Analysis of Satellite Imagery for Timbuktu, Republic of Mali

Prepared for the International Criminal Court as Input to the Investigation on the Situation in the Republic of Mali (ICC-01/12)

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unitar
United Nations Institute for Training and Research

UNOSAT

Palais des Nations
1211 Geneva 10
Switzerland
[redacted]

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Introduction

In April 2014 the United Nations Institute for Training and Research Operational Satellite Applications Program (UNITAR/UNOSAT) conducted satellite imagery analysis of locations in the city of Timbuktu, Mali at the request of the Office of the Prosecutor of the International Criminal Court (ICC)[1]. The ICC requested satellite imagery analysis of multiple mausoleums and monuments within Timbuktu relating to the case ICC-01/12. UNOSAT acquired satellite images for ICC locations of interest (LOIs) and subsequently sought to document evidence of changes to the status and appearance of the LOIs consistent with their reported destruction. This report provides results of this analysis as well as an overview of methods and data sources used.

Methods and Data Sources

To document the status of mausoleums and monuments in Timbuktu UNOSAT reviewed the locations provided by the ICC and acquired and analyzed multiple commercial high-resolution satellite images. The satellite images used by UNOSAT were acquired by satellites prior to and after the reported destruction of the LOIs. UNOSAT analysis reviewed the images for each LOI and the appearance of the LOI was assessed in the image acquired prior to the events in question and again in the image acquired after the events. Dates of interest and the specific locations of the monuments were provided in detail by the ICC in their letter of request. Monument locations and associated metadata describing each image analysed for each monument are provided in Table One. A map describing the locations of the monuments and their associated analysis figure is provided as Map One.

Table 1: Summary of Locations and Imagery Analyzed

Monument	Longitude	Latitude	Date of Interest	Before Image	After Image
Mausolea Ahmadou Foulane and Baber Babadje	-3.010336	16.7714	July 10, 2012	WV02, 18 June 2012 (1030010019914F00)	WV02, 15 July 2012 (103001001B4EBC00)
Sidi Mahmoudou Ben Omar Mohamet Aqit	-3.004883	16.7824	30 June - 1 July 2012	WV02, 18 June 2012 (1030010019914F00)	WV02, 15 July 2012 (103001001B4EBC00)
Cheick Sidi Ahmed Ben Amar Arragadi	-3.01325	16.7725	July 1, 2012	WV02, 18 June 2012 (1030010019914F00)	WV02, 15 July 2012 (103001001B4EBC00)
Cheick Aboul Kassim Attouaty	-3.01274	16.7719	July 1, 2012	WV02, 18 June 2012 (1030010019914F00)	WV02, 15 July 2012 (103001001B4EBC00)
Cheik Mouhamad El Micky	-3.01274	16.7718	July 1, 2012	WV02, 18 June 2012 (1030010019914F00)	WV02, 15 July 2012 (103001001B4EBC00)
Cheick Mouhamed Tamba-Tamba	-3.010174	16.767	December 23, 2012	WV02, 22 December 2012 (103001001D987E00)	WV02, 25 December 2012 (103001001D83AF00)
Cheik Sidi El Mokhtar ben Sidi Mouhammad Ben Cheikh Al Kabir	-3.00085	16.7782	June 30, 2012	WV02, 18 June 2012 (1030010019914F00)	WV02, 15 July 2012 (103001001B4EBC00)
Alpha Moya	-3.002257	16.7723	30 June - 1 July 2012	WV02, 18 June 2012 (1030010019914F00)	WV02, 15 July 2012 (103001001B4EBC00)
Al-Farouk Monument[2]	-3.0082	16.7708	October 27, 2012	WV01, 26 October 2012 (102001001D7E8200)	WV02, 29 October 2012 (103001001C7F9000)

Satellite Images and Processing

The main satellite images used in the analysis are portions of six separate images acquired primarily by the WorldView-2 satellite, with one image acquired by the WorldView-1 satellite, on multiple dates spanning 18 June 2012 to 25 December 2012.

[1] The request from the ICC was received via DHL on 11 March 2014 and is attached to this report as Appendix A. Initial discussions on this topic with the ICC began in November 2013.

[2] Analysis of Al-Farouk also used images from 15 October and 21 October 2012, along with numerous images found on Google Earth, to develop understanding of the shadow cast by the monument.

MAP 1: ICC LOCATIONS OF INTEREST IN TIMBUKTU, MALI

Satellite Data: WorldView-2
Imagery Date: 18 June 2012
Resolution: 50 cm
Copyright: DigitalGlobe
Source: European Space Imaging

Analysis : UNITAR / UNOSAT
Production: UNITAR / UNOSAT
Analysis conducted with ArcGIS v10.1

Coordinate System: WGS 1984 UTM zone 30N
Projection: Transverse Mercator
Datum: WGS 1984

MLI-OTP-0017-0032

WorldView-2 is a commercial satellite owned by DigitalGlobe with an optical sensor that records imagery at 0.46 meter[3] resolution in the panchromatic band and 1.85 meter resolution in eight wavelengths of the electromagnetic spectrum[4]. The WorldView-2 satellite was launched on 8 October 2009 and, following a calibration period, has been used continuously by governments, industry, and other sectors around the world for many applications[5]. WorldView-1 is also a commercial satellite owned by DigitalGlobe with an optical sensor that records imagery at 50 centimeter resolution in the panchromatic band. The WorldView-1 satellite was launched on 18 September 2007 and, also following a calibration period, has been used continuously by governments, industry, and other sectors around the world for many applications[6]. Images collected by these satellites are done so either via direct request from a client (a government, business, organization, individual, etc.) or by the company at its own discretion for internal reasons. Images can vary in size depending on the particular satellite, though the spatial resolution stays the same, and can cover anywhere from a few square kilometres to more than 2,000 square kilometres in area.

