the open data are coming from
- Location verification techniques: how the location depicted in the data is determined
- Geolocation clues used: what visual information is used to determine the location
- Geolocation tools: any tools that were used in the geolocation process
- Date/time verification techniques: how the date and time the data was captured are determined
- Actor verification techniques: how the identity of the individuals depicted or the perpetrators of the acts depicted are determined
- Other verification techniques: any other techniques used
- Photo verification techniques: techniques used that are specific to verifying still images
- Other tools used: any other tools used
- Metadata collected: data about the data (i.e. video upload time) that can be discovered using open data sources

- Availability of data: how can the OSINV findings and processes be accessed by the public
- Methodology gaps self-identified: gaps in the process that are identified by the organizations

Table 5 is used to study the social structure of the organizations conducting the investigations and includes the following categories:

- Type of organization: NGO, INGO, academic institution, think tank, government entity, etc.
- Organization location: where is the organization headquartered
- Personnel training/expertise: what is the training and background of the members conducting OSINVs
- Number of employees: how large is the organization, how many individuals are conducting OSINVs
- Organizational set up: how the organization is structured (i.e. physical offices, online presence, crowdsourced)
- Partners: who the organization partners with
- Subject of investigations conducted: what are they investigating (i.e. airstrikes, massacres, illegal trafficking, etc.)
- Type of investigation: what type of investigation is conducted (i.e. compiling data, image analysis, video analysis, geolocation, etc.)

- Funding sources: how are they funded
- Motivation for work: why they are conducting their investigations, what is their mission statement
- Geographic areas of interest: in what areas do they conduct their research
- How findings are shared: where and how can the findings of the investigations be accessed by the public
- Relationship to Subject Studied: what are the personal or professional connections between the individuals conducting the investigations and the events and people being investigated

3.3.3 Process

The research on the organizations and their methodologies primarily consists of examining available online information, including organizational websites, methodology documentation, related white papers, published articles, and blog posts.

3.4 Results

The findings from the study are organized into the relevant tables (Tables 4 and 5 below). Recurring procedural themes are identified across each of the organizations, and prevalent methodological bottlenecks are summarized below.

Table 4: Categories to evaluate Syrian OSINV methodologies

TABLE 4	**Bellingcat**	**Airwars**	**Syrian Archive**	**Physicians for Human Rights (PHR)**	**Amnesty International**
Source Verification Techniques	Cross referencing between sources, checking people and phone number registries, check with company registries, check presence of bots with bot checking tools (TwitterAudit)	Follow up with belligerents when possible, cross reference events with official military reports and with biographical, photographic, or video evidence from the ground	Verify how long the source has been reporting, check where the source is based, check the logo consistency, check if the content is original, has it been used by the Syrian Archive before, rely on a team of local citizen journalists They have created a database of credible sources for content and credible sources for verification	Cross reference reports with published reports of similar attacks from sources like the UN, governments, news agencies, journal articles, dissertations, social media, sites. Reviewed by a panel from PHR judging the presentation of consistent relevant facts, level of detail, and any bias Strives to corroborate incidents with at least three independent sources	Cross reference with other media and local testimonies, interviews with locals, experts, and officials General Google searches to corroborate information
Sources Used	YouTube, Twitter, LiveLeak, Instagram, Vimeo, Telegram, TikTok, Tumblr,	Airstrike reports and military briefings from US-coalition, Russian	International and local media outlets, human rights organizations or	Published reports from UN, governments, news agencies, NGOs,	Testimonies from people on the ground, Social media (Twitter, Facebook, etc)

	Snapchat Map, Reddit, LinkedIn, news organizations	Military, local Arabic media, social media, NGO reports, local and international news agencies, YouTube, Twitter, militant propaganda, AFRICOM	citizen reporters on Twitter, Facebook and Telegram	social media and video sites Medical organizations and personnel in the field Violations Documentation Center of Syria Submitted information from medical workers in the region	
Location Verification Techniques	- Map and mark landmarks in the area using Google Earth -Attach street view images of the landmarks to the Google Maps points and use them as a set of reference images - Use handwritten sketches of the visible information and road networks to help search through satellite imagery -Use audio clues (dialects and tones of Arabic)	- Due to the volume of airstrikes they archive and record, Airwars does not always geolocate the coordinates of the attack, but instead rely on the location provided by the military report.	-Compare reference points with satellite imagery -Reference the dialect and accent of the Arabic spoken to specific regions -Contact the source direction or check with other journalists	-Communicate with field sources throughout Jordan, Syria, and Turkey – in both Arabic and English – via Skype, telephone calls, and emails	-Use the Digital Verification Corps to analyze open source imagery and videos -Compare with Google Earth satellite imagery

	-Geo based search engines (ex. LiveUAMap, GeoNames) -Explore online satellite Imagery databases				
Geolocation Clues	Building, tree, dirt track, orchard, electricity pylon, mosques, tall buildings, road characteristics (width, media, pavement, color)	Building damage, information from military reports	Buildings, mountain ranges, trees, minarets, accents	Indication of medical use, interior signage, medical equipment, patients	Roofs, doorways, building materials, building shape
Geolocation Tools	Google Earth (terrain view, streetview), Yandex (specifically for Russia street view), Baidu (for Chinese street view), OpenStreetCam, OpenStreetMap, Wikimapia, QGIS, Mapillary, ESA Earth Online, NASA Earth Data, Radiant Earth, Sentinel Hub Playground	Satellite imagery, local reports	Google Earth, Microsoft Bing, Digital Globe	A network of contacts on the ground	Satellite imagery, Google Earth, a crowd sourced network of volunteers, YouTube Geosearch Tool, Wikimapia, GeoNames, Open Street Map, Tweetdeck, WhoPostedWhat
Date/Time Verification Techniques	- Use direction and length of shadows -Compare with historical imagery	- None provided	- Cross reference the publishing date with related reports from local media, human rights	- None provided	-Compare with existing photos, videos, and historical satellite imagery

			organizations, and from a network of citizen reporters		-Wolfram alpha, SunCalc, Time Zone converter
Actor Verification Techniques	-User online people search registries, analyzing uniforms, analyzing weapon types and labeling	- Identify the victims of attacks via social media claims, local media organizations, activists, and monitors like the Violations Documentation Center	- Analyze regional accents and dialects	- None provided	- Analysis of uniforms worn, contextual clues in speech, type of weapons used -Pipl.com, Who.is profile searches
Other Verification Techniques	- Archive videos and webpages used -Sketching out the location of buildings shown in videos to orient the filming	- Archive all reports on a database that compiles related news and social media reports about each attack	- Scrape and store all the original content from corporate platforms and from social media platforms -Contact the source directly to confirm the location -Consult existing network of journalists inside and outside Syria	- None provided	- Create panoramas from video stills -Archive videos
Photo Verification Tools	- Reverse image search (for logos or for online posts)	- None provided	- Panoramio	- None provided	- Google Images, RevEye Reverse Image search

Other Tools Used	Keep, Meedan (archiving), Google Images, TinEye, Sun Calc, SearchFace, Flight Radar 24, Radar Box, Online privacy tools, Data visualization tools, company registries, website and IP address trackers (an exhaustive list can be found here)	None provided	Stack, SugarCube, Google Sheets, Check, Enigio timestamp	None provided	YouTube data viewer, Hugin, P-code Atlas of Syria from MapAction, googleDorking, YouTube Geosearch Tool, Tracker, VLC media player, Google Translate, YouTube's blurring feature
Metadata Collected	The collect tags on location (regional and country) and subject matter of each investigation blog post to organize the content on their website	Grading system of allegation veracity (Confirmed, Fair, Weak, Contested, Discounted, No Civilian Harm Reported), photographs and biographical information of the victims	Weapons used, type of attack, category of human rights violation, location, date, video origin, upload date and time, uploader's name, title and description of the video	Medical facility name, town, and governorate; date(s) of attack; perpetrator; mode of attack; weapons used; material damage; injuries or casualties; history of the militarization of a facility or non-medical use; and hyperlinks to all sources relied upon which document the attack	None provided
Availability of Data	The findings of their investigations are published publicly on blog posts. They do not offer a centralized	The data used and the findings of their investigations are compiled into a central searchable	A public searchable database, but the underlying data is	A public visualization, but the underlying data is not available for export	The findings of the investigations are published in articles included on the Amnesty Website and

	dataset of their investigative findings.	database. The also publish in-depth reports and monthly and annual assessments	not available for export		sometimes in depth reports. The data used to evidence the study is not always provided.
Methodology Gaps Self-Identified	None provided	Often unable to follow up or to further verify every claim Difficulty connecting the published military reports to the location of the actual airstrike Often cite limited information available to Airwars as a reason for not verifying the location further than town name provided by the military report	Due to time and capacity limitations means all incidents cannot be analyzed in-depth.	Relies primarily on open sources, which means it is often difficult to verify smaller-scale incidents which tend to receive less media coverage Difficult to verify incidents that occur in more dangerous or restricted areas	None provided

Table 5: Categories to evaluate the social frameworks of organizations conducting Syrian OSINVs

TABLE 5	**Bellingcat**	**Airwars**	**Syrian Archive**	**Physicians for Human Rights (PHR)**	**Amnesty International**
Type of Organization	Citizen journalist blog	Not for profit research project	Human rights activist collective	NGO	International NGO
Organization Location	Online, no physical location, contributors from over 20 countries	Headquarters in London, UK with staff based in MENA, Europe, North America	Berlin, Germany, with network of on the ground citizen journalists and local search-and-rescue actors	Headquarters in NY, With offices in Boston and Washington, Partners around the world	Global, headquarters London, UK
Date Founded	2012	2014	2011	1986	1961
Personnel Training	Run training workshops, have many analysts with extensive open source backgrounds	No standardized training for analysts mentioned.	No standardized training, but team members have previous open source experience at human rights organizations	No training for open source analysis listed	Analysis are volunteers that are trained in open source investigation methods

Staff Expertise	Journalists, ex-army officers, IT specialist, translators, PhD/masters students, private consultants	Newspaper journalists, editors, Current PhD/ Masters students in Journalism/ Media/ international Affairs	Front end developers, medicine, Arabic editors, human rights research	Torture documentation expert, Forensic medical expert, Medical expert, Chemical weapons expert, Country experts	Students with a background in human rights law, some are professional investigators and weapons experts
Number of Employees	10 staff, 80 contributors	14 staff, unknown number of volunteers	7 member staff	~60 member staff	3 million supporters, members and activists in over 150 countries Between 1000 and 5000 employees
Organizational Set Up	Independent international collective of researchers, investigators and citizen journalists, collaborative model	Team of researchers and analysts based in the Middle East, Europe, North Africa and North America that work under an organizational team in the UK	Team is based mainly in Europe and is comprised of analysts and developers lead by a director	Comprised of a board of directors, a global network of scientific and medical experts, and an administrative staff	Core group of employees is the International Secretariat, which is supported by regional sections, community groups, and individual donors
Partners	International Criminal Court's (ICC) Technology Advisory Board, Open Information Partnership, Global Investigative Journalism Network, Global Legal Action	Department of Media and Communications at Goldsmiths, University of London, Every Casualty's Casualty Recorders Network	The United Nations Office for High Commissioner of Human Right: Inquiry on Syria, Witness, Bellingcat,	German Federal Foreign Office for the Syria Health Facilities Mapping Project	Future Learn, UC Berkeley, University of Essex, University of Pretoria, University of Toronto

	Network, Forensic Architecture, Transparency International, Newsy		Enigio, Meedan, Birmingham City University, Amnesty International Digital Verification Corps, Human Rights Center UC Berkeley School of Law, Tactical Technology Collective, Human Rights Watch, The Syrian Network for Human Rights, Sham News Agency, Baladi News Agency, Step News Agency		
Subject of Investigations in Syria	Crimes against humanity, tracking the use of chemical weapons, environmental incidents, destruction of cultural sites, military movement, the	Civilian non-combatant casualties resulting from international military actions – primarily air and artillery strikes, research into archival official military reports, US counterterrorism actions	Weapons used, type of attack, category of human rights violation	Assault on health care facilities and personnel	Civilian casualties, refugee rights, destruction of civilian objects

	development and use of chemical weapons, arms trade, disinformation campaigns				
Type of Investigations	Narrowly focused investigations of singular incidents or a small group of related incidents	In depth investigations, monthly/annual conflict monitoring	In depth investigation of specific events, basic geolocation, tracking supply shipments	In depth case studies, mapping	On the ground interviews, geospatial analysis
Funding Sources	Porticus, Adessium, Open Society Foundation, National Endowment for Democracy, Pax for Peace, Dutch Postcode Lottery, 35% of budge comes from training workshops	Joseph Rowntree Charitable Trust, Open Society Foundations, Stichting Democratie en Media, Reva and David Logan Foundation, J. Leon Foundation	Alternatives international, Open Knowledge Foundation Germany	Donations, Open Society Awards	Member donations
Motivation for Work	Expose conflict, crime, and human rights abuses	Tracking and archiving international military action in conflict zones, research of datasets	Visually document human rights abuses to support human rights campaigns and legal cases	Promote accountability for violations of international humanitarian law in accordance with beliefs in medical ethics	Help individuals claim human rights
Geographic Area(s) of Interest	Global: Yemen, Syria, Iraq, Ukraine, Russia, China, Venezuela,	Iraq, Syria, Libya, Yemen, Somali, Pakistan	Syria	Global	Global

	United Kingdom, Mexico, etc.				
How Findings are Shared	Publicly, in blog posts online	In publicly available reports and in a large searchable, filterable database of archived incidents	Via a public database and online reports	Online publicly available posts	Published reports
Relationship to Subject	The researchers are mainly from foreign universities around the world. None were found to be Syrian nationals. Most are studying subjects related to International Affairs or the Middle East at a graduate level.	Members of the research team include an individual based in the country being studied (Iraq) and a refugee that from Aleppo, Syria. The other researchers are from Europe. They also work closely with casualty monitors in country.	The majority of the team members are based in Europe with no discernable personal ties to the Syrian Conflict	The majority of the team members are based in the US with no discernable personal ties to the Syrian Conflict	Has the resources to work closely with individuals on the ground in Syria

3.4.1 Organizations

<u>*Bellingcat*</u>

Bellingcat is an international collection of citizen journalists that use open source data to probe a variety of subjects, including airstrikes and the use of chemical weapons in Syria. When Bellingcat was started by Eliot Higgins in 2014, it pioneered the OSINV approach of using publicly available data and citizen journalist analysis, and it has led the way in the use of open source investigations in examining the conflict in Syria. Out of the organizations examined, Bellingcat's contributors have the most expertise in geolocation and provide the most extensive documentation of tools and procedures used. One of the most prominent tools used by Bellingcat to geolocate events is Google Earth, which is used for a variety of purposes as shown in Figure 4. Google Earth imagery comes from a collection of different sources (Centre National d'Etudes Spatiales (CNES), Airbus, DigitalGlobe, LandSat, Copernicus and Planet Labs) that each have varying spatial resolution and are available on Google Earth over irregular time periods (i.e. 6 years apart). In addition to using an extensive collection of tools, Bellingcat investigators employ a diverse set of techniques when investigating. The particular application of online tools and the methodological approach used by Bellingcat researchers varies depending on the subject of the investigations, as well as on the academic and professional background of the investigator. Even with this expertise and extensive knowledge of online tools, Eliot Higgins explains that the process of geolocation can be tough and time consuming, noting that some photos from

Bellingcat investigations have taken as long as two years to geolocate (Beauman, 2018).

