# Programs

## Science & Policy



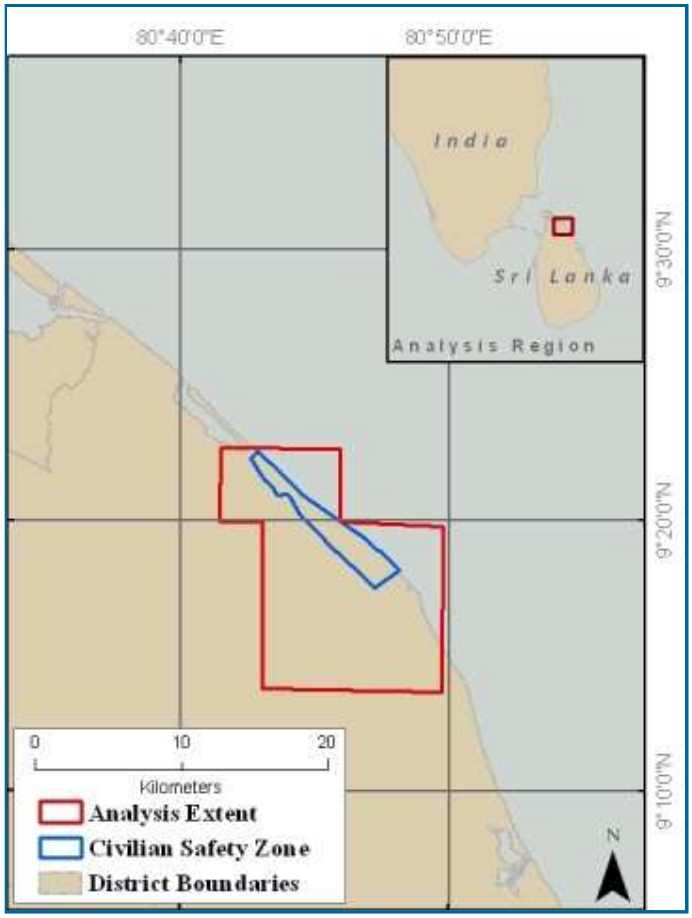
## AAAS Science and Human Rights Program

## High-Resolution Satellite Imagery and the Conflict in Sri Lanka

### Introduction

The Science and Human Rights Program of the American Association for the Advancement of Science (AAAS) acquired and analyzed commercial high-resolution satellite imagery of the Civilian Safety Zone (CSZ) and surrounding environs in northeastern Sri Lanka (Figure One). Imagery analysis was initially requested by Human Rights Watch (HRW) and Amnesty International USA (AI-USA) on May 10, 2009. These organizations expressed concern over the status and condition of civilians in the southern portion of the CSZ, as they were potentially affected by heavy fighting occurring May 9–10, 2009. This fighting was reported by multiple international news sources, including the BBC, and was referred to by United Nations Office for the Coordination of Humanitarian Affairs spokesman Gordon Weiss as a "bloodbath". As no outside parties were allowed access to the area during the timeframe in question, commercial high-resolution satellite imagery was one of the only options for gathering information.

*Figure One:* Civilian Safety Zone and Analysis Area, Sri Lanka




*The CSZ in northeastern Sri Lanka is shown in blue. The area covered by AAAS analysis is outlined in red. Note that analysis of internally displaced persons and possible munitions craters was conducted in a subset of the red area, and focused on the southern portion of the CSZ only.*

Analysis from AAAS, initially released in draft form on May 12, 2009, sought to provide information regarding the status of internally displaced persons (IDPs) within the southern portion of the CSZ. Following this initial analysis, AAAS sought to identify changes in three graveyards found in both the northern and southern portions of the CSZ, and to identify locations in the CSZ and surrounding territory which might have held artillery or mortar positions. This report summarizes results of satellite imagery analysis concerning possible indications of shelling, IDP movements, changes in gravesites, and possible artillery and mortar positions. Selected images and analysis results described below have been made available on GoogleEarth for public use.