As requested by the ICC in November 2013, a review of commercial high-resolution satellite images available for the ICC LOIs was conducted by UNOSAT. The best candidates for analysis were those images collected closest to the date of interest provided by the ICC, and each location had an image acquired both before and after the events in question. Summary metadata for images utilized in this analysis are presented in Table One with each location listed along with its corresponding images used for analysis. Note that as satellite images can span thousands of square kilometres, subsets of imagery were purchased by UNOSAT for the analysis requested by the ICC. To purchase subsets of the images, after reviewing available imagery and selecting candidates for purchase, UNOSAT defined an area of 25 square kilometers[7] which includes all the city of Timbuktu and the LOIs. The ICC request letter stated that analysis should be confined directly to the locations of monuments provided and so no analysis of surrounding areas was performed for this project[8].

These satellite images, all copyright 2014 DigitalGlobe, were purchased by UNOSAT from European Space Imaging[9] and downloaded in GeoTIF[10] format onto the UNOSAT computer network. Processing of the GeoTIF files to prepare them for analysis consisted of loading the images into an ArcMap 10.1 Geographic Information System (GIS)[11] using standard tools and specifications[12], then saving those GIS instances as MXD files[13] to link all associated data including the ICC LOIs, satellite imagery, and UNOSAT analysis. Once both the 'before' and 'after' images were loaded into the GIS then the precise location of each monument was viewed at the maximum level of detail possible. The two images were then directly compared with one another and changes between the two dates were visually assessed by UNOSAT.

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[3] For non-US government clients the imagery is resampled to .50 meter resolution in accordance with US law.

[4] Satellites like WorldView-2 measure electromagnetic radiation originating from the sun and reflected off the surface of the earth. The full range of potential electromagnet radiation is referred to as the electromagnetic spectrum and includes multiple wavelengths. The spectrum includes light that is visible to the human eye in the red, green, and blue wavelengths, as well as wavelengths not visible to the human eye such as the near infrared. Common terms for describing other parts of the electromagnetic spectrum include X-rays, ultraviolet light, and radio waves. The satellites measure the electromagnetic radiation reflected off the Earth in different resolutions which results in different levels of detail. For example, the .46 meter resolution panchromatic sensor on WorldView-2 is able to image objects with a width of at least .46 meters, while the multispectral sensor can image objects 1.85 meters across.

[5] DigitalGlobe provides descriptive information on the WorldView-2 satellite online here: http://www.digitalglobe.com/sites/default/files/DG_WorldView2_DS_PROD.pdf

[6] DigitalGlobe has a data sheet for WorldView-1 available here: http://www.digitalglobe.com/sites/default/files/WorldView1-DS-WV1-Web.pdf

[7] This is the minimum area that can be purchased from DigitalGlobe, i.e. smaller areas cannot be purchased according to company policy.

[8] Note that UNOSAT did release a map related to the monuments of Timbuktu, Mali, on 31 January 2013, and also analyzed two refugee camps for Malians in Niger in October 2013. These products can be viewed at: http://www.unitar.org/unosat/maps/MLI

[9] European Space Imaging is one of many resellers of DigitalGlobe and other satellite imagery. It is a primary vendor for acquisition of satellite images by UNOSAT.

[10] A GeoTIF file format is one of many possible ways to store a satellite image on a computer system. The satellite image is stored in the Tagged Image File Format (abbreviated as TIF), a commonly used image storage format, and has additional geographic information embedded in the file to position it correctly within a coordinate system in a GIS or similar software.

[11] A geographic information system (GIS) is software commonly used for decades in many sectors for tasks involving satellite imagery, mapping, and related requirements such as calculation of distances and potential travel times. The ArcMap GIS is commercial GIS software produced by the Esri corporation (http://esri.com) and widely used around the world.

[12] Loading data on any computer or software requires certain tools and specifications to ensure proper display of the data. For ArcMap GIS the tool for loading data is simply a button found on the user interface, like opening a Word document, and the specifications dictate how the satellite image is displayed and viewed by the user.

[13] An MXD file is how an ArcMap GIS stores all information about particular datasets that the user would want to reload at a later time. It is the conceptual equivalent of a Word document (DOC) or an Excel document (XLS).

When viewed in pairs of satellite images collected on two dates, the removal of entire buildings in a period between those dates is immediately apparent. Specifically, the building simply disappears from the 'after' image, in some cases debris or signs of destruction are visible, or discoloured soil, and the lack of a shadow cast by a standing structure after its removal is also visible in the imagery. Given these factors and the precise locations of the monuments provided by the ICC, documenting the removal of monuments and buildings was a simple and straightforward process for UNOSAT. Initial data review, image acquisition, and preliminary analysis was done by a UNOSAT [redacted] with full review then undertaken by the UNOSAT Principal Analyst (Lars Bromley), who also authored this report.