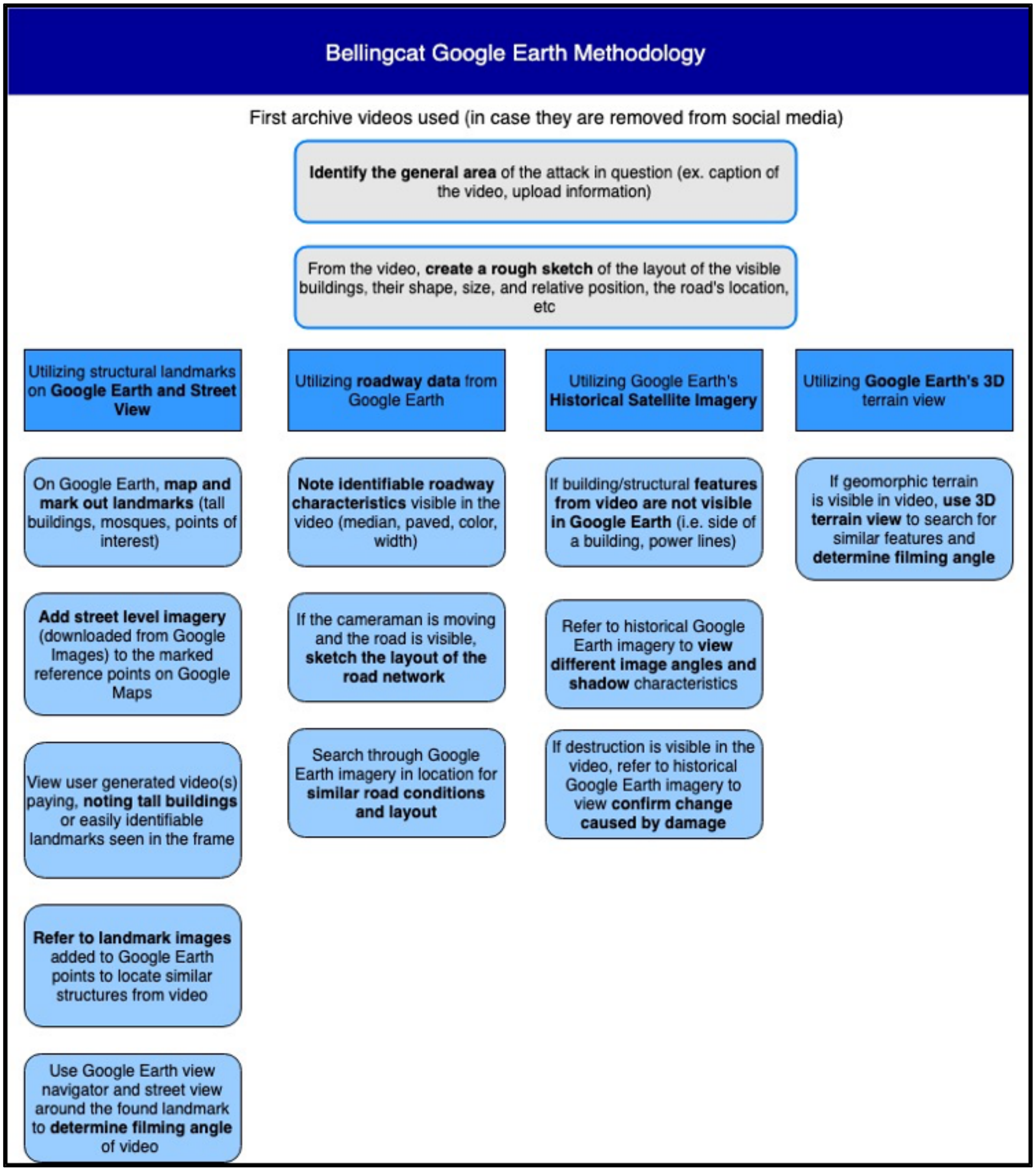

Figure 4. Overview of how Bellingcat employs Google Earth in its geolocation methodology (Source: Sam Tingle)

Airwars

Airwars is a research project focused on documenting civilian casualties resulting from international military action. Their geographic focus is on Syria, Iraq, and Libya. Unlike Bellingcat investigations that may stem from social media or local news reports, Airwars investigations begin with official state reports on military actions. Airwars analyzes official reports from the US Coalition, as well as from the Russian Military, and tracks their reported civilian casualty claims against the reports of local Arabic-language media, social media sites, NGO reports, and occasionally militant propaganda.

Whereas Bellingcat's is often narrowly focused on gathering information on a specific event, Airwars functions more as an archive that aims to collect and organize as much publicly available data on as many civilian casualties as possible. The organization has identified a startling disconnect between official military counts of civilian casualties and numbers reported from the field. Airwars collects and organizes open source information to bridge that gap and to force militaries to concede the impact of their military actions. Airwars assess the validity of each claim using their own grading system: Confirmed, Fair, Weak, Contested, Discounted. An example of an Airwars database entry in shown in Figure 5. The entry is for an attack that killed a family of five. It compiles seven sources across Facebook and Twitter that corroborate the event and also includes information released by the Coalition about its airstrike activity in the area and on dates that match the other sources. Airwars grades the strike as “Fair” and records the location as coordinates of a neighborhood where the strike was reported to have occurred. Airwars lacks the resources to geolocate the specific coordinates of each strike, and instead often provide the town or village location that is published in the military report.

CS1915

PREVIOUS CODE
S1791

INCIDENT DATE
March 15–21, 2019

LOCATION
مخيم الباغوز, Al-Baghouz camp, Deir Ezzor, Syria

GEOLOCATION
34.447579, 40.953426

GEOLOCATION ACCURACY
Neighbourhood/area

Web link

Airwars assessment

Local sources reported that a family of five including three children were killed in alleged Coalition bombing in Al-Baghouz camp days several days before March 20th. The exact date they were killed remains unknown.

Ahmad Abd Al Rzzaq said: "My cousin Louay Abdel Wahab Al-Hamad Al-Ibrahim Al-Abdullah and his wife Nadra Abdul Aziz Al Thabet Al Khudur, and their three sons Khalil, Isra and Yaqoout" were killed – but said that they died in Hajin which would mean they were killed before December 15th 2018.

But all other sources said that the family died at Al Baghouz camp. Ahmad Abd Al Rzzaq noted that the family were refugees from Hajin, though @DeirEzzor24 said that they were from Al Mayadin city.

Airwars can't confirm any more details at this time.

The local time of the incident is unknown.

The victims were named as:

Family members (5)

- Louay Abdel Wahab Al-Hamad Al-Ibrahim Al-Abdullah, adult, male, killed
- Nadra Abdul Aziz Al Thabet Al Khudur, adult, female, Wife of Louay Abdel Wahab Al-Hamad Al-Ibrahim Al-Abdullah, killed
- Khalil, child, male, Son, killed
- Isra, child, male, Son, killed
- Yaqoout, child, male, Son, killed

Geolocation notes (0) [↑ collapse]

US-led Coalition Assessment:

Suspected belligerent	US-led Coalition
US-led Coalition position for incident	Not yet assessed

Original strike reports

US-led Coalition

"Between March 10 - 23 2019, CJTF-OIR conducted 250 strikes consisting of 398 engagements against Daesh targets in Syria and Iraq.

In Syria, CJTF-OIR conducted 193 strikes consisting of 338 engagements, engaged 346 Daesh tactical units, and destroyed 104 vehicles, 63 supply routes, 39 fighting positions, 31 vehicle borne improvised explosive devices, nine tactical vehicles, six fuel tankers, four weapons caches, two command and control nodes, one tunnel, one tanker for petroleum oil and lubricants, one mortar system, and one checkpoint."

Summary

Civilians reported killed (3 children, 1 woman, 1 man)	5
Airwars grading	Fair
Suspected belligerent	US-led Coalition

Sources (7) [↑ collapse]

Al Mayadin city	FACEBOOK, ARABIC	Archive
Ahmad Abd Al Rzzaq	FACEBOOK, ARABIC	Archive
Deir Ezzor live	FACEBOOK, ARABIC	Archive
Mohammad Jassem	FACEBOOK, ARABIC	Archive
Alsharqia24.media	FACEBOOK, ARABIC	Archive
Furat river network	FACEBOOK, ARABIC	Archive
@DeirEzzor24	TWITTER, ARABIC	Archive

Figure 5. Airwars investigation of a 2019 Syrian airstrike

Syrian Archive

Similar to Airwars, the Syrian Archive maintains a database of media that depicts human rights violations with the goal storing evidence for future legal cases. Unlike Bellingcat or Airwars, the Syrian Archive is a very small organization (only seven team members) and is focused solely on Syria. Their database has archived 1.5 million pieces of digital content, of which around 4,400 have been fact-checked (Schaer, 2018). An example of an entry in their archived is shown in Figure 6. The Syrian Archive recognizes that social media and news coverage is not complete and many incidents of the war have been missed or under-reported. The goal of their publicly available and searchable archive is to raise awareness and preserve evidence of all attacks and violations, even ones that go unnoticed. Unlike some of the other organizations evaluated, the Syrian Archive has published a clear methodology that outlines the extensive network of local sources used, the technical details of their archival process, their metadata scheme, and their rigorous verification process.

Each video published in their archive goes through basic geolocation to verify that it has been captured in Syria. When the Syrian Archive team conducts an in-depth verification of an incident beyond the basic geolocation, they use similar geolocations techniques as Bellingcat (i.e. starting with landmarks, confirming damage with historical Google Earth imagery). One difference between the two organizations, however, is that compared to Bellingcat's broad array of sources, the Syrian Archive seems to rely primarily on local sources: civilian Facebook posts, local militia websites, local news Facebook posts, local YouTube uploads, and local media center uploads.

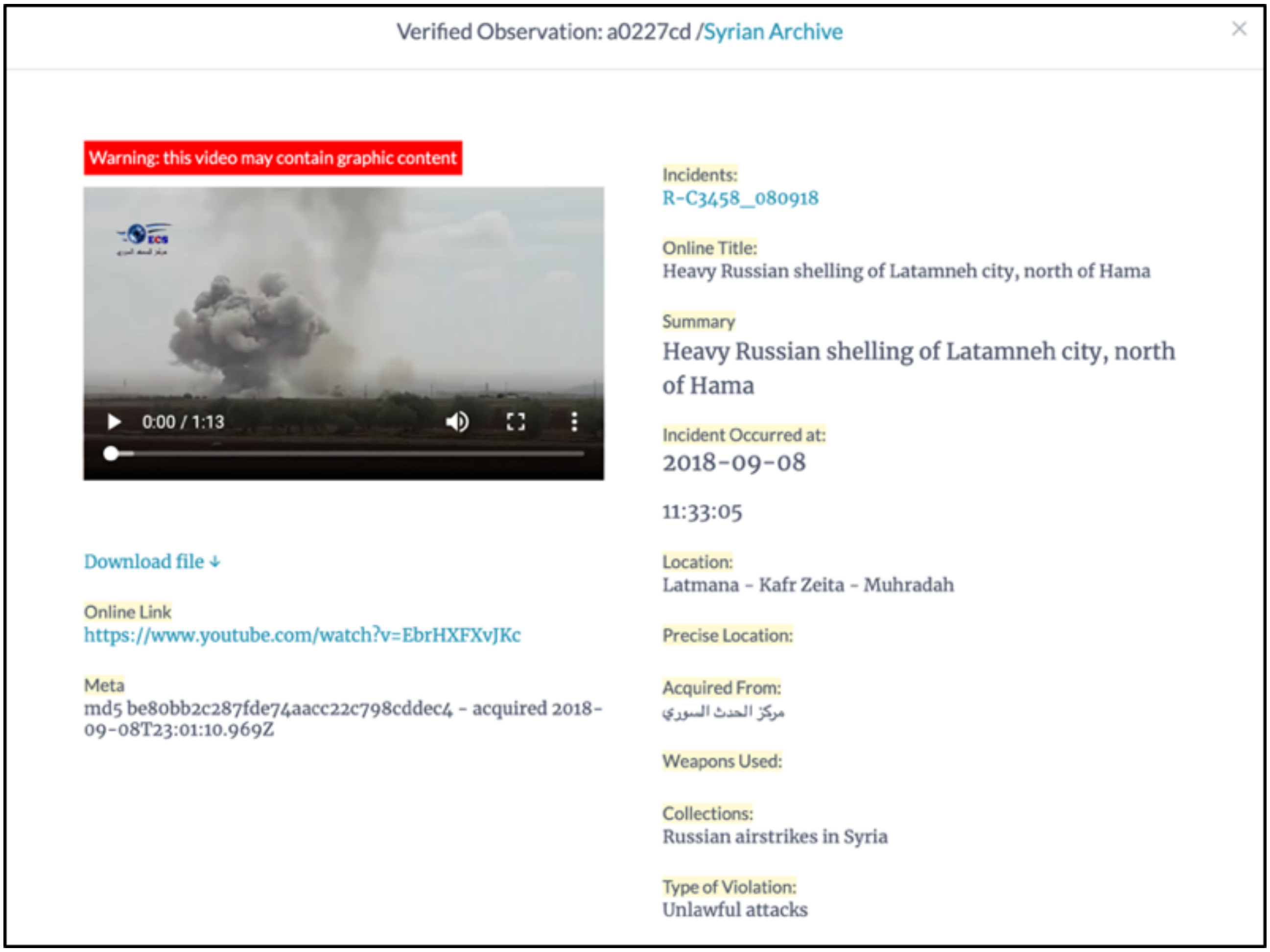

Figure 6. An example of a Syrian Archive database entry

<u>Physicians for Human Rights (PHR)</u>

Although Physicians for Human Rights also investigates and documents human rights violations, its work in Syria differs from the previous three organizations by focusing primarily on the conflict's impact on health care facilities. Attacks targeting health facilities is illegal under international human rights law, and Physicians for Human Rights has systematically documented and mapped these war crimes since the start of the Syrian conflict in 2011 (UN General Assembly, 1970). PHR gathers data through online and field sources and is able to corroborate approximately 30-40% of all received reports with independent sources. They rarely engage in geolocation of the open source data themselves, but instead cross-referenced multiple reports to identify locations and rely on a network of contacts to further confirm events. In total, their OSINVs have mapped 583 attacks on Syrian medical facilities. The map of the facilities targeted is shown in Figure 7.

