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A New Forensics: Developing Standard Remote Sensing Methodologies to Detect and Document Mass Atrocities

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Abstract:

Aim: The aim of this article is to highlight potential methods applicable to a standard forensic approach for the analysis of high-resolution satellite imagery that may contain evidence of alleged mass atrocities.

Methods: The primary method employed is the retrospective analysis of a case study involving the use of high-resolution satellite imagery analysis to document alleged mass atrocities. The case study utilized herein is the Satellite Sentinel Project's reporting on the May 2011 sacking of Abyei Town by Government of Sudan-aligned armed actors. In the brief case study, categories of objects, patterns of activities, and types of alleged mass atrocity events are applied to the Abyei Town incident.

Results: Categories of activity patterns, visible phenomena, and relevant objects leaned from the Abyei Town case study may provide a scalable example of how accepted forensic standards for remote sensing analysis of alleged mass atrocities may be further developed.

Conclusions: The methods and frameworks applied in this research to the Abyei Town case study should be tested and refined through further case studies. The sources of these case studies may be both past reports by civil society, governments, and international judicial bodies and new analyses of previously unanalyzed high-resolution satellite imagery of alleged mass atrocities.

Keywords: satellite, imagery, forensic science, pedagogy, mass atrocities, human rights, remote sensing, Sudan, war crimes, analysis

MARS: The Application of Remote Sensing to Mass Atrocity Contexts

Prior to the United States Government allowing the commercial sale of high-resolution satellite imagery in the early 1990's, high-spatial resolution¹ (afterwards, "high-resolution") satellite imagery was almost solely available only to governments, their militaries, and their intelligence agencies.² This change in policy has enabled NGOs and international agencies to begin employing this specific type of remote sensing technology to document alleged mass atrocity events.³

The use of high-resolution satellite imagery analysis to document mass atrocity events, which is referred to hereafter as Mass Atrocity Remote Sensing (MARS), has demonstrated utility for these groups.⁴ Remote sensing can provide unique, sometimes otherwise unavailable, information about events occurring in extremely non-permissive environments,⁵ over large geographic areas, and across long and multiple timeframes. Regions where mass atrocity events occur are typically inaccessible to outside observers, particularly civil society groups and international agencies.

There are several distinct applications for MARS involving the analysis of high-resolution satellite imagery, including retrospective documentation of events for accountability and advocacy purposes,⁶ detection of potential indicators that a mass atrocity may soon occur,⁷ and as a data source for researching historical activity

patterns that may occur during certain armed conflicts.⁸ Some advocacy organizations currently employing MARS to document specific types of mass atrocities include Human Rights Watch, Amnesty International, the Enough Project, and Physicians for Human Rights. Reports released by these organizations have focused on nations that include Syria, Sudan, Nigeria, Burma, and Central African Republic.⁹

Academic research institutions also conduct high-resolution satellite imagery analysis of alleged atrocity events, and their research has helped support the adoption of these tools and methods by civil society groups. Notable examples of these types of research centers include the American Association for the Advancement of Science's (AAAS) Geospatial Technologies and Human Rights Project¹⁰ and the Harvard Humanitarian Initiative's (HHI) Signal Program on Human Security and Technology.¹¹

International agencies and governments are involved in this type of work as well. The United Nations Operational Satellite Applications Programme (UNOSAT) is a leading example of the increased use of remote sensing by international agencies in potential mass atrocity producing contexts.¹² UNOSAT has provided analysis of imagery, generated maps, and created other products related to the mass displacement of civilian populations in South Sudan, Syria, and elsewhere.¹³ Recently, the United States Department of State's Humanitarian Information Unit has started releasing commercial imagery of alleged mass atrocity events to voluntary technical organizations, NGOs, and other civil society groups.¹⁴ Examples of MARS-relevant data released so far by the US State Department through this initiative include commercial imagery captured over Syria, among other locations, where armed conflict is ongoing.¹⁵

Additionally, intelligence services and other executive agencies of various national governments, including the European Union¹⁶ and the United States' intelligence community, are increasingly expressing public interest in improving mass atrocity Early Warning Early Response (EWER) capabilities.¹⁷ The full scope of the interest and investment of these agencies in MARS applications, however, is difficult to fully assess, in part, due to the classified nature of some of these activities.

In the past approximately twenty years, MARS-type analyses of high-resolution remote sensing data, including aerial reconnaissance photography, have been admitted as evidence in cases before the International Criminal Tribunals for the former Yugoslavia and Rwanda, the International Criminal Court (ICC), and the International Court of Justice (ICJ), amongst other national and international venues.¹⁸ However, it can be argued that civil society's use of high-resolution remote sensing specific to the mass atrocity context is still very much a recent development.

The MARS Methodology Gap

Despite the growing number of organizations engaged in this space, little formal pedagogy specific to this emerging field exists. Thus, efforts to professionalize and standardize the application of remote sensing in the context of mass atrocities has lagged behind the pace at which organizations are adopting this technology for these purposes. Analysts using these technologies have little documented past practice to draw upon.