To derive this information, AAAS analyzed multiple high-resolution satellite images of the CSZ collected by publicly accessible commercial satellites. A scene collected from the DigitalGlobe QuickBird satellite on May 9, 2005 (prior to the current period of conflict), found on GoogleEarth, was used for historical comparison. An image from the GeoEye satellite Ikonos, acquired on March 23, 2009, was used together with a scene from DigitalGlobe's WorldView satellite, acquired on April 19, 2009, to verify conditions in the CSZ immediately prior to the conflict in question. Imagery collected by the WorldView satellite includes scenes acquired at approximately 11am local time on May 6 and May 10, 2009, prior to and after reportedly intense fighting in the CSZ. Finally, a scene from GeoEye-1, collected on May 24, was analyzed to determine post-conflict conditions. These images are summarized in Table One, and more information about the image sources is provided below.

**Table One: Image Summary**

| *Sensor* | *Company* | *Image Date* |
|---|---|---|
| QuickBird | DigitalGlobe, via GoogleEarth | May 9, 2005 |
| Ikonos | GeoEye | March 23, 2009 |
| WorldView | DigitalGlobe | April 19, 2009 |
| WorldView | DigitalGlobe | May 6, 2009 |
| WorldView | DigitalGlobe | May 10, 2009 |
| GeoEye-1 | GeoEye | May 24, 2009 |

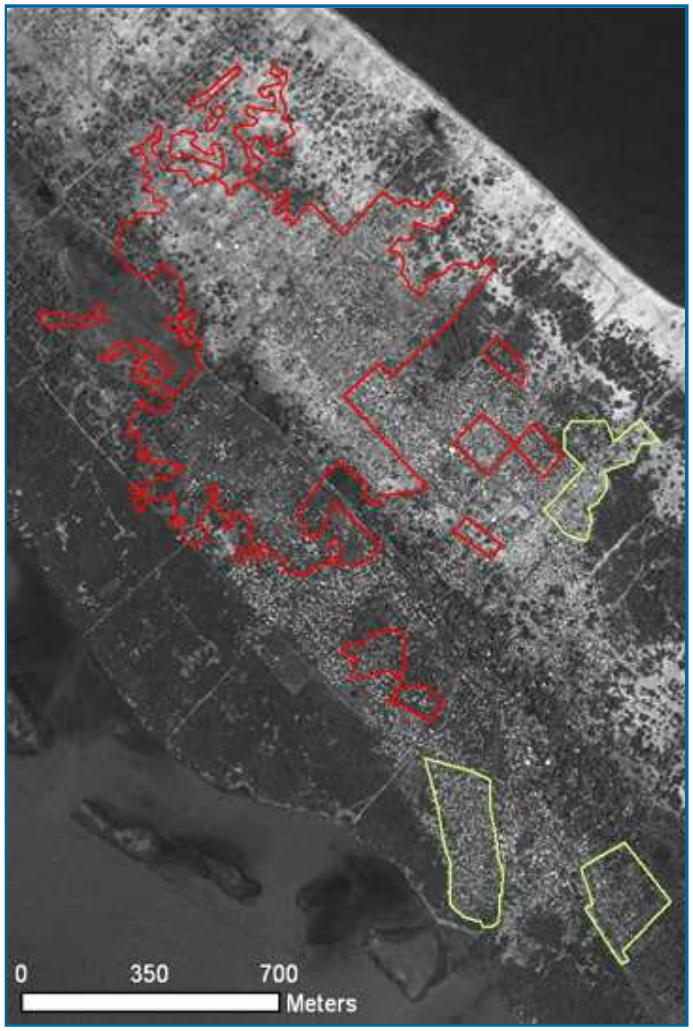
Additional information used in the AAAS analysis process include public statements from the Sri Lankan Government and the Liberation Tigers of Tamil Eelam (LTTE), as well as media reporting, though none of these sources were assumed to be accurate. Importantly, a set of photographs taken during a helicopter

over flight of the CSZ by UN Secretary General Ban Ki-moon on May 22 provided critical information which aided imagery analysis. These photographs were georeferenced by AAAS, and some are available via the AI-USA site . Lastly, ancillary information on mortar and artillery was derived from publicly available United States Army Field Manuals, as indicated below.