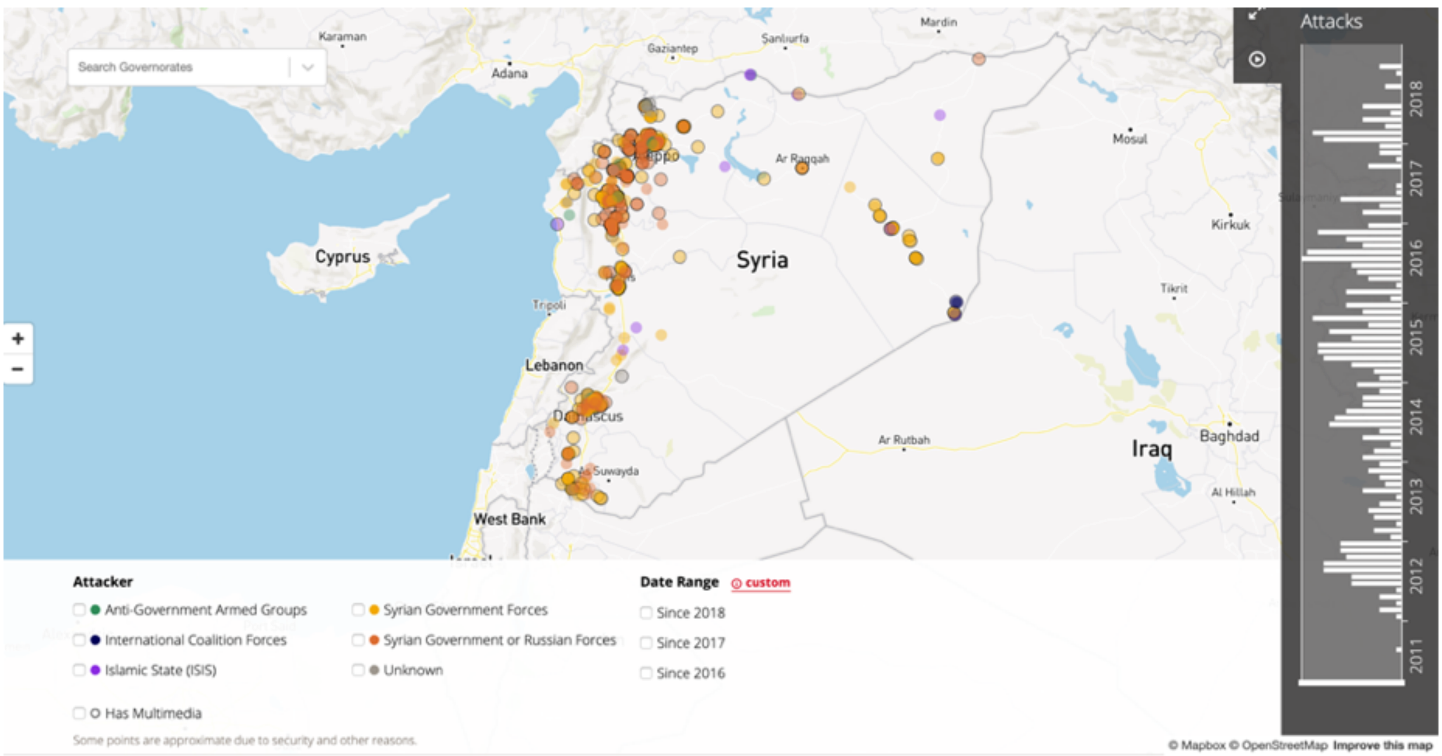

Figure 7. PHR map of illegal attacks on health care in Syria

Amnesty International

Amnesty International is a non-governmental human rights organization with millions of members and supporters around the world. Amnesty is much older than any of the other organizations and they have the experience to show for it. Amnesty's forensic analysts have been investigating the impacts of conflict for decades, and they have created a website, Citizen Evidence Lab, where they share their techniques and tools for authenticating user-generated content. The materials they provide detail a geolocation method that is generally similar to that of Bellingcat and Airwars, but also introduces a few new tools.

Unlike any of the other organizations, Amnesty uses crowdsourced volunteers to help experts tackle the vast amount of online data. The Digital Verification Corps is a global network of volunteers from 6 major universities that Amnesty has trained in open source analysis. The volunteers contribute to investigations by combing through and verifying relevant social media data.

Organizations Summary

Overall, whether their motivations are archival or to increase government accountability, the OSINV efforts of the five organizations rely on remarkably similar methodologies for open data verification and geolocation and utilize the same set of tools. The next section considers these methodologies and their limitations in more detail.

3.4.2 Methodological Gaps Identified

From the study, some reoccurring methodological shortcomings emerge. To geolocate visual evidence, these five studies relied heavily on Google Earth imagery. To clarify, Google Earth is different from Google Earth Engine (which will be used later in the project), as Google Earth simply visualizes specific Google-selected satellite images and Google Earth Engine is an analysis tool for petabytes of satellite imagery archives. While Google Earth has many valuable features, the platform’s satellite imagery has inconsistent temporal and spatial resolution. The imagery used on Google Earth comes from a collection of different sources, including the Centre National d'Etudes Spatiales (CNES), Airbus, DigitalGlobe, LandSat, Copernicus, and Planet Labs. Because the imagery is a collection of different sources, the historical imagery available consists of images that could be days or years apart depending on the location. Further, a single displayed image can be a mosaic of multiple satellite photos taken over days or months, thus presenting issues with accuracy when trying to use the images to determine the date of an event. Google Earth imagery also lacks high-resolution consistency; Google Earth provides high-resolution image data for major metropolitan areas, but often outlying areas imagery have lower resolution.

The geolocation methods used are resource and time intensive, resulting in a limited number of events being located. While Airwars and the Syrian Archive's goals are to collect information on as many events as possible, they are only able to geolocate claims when resources allow. Only a portion of the events in their dataset are able to be located, and the remaining events are stored with a general location, like the region or city. The current geolocation process is too cumbersome to be conducted widely; it requires comparing multiple sources of visual evidence with large geographic areas Google Earth imagery to locale a small visual connection. This time-consuming process to connect open data (in this case a video on Twitter) with a physical location is shown in Figure 8.

Figure 8. An example flow of an OSINV geolocating Twitter media (Source: Bellingcat)

Another shortcoming uncovered from the OSINV evaluation is the over reliance on social data and online user-generated content to inform the genesis of an investigation. Not all events are covered equally (or at all) by social media and news organizations. Conducting investigations only on published online social data runs the risk of focusing only on events that received major coverage and missing smaller scale events. For example, consider of health facility attacks that PHR investigated. PHR's reliance primarily on open sources and published reports made it difficult to verify incidents that occurred in more dangerous or restricted areas (e.g. ISIS-controlled areas, areas under siege). They had trouble corroborating incidents in Eastern Ghouta, as medical facilities there were trying not to publicize attacks out of fear of retaliation.

An overreliance on social media data may also impact the credibility of the OSINV's overall findings. The tests carried out by PHR, Airwars, and Syrian Archive to verify the authenticity of data focused on the corroboration of multiple similar online sources as the litmus for a credible event. As outlined in Section 3.2.2, Syria's social media has its own online geography that can create a skewed presentation for real world events and potentially bias the findings of these OSINVs.

3.5 Conclusions

The study identifies a widespread adoption of similar OSINV methodologies across the five organizations. In general, they all begin investigations by compiling different sources of online social data on a single event. They then validate specific details of the event (location, time, actors involved) with physical data (Google Earth) or other social data. This validation process relying on Google Earth to geolocate events uncovered by social data has many limitations.

An overreliance on social data to start OSINVs and substantiate evidence raises the risk of the investigations being misled by the subjective and intentionally manipulated social media landscape. Additionally, Google Earth imagery presents problems as a source of physical data due to its inconsistent temporal and spatial resolution. Further, the manual procedures to geolocate social data are time-intensive and limit the resources available for other investigations. The speed and accuracy of the current geolocation procedure depends heavily on the expertise available in the organizations. This expertise varies between organizations, leading to differences in the scope and amount of geolocations conducted. These concerns indicate a need for improved sources of physical data to both begin and substantiate investigations, as well as a new tool that can make the geolocation process faster and easier for non-specialists.

The study also provides evidence that the organizations would be able to integrate a new tool into their existing technical workflows and social frameworks. All of the organizations already use online analysis tools and each has at least one individual that is experienced in open source analysis.

Based on these findings, this project proposes a new tool that addresses the gaps identified. The proposed tool will be built with Google Earth Engine and will analyze Sentinel-1 satellite imagery to detect damage that occurs in a user-specified area during user-specified dates. The Sentinel-1 imagery archive is a robust dataset with consistent temporal and spatial coverage of Syria. Using Google Earth Engine, the proposed tool will analyze hundreds of images to extract useful damage information for OSINV analysts. The goal of the tool is to provide a source of physical data that is consistent, easily accessible, and can be used to improve the geolocation process. By making high-level remote sensing analysis available through a simple online user interface, the tool could be used as a new source of physical data to validate and start OSINVs.

With such a tool, investigations would no longer be solely reliant on social data to begin. Instead, they could start with physical data, which would circumvent some of the limitations of Syria's politically manipulated social data environment. For example, attacks on hospitals are sometimes under reported on social media to prevent retaliation. OSINVs that use physical data to begin could more effectively investigate these strikes compared to OSINVs that only relied on social data.

When combined with other open data, the proposed tool and the insight it would provide could pioneer new ways of conducting OSINVs and further advance the use of open data to understand conflict.

CHAPTER 4: DEVELOPING A DAMAGE DETECTION TOOL

4.1 Introduction

Chapter 3's evaluation of OSINVs points to the potential of a new tool that could improve OSINV methods in three main ways. First, it could provide a new source of consistent physical data to use to verify events as an alternative to inconsistent Google Earth Imagery. Second, it could make the geolocation process faster, less resource intensive, and more accessible to non-specialists. Third, it could counter the current overreliance on subjective social data to start and substantiate OSINVs.

This chapter outlines the development of the proposed tool by exploring relevant literature, constructing a damage detection methodology, and discussing the results. It begins by reviewing literature on damage detection methods that have been used in Syria, and then explores other damage detection projects that have used open data. A methodology is proposed to develop a tool that can meet the three goals. Finally, the results of the tool's development are presented, along with limitations faced and future recommendations.

4.2 Background

4.2.1 Syrian Civil War Damage Detection

While the literature on using satellite imagery for damage detection predominantly focuses on damage caused by natural disasters, a small subset exists focused on detecting damage caused by warfare. Within this subset is an even smaller subset of research that focuses on detecting damage resulting from the Syrian Civil War. A variety of approaches achieve differing degrees of success in detecting building damage in Syria. Both moderate resolution (i.e. pixel sizes between 15 to 100 meters) optical and radar imagery have been used. Research that uses both backscatter and phase information of Sentinel-1 Synthetic Aperture Radar (SAR) images have been able to detect large damage captured in the imagery's resolution (Braun, 2018; Washaya et al., 2018). Landsat imagery was used to detect damage by analyzing changes in surface reflectance values. While the approach was 74% accurate, it was computationally expensive and took over ten days (Marx, 2018).

Compared to moderate resolution imagery, research on high resolution (i.e. pixel size 1 to 5 meters) and very high resolution (i.e. < 1 meter) imagery is much more common and more successful in detecting building damage in Syria. Analysis of backscatter changes in high resolution radar imagery was successful in detecting urban damage in Homs, Syria (Tapete et al., 2015). Texture features, metrics calculated to perceive the texture of an image, were used to detect buildings in high resolution optical imagery and then used identify damage in post imagery for urban areas and archaeological sites in Syria (Cerra et al., 2016; Ghandour & Jezzini, 2018).

A variety of change detection approaches are successful in the literature for detecting damage caused by conflict in Syria (shown in Table 6). The algorithm and dataset used for this project were selected based on their ability to be integrated into a publicly available online change detection tool.

Table 6. Compiled information on approaches for Syrian damage detection

Author	Imagery Source	Resolution	Type	Method	Geographic Area
Braun, 2018	Sentinel-1	Moderate	Radar	Persistent Scatters	Raqqa
Washaya et al, 2018	Sentinel-1	Moderate	Radar	Coherence Change Detection (CCD)	Aleppo
Marx, 2018	Landsat	Moderate	Optical	Modeling surface reflectance value changes	Aleppo and Damascus
Tapete et al., 2015	StripMap TerraSAR-X	High	Radar	Backscattering changes	Homs
Ghandour & Jezzini, 2018	GeoEye-1	High	Optical	Gray Level Co-occurrence Matrix (GLCM)	Zabadani
Cerra et al., 2016	WorldView-2 satellite	High	Optical	Gabor texture features	Palmyra archaeological site

4.2.2 Google Earth Engine

For the proposed tool to fill the methodological gaps identified above, it should satisfy two main requirements. First, the tool should be able to automatically identify changes in satellite imagery (buildings damaged by airstrikes) across target areas located within a large spatial scale (Syria) and within an extended temporal range (2011 to present). Second, the tool should also be publicly available and user-friendly for non-remote sensing specialists.

An examination of related literature on tools able to meet these requirements and carry out such analysis point to Google Earth Engine (GEE) as the most appropriate for this application. The other tools that have been developed to conduct large-scale processing of geospatial data, including TerraLib (Camara et al., 2000), Hadoop (Whitman et al., 2014), GeoSpark (Yu et al., 2015), and GeoMesa (Hughes et al., 2015), require considerable technical and data management expertise.

GEE, on the other hand, is a cloud computing platform that not only provides geospatial analysis capabilities, but also easy access to a huge collection of geospatial datasets, including the entire Landsat archive (1972 to present) as well as the complete archives from Sentinel-1 (2014 to present) and Sentinel-2 (2015 to present) (Mutanga & Kumar, 2019).

The use of GEE for this project is ideal for a number of reasons. First, not only does GEE provide access to an archive Landsat and Sentinel datasets, but it has preprocessed and georeferenced each of them to facilitate efficient searching and incorporation into analysis. GEE data storage structure allow users to search through millions of individual images and select relevant data. This capability streamlines data management processes that are typically cumbersome and would prevent the analysis of such large datasets. Second, GEE's data catalog is continuously updated with scenes from active missions. New images become available on the platform with a latency as fast as 24 hours from scene acquisition time, allowing for up-to-date analysis (Gorelick et al., 2017). Third, the cloud-based processing provides unprecedented computational speed for analyzing incredibly large datasets. GEE is quickly able to analyze satellite images data across both large spatial and temporal scales, something required for this project. Third, GEE's development environment is designed for rapid prototyping and can easily visualize of the results of complex spatial analysis. Finally, GEE supports the development of Earth Engine Apps—dynamic, publicly accessible user interfaces that non-experts can interact with to conduct spatial analysis with or without a GEE account. This feature allows the tool created in the project to support open source principles and be available and usable to open source investigators.

For clarity, it is worth noting the differences between Google Earth Engine (GEE) and the more familiar Google Earth. Google Earth enables users to visually explore curated satellite imagery, terrain, and building data by interacting with a virtual globe. Google Earth Engine, on the other hand, is a tool for analyzing large sets of geospatial data.