The net result is that MARS practitioners are currently without accepted forensic standards specific to corroborating through primarily remotely observed phenomena whether an alleged mass atrocity has likely occurred.¹⁹ This core gap is the result, in part, of little extant research intentionally treating MARS as its own distinct discipline within remote sensing, with its own distinct operational challenges and requirements.

As a consequence, MARS appears to most often be applied by organizations to create incident specific analysis products. These products may aim to enhance current situational awareness or support advocacy efforts to shift public opinion and policy around a particular issue.²⁰ Few current MARS products, however, appear specifically intended to create generalizable knowledge leading to the development of standard methodologies for applying MARS across incidental and regional contexts.

Some analysis techniques originally developed for military intelligence purposes (known as "geospatial intelligence" or "GEOINT") that are relevant to MARS work can sometimes be gleaned from both unclassified and declassified United States Government imagery and analysis products.²¹ While of general value to the MARS field, past GEOINT practices alone are not enough of an antecedent to develop standard theoretical and methodological approaches to MARS work.

Publicly available GEOINT examples rarely include previous analyses of mass atrocity incidents. A notable exception is declassified satellite imagery and aerial reconnaissance photography related to the 1995 Srebrenica massacre. This imagery was later released after it was used as evidence exhibits in the International Criminal Tribunal for the former Yugoslavia.²² The Srebrenica images are unique in this regard.

Original, cross contextual MARS-specific research will thus be required if analysts are to learn what potentially observable objects and corresponding activity patterns involving those objects may be detectable

through remote sensing. Additionally, this research should seek to understand the unique identifiable characteristics of activity patterns that may generally occur during mass atrocity events within certain regions (i.e., East Africa, Middle East, North Africa, etc.) and environments (i.e., desert, savannah, mountains, urban settings, etc.). Research should prioritize geographic areas and contexts where past experience demonstrates mass atrocity events are more likely to occur.²³

A New Forensics of Remotely Observed Objects and Activity Patterns

MARS-relevant patterns should be based upon certain repeating observable objects (i.e., military vehicles, newly razed buildings, shell craters, etc.) and phenomena involving these objects and features (i.e., apparent troop movements, infrastructure construction patterns, indiscriminate bombardment, civilian displacement, house-to-house searches, etc.) found in some form across these contexts and regions. These observable objects and phenomena may be visible either prior to a mass atrocity event occurring, during the alleged perpetration of a mass atrocity event by armed actors, or as a result of changes to objects and the surrounding physical environment after a mass atrocity event has allegedly occurred.

This task is complicated, though, by the fact that the remote collection of evidence from alleged mass scale crimes requires its own unique set of criminalistics (i.e., scientific methods for collecting and analyzing evidence). Currently, there are no established criminalistics for MARS.²⁴ The establishment of criminalistics for MARS will likely be based on indicators and phenomena that have few antecedents in both traditional criminal forensics and what can be learned from non-classified examples of GEOINT.

The lack of previous antecedents for this type of forensic analysis is partly due to the fact that MARS practitioners analyze events occurring within areas of interest (AOI) that can encompass several thousand square kilometers and across timeframes spanning several days, months, or even years. Thus, a new discipline of remote forensic analysis specific to the evolving MARS field must be developed from the integration of several sources of past practice. These sources of applicable past practice may include, though are not limited to, the following fields: Remote sensing analysis of environmental factors, photogrammetry, crime scene investigation by law enforcement agencies, and military and intelligence approaches to geospatial intelligence collection and analysis.

To develop a forensic science tailored to support MARS applications, a common approach for identifying and classifying examples of activity patterns comprised of certain observable objects with potential probative value should be identified, tested, and subjected to peer review. This approach should draw on the growing body of public, incident specific reports, like those mentioned above, that are being generated in recent years by NGOs, academic researchers, and international agencies.

In time, legal standards of what constitutes potential evidence of specific mass atrocities could likely be cross-referenced and integrated with these case studies for the purposes of identifying and agreeing evidence examples. Eventually, best practices for MARS evidence collection, annotation, and storage may be able to be developed from that resulting corpus of evidence examples.

This paper, however, solely addresses only one of the methodological and pedagogical gaps mentioned above. That gap is the absence of a standard approach for the classification of phenomena involving observable objects into categories of activity patterns relevant to certain mass atrocity events.

The analysis of one case study—the alleged May 2011 razing of Abyei town by Sudan Armed Forces—is examined within this article. The case study data is derived from the reports of the Satellite Sentinel Project²⁵ and the HHI Signal Program study, “*Sudan: Anatomy of a Conflict*.”²⁶ The goal of the case study is to demonstrate a potential framework for approaching the challenge of standard identification and classification of MARS-related activity patterns and observable objects.

Though specific to objects and patterns common to the context of armed conflict in East Africa, the authors intend for the framework to be of broader value outside Sudan and similar nations. It is expected that this initial approach may likely have some relevance for MARS practitioners conducting analyses of alleged mass atrocities across diverse regional and operational contexts. Other similar case studies from different regions, timeframes, and/or operational contexts may aid in refining and scaling this evolving methodology for general use.