Satellite Image Analysis Results

All LOIs provided by the ICC were determined to have been removed in some fashion by the analysis of satellite imagery, and a summary of results are presented in Table Two. The Google Earth screen captures provided by the ICC were highly detailed and indicated precisely the location of each structure in question. Thus, each monument was easily assessed by comparing the pre-event and post-event imagery and in almost all cases the structures comprising the monuments were certainly determined to have been removed in the time period between the collection of the two images used. Results of these analyses are presented in Figures One through Seven on the following pages.

One monument which proved slightly more problematic to assess was the Al Farouk Monument as it is apparently comprised of a thin, standing piece and not a building as the other monuments. When viewed by a satellite from above the Al Farouk Monument can therefore be difficult to see, though some images acquired at an angle do show its front and back sides. Instead, UNOSAT analysis relied primarily on viewing the shadow cast by this monument to indicate whether it was still standing or not. Therefore, images from Google Earth were consulted, and additional images were acquired of the area, in order to better visualize and confirm the presence of the monument's shadow. In the image acquired on 29 October 2012, after the reported demolition of the monument, the shadow has disappeared and what appear to be the remains of the monument are instead visible and lying flat on the ground. Results of this analysis are presented in Figures Eight A and B.

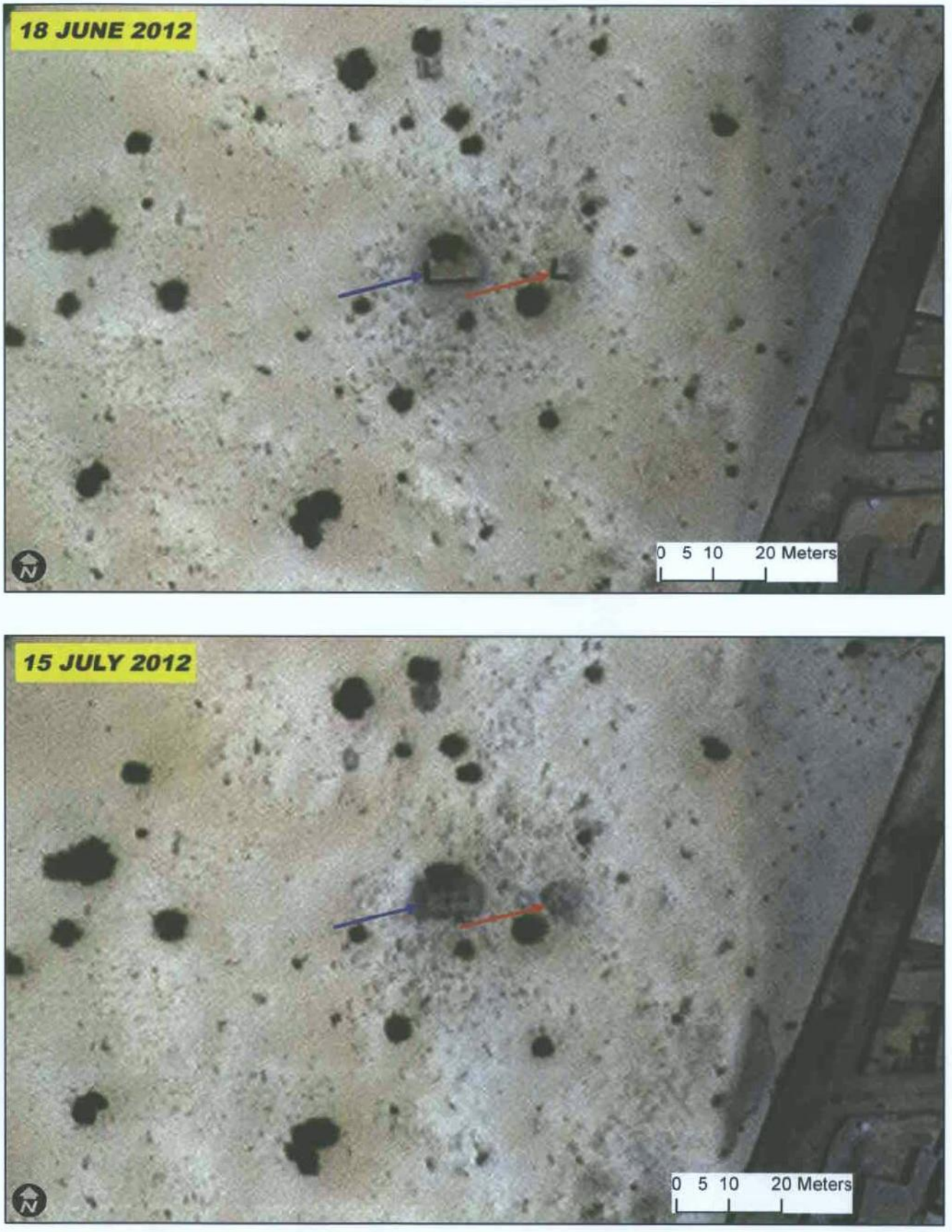
Table 2: Summary of Imagery Analysis Results

