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Detecting urban destruction in Syria: A Landsat-based approach

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ABSTRACT

The Syria conflict is characterized by ongoing human rights violations, a disregard for international law, and little fear of accountability. The Syrian government has repeatedly violated international law by employing punitive barrel-bomb and missile attacks and demolitions of neighborhoods accused of supporting opposition forces. Documentation efforts using high-resolution satellites have fallen short in this widespread and long-running conflict, providing poor precision for when attacks take place and reducing their evidential strength in International Courts. By capitalizing on the Landsat constellation's systematic observations and historic archive, we present an approach that examines affected areas as little as every eight days to identify when urban buildings are destroyed. Using a pre-conflict baseline of six years, we model the daily expected surface reflectance for every urban pixel in Aleppo and Damascus and compare pixels recorded during the first year of the conflict with this expected value. Leveraging high-resolution satellite documentation efforts, we create a composite band sensitive to urban destruction. This approach is accurate within 74% of the ground-reference dataset, providing the international community way forward to monitor and document urban destruction in arid environments.

1. Introduction

The conflict in Syria is the largest human rights tragedy in the 21st century. According to the Office for the Coordinator of Humanitarian Affairs (OCHA), over 250,000 people have been killed and over one million injured. Human rights violations and abuses are widespread with no regard to international law. Due in large part to the heavy-handed and indiscriminate military actions of the Syrian government, more than half of all Syrians have been forced to flee their homes (OCHA, 2015). These actions include the demolition of entire city blocks and the use of inaccurate short-range ballistic missiles (SRBMs) and large-caliber bombs into dense residential areas (Gordon and Schmitt, 2012). These attacks have served dubious military objectives and have been described by an UN Commission of Inquiry as punitive, or as a terror campaign against civilian neighborhoods accused of supporting opposition forces (United Nations Human Rights Council, 2013).

Indiscriminate attacks not serving a military objective are a violation of the Rome Statute of the International Criminal Court (United Nations, 1998) and have been prosecuted as war crimes (International Criminal Tribunal for the Former Yugoslavia, 2010). While residents report many of these attacks on social media, there are few international observers in Syria and objective corroboration of these attacks remains challenging. This lack of corroborating evidence is typical in situations of internal conflict where regimes limit international access, information outflow, and aircraft overflights (Marx and Goward, 2013). Because of these limitations, organizations that monitor human rights have increasingly turned to imagery from high-resolution commercial satellites for documentation. However the cost of imagery from high-resolution satellites makes the monitoring of large-scale conflicts over many years prohibitive.

For use in International Criminal Courts, satellite-derived evidence of human rights violations, such as the burning of a village, is most effective when it can narrow the time window of when an attack took place, documenting when the village was first detected as destroyed and when it was last intact (Lyons, 2015). Because evidence of genocide, which by definition is systematic, requires a time series analysis of violations (United Nations, 1998), the narrowing this time window will increase temporal fidelity and strengthen the use of satellite imagery as evidence. While the proposed analytical approach strictly monitors urban areas for destruction, this information could be used with a variety of additional information such as refugee surveys (U.S. Department of State, 2004) or government-derived datasets (HIU, 2010) to support claims of human rights violations or genocide.

The use of remote-sensing to monitor conflict has increased over the past ten years (Witmer, 2015), but these efforts continue to lag behind other fields. Moderate resolution satellites are already employed in monitoring campaigns to detect conditions and provide alerts to users. The Famine Early Warning System Network incorporates remotely-sensed data with field-collected information to identify conditions that may lead to food insecurity (http://www.fews.

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net); Webfire Mapper provides near real-time information on fires worldwide using the Moderate Resolution Imaging Spectroradiometer (MODIS) (Wilhite and Svoboda, 2000); and Global Forest Watch uses Landsat-based algorithm to allow users to sign up for alerts when deforestation is detected in their area of interest (http://www.gfw.org) (Hansen et al., 2013). Like these moderate resolution-based monitoring programs which look for a observable change on the Earth's surface, this approach also detects an observable change to the Earth's surface (the destruction of a building or buildings). This information can be used to corroborate eyewitness claims of human rights violations.