Case Study: The Alleged May 2011 Razing of Abyei Town by Government of Sudan-Aligned Forces

In January 2011, the people of the nation that is now South Sudan voted in a referendum to overwhelmingly secede from Sudan. A bloody, decades long civil war between Sudan and southern Sudan ended with the signing of the Comprehensive Peace Agreement (CPA) in 2005. The accord provided an opportunity for the southern part of the nation to vote on self-determination.²⁷ In July 2011, South Sudan officially became the world’s newest nation.



Figure 1. Map of the Abyei Administrative Area.

However, the CPA did not resolve the final status of the Abyei Administrative Area, a region straddling a long-contested border area between Sudan and South Sudan. Thus, at the time of the January 2011 referendum, Abyei residents technically belonged to both West Kordofan state, Sudan and Bahr-el-Ghazal, a state in what is now South Sudan.²⁸

The majority of Abyei's population is from the Ngok Dinka, a southern Sudan-aligned ethnic group, who inhabit the region's largest city, Abyei Town, as well as most of the area immediately surrounding it. The second largest ethnic group present the region is the Misseriya, an Arab ethnic group traditionally aligned with Sudan. The Misseriya, semi-nomadic pastoralists, move seasonally into the Abyei region to graze their cattle via a series of traditional migration routes, known as *murhals*.²⁹

A referendum to resolve the status of the Abyei region was originally scheduled for around the same time as the vote to decide the future of southern Sudan. Ordered by a decision from the Hague-based Permanent Court of Arbitration (PCA) in 2009, the referendum was intended to peacefully resolve the tensions between Sudan and the then southern Sudanese.³⁰

However, the PCA decision was not implemented due to disputes over Sudan's insistence that the Misseriya, who are seasonal residents, be allowed to vote in the referendum.³¹ Towards the end of 2010 and in the spring of 2011, clashes broke out between the Misseriya and southern Sudanese-aligned forces inside the Abyei region, leading to the destruction of villages and the forced displacement of primarily Ngok Dinka civilians.³²

Forces aligned with both Sudan and southern Sudan took up positions inside the Abyei region, constructing fortifications and hardening their emplacements. It was during this time that Sudanese regular forces, in addition to Misseriya militias apparently already operating within Abyei, began to build-up their strength at bases inside Sudanese territory. These tanks, planes, infantry, and other units were arrayed within air and ground strike range of Abyei Town.³³

The tense situation, which had been punctuated for months by seemingly isolated incidents of violence, devolved into an all-out invasion of Abyei Town by Sudanese forces. Following a shootout between Sudan Armed Forces (SAF) and Sudanese People's Liberation Army (SPLA) at the Dokura checkpoint on the night of May 19, 2011, SAF engaged in artillery bombardment of SPLA positions at Todach and Tajalei, areas to the north of Abyei Town proper on May 20.³⁴

By the end of the next day, May 21, Abyei Town was firmly in the control of SAF-aligned forces. Over 30,000 residents of the town had fled. Houses were on fire. Misseriya militia and SAF forces allegedly moved freely throughout Abyei Town, despite the presence of UN peacekeepers, looting and burning civilian property on a large scale.³⁵

Over the next few days, more than a third of all standing structures in Abyei Town were razed, the World Food Programme compound was looted, and the central market was destroyed.³⁶ Four senior former prosecutors and US State Department war crimes officials would later determine that the actions of SAF-aligned forces during the Abyei Town incident potentially rose to the level of war crimes.³⁷

Categories of Observable Objects Likely Relevant to the May 2011 Abyei Incident

The following observable objects, or “observables”, may often be observed using remotely sensed imagery in the context of other rural and semi-urban East African armed conflict settings, including the ongoing conflict in Darfur, Sudan.³⁸ The 2011 razing of Abyei Town in the disputed Abyei Region bordering Sudan and South Sudan, the case study in this article, falls within this specific context. Some likely techniques a MARS analyst would employ to identify (or “type”) these observables are included for each category of object as well.

The table below is based on data solely from the Signal Program for Human Security and Technology at the Harvard Humanitarian Initiative’s (HHI) 2013 satellite imagery-based study, Sudan: Anatomy of a Conflict. It is specific to that study’s section on the alleged May 2011 razing of Abyei Town by Government of Sudan-aligned forces (GoS).³⁹

While these observables are common in multiple East African MARS settings, the table is not meant to be exhaustive, nor are all examples inclusive to the context of the Abyei Town incident.⁴⁰ The table is intended to both serve as a practice example of a MARS specific observable object and typing chart, as well as a resource to inform the interpretation of imagery examples later in the case study.