Monument	Longitude	Latitude	Figure	Results
Mausolea Ahmadou Foulane and Baber Babadje	-3.010336	16.7714	1	Structure clearly removed.
Sidi Mahmoudou Ben Omar Mohamet Aqit	-3.004883	16.7824	2	Structure clearly removed.
Cheick Sidi Ahmed Ben Amar Arragadi	-3.01325	16.7725	3	Structure clearly removed.
Cheick Aboul Kassim Attouaty	-3.01274	16.7719	4	Structure clearly removed.
Cheik Mouhamad El Micky	-3.01274	16.7718	4	Structure clearly removed.
Cheick Mouhamed Tamba-Tamba	-3.010174	16.767	5	Structure clearly removed.
Cheik Sidi El Mokhtar ben Sidi Mouhammad Ben Cheikh Al Kabir	-3.00085	16.7782	6	Structure clearly removed.
Alpha Moya	-3.002257	16.7723	7	Structure clearly removed.
Al-Farouk Monument	-3.0082	16.7708	8	Monument not clearly visible but certainly damaged and likely removed.

Figure 1: Mausolea Ahmadou Foulane and Baber Babadje

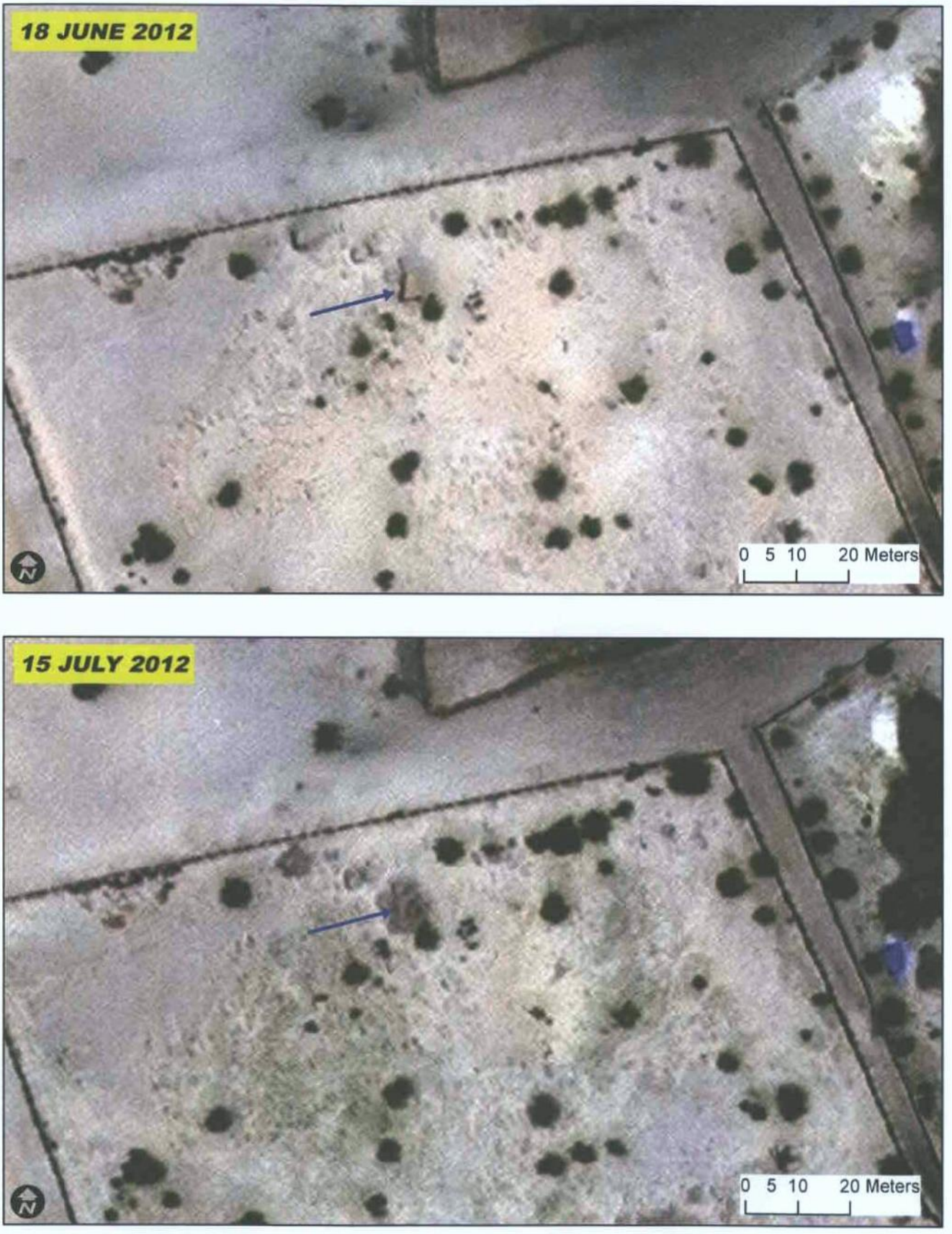
The area of the Djinareiber Mosque as seen on 18 June 2012 (top). A small structure is visible along its western wall (yellow arrow) identified as the Mausolea Ahmadou Foulane And Baber Babadjé monument according to the ICC Google Earth screen capture MLI-OTP-0012-0993. By 15 July 2012 (bottom) this structure is no longer visible and has likely been removed, with possible debris remaining in its place. Imagery Copyright 2014 DigitalGlobe.