Since GEE is relatively new, only a few studies exist that leverage GEE for change detection purposes. Celik's research analyzed GEE's archive of both Sentinel-1 and Sentinel-2 imagery to identify changed neighborhood units in Ankara, Turkey. Image subtraction and binary classification were successfully used to identify changed neighborhood areas with a 91% accuracy (Celik, 2018).

van Heyningen's GEE research uses Sentinel-1 imagery to create maps of earthquake damage to be used by search and rescue teams in the Netherlands. Similar to Washaya et al. (2018), van Heyningen (2018) detects building damage by measuring backscatter changes between a pre-event time series and post event imagery. Unfortunately, the tool is not easily accessible. It does not have a public interface, users need a Google Earth Engine account to access it, and some basic coding is required to input date and location parameters before running it. However, the damage map created was created quickly (around 90 seconds), can be easily explored in the GEE interface, and can exported as a KML file. An example of a created damage map is shown in Figure 9. The damage detection approach was most successful in detecting damage areas larger than the Sentinel-1 resolution cell (20x20m). When the spatial extent of a damaged structure was smaller than or equal to the resolution threshold, the effect of building damage did not register on the damage map (van Heyningen, 2018).

Figure 9: Results of the van Heyningen (2018) GEE script to detect damage after an earthquake in the city of Amatrice in Central-Italy

The algorithms and scripts of existing GEE projects provide a useful framework for developing a new tool specifically intended to detect airstrike damage and support OSINV geolocation.

4.2.3 Sentinel-1 Data

Of the many satellite imagery datasets available on GEE, Sentinel-1 imagery is the most appropriate for this project based on its spatial resolution, temporal coverage, and prevalence in the relevant literature in its use for damage detection. Information on the Sentinel-1 data used in this project is shown in Table 7 and detailed below.

The Sentinel-1 program is managed by the European Space Agency and consists of two satellites (A and B) that collect radar imagery with a variety of polarizations and spatial resolutions (Yagüe-Martínez et al., 2016). Sentinel-1 uses synthetic aperture radar, or SAR, to emit and receive a signal while moving over a target region (ESA Online, 2016). Differences in how the signal is scattered and reflected back by vegetation, flat areas, or built areas allows the sensor to create an image. Unlike optical imagery, Sentinel-1's active sensor radar imagery is unaffected by the weather, smoke, or cloud cover, and it can collect continuous imagery throughout both the day time and nighttime. That is why it was chosen over optical sources with similar resolution like Landsat and Sentinel-2 which rely on sensors recording the sun's energy reflected off the Earth's surface.

Sentinel-1 imagery is processed by both the European Space Agency (ESA) and GEE before it is publicly available. ESA's processing steps are shown in Figure 10.

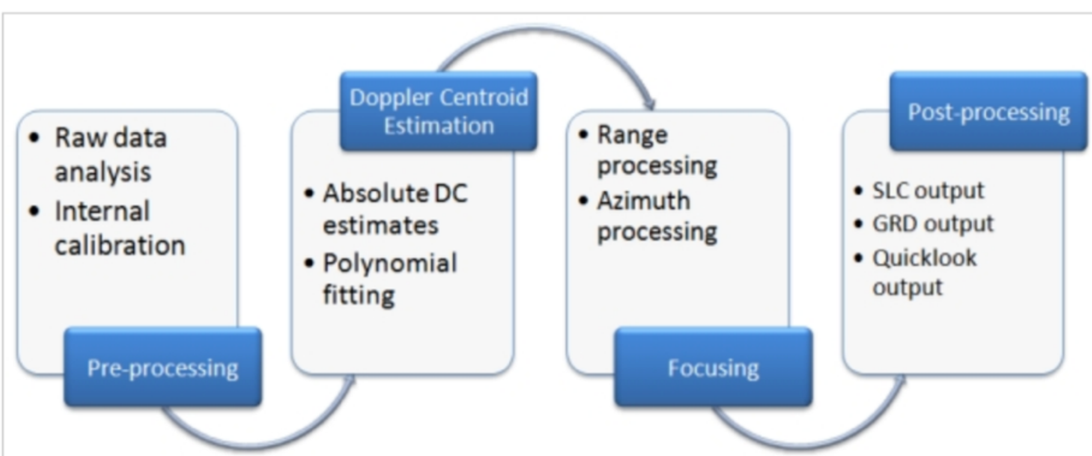

Figure 10. ESA Level-0 to Level-1 processing flow (ESA Online)

The Sentinel-1 data available in GEE have been processed as a Ground Range Detected (GRD) product. GRD images have been projected to ground range using the Earth ellipsoid model WGS84 and are corrected for terrain height. GRD imagery has approximately square resolution pixels, reduced speckle, and pixel values representing detected amplitude (ESA Online, 2016). GEE then processes the GRD images by computing the backscatter intensity for each pixel and orthorectifying the data (Sentinel-1 Algorithms, 2019).

Although Sentinel-1 is collected in three different instrument modes, Interferometric Wide Swath mode (IW) is the standard capture mode over land and is the only mode relevant to this project. Images collected in IW mode have a pixel spacing of 10 x 10m, a resampled spatial resolution of 20 x 22m for high resolution, and the polarization bands of VV and VV+VH . Polarization describes the orientation of how the radar signal is transmitted and received. A VV signal is transmitted vertically and received vertically, while a VH signal is transmitted vertically and received horizontally. The different orientations of the signals captures different aspects of the physical environment. Of the two polarizations available, Parizzi et al. (2016) finds that polarizations with more co-polar content, so VV, present the best performance in terms of detection and accuracy for urban areas. Therefore, VV will be the polarization initially focused on in this project.

There is a gap of three years between when the Syrian Civil War began in 2011 and when Sentinel-1's coverage starts in 2014. However, it is estimated that most of the heavy damage of the Syrian Civil War began occurring in 2014, so Sentinel-1's temporal coverage will have captured most of the damage (Hassan, 2017).

In summary, the Sentinel-1 imagery available on GEE that will be used for this project is Ground Range Detected, collected with IW instrument mode, has a pixel spacing of 10m x 10m, with a resolution of 20 x 22 m, has VV and VH polarization, and its pixel values represent backscatter intensity (also referred to as backscatter signal). These details are shown in Table 7.

Table 7: Sentinel 1 data used for this project

Dataset	Pixel Size	Pixel Spacing	Mode	Temporal Granularity	Temporal Coverage	Spatial Coverage
Sentinel 1 A/B Ground Range Detected	20 x 22 m	10 x 10 m	IW (Inter-ferometric wide swath)	2014 to June 2016: 12 days June 2016 to present: 6 days	2014 – Now	Global

4.2.4 Building Backscatter

The algorithm used in this project measures the change that occurs in a pixel's backscattering signal (represented by σ_0) across a time series to detect building damage. The algorithm is related to the differencing approach that Matsuoka and Yamazaki (2004) use to detect earthquake damage and is similar to the algorithm used in van Heyningen's project (2018).

The algorithm follows the logic that although radar pixel values may have natural backscatter variation throughout a time series, changes resulting from an airstrike will cause a much more significant backscatter change. The sudden change of a pixel's σ_0

value (could be either an increase or decrease) after an airstrike would be greater in magnitude than the previous backscatter fluctuations.

Measuring changes in backscatter signal is particularly effective for detecting building damage because buildings are stable corner scatterers. This means they have relatively consistent backscatter values caused by a strong reflection of radar signals off man-made objects due to building corner reflection, building materials, and a stable orientation towards the sensor (Ferro et al., 2011; Usai, 1997; Usai & Hanssen, 1997; Henderson & Xia, 1997; Lee, 2001). Because the reflectance of buildings is strong, changes in that reflectance result in notable difference in the backscatter signal detected. Figure 11 shows how the reflectance changes after a building's collapse. The algorithm developed in this project relies on the significant changes in backscattering values that result from a building's collapse in order to detect damage.

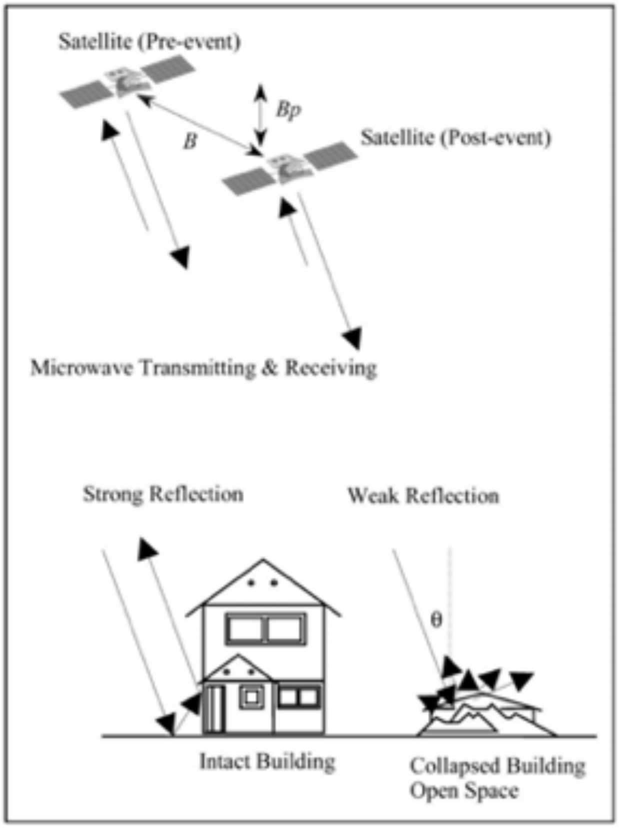

Figure 11: Schematic representation of backscatter intensity for an intact building versus a collapsed building (Matsuoka & Yamazaki, 2004)

4.3 Methodology

The damage detection system consists of three separate processes that work together to create the final damage map. The first is the backscatter change detection process that uses Sentinel-1 data to detect damaged pixels. The second uses Landsat imagery to create a mask for water and vegetation areas. The third incorporates Open Street Map building polygon data to visualize buildings that intersect with damaged areas. All of these processes are housed within a user interface that makes the analysis and results available to anyone using the application, regardless of their technical skill.

The multiple flows of the entire damage detection system are shown in Figure 15 at the end of this section.

4.3.1 Damage Detection

<u>Data Filtering</u>

Before running any calculations, the tool's script searches Sentinel-1's archive for high resolution images of the selected area of interest (AOI) collected in IW mode that were captured prior to the beginning of the date range selected by the user. The script then refines the search further based on the direction the satellite was passing when each image was captured—either ascending or descending. Due to how different looking angles capture different geometric angles of buildings, imagery captured of the same area but in different ascending and descending directions can look completely different. Ascending images should only be compared with other ascending images and descending images with other descending, so the script separates the time series into two stacks—ascending and descending.

The two ascending and descending stacks are then each further divided into the two possible polarizations of the images—VV and VH. The search process results in four different imagery stacks that capture every possible look and polarization combination: Descending VV, Descending VH, Ascending VV, and Ascending VH. Finally, each of the stacks are clipped to the user-selected Area of Interest (AOI).

In the early phases of the tool's development, the search process only returned VV polarization because previous studies pointed to VV polarization working better in urban areas (Parizzi et al., 2016). However, after reviewing Sentinel-1 imagery, it was found that VH polarization yielded more detail than VV for some areas depending on the date of capture and the orbital angles. The algorithm was tested on both VV and VH imagery separately and each was found to detect different areas of damage. Thus, both types of polarization were included in the algorithm's analysis. Figure 12 depicts how combinations between the different orbital directions (ascending, descending) and polarizations (VV, VH) capture different reflectance values resulting in different images for the same area and time period. These images show the city of Aleppo, Syria in June 2016.

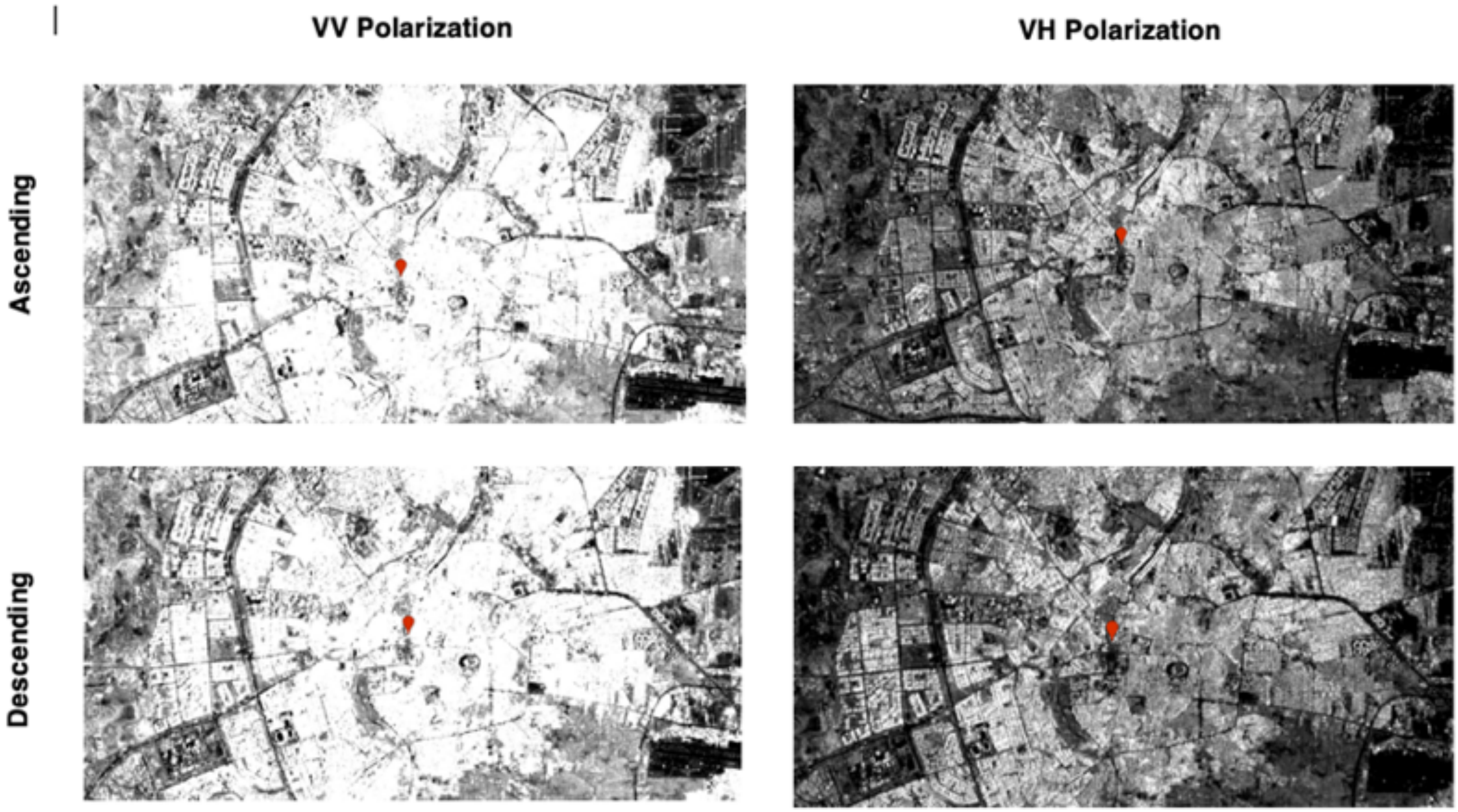

Figure 12. Comparison of Sentinel 1 intensity imagery of Aleppo by polarizations and orbital direction.