Table 1. MARS-Relevant Observables and Corresponding Typing Methods (Alleged Razing of Abyei Town by Sudan-Aligned Forces, May 2011)

MARS-Relevant Observables	Typing Methods
<u>VEHICLES:</u> <ul style="list-style-type: none"> ● Military-use ground vehicles (i.e., tanks, armored personnel carriers, heavy transport trucks, water and fuel tankers, etc.) ● Civilian-use ground vehicles (i.e., Land cruisers, lorries, etc.) <ul style="list-style-type: none"> ○ NGO/UN branded vehicles ○ Fuel, water transport tankers ○ Livestock transport vehicles ○ Earthmovers (i.e., backhoes and road graders) 	<ul style="list-style-type: none"> ● Dimensions, color patterns, and unique features of an object can be compared with publicly available databases, such as Jane’s reference materials (hereafter, “DCU comparison”). ● Observable Object Context Analysis (hereafter, “OOC Analysis”): The context in which specific observable objects repeatedly appear can often help indicate their identity and/or current use (i.e., Presence of white, uniformly shaped vehicles at a known hospital may likely be ambulances, etc.).
<u>AIRCRAFT:</u> <ul style="list-style-type: none"> ● Fixed wing (i.e., fighter jets, transport planes, bombers, etc.) ● Rotary wing (i.e., attack helicopters, transport helicopters, etc.) 	<ul style="list-style-type: none"> ● DCU Comparison. ● OOC Analysis. ● Measurement of runway length to help determine minimum takeoff and landing requirements for aircraft present.
<u>ARTILLERY:</u> <ul style="list-style-type: none"> ● Towed artillery (i.e., Howitzers, other large caliber ordnance that can be pulled behind a vehicle) ● Mechanized tube artillery (i.e., multiple launch rocket systems, etc.) ● Fixed artillery (i.e., large, long-range weapons that are not mobile) 	<ul style="list-style-type: none"> ● DCU Comparison. ● Presence of “V” shape at back of long, gun-shaped weapon consistent with towed artillery. ● Object placement in circular depression (also called an “artillery berm”). ● Position of “gun barrel” feature on the object changes over time.

<p><u>MILITARY INFRASTRUCTURE:</u></p> <ul style="list-style-type: none"> ● Permanent encampments (i.e., major bases, including unit headquarters, containing more permanent buildings and infrastructure) ● Temporary encampments (i.e., forward operating bases created as part of operations, fortifications, groups of tents, etc.) ● Air bases (i.e., airstrips, aprons, hangars, logistical support buildings and equipment, fuel tanks, air traffic control, and communications towers, etc.) 	<ul style="list-style-type: none"> ● Presence of external and/or internal security perimeters comprised of trenches, berms, checkpoints, guard towers, fences, wooden corrals, or fighting positions (“foxholes”). ● OOC analysis of military vehicles in and around structures, perimeters, etc. ● Visible communications infrastructure, including radio towers, satellite dishes, etc. ● Potential housing, supply and logistics buildings (i.e., barracks, motor pools, ammo dumps, external water and fuel tanks, etc.). ● Tents of various shapes, colors, sizes, and arrangements.
<p><u>CIVILIAN INFRASTRUCTURE:</u></p> <ul style="list-style-type: none"> ● Civilian dwellings <ul style="list-style-type: none"> ○ Tukuls (traditional huts) ○ Metal roof structures ● Water points (including catchment basins, boreholes, water towers/tanks) ● Agriculture <ul style="list-style-type: none"> ○ Fields ○ Orchards ○ Irrigation infrastructure ● Markets ● Religious sites <ul style="list-style-type: none"> ○ Mosques ○ Churches ● Hospitals/clinics, schools 	<ul style="list-style-type: none"> ● Tukuls: Circular mud and thatch structures with cone shaped roofs, often surrounded by a some form of corral or other enclosure composed of brush. ● Non-tukul structures consistent with civilian dwellings: Square/rectangular buildings with reflective roofs, presence of corrals, walls, or other enclosures. ● Water points, etc.: Gathering of animals, crowds around standing water, enclosure with large basin or pump house, etc. ● Agriculture: Visible evidence of cultivation, presence of nearby trenching (i.e., possible irrigation), trees arrayed in rows, etc. ● Market: Presence of irregular stalls with metal, tarp, and/or fabric roofs; livestock holding areas; gathering of vehicles. ● Religious sites: Mosques may or may not have visible minaret structures present, dome, or Mecca-facing orientation. Churches may or may not have visible steeples. In both cases, non-imagery data corroboration is required. ● Hospitals/clinics, schools: These and other similar structures require non-imagery data corroboration. Though features present in imagery may support identification, none of these features are usually dispositive by themselves.
<p><u>HUMANITARIAN INFRASTRUCTURE:</u></p> <ul style="list-style-type: none"> ● Humanitarian agency compounds <ul style="list-style-type: none"> ○ Warehouses ○ Administrative Buildings/Tents ○ Motor pools ● Displaced persons camps <ul style="list-style-type: none"> ○ Tents ○ Water and Sanitation infrastructure ○ NGO/UN vehicles ○ IDP/Refugee built housing (i.e., tarp and/or stick huts) 	<p><i>Humanitarian compounds and/or displaced persons camps may be characterized by some or all of the following features:</i></p> <ul style="list-style-type: none"> ● Presence of uniform colored vehicles (usually white Land Cruiser-type). ● Uniform or similar shaped temporary structures (i.e., tents) with agency logos sometimes visible on roof. ● Large numbers of tarp and/or stick based structures (with or without corrals). ● Apparent WASH (Water, Sanitation, and