Figure 2: Sidi Mahmoudou Ben Omar Mohamed Aqit



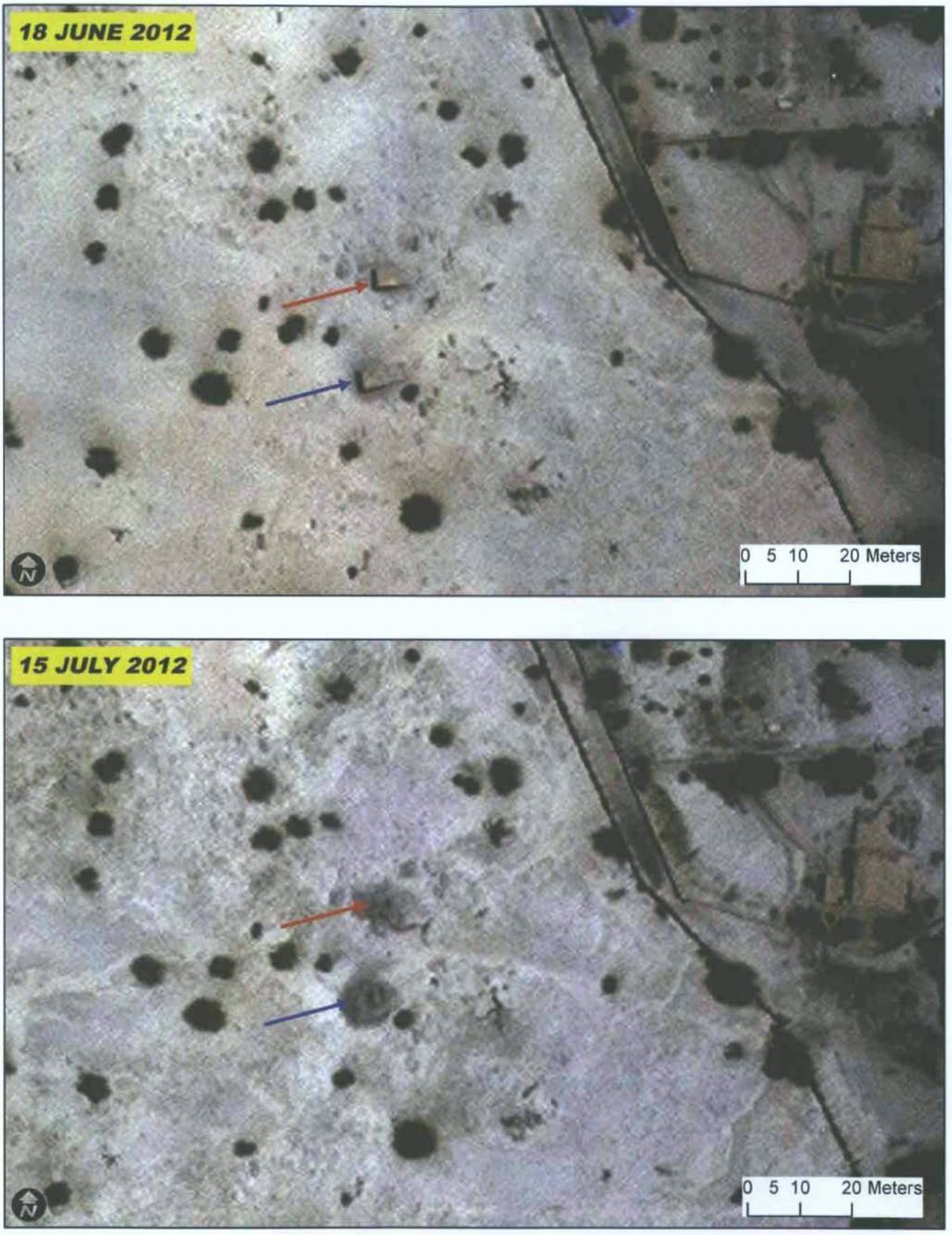
An image of the Sidi Mahmoudou Ben Omar Mohamed Aqit monument in the Sidi Mahmoud Cemetery of Timbuktu as seen on 18 June 2012 (top). The larger structure (blue arrow) is identified in the ICC Google Earth screen capture MLI-OTP-0012-0995, and a smaller nearby structure is also visible (red arrow). By 15 July 2012 (bottom) both structures have been removed with discolored soil remaining. Imagery Copyright 2014 DigitalGlobe.

Figure 3: Cheick Sidi Ahmed Ben Amar Arragadi



The Cheick Sidi Ahmed Ben Amar Arragadi monument (blue arrow) in the north part of the Cemetery of the Three Saints of Timbuktu as seen on 18 June 2012 (top) and as identified in ICC Google Earth screen capture MLI-OTP-0012-0997. As of 15 July 2012 (bottom) the structure has been removed, and soil discoloration and possible debris remain. Imagery Copyright 2014 DigitalGlobe.