The damage detection algorithm was run on each of the four image stacks separately, and then the results from each are combined into a single map. While using all four of the time series for analysis allows for more damage to be detected, it also runs the risk of potentially creating more false positives than if just one or two stacks were used.

Damage Detection Algorithm

For each of the four time series, the difference between pixel values in subsequent images is calculated by:

$$d = Ia_i - Ib_i \qquad (\textit{Equation 1})$$

with d being the difference between the backscatter value, I, of pixel i in image a and the same pixel i in image b (Matsuoka & Yamazaki, 2004). This equation is used to compute a separate time series where the pixel values of each image represent the change between pixel values of two adjacent image acquisitions in the original time series:

$$C_{Ni} = O_{(N+1)i} - O_{Ni} \qquad (\textit{Equation 2})$$

where C_{Ni} represents the Nth image of the new time series containing the change in pixel values between image N (O_{Ni}) and subsequent image N+1 ($O_{(N+1)i}$) of the original time series (van Heyningen, 2018). Across the entire pre-date range time series, the maximum value of backscatter change ($\Delta\sigma_0$) for each pixel is calculated. For the date range selected by the user, the difference between the pixel values of the image at the end of the date range and the image at the beginning are calculated using Equation 1.

If a pixel's $\Delta\sigma_0$ during the user-selected date range of interest exceeds the maximum $\Delta\sigma_0$ from the pre-date range, that pixel is indicated as significantly changed and noted as building damage.

In order to visualize and interpret the severity of the change between the selected date range's $\Delta\sigma_0$ values compared to pre-date range's $\Delta\sigma_0$ values, a ratio between the two is calculated and the pixels are colored according to the value of the ratio. For a given pixel, if the date range $\Delta\sigma_0$ value exceeds the highest observed pre-date range $\Delta\sigma_0$ value, the following ratios are calculated:

$$S_{\Delta\sigma 0}Max = \Delta\sigma_0 \text{ date range / max } (\Delta\sigma_0 \text{ pre-date range}) \qquad (\textit{Equation 3})$$

$$S_{\Delta\sigma 0}Min = \Delta\sigma_0 \text{ date range / min } (\Delta\sigma_0 \text{ pre-date range}) \qquad (\textit{Equation 4})$$

Since the $\Delta\sigma_0$ value is capturing increasing or decreasing backscatter change, one ratio ($S_{\Delta\sigma 0}Max$) compares maximum positive change occurring in the pre-date range to the change in the date range and another ratio ($S_{\Delta\sigma 0}Min$) compares the minimum negative change occurring in the pre-date range to the change occurring in the selected date range. Both minimum and maximum values from the pre-date range are used since damage can result in both positive and negative changes in backscatter values. The maximum ratio values from each ratio calculation, which indicate the greatest degree of change that occurs for each pixel, are combined into one image.

This algorithm is run for each of the four imagery stacks (Descending VV, Descending VH, Ascending VV, and Ascending VH) and the maximum value of each pixel across the four maps are combined into one final map. The pixels of the final damage map contain the results of the ratio calculations which range from 1.0 to 2.0.

The pixels are visualized on the map from yellow to red, with smaller values shown in yellow and larger values in red.

The initial output from the algorithm was noisy, especially in urban areas, and included a lot of very small false positives that made the damage map difficult to interpret. To address this, an image filtering step was added to the damage detection process to remove smaller clusters of damage pixels. Clusters of damaged pixels that contained less than 440 pixels were filtered out. Through an iterative process of testing different sizes, the threshold of 440 pixels was found to filter out the most false positives while also retaining accurate damage results. The results of the cluster filtering are shown in Figure 13.

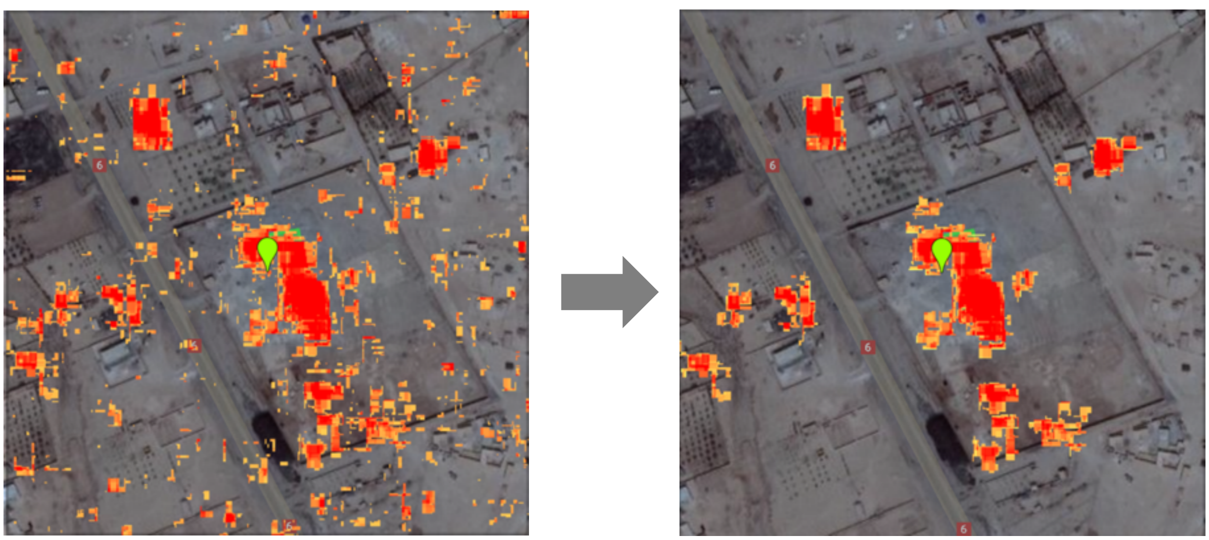

Figure 13. Effects of clustering on damage results

<u>Other Algorithms Tested</u>

In addition to the backscattering change approach, two other algorithmic approaches were tested and ultimately not included in the final tool. First, the omnibus test statistic was explored. This complex test statistic was developed by Conradsen et al. (2016) and transcribed to Javascript to be used in GEE by Mort Canty. The omnibus statistic is a likelihood ratio test statistic that calculates the homogeneity of several complex variance-covariance matrices and can be used to detect significant change in a time series of SAR data (Conradsen et al., 2016). However, when the test statistic was applied toward detecting damage in Syria, the analysis frequently timed out and was deemed too computationally expensive for the scope of this project.

The other damage detection approach attempted to use changes in the correlation coefficient of intensity values in subsequent image pairs to detect damage. A similar method was used by Matsouaka and Yamazaki (2004) to detect earthquake damage in radar imagery. Using a built-in GEE algorithm, the Pearson's correlation coefficient was calculated between pre and post imagery intensity values using a kernel window size of 7x7 pixels. The results of the change in correlation did not provide additional or more accurate detection compared to the time series backscatter coefficient change differencing approach. Due to this, using intensity correlation to detect damage was not included in the final algorithm.

4.3.2 Building Search Functionality

To add the functionality to detect damage for specific building types, Open Street Map polygon data are incorporated into damage detection algorithm. Open Street Map (OSM) is an online crowdsourced mapping platform that contains spatial data on buildings, roads, and points contributed by volunteers (Haklay & Weber, 2008). OSM building data from Syria was downloaded from the Humanitarian Data Exchange website (https://data.humdata.org/) and uploaded into the GEE development environment. The OSM dataset in Syria includes over 100,000 building polygons. Examples of the polygons across Syria and the OSM interface are shown in Figure 14.

Figure 14. Open Street Map data for Syria

To allow the user to search for damage that occurs to specific types of buildings, a drop-down selection widget was added to the user interface that was populated with the types of the OSM buildings contained inside of the selected AOI. Some examples of the different building types included in the Syrian OSM building dataset are apartments, mosques, hospital, schools, universities, stadiums, hotels, and farms. After the damage detection algorithm was completed, the resulting raster dataset of the damage pixels had to be converted to a vector dataset in order to analyze how it intersects with OSM polygons. To convert the damage raster to a vector format, the final damage image was first converted to a byte image and then reduced to a vector using a built-in GEE reducer. A spatial join between the resulting damage vectors and the OSM polygons was run to identify buildings that were within a 7-meter distance of damaged areas. The OSM polygons that were identified as damaged after the intersection analysis were then added to the final damage detection map interface.

4.3.3 Landsat Mask

Landsat 8 OLI imagery was used to improve the tool's damage detection capabilities. The Normalized Difference Vegetation Index (NDVI) and Normalized Difference Water Index (NDWI) were calculated from the 30-meter resolution Landsat 8 dataset available on GEE. These indexes were used to create a non-urban mask that was used to remove vegetation and water areas from the change detection process. Landsat 8 imagery was imported, searched for the AOI, and searched to the time range of Sentiel-1 imagery available before the user selected date range. The NDVI was calculated per pixel for each individual image (using Equation 5) and the maximum NDVI value per pixel across the entire time series was compared to a threshold value of 0.8 to filter out the highest density of green vegetation. If the maximum NDVI value exceeded this threshold, it would mean that during the aforementioned time range the pixel had been classified as heavy vegetation at least and would not be included in analysis of building damage.

$$NDVI = (NIR - RED) / (NIR + RED) \quad \text{(\textit{Equation 5})}$$

The Normalized Difference Water Index (NDWI) for open water bodies was used to mask out water areas. It was calculated using the Green (band 3, 0.53 – 0.59 µm) and NIR (band 5, 0.85-0.88 µm) from the same Landsat 8 dataset using equation 6 (McFeeters, 1996).

$$NDWI = (GREEN - NIR) / (GREEN + NIR) \qquad \text{(}\textit{Equation 6}\text{)}$$

The NDWI varies from -1 to +1 and was calculated for each pixel of every image in the time series. In this study, the median NDWI value for each pixel across the time series was found and a threshold of 0.5 was applied to that image to classify areas with detectable water (NDWI 0.5 and above). If the pixels were determined to contain water, they were masked out of the damage analysis.

Vegetation and water were masked to improve the computational efficiency of the algorithm and to minimize false positives. During testing, this mask was found to only make a difference when the analysis was run in vegetated areas near Syria's rivers. It made little to no difference when analysis was run in dense urban areas where the presence of water and vegetation was minimal.

Figure 15: Flow of backscatter change algorithm (Source: Sam Tingle)

4.3.4 Tool Interface

The tool's interface sits above the damage detection algorithm and is used to collect input from the user, display results, and allow the user to interact with those results. The interface was developed using JavaScript to access the GEE user interface API. Client-side user interface widgets, like buttons and drop-down menus, were used to collect user input and control the damage detection algorithm. The different elements of the interface were arranged and stylized using GEE containers and CSS code.

The study area is selected when a user clicks a point on the map. A 600 by 600 meter square area is automatically drawn around that point to create the AOI used for analysis. The buffer size of 300 meters (resulting in a 600 x 600 square) was found to provide a balance between computational speed and scope of analysis.

Date information is selected using drop down lists that automatically populate given the month and year previously selected. The user is also able to select a type of building to detect damage on from a drop down menu. The contents of the building-type menu are dynamically populated to reflect the building polygons that are present in the AOI selected. Finally, the interface has been published on an Earth Engine App that can be widely shared and is publicly available.

4.3.5 User Testing

To test if the tool can be used operationally to help conduct OSINVs, I contacted members from multiple organizations and asked them to use an early version of the tool and provide some short feedback. The feedback was elicited via a Google Form questionnaire that I emailed to the participants. A list of contacts is shown in Table 8.

The questionnaire asks for general information about the participant (name, organization and role), feedback about the functionality of the tool, how it can be applied to their work, and feedback about the user interface. A copy of the form that is also available online is included in the appendix. (The project was submitted for IRB approval and did not qualify as human research.)

Table 8: Contacts for user testing of tool

Name	Organizations	Position	Contact Information	Contacted	Expressed Interest
Milena Marin	Amnesty International	Lead at Decoders	milena.marin@amnesty.org	Yes	No response as of 11/1/2019
Media at PHR	Physicians for Human Rights	General Contact	media@phr.org	Yes (10/10/19)	No response as of 11/1/2019
Jeff Deutch	Syrian Archive	Lead Researcher	jeff@syrianarchive.org	Yes (10/11/19)	Expressed interest in the tool
Chris Woods	Airwars	Director	chriswoods@airwars.org	Yes (10/14/19)	Yes, via Skype, agreed to test (10/17/19)
Josh Lyon	Human Rights Watch	Director of Geospatial Analysis	josh.lyons@hrw.org	As of 10/21/19 not yet contacted	
Christiaan Triebert	New York Times / Bellingcat	Visual Investigations with NYT, previously an analyst with Bellingcat	christiaan.triebert@gmail.com	As of 10/21/19 not yet contacted	

4.4 Results

4.4.1 Tool Interface

The tool is available online at samueltingle.users.earthengine.app/view/syrian-damage-detection-tool. Figure 16 shows the opening page of the online application. It is separated into two main panels: a side panel where the user inputs data to determine the scope of the analysis and the main map panel. The default location shown on the map was chosen to be Raqqa as it has been one of the cities most damaged in the Syrian Conflict. The two panels can be resized easily by dragging the bar that separates them. The base layer of the map was made to be high resolution satellite imagery provided by Google Earth Engine. The high resolution satellite imagery base map is helpful when choosing an area to investigate and when investigating the accuracy of the damage detection results.

After a point is selected on the map and the date range and building type are entered, the analysis can be started by selecting the run button. The results that are displayed after the analysis is complete are shown in Figure 17. The damage pixels are shown in a range of yellow to red and the OSM polygons that intersect with the damage are shown in green. The map area includes a damage detection legend as well as an info box that shows the coordinates of whatever point is clicked on the map and the building type if a building is clicked. The layers tab in the top right corner of the map allows the user to toggle on and off which layers to display on the map. A layer that contains all OSM buildings in the AOI (not just the damaged ones) can be toggled on to be shown, but it is not shown automatically. To run the analysis again, the 'Start New Analysis' button can be selected to restart the entire process.

The final user interface is simple and straightforward. It provides ample instruction on how to use the tool, while also not complicating the data entry process. The displayed results are clear, easily understood, and provide helpful damage and building information. The user can easily interact with the map, zooming in and out to examine the results and can click for more detailed information. Running the tool and interpreting the displayed results does not require any specialized geospatial or remote sensing knowledge and could be integrated into existing OSINV workflows. The one notable limitation of the interface is that it is slow to visualize the damage layers, taking around 60 seconds, and that it goes through the process of re-visualizing the layers every time the zoom is changed. A method that converts the output layers to byte images so that they can be visualized faster could be explored to mitigate this limitation.

Overall, the tool's interface accomplishes its intended goals of being accessible to non-technical specialists and allowing users to easily access Sentinel-1 damage detection analysis via the internet.