	<p>Hygiene) infrastructure (either stockpiled or deployed), including tanker vehicles, washrooms/shower houses, water storage vessels, etc.</p> <ul style="list-style-type: none"> ● Helipad and/or airstrip with white painted fixed wing transport, rotary, or other aircraft.
<p><u>TRANSPORTATION INFRASTRUCTURE:</u></p> <ul style="list-style-type: none"> ● Roads ● Bridges ● Bus stations/transit centers 	<ul style="list-style-type: none"> ● Roads: Presenting as dirt tracks, surfaced (i.e., paved) roads, or as elevated dirt tracks (i.e., roads built-up out of compressed earth). ● Bridges: Can be concrete or metal structures present over rivers. ● Bus stations/transit centers: Characterized by the routine presence of buses, transport vehicles, often located in towns/cities of larger size.

Primary Imagery Analysis Methods for Identifying Mass Atrocity-Related Activity Patterns

MARS analysts may use multiple accepted remote sensing analysis methods, either individually or in combination, to identify observable objects and apparent patterns of activity involving those objects. Of particular importance to the MARS analyst is the observation of changes to the physical environment over time. These observations can occur based on the analysis of one or more satellite images of one or more AOIs over a timeframe of days, months, or years.

Analysts attempt to draw probabilistic inferences about the potential causal and/or correlative relationships between the absence, presence, or change in position of observable objects and changes to the physical environment of an area. Three methods, in particular, are useful for analyzing activity patterns and attempting to understand their significance:

- *Multi-temporal Change Detection:* Multi-temporal change detection involves the comparison of two or more images of the same area captured at different times.⁴¹ The analyst will attempt to detect differences in the coloration, visual properties, presence, absence, and/or position of objects across the images, drawing inferences from those changes. This analysis is often performed with the support of imagery analysis software, such as ERDAS Imagine or other computer programs.⁴²
- *Multispectral Analysis:* Multispectral images are satellite images that capture more than one wavelength (or band) of electromagnetic energy.⁴³ A commonly used multispectral band is near-infrared (NIR), which is most often used for detecting changes to vegetation, especially ground cover, in a satellite image.⁴⁴ This approach is especially helpful in seeing vehicle tracks, such as tank or tire tread marks.
- *Non-imagery Data Cross-Referencing:* Whenever possible, imagery is cross-referenced with non-imagery data to help identify observables, provide context to their behavior and disposition, or to help identify the potential AOI itself. Non-imagery data may include history of past conflict, the affiliation of armed actors, and relationships between ethnic or religious groups. There are many sources of non-imagery data in MARS contexts that may be cross-referenced with imagery. Some of the most common include news articles, reports from NGOs and international agencies, such as the UN, crowd sourced map data, and even the public statements of the alleged perpetrators themselves. It is optimal for MARS analysts to structure their collection of non-imagery data by its spatio-temporal metadata (i.e., place and time information common to each report) to more effectively integrate these streams with remote sensing data.

Factors Affecting the Identification of Objects and Activity Patterns

The analysis of remote sensing data of an object alone does not allow an analyst to scientifically reach a level of absolute certainty as to the definitive identity of that object, nor to the nature of its status and/or activity at the time the image was captured. An object or phenomenon present in remote sensing data can, at most, only be “consistent with” the known visual properties that object is believed to have when apparently visible in a satellite image.⁴⁵

Thus, identifying MARS-related objects (and the activity patterns which they comprise) to the highest level of probabilistic certainty possible depends, in large part, on three interdependent sets of factors. These factors can affect—both negatively and positively—the degree to which an analyst can reach the highest level of probabilistic certainty possible:

- A) *Available Data*: The volume, quality, and potential relevance of both imagery and non-imagery data available to the MARS practitioner related to the area of interest required to identify the presence of the visual properties consistent with these objects and patterns;
- B) *Technology*: Certain MARS-relevant objects and patterns may or may not be detected through available remote sensing technologies and analysis methodologies across any or all operational contexts and situations;
- C) *Relevance*: An analyst's understanding of what objects and patterns are potentially relevant to MARS analysis, including the visual characteristics and properties of the objects comprising those patterns.

First, it is the interplay of these three sets of factors that often determine what observable objects present in imagery an analyst may be able to reliably identify. Second, the interaction of these factors also help determine what inferences and insights about the potential activity of those objects an analyst may be able to draw.

Lastly, these factors also impact the degree to which a MARS analyst may or may not be able to connect any apparent activity patterns to any specific types of alleged mass atrocities that may be detectable through remote sensing. To assess and mitigate how these factors may affect the quality and accuracy of analysis, analysts should be fluent in the basic technical capabilities and expected limitations of publicly available remote sensing technologies.