Figure 4: Cheick Aboul Kassim Attouaty and Cheick Mouhamad El Micky

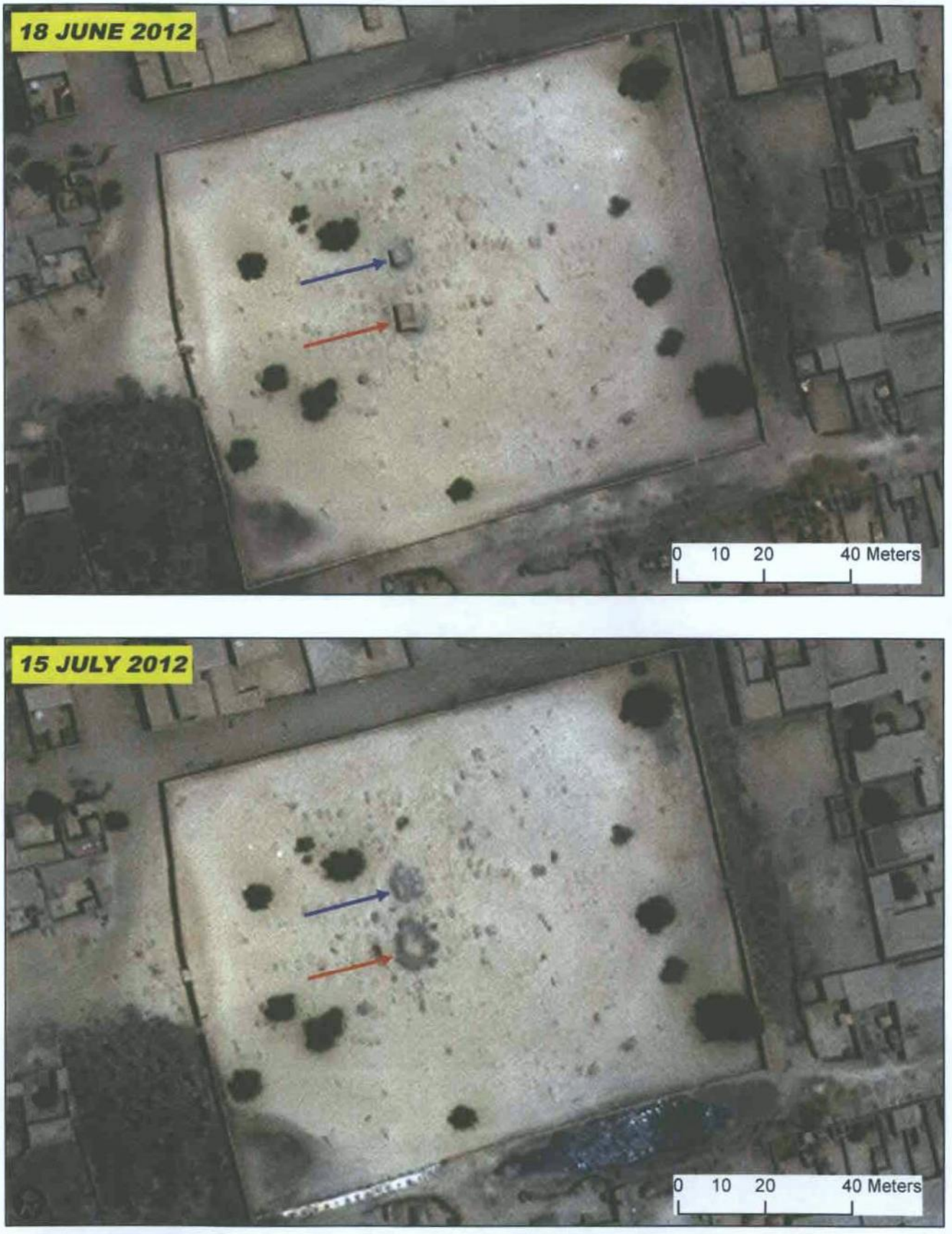


An image of Cheick Aboul Kassim Attouaty monument (red arrow), and Cheick Mouhamad El Micky monument (blue arrow), as idenfitied in the ICC Google Earth screen captures MLI-OTP-0012-0999 and MIL-OTP-0012-1001 respectively, as seen on 18 June 2012 (top). As of 15 July 2012 (bottom) the structures have been removed and debris and discolored soil are visible. Imagery Copyright 2014 DigitalGlobe.