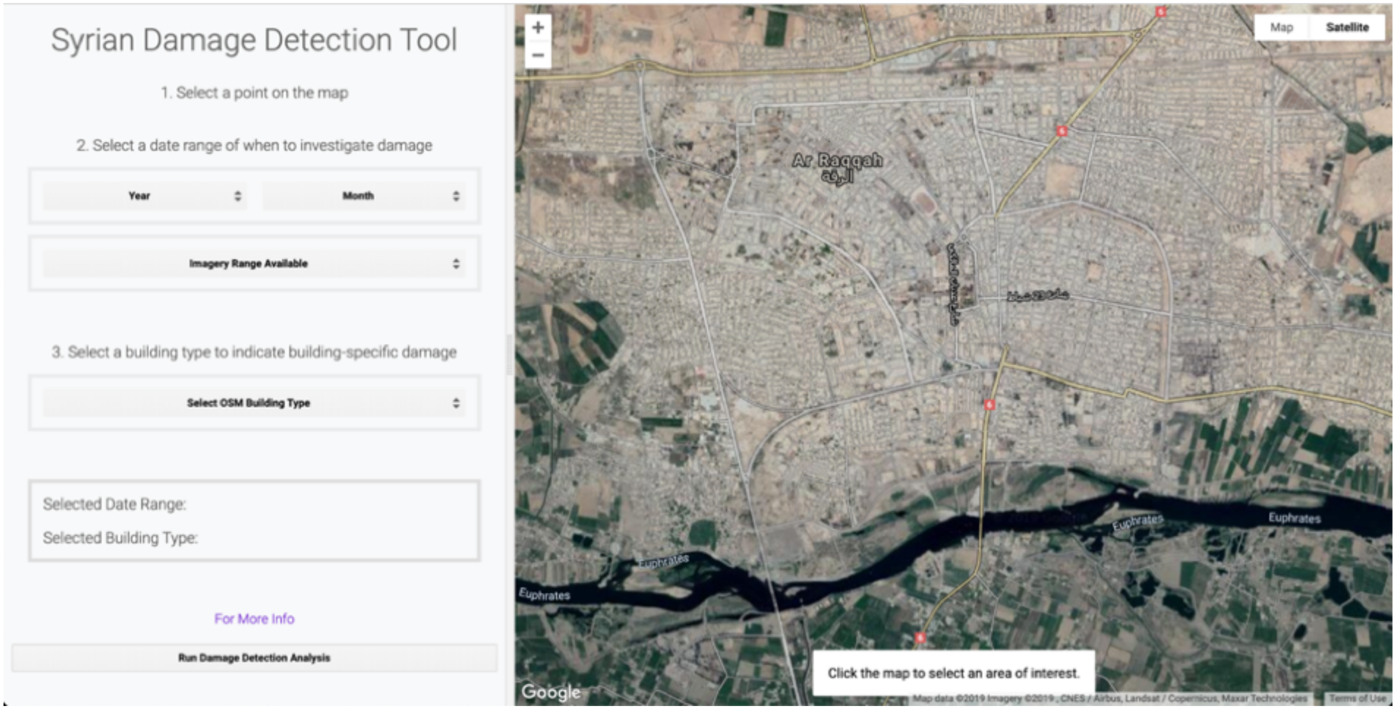

Figure 16. The initial user interface of the tool for data entry

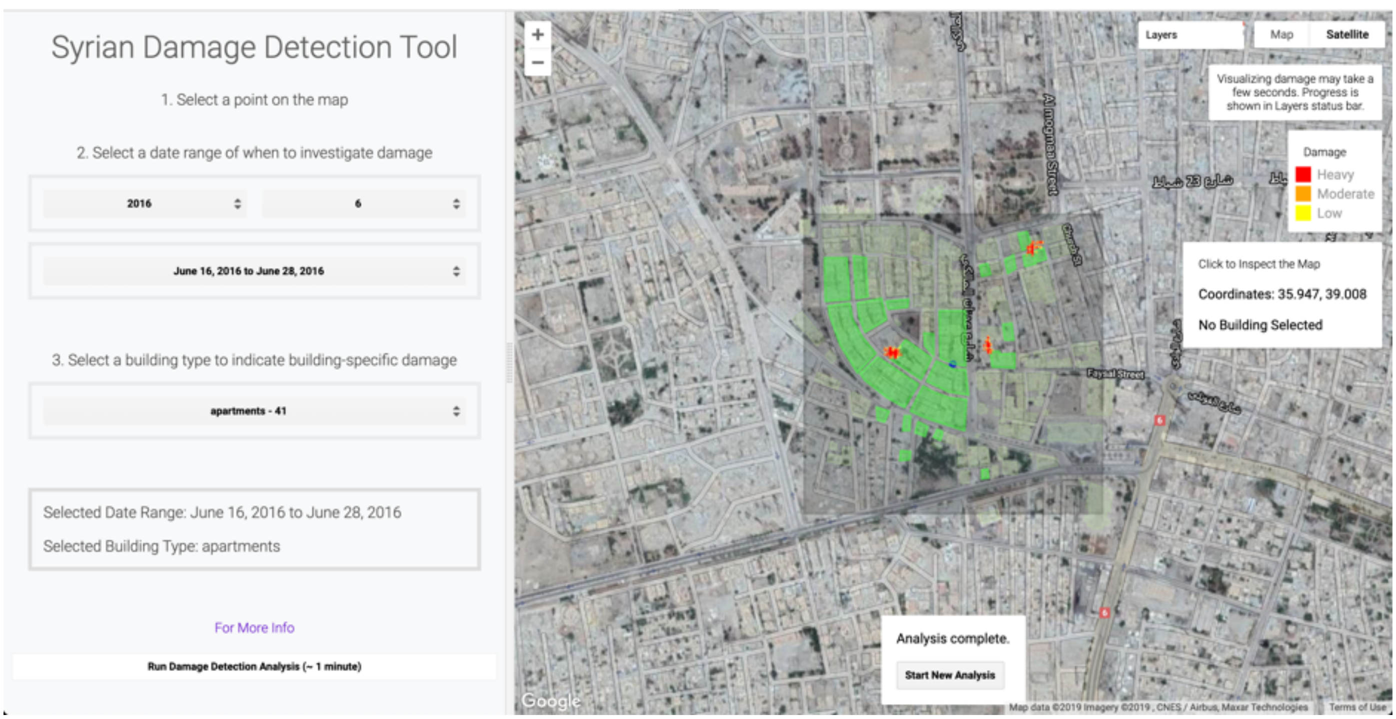

Figure 17. Tool interface displaying results of damage detection

4.4.2 Damage Detection Algorithm

The results of the damage detection algorithm will be visually compared with recorded instances of airstrike damage to assess the accuracy of the algorithm. The test data used contain the exact coordinates of building damaged and the exact day that the damage occurred, allowing for testing of both the spatial and temporal accuracy of the algorithm.

Ideally, the accuracy of the damage detection algorithm would be evaluated in comparison to detailed maps of extensive ground truth damage data. This would give a more comprehensive insight in the performance of the change detection algorithm across greater spatial area. To be able to test both the temporal and spatial accuracy of the tool comprehensively, the testing dataset would have to contain both the location of multiple damages sites and the date that the damage occurred. Unfortunately, such a dataset is not openly available and could therefore not be used in this research. For now, this project will rely on visual comparison to determine the accuracy of the tool.

To evaluate the algorithm's ability to provide a consistent source of physical data in the form of damage detected, its performance will be measured on the following metrics:

- Accuracy in identifying damaged buildings as determined through visual evaluation
- Amount of false positives present in final damage map
- The computational speed of the algorithm

False positives are pixels detected as changed that do not cover collapsed buildings. These metrics will be evaluated in 4 case studies that are comprised of airstrike damage from rural and urban areas, from varying building sizes, and from different times within the available imagery date range (October 2014 to now). A summary of the case studies is provided in Table 9 and a map of their locations is shown in Figure 18. The damage detection algorithm is run for each location using a date range that includes the day the attack was reported. An AOI of 400 x 400 meters is used to calculate false positives against Google Earth's high resolution satellite imagery.

Table 9. Information on the four test study sites used for accuracy testing.

Test Site Number	Type of Building	Location of Building	Coordinates (Latitude, Longitude)	Date of Damage	Belligerent	Impact	Source
1	Apartment	Raqqa	35.946913, 39.008374 (within 100 m)	06/21/2016	United States	23 to 38 civilians killed	Airwars
2	Al Badiya school	Al-Mansurah (Small village)	35.817351, 38.756073	03/20/2017	US Led Coalition	40 to 420 civilians killed	Airwars
3	House	Dali Hasan, Aleppo	36.56301, 38.369558	06/07/2015	US Led Coalition	8 civilians killed	Airwars
4	Al-Hani mosque area	Al-Sakhani, Raqqa	35.9522, 39.0164	08/22/2017	US Led Coalition	33 to 60 civilians killed	Amnesty Intl, Airwars

Figure 18. Map of Syrian with the locations of the four testing sites

Test Site 1: Apartment, Raqqa

The first test site is an apartment building with a footprint of about 370 square meters located in a dense urban area of Raqqa. The pre and post-strike satellite imagery depicted in Figure 19 show that the damage was contained to just a single building in the area. The tool's algorithm detected damage to the apartment building as evidenced by a collection of orange and red pixels over the damaged building (shown in Figure 20 with the blue pointer). The six other clusters in the image do not cover damaged buildings and are false positives. The buildings that the false positive pixel clusters cover seem to be the tallest buildings in the area. The final damage map also shows the OSM buildings that were detected as damaged. The individual apartment building that was detected as damaged was part of a large OSM polygon for the block.

Figure 19. Test Site 1: Before and after Google Earth imagery of an airstrike on an apartment building in Raqqa

Figure 20. Test Site 1: Damage maps for apartment building in Raqqa, one with damaged OSM building polygons and one without

Test Site 2: Al Badiya School, Al-Mansurah

Test site 2 was the most successful in detecting damage. The large 2,145 sq m school located in a small village was completely demolished as shown in Figure 21 and Figure 22. The damage detection algorithm was successfully able to detect damage for almost the entire extent of the building's footprint. Seven other damaged pixel clusters are present in the final damage map. Of these clusters, six were determined to be false positives and one was determined to accurately cover evidence of damage that occurred as a result of the airstrike. There was only one OSM polygon in the AOI, and it was the school. It is not visible in Figure 23 because it is underneath the damage pixels.

Figure 21. Test Site 2: Before and after Google Earth satellite imagery of an airstrike on a school in Mansoura.

Figure 22. Test Site 2: Still photos of the school before and after the attack

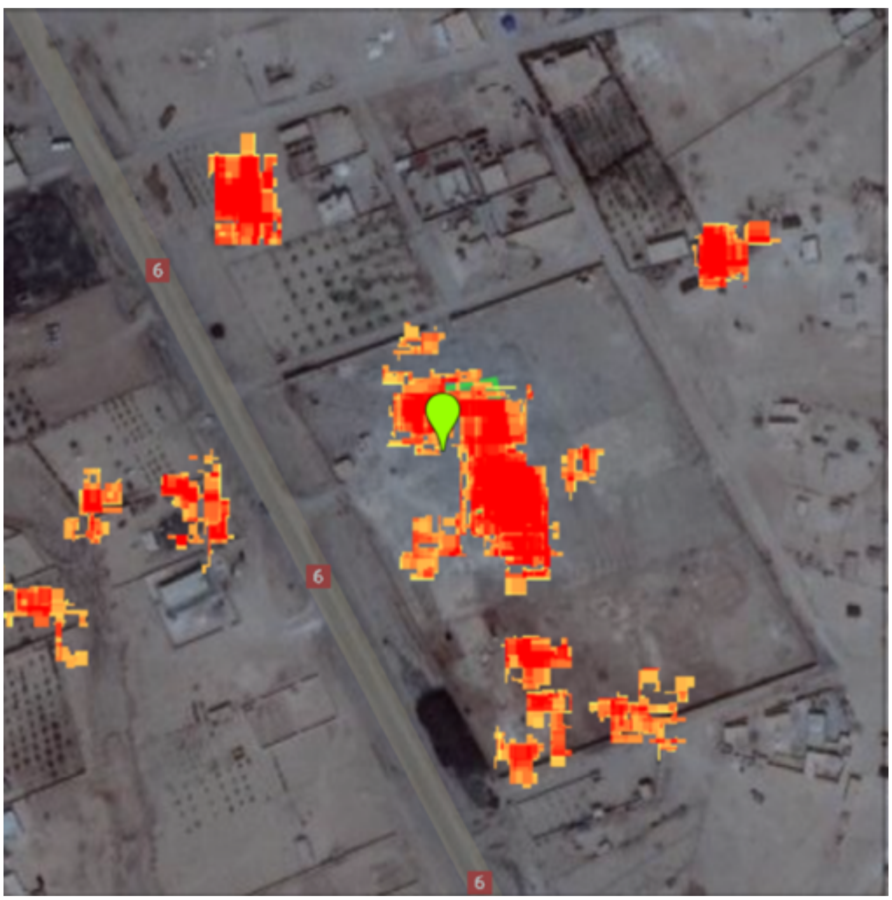

Figure 23. Test Site 2: Resulting damage map for rural school with OSM building polygons visualized underneath the damage layer

Test Site 3: House, Dali Hasan, Aleppo

The third case study tests the accuracy of the algorithm when detecting damage that occurred early in the time series. The test site is a house located in a northern village that was damaged by an airstrike in June 2015. Since Seninel-1 imagery begins in October 2014, the pre-date range time series used in this analysis is smaller than in the other case studies. The smaller pre-date range does not seem to affect the analysis. The damage that occurred to the house was successfully detected. Of the fifteen other clusters, five were found to cover visible remains of damage. Although, there is some uncertainty that the damage occurred in the date ranges used for analysis, those five clusters were not included in the false positive count. Seven of the false positives were found to cover empty fields. There was no OSM building polygon data located in this AOI.