Limitations of Remote Sensing Technologies

Until June 2014, the highest resolution of publicly available (i.e., non-classified) satellite imagery accessible to civilian actors is approximately 50 centimeters.⁴⁶ At this resolution, analysts can expect to reliably identify, or “type”, certain categories of commonly repeating objects the size of vehicles, buildings, and major infrastructure, such as roads and bridges, through satellite imagery analysis. Crowds of livestock and people can sometimes be visible, though the exact composition, size, and object type of these crowd configurations cannot be reliably determined. Additionally, “micro interactions”, such as the movement of small groups of individuals and the positioning of small weapons, cannot be reliably identified and tracked.

However, it must be noted, that both the quality of imagery, the number of recent and/or relevant images of an AOI available (known as “temporal resolution”),⁴⁷ and the level of corroborating non-imagery data available to the MARS analyst are dynamics that may also determine whether an observable object can be typed. Multiple factors outside of the analyst's control determine the overall quality of a high-resolution satellite image.

These factors may include, though are not limited to, the angle at which the satellite was positioned when the image was captured (known as “off-nadir angle”);⁴⁸ the position of the sun overhead at the time of the image (known as “solar azimuth angle”);⁴⁹ the presence of clouds, smoke or other particulate matter in the air at the time the image was taken; and the degree to which seasonal variables effect the presence of trees, ground cover vegetation, and other flora that may obscure objects present in the image.⁵⁰

Cross-referencing imagery with all available potentially relevant non-imagery data is necessary. Corroborating analytic conclusions about objects and other phenomena present in an image rarely can occur based on imagery alone. Some of these sources of non-imagery data useful for corroboration of imagery analysis can include eyewitness testimony, news articles and other open source reports from NGOs.

Data with probative value for MARS analysis may also be gleaned from ethnographic studies of populations present within the AOI. Past studies of regionally and culturally specific macro trends related to armed conflicts, economic development, and population movements may also be of value.

One of the defining features of MARS analysis is its inherently interdisciplinary nature, as the diverse sets of factors listed above demonstrate. Thus, practitioners are often faced with a heterogeneous mixture of potentially relevant data, often in several languages. These diverse streams of data may require simultaneous application of multiple mixed quantitative and qualitative methods to analyze them.

Additionally, predictable situational variables across regional, operational, and environmental contexts of MARS analysis must also be taken into account. Identifying these variables can help analysts anticipate and acquire the potential sources of imagery and non-imagery data that may be required to apply MARS to a specific regional context.

Repeating Situational Variables Across MARS Contexts

Each potential MARS context is shaped by its own particular set of dynamic variables. However, most of these variables can be isolated into distinct categories and anticipated to some degree. Categories of situational variables repeating across MARS contexts may include the following:

- *Natural Environment:* Climate type and seasonal variations can affect MARS analysis significantly. Deserts, for example, have higher visibility than jungles due to having little to no tree canopy. Additionally, regionally specific rainy seasons can cause major changes in ground vegetation, and their corresponding cloud cover may severely restrict the use of space-based sensors during that period;
- *Civilian Disposition:* Assessing the disposition of civilian populations that are potential targets of alleged mass atrocities is a critical consideration. These dispositions can include sedentary agrarian, urban industrial, semi-nomadic, or fully nomadic pastoralist. In some cases, multiple dispositions can be found within one geographic area or ethnic group;
- *Civilian Livelihoods:* Understanding how different civilian populations with different dispositions support themselves is key to evaluating if they have been targeted for attack. Contextually specific observable objects may be likely indicators of intentional attacks against that population. For example, agrarian civilian populations that cultivate crops may have those crops intentionally burned if attacked. Apprehending these likely indicators helps analysts identify potential activity patterns consistent with specific types of mass atrocity events (i.e., indiscriminate bombardment, forced displacement, destruction and looting of civilian property, etc.);
- *Armed Actors:* Potential armed actors present in MARS contexts can vary significantly across scenarios. Often, multiple force types are present at once. There are two primary categories for the varying force types of armed actors: Regular and irregular. Regular forces are the standing military and/or security services of a nation state. Irregular forces are not members of organized military or security services, and can include rebel groups, militias, mercenaries, mobs, paramilitary forces, and other non-state fighters.
- *Force Profile:* Conducting an assessment of the mean (or baseline) military capability of both regular and irregular forces specific to a MARS context is critical for building a force profile of different armed actors. A force profile of each armed actor in a MARS context is important to have for two reasons. First, understanding the unique capabilities of one force versus another provides important circumstantial data that helps differentiate what unit may have perpetrated an alleged mass atrocity event. For example, tanks appear in a recently attacked village that had been previously controlled by a force that does not possess tanks. An analyst may be able to more fully corroborate the identity of the attackers if they can show that the force hostile to that village's population is known to have those particular types of tanks in its arsenal. Secondly, understanding the force profile for each force helps analysts identify units consistent with the capabilities of that force in the field. For example, an analyst can use his or her assessment of the mean military capability of a force to attempt to track the movements of observable objects consistent with that assessment over time.

Inferred Observable Object Activity Patterns and Evidence of Alleged Perpetrator Actions

In the table below, three apparent categories of actions by GoS-aligned forces, the alleged perpetrators of the May 2011 attack on Abyei Town, are broken down across four categories. These categories are based on the observable objects outlined in the table above, their apparent activity patterns, unique phenomena that helps corroborate the perpetrator's apparent action, and the analysis methods that could likely be used to interpret the imagery data.