Figure 5: Cheick Mouhamed Tamba-Tamba

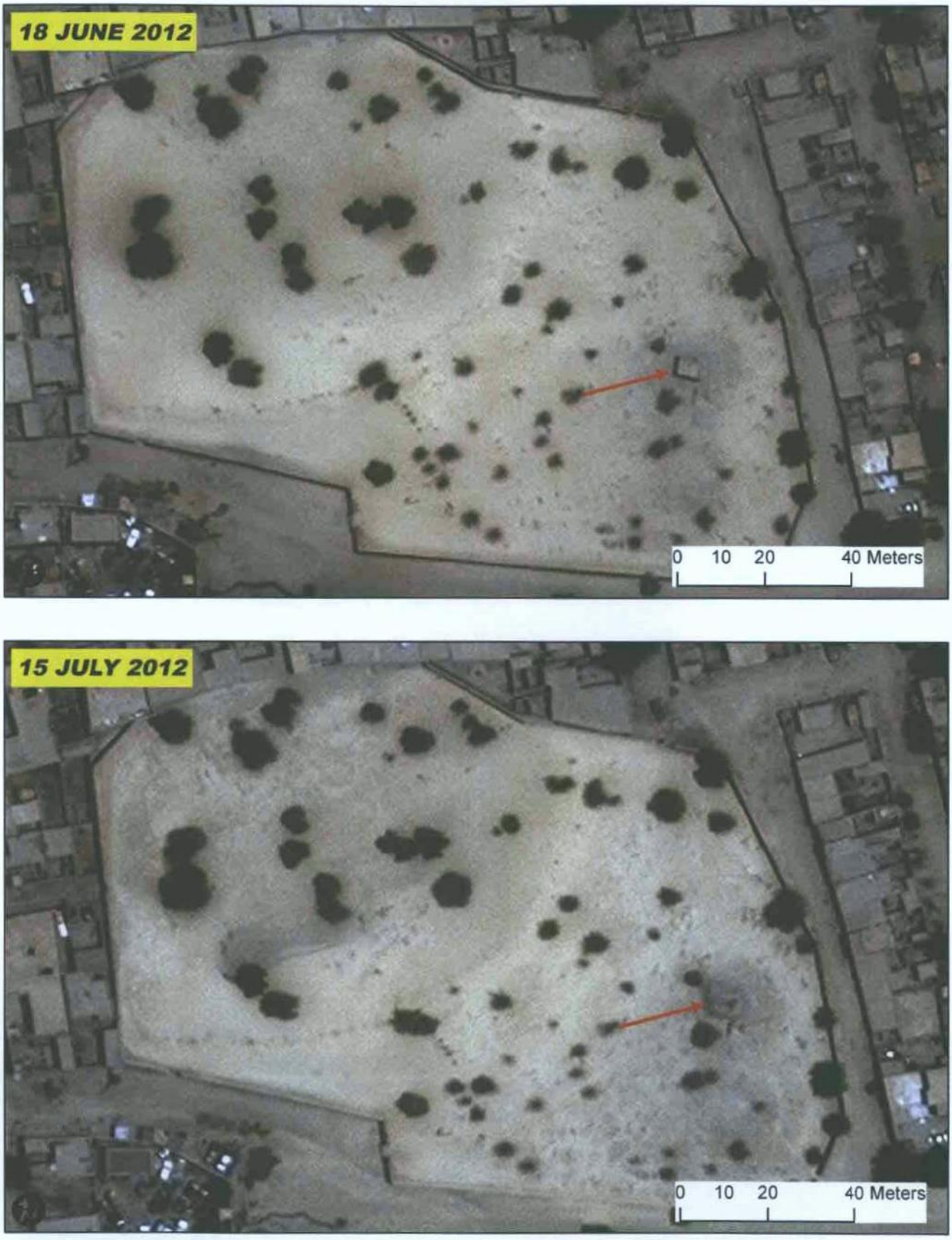
An image of the Cheick Mouhamed Tamba-Tamba monument (red arrow) in Timbuktu, identified by the ICC Google Earth screen capture MLI-OTP-0012-1003, as seen on 22 December 2012 (top). As of 25 December 2012 (bottom) the structure and surrounding wall have been removed with soil discoloration and possible debris visible. Images Copyright 2014 DigitalGlobe.

Figure 6: Cheick Sidi El Mokhtar ben Sidi Mouhammad Ben Cheikh Al Kabir



An image of the Cheick Sidi El Mokhtar ben Sidi Mouhammad Ben Cheikh Al Kabir monument (red arrow) in the Sidi Mokhtar Cemetery of Timbuktu as of 18 June 2012 (top). Identified in the ICC Google Earth screen capture MLI-OTP-0012-1005, as of 15 July 2012 (bottom) the structure has been removed and soil discoloration and possible debris remains. An adjacent structure (blue arrow) has also been removed. Images Copyright 2014 DigitalGlobe.