Figure 24. Test Site 3: Before and after Google Earth satellite imagery of an airstrike on a house in Dali Hasan, Aleppo

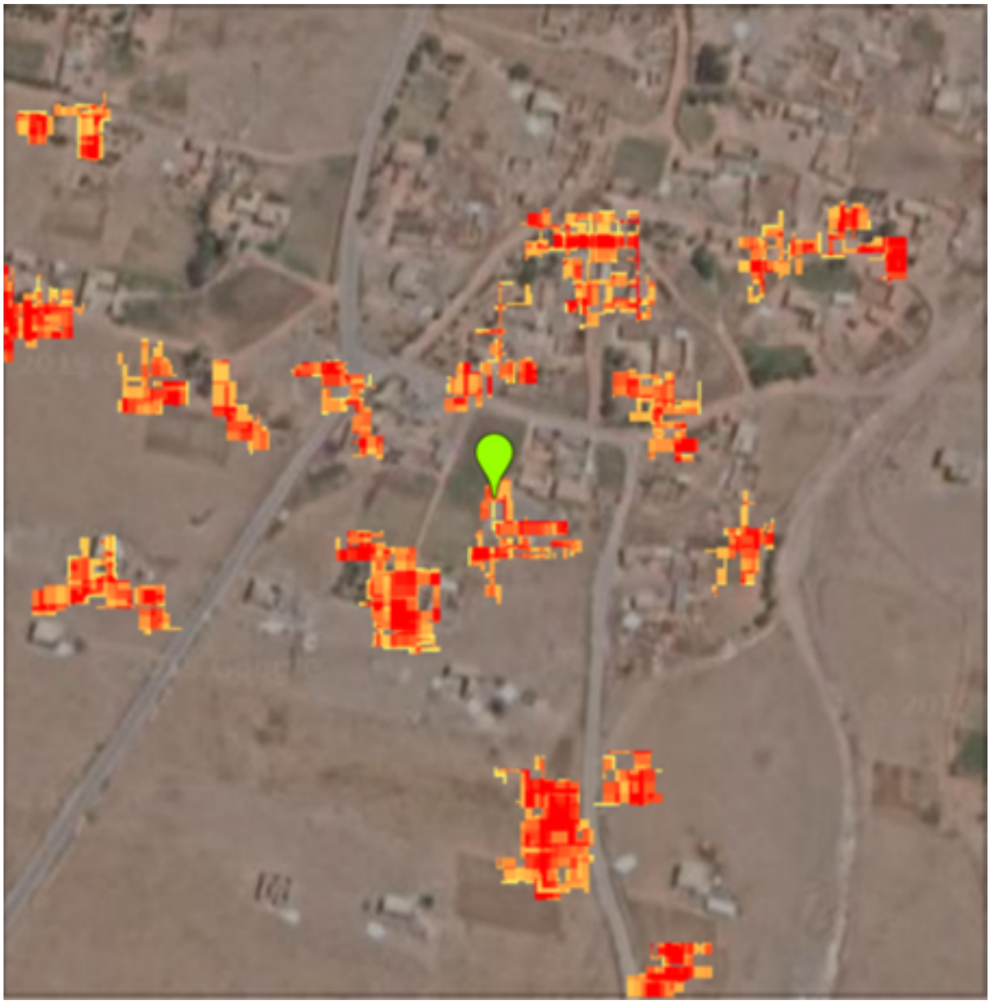

Figure 25. Test Site 3: Damage map for a house in the village Dali Hasan

Test Site 4: Neighborhood near a mosque, Al-Sakhani, Raqqa

The fourth and final test site is located in a dense urban area of Raqqa. The analysis was unsuccessful in detecting damage for the two residential buildings that were the targets of the strike (as reported by Airwars), but was able to successfully detect six other sites of damage for the selected date range. Thirteen damage clusters are visible on the final map. By investigating satellite imagery, it was found that six of those clusters covered damaged buildings and the remaining seven were false positives. The five OSM building polygons that were included in the final maps were accurately detected as damaged.

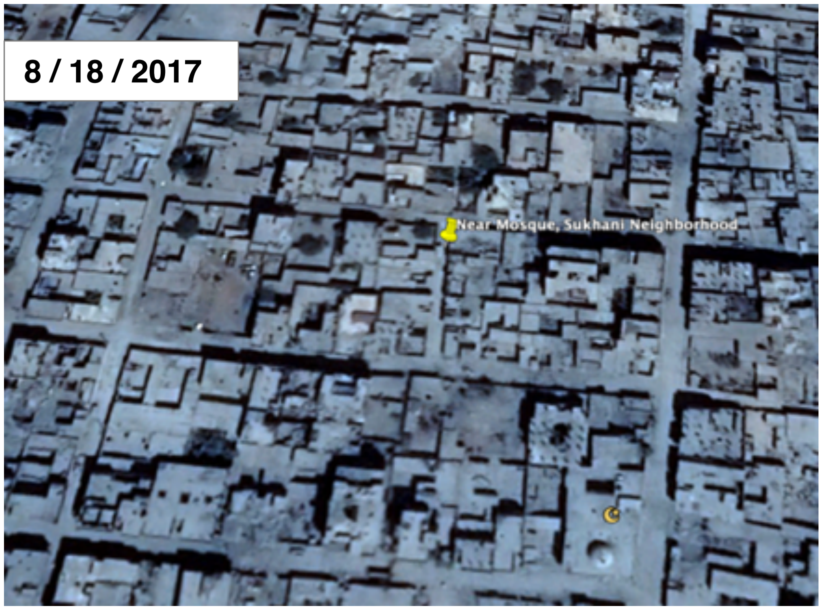

Figure 26. Test Site 4: Before and after Google Earth imagery of an airstrike in a neighborhood near a mosque in Al-Sakhani, Raqqa

Figure 27. Test Site 4: Damage map showing detected damage in the neighborhood near a mosque in Al-Sakhani, one with damaged OSM buildings polygons and one without

Table 10. Results of damage detection visual analysis

Case Study Number	Size of Building Damage	Target Damage Detected	Other Damage Detected	Type of Area	Total Number of Clusters	False Positives	Analysis and Viz Speed for 1 km AOI	OSM Building Present and Detected	Date of Damage
1	376 sq m	Yes	No	Urban	7	6	70 seconds	Yes	06/21/2016
2	2,145 sq m	Yes	Yes	Rural	8	6	51 seconds	Yes	03/20/2017
3	335 sq m	Yes	Yes	Suburban	16	10	85 seconds	N/A (no data present)	06/07/2015
4	400 sq m	No	Yes	Urban	13	7	40 seconds	Yes (not for the case site)	08/22/2017

Summary

As determined through a visual accuracy assessment, the tool was able to successfully detect damage for three of the four buildings that were the targets of the airstrikes in each test site (75% accuracy). The size of the footprint of the building's damage and the location in an urban or rural environment both played a role in how successfully the damage was detected. The most successful test case was for the largest building (2,145 meters in Test Site 2). In this site, the damaged pixels covered almost the entire damaged area of the building. The success of the large building damage is likely due to the fact that it was more visible in the 20 x 22 m size of the Sentinel-1 resolution cell than the other building footprints. If a building and its resulting damage footprint is smaller than the size of the Senitnle-1's resolution cell, the algorithm is less likely to register the entire footprint of the damage or the damage at all. This is evident in Test Site 1 where only part of the damage footprint was detected and in Test Site 4 where no damage to the target building was detected.

Although damage was correctly detected for surrounding areas, damage for the target building in Test Site 4 was the only target building whose damage did not register at all. Since damage to a similarly sized building also located in a dense urban environment (Test Site 2) was detected, the failure in Test Site 4 could be due to causes other than the size of the damage. These causes may be related to the reflectance angles of those specific buildings and how they were captured in the images used to calculate damage within the date range.

The damage detection algorithm relies on the Sentinel-1 imagery to be able to capture the reflectance value of one building and how it changes over time. Buildings in urban and rural areas are surrounded by different spaces and structures, which impact how well the Sentinel-1 sensor is able to capture a single building's reflectance value. For example, while buildings in rural areas have high contrast in reflectance values with the surrounding land, buildings in urban areas are surrounded by the constant high reflectance values of other man-made structures. This may prevent the SAR sensor from detecting reflectance changes of one building because is surrounded by a lot of other building reflectance. This creates a problem for the damage detection algorithm in urban areas and could be used to explain the fact that the damage detected in the urban test sites did not cover the entire damage footprint. Similarly, this explanation accounts for why damage for the test sites located in rural areas (Test Site 2 and 3) was detected for the entire building footprint. Speckle filtering and the integration of optical data are discussed in the recommendations section as possible avenues to improve the algorithm and address these limitations.

Across all four test sites, there was an average of 7.25 false positives. Some of the clusters resulting from the damage detection indicated damage that was not reported in the information used from Airwars for the testing. To descriptively analyze the false positives identified by the algorithm, high resolution satellite imagery was used to confirm that the damage occurred in the date range in which the analysis was run and to investigate the surrounding terrain. In Test Sites 1 and 3, the false positives were found to consistently cover the tallest buildings and large open fields, respectively.

Further research could be done to determine the specific reflectance signatures of those specific areas across the time series and remove them from the final damage analysis to minimize false positives.

The time it took to run the analysis and visualize results is an average of 62 seconds, which is an acceptable amount given the level of analysis conducted. This is a much faster speed compared to some of the other methods discussed in the background section that conduct similar time series analysis.

The use of specific building type functionality was successful. Building types that were selected in the interface and that intersected with damage pixels were successfully highlighted. However, the test site show that the coverage of the OSM building polygon dataset available is limited in urban areas and significantly lacking in rural areas.

In conclusion, the algorithm can detect building damage and is most successful with larger buildings and in rural areas. The results are compiled above in Table 10.

4.4.3 User Feedback

Interest in the tool has been strongly expressed by multiple practitioners that conduct OSINVs on Syria or neighboring areas. However, not enough feedback has been collected to present meaningful results from user testers. Given the recent events occurring in Syria (US's withdrawal from the northeast and Turkish advances in that area) a few of the individuals contacted have expressed that they are currently busy, but may have time to evaluate the tool soon.

4.5 Conclusions

The aim in creating this tool was to explore the use of Google Earth Engine and publicly available satellite imagery to support OSINVs. In that endeavor, it was successful. The tool provides ample evidence of the potential of Google Earth Engine to yield insights from large amounts of satellite imagery and can help to better understand where and when damage occurred in Syria. In addition to functioning as an exploratory project, the tool's development also has the more specific goal of mitigating the methodological shortcomings identified in the OSINV evaluation, specifically the following: (1) make the geolocation process faster, more accessible, and easily integrated into existing workflows, (2) provide an alternative source of consistent physical data, and (3) enable the reconstruction of the OSINV process so analysts can rely on physical data as well as social media data to begin investigations.

In terms of the first two shortcomings, the tool does provide detection functionality that can be used to make the geolocation process faster and more accessible, and the tool's straightforward interface can quickly integrate into existing OSINV workflows to accomplish these goals. Consider the OSINVs conducted by Airwars and the Syrian Archive for examples of how the tool adds value. Their OSINVs first gather information from many different sources about as many different events as possible. They then organize the data by event in an archival database. Both organization state that they are unable to geolocate the exact location of all of the events in the database because it is too resource intensive. Using this tool, the organizations can input information they have already gathered about the date of the attack, the general region or city it took place, and the type of building targeted, and in about one minute receive a map that shows the damaged areas for that specific criteria. Although the map may contain some false positives, the damage clusters can quickly be inspected and compared with the high resolution base map to geolocate the exact coordinates of the damage. This process is faster and even easier if the OSM dataset contains the polygon of the building being geolocated.

The location found using the tool can then be cross-reference with the other data compiled by Airwars or the Syrian archive to confirm the location of the database entry. This process is much faster than the current one which consists of combing through Google Earth imagery, looking for specific landmarks that match videos and photos, and then searching through the surrounding area for damage.

After testing the accuracy of the tool, it can be concluded that in some aspects the tool does provide a consistent physical dataset as an alternative to Google Earth and in some ways it does not, depending on how it is used in an investigation. The tool does provide more temporally consistent data due to the frequency of Sentinel-1 image acquisitions and how quickly they are uploaded into GEE. Also, where Google Earth imagery sometimes has lower resolution for rural areas outside of metropolitan area, this tool detects damage more accurately in rural areas than in urban ones. On the other hand, the false positives and limited accuracy with smaller buildings raise concerns regarding the tool's consistency in detecting all types of damage in all of Syria. Just like the Google Earth dataset, the data provided by this tool has its own limitations. This tool should not completely replace the use of Google Earth in OSINVs, as each data source provides different utility. There is no alternative to the high resolution visual assessment that can be conducted with Google Earth imagery. Instead, the two tools should be used together to improve the open data used in OSINVs.

Finally, the tool will likely not be able to largely replace social data as the starting point for the majority of OSINVs. However, in some specific situations, this tool and its building specific damage functionality could be used to discover and quantify damage that is not widely visible with social data.

Using the best imagery that was publicly available, this project developed a cloud-based online application that can be used to detect damage for a user-specified area, date range, and building type. It integrated crowdsourced polygon data to provide valuable functionality of searching for damage that occurs to a specific building type. The tool can be accessed anywhere in the world with an Internet connection and is straightforward enough to be used by non-specialists. Although the tool is limited by the resolution of the satellite data it uses, it is able to clearly detect damage for buildings in both rural and urban areas, but is more successful for larger building and in rural areas. Tools such as these are in continual development as new data become available and new algorithms are tested. To position this tool on a forward trajectory toward continual development, its current limitations will be defined and suggestions for its future development will be provided.

4.5.1 Limitations

The accuracy testing was conducted with only four test sites due to limits in available testing data. More extensive testing will be required to fully explore the accuracy of the algorithm and to better understand its limitations to inform future development.

No project is without limitations and a few exist with the current iteration of this tool. Most prominent are the limitations stemming from the resolution of the Sentinel-1 imagery used. The 20x22 meter resolution prevents some accurate damage detection for some areas not large enough to be detected in the pixel size. This is a notable limitation as one of the goals of the tool was to detect individual building damage regardless of the building size. However, it should be noted that the Sentinel-1 archive provided the best resolution with the longest temporal range of any publicly available dataset on GEE. Since this project required the use of GEE to conduct the analysis and create a sharable tool, the Sentinel-1 dataset was the best dataset available for this project.

Another limitation is that every time the map is zoomed in or out the damage layer is reloaded, taking anywhere from around 30 to 60 seconds. This reloading time is inconvenient when the user is trying to quickly explore the displayed results.

The OSM data used for the building detection functionality is very limited as the dataset only contains around 100,000 buildings in a country with many many more. The good news is that the dataset is constantly growing as OSM users contribute more polygon building information. This is promising for future iterations of the tool that can use a larger, more complete OSM dataset.

Finally, Google Earth Engine presents some restrictions regarding the future scaling and widespread use of the tool. Google Earth Engine has a quota per user for the amount of computation and concurrent queries that can be completed. Because all uses of the application would be run through a single user account, it is possible the widespread use of the tool could quickly meet the quota. Once the quota is met, analysis could no longer be completed. Google is not very clear about the specific limits of the quota, but they do indicate that, if contacted, they may raise the limits for specific users in special cases.

4.5.2 Recommendations

To improve the tool moving forward, possible algorithm improvements can be made. The accuracy of the damage detection could be affected by speckle noise from the Sentinel-1 SAR system, which can degrade the quality of the intensity images (Ulaby et al. 1982). Lee filtering could be applied to the time series for speckle noise reduction (Lee, 1980).

The fusion of optical with radar image data is worth exploring to improve the tool's detection analysis. Ban and Yousif (2014) show that change detection analysis can benefit from the complementary nature of the change information represented by both SAR and optical multitemporal datasets. GEE provides two large optical archives: Landsat and Sentinel-2 MSI data. Depending on the location, optical images sometimes show more detail than radar and allow the detection of sharp edges and region boundaries (Orsomando et al. 2007). Sentinel-2 imagery has similar resolution to Sentinel-1 and is available starting in June 2015. Using Sentinel-2 and Senitnel-1 data together would be feasible on GEE and should be explored.

Some users might be interested in damage that occurs over a date range larger than the 6 or 12 day ones provided in this tool. A new algorithm that adapts the damage detection to larger date ranges could be devised and tested.

Finally, this tool should use new higher resolution imagery datasets as they become publicly available.