The use of moderate resolution sensors to detect a signal that may be associated with a human rights violation is most effective in areas large areas with limited access to investigators. Bromley (2010) showed that the Moderate Resolution Imaging Spectroradiometer (MODIS) Thermal Anomalies and Fire Detection data product could be linked to eye-witness reports of village destruction in Darfur. Prins (2008) demonstrated that Landsat could be used to detect the burning of Darfur villages on an annual basis. Marx and Loboda (2013) modified this approach to reduce the time a village was detected as burned to every 16 days. While burned villages were small and could consist of only twenty of Landsat's pixels, this work exploited the large spectral separation in near-infrared reflectance (NIR) between pre- and post-burned images.

The Landsat constellation is a good option for monitoring and documenting urban destruction in arid regions. It provides a large archive of past imagery due to its strategic acquisition plan (Goward et al., 2006), temporal fidelity as great as eight days, radiometric consistency (Markham et al., 2004), and excellent orthorectification. These four characteristics, in addition to imagery now being provided free to the users (Woodcock et al., 2008), permits the development of accurate historic baselines for every pixel Landsat captures since 1982 (Zhu et al., 2015).

Using Landsat-derived data presents a clear set of advantages, but there are also disadvantages in employing data from this sensor. Challenges in a Landsat-based detection of destroyed residential buildings in Syria include the small spatial scale of the destruction (as small as four pixels or 120 sq meters) and the limited spectral separation between pre- and post-destruction images. In response to these challenges, we demonstrate a Landsat-based approach which provides an accurate, automated detection of a variety of destruction events in urban areas in Aleppo and Damascus, Syria's two largest cities. This is for a one-year study period, from July 1, 2012 to July 1, 2013. These events include demolitions (Fig. 1) and large-blast explosions from missiles or bombs (Fig. 2). This approach creates an expected value for every pixel of these two cities at every date of the year, based on that pixel's historic baseline. The signal for newly destroyed buildings is detected when their post-destruction pixel value is significantly higher than their expected value for that date, producing a 74% accuracy level. This study demonstrates an economical and viable approach to document all urban destruction during the Syrian conflict and to continually monitor the crisis for future destruction.

2. Study area

The Syrian Civil War began in the spring of 2011 with Arab Spring protesters in Damascus demanding democratic reforms and the release of political prisoners. The government escalated the conflict with heavy-handed responses, spurring more protests and a shift in demands to the removal of the Assad regime (Fahim and Saad, 2013). In June 2012, the UN officially proclaimed Syria to be in a state of civil war and fighting moved from smaller villages and surrounding neighborhoods into Syria's two largest cities, Aleppo and Damascus.

With the Syrian government unsuccessful at defeating the opposition in the first year, they began to increasingly use large, indiscriminate weapons. July 25, 2012 was the date of the first documented use of aerial bombardment in Damascus and Aleppo (Weaver and Whitaker, 2012). In August 2012, the first 'barrel bomb,' a low-tech, high-blast weapon, was reportedly dropped in a residential district in Aleppo (Marcus, 2013). February 2013 saw the first use of short-range ballistic missiles (SRBMs) fired into residential neighborhoods in Aleppo (Schmitt, 2012). The government's use of large-caliber munitions into residential, urban areas has increased as the conflict has continued (AAAS, 2014).

These measures are not limited to Aleppo and Damascus or to the use of weapons. The Syrian government has demolished suspected opposition strongholds in cities across Syria in an attempt to reduce their strength. Since July 2012, Syrian authorities have used explosives and bulldozers to demolish thousands of residential buildings in areas (Neistat, 2014). See Neistat (2014) Chapter 8: Legal Framework for the connection between illegal demolitions and human rights violations.

The algorithm detects the remotely-sensed phenomenon associated with the destruction of urban buildings. Specifically, the algorithm detects a change in surface reflectance from pre-destruction pixels (concrete building roofs) and post-destruction pixels (concrete rubble or soil). This approach provides a high degree of accuracy because such destruction in the conflict in Syria is almost always due to illegal demolitions or the use of high-caliber munitions in missiles or bombs.

The study area consists of the urban areas of Aleppo and Damascus, Syria's two largest cities, contained by Landsat World Reference System Path/Rows 174/35 and 174/37 respectively. The study includes two contiguous time periods: (1) a pre-conflict

Fig. 1. Eyewitness accounts of the early September 2012 razing of residential housing in Damascus (Table 2: Site 4) was corroborated with high-resolution imagery as occurring between September 2 and 22 (Neistat, 2014). The proposed Landsat-based method detected the destruction occurring between September 11 and 27. Eight of the ten 30 m pixels used for this location are indicated in red. Imagery shown is from September 2, 2012 and January 1, 2013 (Google Earth, 2015b). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)