Figure 7: Alpha Moya

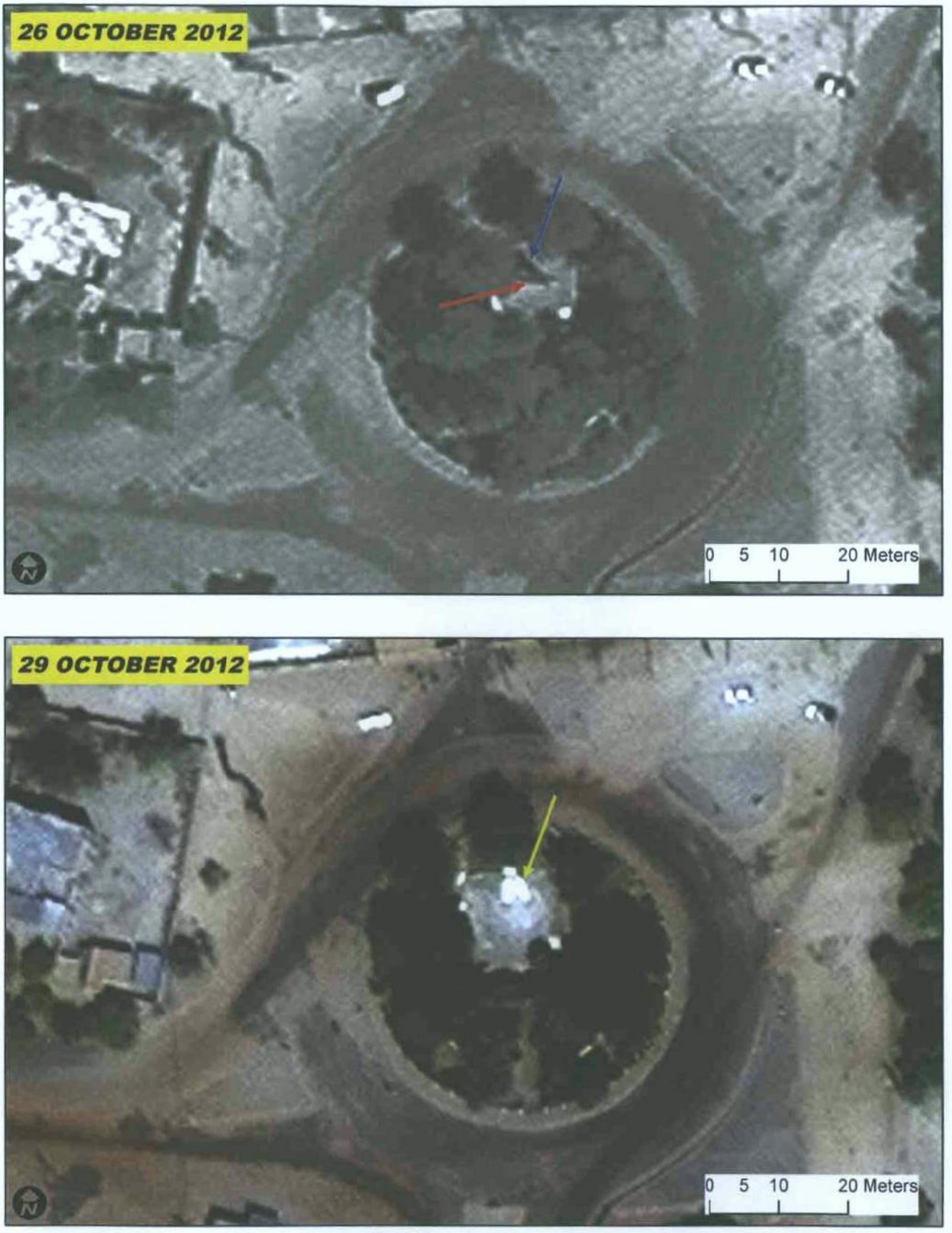


The Alpha Moya monument (red arrow) in Alpha Moya Cemetery of Timbuktu, identified in the ICC Google Earth screen capture MLI-OTP-0012-1007 and as seen on 18 June 2012 (top). As of 15 July 2012 (bottom) the structure has been removed and debris and soil discoloration remains. Images Copyright 2014 DigitalGlobe.

Figure 8(A): Al Farouk Monument

The Al Farouk monument (red arrow) on the Place of Independence in Timbuktu, identified by ICC Google Earth screen capture MLI-OTP-0012-1009, as seen on 15 October 2012 (top), and on 21 October 2012 (bottom). As this monument is comprised of an upright placard of some sort it is difficult to see in the overhead view provided by satellites. However, it can be seen to cast a shadow (blue arrow) which indicates it remains upright as of 15 October and 21 October 2012. Images Copyright 2014 DigitalGlobe.

Figure 8(B): Al Farouk Monument



The Al Farouk monument (red arrow) on the Place of Independence in Timbuktu, identified by ICC Google Earth screen capture MLI-OTP-0012-1009, as seen on 26 October 2012 (top). While image quality and angle are poor, a shadow can be seen (blue arrow) that is cast by the upright monument as it appears on previous days (see Figure 8(A)). As of 29 October 2012 (bottom) no such shadow is visible though proximate trees still cast shadows. In addition, white debris is now visible at the site, including what is likely the remnants of the white monument placard itself (yellow arrow). Images Copyright 2014 DigitalGlobe.

Conclusion

Based on review of the LOIs provided by the ICC in their letter of request, UNOSAT acquired and analysed multiple satellite images to detect changes consistent with destruction of the LOIs. In all cases image analysis clearly indicated destruction of the locations in question, generally consisting of complete removal of structures and oftentimes with visible debris and discoloured soil remaining at the location where the structure had been. The analysis of the Al-Farouk Monument was slightly more problematic as it consisted of an upright, thin monument piece which is therefore not always very visible in satellite imagery. Additional imagery was acquired, and images on Google Earth also referenced, to denote the position of the shadow of the monument and its subsequent disappearance. Regardless, the Al-Farouk Monument was likewise determined to have been destroyed.

This is a preliminary assessment and has not yet been validated in the field. Please send feedback to UNITAR/UNOSAT at the contact information below. Report prepared by Lars Bromley, Principal Analyst, UNITAR/UNOSAT.

Signed:

[redacted]

Date: 13 July 2014

UNOSAT Contact:

[redacted]

Post address

[redacted]

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United Nations Institute for Training and Research

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