## Changes to IDP Areas

Initial analysis sought to denote changes over time to IDP shelters within the southern portion of the CSZ using pre-conflict imagery together with the images acquired on May 6 and May 10. IDP shelters appeared in significant numbers within the CSZ as the conflict developed, and were found throughout the area by the time of the May 6 image acquisition. Within the southern portion of the CSZ, the salient feature of the May 10 image, when compared to the May 6 image, is the obvious removal of thousands of likely IDP structures from the southern CSZ (Figure Two). While some new areas of IDP structures did appear in the same time period (Figure Two) their quantity is not enough to compensate for the number of removed IDP structures.

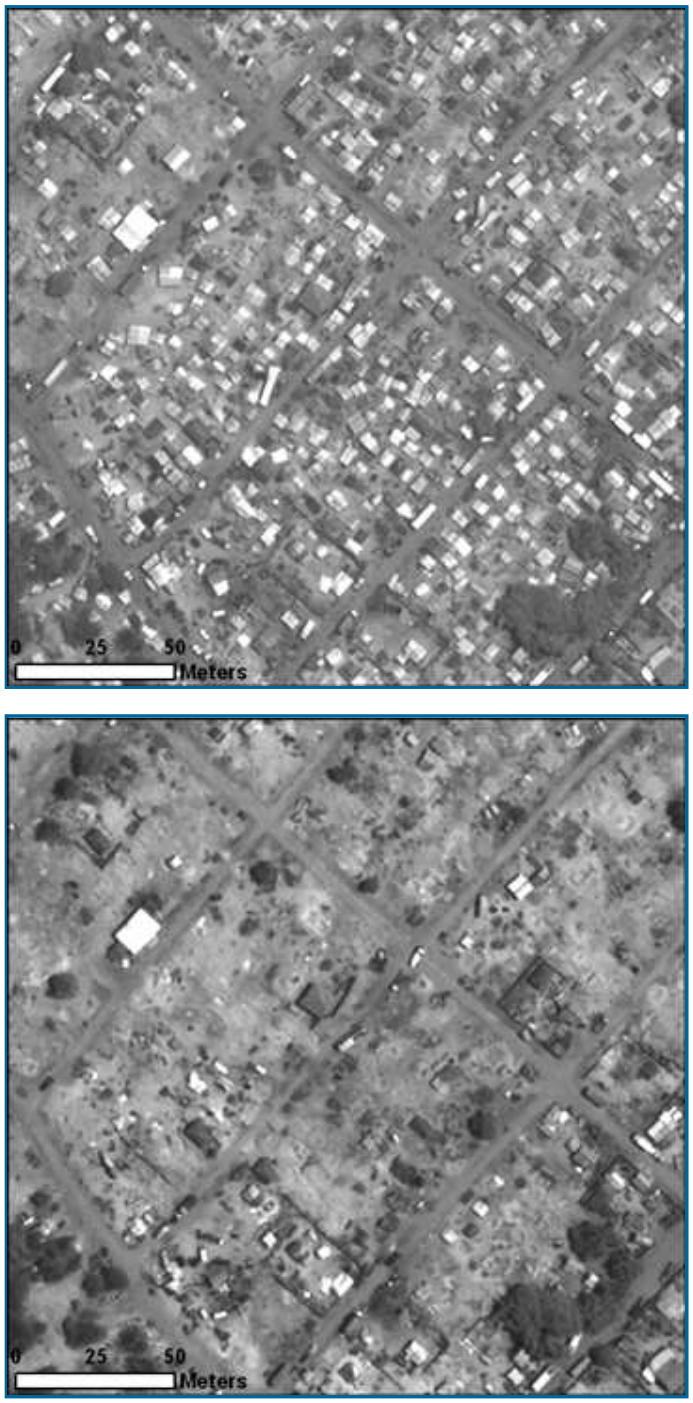
*Figure Two:* Changes in IDP Population within the CSZ between May 6 and May 10, 2009