CHAPTER 5: CONCLUSION

5.1 Implications

To conclude this project, this chapter will begin by discussing the larger implications that OSINVs and this project's tool have for political, social, and geographic contexts.

5.1.1 OSINVs for Conflict Accountability

OSINVs have established new methods for producing knowledge about conflicts. By extracting information from the diverse array of online data, OSINVs are able provide visual and social evidence for places and events that had previously been inaccessible. In conflict areas controlled by authoritarian regimes, the power of OSINVs to uncover information is especially vital. Authoritarian regimes control the flow of information within and without their borders by enacting strict restrictions, like banning foreign journalists or censoring websites and manipulating the online environment by spreading false information or polluting the online discourse. To counteract both online misinformation and barriers to information access, OSINVs can act as a source of verified information that can be made quickly and widely available. By using a systematic process to gather and corroborate online evidence, OSINVs establish the validity of online data and invalidate inaccurate data. Furthermore, by relying on publicly available online data, they are not restricted by physical barriers and can provide a source of information into isolated conflict areas.

The systematic approach of OSINVs is necessary when gathering information to subvert authoritarian control because any dissenting findings will be refuted and delegitimized by the authoritarian state. The OSINV procedures of constantly cross-referencing data, integrating data from many sources, validating new data at every step, and storing the data offline, yields proof that cannot easily be refuted. The results of well-executed OSINVs can provide not just a snapshot of what transpired, but evidenced findings that include the who, what, when, where, and why of an event—findings that are comprehensive and difficult for a state to invalidate. This project's tool were created to further support this systematic approach.

OSINVs can be used to subvert the information control of not just regime states but of other states as well. All states construct narratives both online and offline to serve the purposes of their government, especially when involved in conflict. OSINVs provide a method to check those narratives. For example, Airwars investigations into the civilian impact of Coalition airstrikes forced the US and other Coalition members to concede that they were killing more civilians than they were reporting ("Syria: Unprecedented investigation reveals," 2019). For militaries engaged in war, there is little consequence for killing civilians or engaging in war crimes if people are unaware it is happening. Unless there is evidence of military wrongdoings, it is impossible to enact any sort of accountability for their actions. OSINVs and the tool created in the project examine the events of conflict in a evidenced procedure, uncovering information that can be used to hold governments accountable for their actions and provide consequences by exposing their wrongdoings to the eyes of the world. Furthermore, the open data corroborated by

OSINVs can be used to support legal consequences, as there is precedent of open data being used to prosecute crimes against international law (Anderson, 2017).

OSINV techniques have broader application not just for exposing events during war but also for tracking emerging conflicts so precautionary steps can be taken to deescalate a situation. Using tools like the one created in this project, OSINVs can help provide evidence of transgressions before they devolve into war crimes and can monitor unrest before it becomes war. By providing new insight into restricted areas and directing public awareness toward events as they happen, OSINVs have the potential to create avenues by which international monitoring of crisis events can prevent major losses of life.

5.1.2 This Project's Tool

As access to the internet and open data grow, the power of OSINVs grows as well. The tool created in this project provides a framework for how OSINV methodologies can adapt to incorporate emerging datasets and new analytical tools. This project's tool contributes to existing OSINV procedures in three main ways. First, by making formal sources more accessible. Second, by providing a new source of physical data, and third, by helping to make the overall process of geolocation faster and easier.

The OSINVs evaluated in Chapter 3 relied primarily on informal sources of data, predominately social media, because formal sources were not as easily accessible for the investigations. Consider the formal data source of Sentinel-1 imagery created by the European Space Agency. It is a large dataset that, although publicly available, is difficult to access and manage. It requires high levels of geospatial processing and remote sensing abilities to extract useful insight from. Traditionally, it would be unrealistic for an open source analyst to take the time to incorporate Sentinel-1 data into their investigation. The tool created in this project, however, harnesses the extensive Sentinel-1 dataset to provide insight to anyone with an internet connection. In just a few clicks, the tool's users can conduct in-depth spatial analysis to yield damage results and can incorporate a formal source that was previously inaccessible into their OSINV workflow.

In addition to making formal sources more accessible, the tool also tackles the lack of temporally consistent physical data. Although social data can be easily manipulated, it provides a more up-to-date and immediate representation of reality compared to the physical data widely available. That is why in the Syrian focused OSINVs studied, physical data (Google Earth Imagery) was always used as a secondary source to social data.

To address the lack of timely, regularly updated physical data, the tool developed in this project uses Sentinel-1 imagery to provide physical data at a pace that can more closely track with social media data. Compared to Google Earth where there are sometimes years-long gaps between available images, Sentinel-1 imagery provides a temporal frequency of 6 to 12 days and an up-to-date archive that better matches that pace of social data. By providing a more temporally relevant dataset, the tool supports a more balanced integration of both physical and social data in OSINVs, as the two types of data can now better intersect in both space and time. The improved temporal frequency provided by the tool has increased benefits when used to investigate armed conflicts in which events unfold quickly and documenting the timing of events is essential when gathering evidence of human rights violations.

Furthermore, this tool illuminates the possibility for a reversal in how investigations are started. With the physical data provided by the tool, investigations have the potential to no longer solely rely on social data at the onset of an investigation. Instead, they can start with physical data, which would circumvent some of the limitations of Syria's politically manipulated social data environment and be able to better investigate events that are not covered on social media. Further, the physical data derived from satellite imagery is augmented by additional physical data from Open Street Map in the form of building locations and types. The functionality of being able to search for damage that occurs to a specific type of building can be used to further streamline the geolocation process for some OSINVs.

The tool created in the project is just one example of how open data can be better leveraged for OSINVs. While the tool created has limitations in its accuracy and ability to detect small and urban areas of damage, it takes a step forward in establishing a framework of how to better incorporate satellite imagery analysis, formal datasets, and physical data into the existing OSINVs workflow. This framework will be useful in the future as more comprehensive and detailed open data become available.

By making high level analysis of a satellite imagery dataset widely accessible to the public, this tool contributes to improving the infrastructure of open data available for

OSINVs and supports investigations to be more impactful in uncovering and documenting events of conflict.

5.1.3 Social Implications

Current frameworks around war in America situate it in an abstract environment separate from our own daily lives. OSINVs shift those interactions by providing a different means to connect with the impact of war. When one conducts an OSINV and engages with original data from conflict areas, war is no longer communicated with an abstract vocabulary of death tolls or air campaigns, it is communicated in very strong terms of destroyed homes and injured bodies. Interacting with conflict data in this way brings a digital proximity and solidity to events that were previously abstract.

Additionally, current social frameworks prioritize interactions with war only in structured spaces that are manufactured by journalism norms or state framing. OSINVs alter these structured frameworks around war by providing a methodology to interact with conflict in the unstructured, messy spaces of the Internet. The general steps to conduct an open source investigation are largely accessible to anyone with an internet connection. OSINVs provide a straightforward procedure with which any individual can dive into the digital realities that exist online and navigate those realities to investigate conflict on their own. Conducting online investigations shifts individuals from being passive recipients of structured information about conflict via the news or government reports to actively participating in uncovering knowledge. Crucially, this active interaction with conflict can change one’s relationship and orientation towards it. Much of the online social media used in OSINVs is created by regular people, and it reflects a very human existence, even in times of war. As such, engaging with this data can create a digital connection to an individual's experience that is not filtered through the contexts of governments or journalism, but exists in new contexts that have yet to be fully explored.

5.1.4 Geographic Implications

This project also provides an example of how the internet transcends physical geography to create online geographies that allow for new knowledge production. For this project, a student in Georgia used a tool created in California to analyze satellite imagery collected by an organization located in France to investigate airstrikes that are occurring in Raqqa, Syria. The internet enables information previously limited to the confines of space and time to flow in new ways, changing how questions about the world are asked and transforming how and by whom they can be answered.

For example, this project explores the intersection of human and physical geography in digital space by investigating a process that relies on that intersection to document war crimes and expose civilian casualties. OSINVs use digitized records of physical changes in structures on the earth's surface to better understand the very human process of war. Human and physical geographies have always been connected, but now with significant advances in the availability of online data, digital spaces are able to powerfully reflect that connection and allow it to be rigorously investigated.

5.2 Discussion

This project identified weaknesses in current applications of OSINVs for the Syrian conflict and developed a new tool that uses GEE and Sentinel-1 data to overcome these limitations and better support OSINVs. This section returns to the three initial research questions to discuss how the project achieved its goals.

(1) What limitations exist in the current methodologies used to verify and geolocate airstrike damage in the Syrian Civil War?

After evaluating the five organizations conducting OSINVs into the Syrian conflict and analyzing the methodologies that were used, this project identified the following limitations:

- Heavy reliance on inconsistent Google Earth imagery to validate other open data, which presents obstacles for the geolocation of events that are not visible in Google Earth's historic imagery or where Google Earth imagery has low resolution
- Geolocation is time intensive and requires some expertise, preventing some parts of the OSINV methodology from being accessible and widely used by all organizations and investigators
- Over reliance on subjective social data to validate events, creating avenues by which the finding of OISNVs can be biased by the skew of the social media environment
- Over reliance on subjective social data to begin investigations, resulting in OSINVs possibly missing events not represented on social media

(2) Can openly available tools (i.e. Google Earth Engine) and publicly available satellite imagery be used to improve the geolocation of airstrike damage in open source investigations of the Syrian Civil War?

Google Earth Engine was used to conduct change detection analysis on the entire available archive of Sentinel-1 SAR satellite imagery. A tool was created that connects users with powerful analytical abilities by using GEE to run large scale computations on satellite data from conflict zones and making the results of the analysis accessible via an online user interface. A change detection algorithm was developed, revised, and tested. The final tool can be used to support the geolocation of airstrikes as it provides the functionality to detect damage across a selected area as well as indicate damage to selected building types. By locating damage within a specific area and time frame, investigators can use the tool to better determine the date of when an airstrike happened, geolocate social media to specific coordinates, and discover damage that occurred to a specific building type with a simple search. This user-friendly tool has the potential of making the OSINV geolocation process less time consuming and can provide physical evidence of damage to help investigate other open data.

While the damage detection tool performs well for building damage larger than the Sentinel-1 resolution cell, it does have difficulties with detecting small individual collapsed buildings, especially within a dense urban area. In addition to detecting damage, the algorithm also returns a number of false positives that can make interpreting the analysis results more difficult. That being said, the tool does yield physical evidence of damage and provides the user the ability to search for buildings specific damage. While it may have limitations, it does provide functionality that is useful and can be further developed for increased applicability.

(3) What are the implications of the tool created in this project and OSINVs at large for the control of information in authoritarian regimes and for other political and social frameworks?

As discussed previously in this chapter, the socio-political implications of this tool and OSINVs span individual, national, and international outcomes. Most significantly, OSINVs undermine the control that both authoritarian regimes and other states have over the information environment during and outside of conflict periods. OSINVs have the potential to reshape social frameworks around war and can powerfully explore the digital interplay between physical and human geography. The damage detection tool created presents new opportunities for OSINVs to more easily access both formal and physical datasets to better complement the social data commonly used in investigating conflict. Finally, it also provides a foundation for the future integration of new datasets and analytical abilities into OSINV methodology.

5.3 Outlook

The reality of wars in the Middle East exist in a geography separated from those not immediately involved. Arms, troops, and bombs are shipped along an abstract route to be used in a remote location—a process contained within a separate physical geography that rarely intersects with the lived reality of the American general public. Weapons travel much easier across time and space in one direction than information about how they are used travel back in the opposite direction. The geography of the reality of war is extensive—spanning across oceans and continents, through homes and markets, by air and by sea. The geography of the general public's awareness is secluded from this reality; it is often contained inside domestic borders with a few structured channels arching across the globe to return information from the battlefield packaged in news broadcasts and published images.

However, new digital geographies are shrinking the space separating the reality of war and the public's awareness of it. Social media and open data tell a story of war in a way that Americans have not had access to before. It's a story of horror, of perished families, bleeding faces, destroyed homes, and lost children. It is a story that is told for the first time in real time and for the first time by the people whose homes are being destroyed. Social media and open data are telling stories not of deaths in totaled numbers, but of individual human traumas. And these stories are using a visual vocabulary that is easily understood and deeply felt.

The emerging digital representation of war exists in a geography that transcends physical space. It bridges thousands of miles to connect us to a war we have never truly been separate from. The impact of the weapons and bombs sent over can now flow back digitally in pictures, videos, and satellite images.

Open source investigations leverage the digital space to bring the geography of war further into the public awareness. By examining connections between different open data, OSINVs systematically uncover the actions of those involved in conflict. This project leverages a robust physical dataset of satellite imagery to detect damage and create a tool that is available to everyone online. The physical information uncovered with the tool and future iterations of it can be used with social media data to support new ways of investigating and understanding conflict. Continuing to explore new methods to glean insight from the social and physical data landscapes will allow us to follow the events of armed conflicts more closely and in real time. OSINVs circumnavigate the limitations of traditional information sources and improve our ability to gather evidence of human rights violations and to bear witness to the atrocities of war.

To address a problem, one must first be aware that it exists. OSINVs bring awareness to the tragic consequences of war. War is a living reality for millions of people. The digital reality we all have access is now able to reflect that. We must not look away.

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APPENDIX

Acronyms

AOI	Area of Interest
API	Application Programming Interface
CCD	Coherence Change-Detection
CJTF-OIR	Combined Joint Task Force Operation Inherent Resolve
DOI	Date Range of Interest
DVIDS	Defense Visual Information Distribution Service
ESA	European Space Agency
EU	European Union
GEE	Google Earth Engine
GRD	Ground Range Detected
IW	Interferometric Wide Swath Mode
NASA	National Aeronautics and Space Administration
NDVI	Normalized Difference Vegetation Index
NDWI	Normalize Difference Water Index
NGO	Non-Governmental Organization

OSINT	Open Source Intelligence
OSINV	Open Source Investigation
OSM	Open Street Map
PHR	Physicians for Human Rights
SAR	Synthetic Aperture Radar
UI	User Interface
UGC	User Generated Content
VGI	Volunteered Geographic Information

User Feedback Form

Feedback Survey: Syria Damage Detection Tool

Thank you for providing feedback to help guide the creation of this damage detection tool. I am currently in the development process and your feedback will be vital in shaping this tool to be of use to open source investigations.

Your Information

Name (Optional)

Your answer

Organization

Your answer

Role

Your answer

Functionality Feedback

How likely would you be to use this tool in your open source investigation research?

	1	2	3	4	5	
Not Likely	○	○	○	○	○	Very Likely

Are there any additional features or changes you would suggest to make this tool more useful?

Your answer

Is there any other data you would like to see the tool provide?

Your answer

User Interface Design Feedback

Is the use of the tool intuitive?

	1	2	3	4	5	
Not Very Intuitive	○	○	○	○	○	Very Intuitive

Is the damage map easy to interpret?

	1	2	3	4	5	
Very Complicated	○	○	○	○	○	Very Easy

Any design specific feedback/ suggested changes?

Your answer

Additional Feedback

Any other additional feedback?

Your answer

SUBMIT

Never submit passwords through Google Forms.