Previously analyzed DigitalGlobe imagery by HHI's Signal Program provides examples of each of the three alleged perpetrator actions. Additionally, explanatory notes, based on the HHI study, *Sudan Anatomy*

of a Conflict, are included to explicate the analytic process apparently employed. Each imagery example has the number of the relevant alleged perpetrator action that appears to have occurred.

Table 2. MARS Indicators and Activity Patterns Consistent with Alleged Perpetrator Actions (Alleged Razing of Abyei Town by Sudan-Aligned Forces, May 2011)

Alleged Perpetrator Action	Observable Object Indicators	Apparent Activity Patterns	Unique Corroborating Phenomena	Analysis Methods
<u>1. Apparent Intentional Targeting of Civilian Populations and Forced Displacement</u>	Destroyed structures consistent with civilian dwellings, civilian-use facilities.	Dismounted actors (i.e., on foot) moved building to building burning and/or breaking apart structures.	Absence of ground burn pattern between the razed structures is consistent with intentional destruction of buildings.	Primary: Multi-temporal change detection. Secondary: Non-imagery data cross-reference for reports of attacks and displacement.
<u>2. Apparent Targeting of Humanitarian Facilities, Looting of Civilian Property and Humanitarian Supplies</u>	Irregular shaped objects consistent with debris appears in vicinity of structures consistent with civilian-use/ humanitarian agency infrastructure. Buildings may be either razed or still appear intact.	Dismounted actors haphazardly moved and ransacked items originally within the structures outside of the structures. Often this results in the division of items amongst a group of alleged perpetrators, sometimes as payment for their actions.	The sudden appearance of piles of items, humanitarian goods (i.e., food sacks, etc.), and other unknown objects in an area known to have been recently assaulted by an armed force. Additionally, presence of irregular objects in transport vehicles moving away from area towards friendly territory may be consistent with looting.	Primary: Multi-temporal change detection. Secondary: Non-imagery data cross referencing and object typing of any uniform objects, particularly UN or ICRC (International Committee of the Red Cross) standard use items, such as food sacks; cross-reference reports of attacks.
<u>3. Apparent Forcible Military Control of Area (i.e., Invasion by Hostile Actor)</u>	Observable objects are dependent on force profile of suspected aggressor force. These objects may include, heavy armor vehicles (i.e., tanks), light armor vehicles (i.e., APCs, armored cars, etc.), artillery, Land Cruiser-type vehicles, and/or evidence of dismounted units (i.e., tents, crowds assembled in formations, checkpoints).	Rapid movement of mixed vehicles into an area, which may or may not include either fire support operations by air assets and/or artillery. Forces also likely engaged in operations to secure area and conduct searches, resulting in checkpoints, vehicle patrols on side streets, etc.	Sudden appearance of multiple observable objects consistent with the known force profile of an armed actor in an area that they previously did not control. Analysts should expect to see vehicle track patterns on and around main roads, cratering, and other evidence of combat operations. Other activity patterns consistent with other alleged perpetrator acts are likely occurring at this time (i.e., looting, destruction of building, etc.).	Primary: Multi-temporal change detection; Observable object context (OOC) analysis; and dimensions, color patterns, and unique features (DCU) analysis. Secondary: Non-imagery data cross-referencing reports of force movement.

Imagery captured on 26 May 2011 (Figure 2), soon after the Government of Sudan-aligned forces' invasion into Abyei Town, shows evidence consistent with the majority of the main market area having been burned. The activity pattern is characterized in part by the lack of scorch marks between many of the buildings. The apparent trend of burned structures with uniform gaps in the scorched earth between groups of them is consistent with the intentional destruction of this area by likely dismantled forces. This pattern of destruction was further corroborated by publicly released ground photographs taken during that time⁵¹ and by a UN report.⁵²



11 February 2011. QuickBird-2 satellite.

26 May 2011. WorldView-2 satellite.

Figure 2. Apparent Intentional Destruction of Civilian Property, Targeting of Civilian Populations, and Forced Displacement. (Alleged Perpetrator Actions 1 and 2). *Images courtesy of DigitalGlobe.*

Approximately 30 percent of Abyei Town's apparent civilian dwellings, many of them tukuls, traditional circular mud and thatch huts, appear to have been razed during the invasion.⁵³ The lack of scorched earth between the tukuls and other apparent civilian structures is indicative of intentional burning by dismantled forces (Figure 2.1).



26 May 2011. WorldView-2 satellite.

Figure 2.1. Intentional Targeting of Civilian Populations and Forced Displacement. (Alleged Perpetrator Action 1). *Image courtesy of DigitalGlobe.*

This image shows the World Food Programme's storage facility, located in central Abyei Town (Figure 2.2). In the image captured after the SAF invasion, two tent-like structures are no longer visible and shelves appear overturned in the center of the facility. Activity consistent with looting can be corroborated based on both the regular shaped objects consistent with WFP-size grain sacks, as well as the irregular-shaped objects consistent with unknown debris, present in the streets and loaded on to vehicles in close proximity to the facility. UN reports confirm the looting of 800 metric tons of food and medical supplies from the facility.⁵⁴



11 February 2011. QuickBird-2 satellite.

26 May 2011. WorldView-2 satellite.

Figure 2.2. Apparent Targeting of Humanitarian Actors and Looting of Humanitarian Supplies. (Alleged Perpetrator Action 2). *Images courtesy of DigitalGlobe.*

During the invasion, imagery revealed the presence of armored vehicles and towed artillery consistent with units known to be employed by SAF. The above image shows three T-55 main battle tanks loaded onto heavy equipment transports (HETs), as well as four additional T-55's off-loaded and facing southward.⁵⁵ Also facing southward are three pieces of unhitched 105mm artillery guns and an armored infantry-fighting vehicle, also consistent with the SAF force profile (Figure 2.3).

The positioning of the artillery in a southward direction, toward southern Sudan, is dispositive forensic evidence that those observables are likely controlled by SAF at the time the image was captured. At that time, SAF troops were reportedly moving due south at that time towards SPLA positions along the River Kiir.⁵⁶ The artillery appears to be facing in that vector to provide fire support, if needed, in the direction of the SPLA frontline.



26 May 2011. WorldView-2 satellite.

Figure 2.3 Apparent Forcible Military Control of an Area. (Alleged Perpetrator Action 3). *Image courtesy of DigitalGlobe.*

Suggestions for Further Research

As the Abyei Town incident case study is intended to demonstrate, MARS analysis can be approached in a systematic and standardized way that relies on the iterative comparison of accepted examples of past practice over time. The approaches articulated herein should be studied and built upon through further research that will require the committed involvement of expertise and resources from a diverse community of entities. These actors may include academic institutions, human rights and humanitarian NGOs, international legal experts and bodies, governments, private business, and most importantly, the communities affected by mass atrocities themselves.

If such research is pursued, MARS may eventually have a place in mass atrocity investigations as its own formalized profession. As a result, MARS may be able to play a similar role to the role that DNA analysis, ballistics, forensic anthropology, or any number of traditional forensic sciences currently play in multiple domestic and international criminal justice settings.

Examples of best practices should be both identified and created where required. This effort should occur across various mass atrocity contexts, geographic regions, and operational objectives (i.e., collection of evidence for accountability versus early warning, etc.) for MARS to become a truly scalable tool.

Component pieces that may eventually provide a common forensic methodology for MARS should include, though are not limited to, the following:

- A common approach for the standard identification of potentially relevant observable objects, likely visual properties and/or phenomena associated with those objects, and tested methods to aid in their identification;
- Accepted methods for the identification and testing of apparent activity patterns to determine whether they are consistent with an alleged mass atrocity event type and/or alleged perpetrator action;
- The creation of a common, publicly accessible repository for MARS evidence examples to be presented and critiqued by practitioners. Such an evidence repository may also require the agreement of an annotation method, taxonomy, and presentation guidelines for collecting and storing these examples that should be common to the field;
- Development of common standards for creating, field testing, and evaluating algorithmic feature extraction applications for the automated identification of MARS related phenomena in imagery. The continuing development of algorithmic feature extraction programs presents potential challenges and opportunities for the MARS space that will have to be assessed;
- Research into how remote sensing in mass atrocity contexts may either protect or endanger vulnerable populations or physical evidence on-the-ground, particularly human remains found in mass graves. Related inquiry should occur into determining whether remote surveillance of alleged perpetrators has any causal relationship to changes in the behavior of these actors in any way;
- The integration and cross-referencing of international humanitarian and human rights law (IHHRL) standards, particularly the Geneva Conventions and the Rome Statute, with MARS examples of forensic evidence. This research effort may require interdisciplinary collaboration between the MARS community and IHHRL experts to develop a common reference for forensic examples of alleged war crimes, including genocide.

Significant challenges, however, will have to be overcome to further develop, agree upon, and disseminate a forensic science specific to MARS. The difficulty in accessing sources of geospatial data of alleged mass atrocity acts and related operational patterns has plagued the field for some time. The often exorbitant cost of high-resolution satellite imagery, as well as a limited number of high-resolution satellites available to proactively task, have been major barriers to the advancement of this field.

Innovations to remote sensing, including the deployment of “micro-satellites”, which are often less costly to build, maintain and replace, may offer potential remedies to some of these longstanding barriers to affordable, recently acquired data.⁵⁷

However, new, less costly technologies alone may likely not be enough to support the evolution of this subfield of remote sensing into an established forensic science. Proportionate investment in the agreement of common standards, methods, evidence examples, and the training and development of practitioners is also simultaneously required.

Remote sensing offers potentially powerful insights into the alleged mass atrocities perpetrators commit in some of the world's most inaccessible environments. It is incumbent upon researchers and practitioners of MARS to begin the difficult yet necessary process of becoming more than simply one application of this technology, but instead, a constant process of scientific innovation.

Endnotes

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