*Between May 6 and May 10, 2009, thousands of IDP structures were removed from the CSZ. Areas outlined in red saw an almost complete removal of such structures, while areas in green exhibited relatively small increases in IDP structures. Image © 2009 DigitalGlobe.*

What caused the IDP structures to be removed between May 6 and May 10 is uncertain based solely on the imagery. It is notable how complete the removal of IDP structures appears, in that while some debris and evidence of the structures remains, overall the area appears to have been swept relatively clean (Figure Three). This is less indicative of the entire area being razed by shelling, though it could correspond with an emigration from those specific areas by the IDPs due to some outside driver. Note that several craters are visible in the immediate proximity of the IDP shelters, as are numerous destroyed and damaged permanent structures, discussed below.

*Figure Three:* Removal of probable IDP shelters within the CSZ between May 6 and May 10, 2009




*Detailed view of an area of the CSZ on May 6 (above) and May 10 (below), indicating almost complete removal of IDP structures in the intervening period. Image © 2009 DigitalGlobe.*

## Possible Craters

As with the IDP analysis, crater analysis sought information on the appearance of craters within the southern area of the CSZ between May 6 and May 10. Possible evidence of shelling in the May 6 image, in the form of possible shell impact craters and destroyed structures, are in evidence in and around the southern portion of the CSZ. These possible shell impact craters are found throughout this analysis area, in close proximity to, and intermingling with, IDP shelters and other structures. Analysis found at least 65 craters throughout the May 10 image which were not present on May 6 - many in the immediate area of the removed IDP structures (Figure Four A).

Crater analysis from satellite imagery is problematic, and site visits are needed to confirm presence and origin of the identified possible craters. Anthropogenic features and natural phenomena can often resemble craters, for example the removal of tree stumps can produce a crater-like hole, pooling water in the right conditions can mimic a crater when viewed by satellite, and imprints left by shelters on sand can also appear to be craters. People seeking shelter or water can likewise dig holes, which can resemble craters, as can constructed fighting positions. Throughout this region of Sri Lanka are innumerable

ground features which might be watering holes for livestock, and which are also often similar in appearance to craters. Further, with such an extensive history of conflict, it is possible that craters from shelling are a common feature in this region of Sri Lanka, requiring extra care in analysis. Lastly, some reports indicate possible use of air burst, white phosphorous, or other specialized munitions, which compound the difficulty of crater analysis as they would likely leave little visible signature in the satellite imagery.

Various criteria are used to designate those features appearing in the imagery as possible craters resulting from weapons fire. References for such work are sparse, and include *Field Manual No. 6-50. Marine Corps Warfighting Publication No. 3-1.6.23. Tactics, Techniques, and Procedures for The Field Artillery Cannon Battery (Appendix J - Crater Analysis and Reporting)*, and *US Army Field Manual FM 6-121, Tactics, Techniques, and Procedures for Field Artillery Target Acquisition (Appendix B - Crater Analysis And Reporting)*. A useful text discussing craters in the context of meteor impacts on other planets is *Planetary Landscapes* by Ronald Greeley, specifically the section on *Impact crater morphology and effects of different planetary environments* (Chapman & Hall, London, 1994). Criteria for munitions crater identification include the presence of a raised rim, circular perimeter, patterns of ejecta, and other aspects, described in greater detail below. While few sites will exhibit all of the following properties, the presence of one or more denotes a probable munitions crater.

Raised rims: The violent percussive force of an artillery impact will often leave behind a crater whose perimeter is elevated above the surrounding terrain, forming a circumferential ridge. Depending on the size of the crater and the properties of the affected soil this feature may endure for quite some time, or it may quickly be lost to erosion. Naturally occurring pits with raised rims are comparatively rare, except in areas affected by volcanism or meteorite impact. Similarly, most human excavations will dispose of the spoil in ways that do not result in the formation of a circumferential ridge. A notable exception of course are fighting positions, usually created with a raised rim for cover. Raised rims are identified in satellite imagery primarily by way of the shadows they cast (Figure Four C).

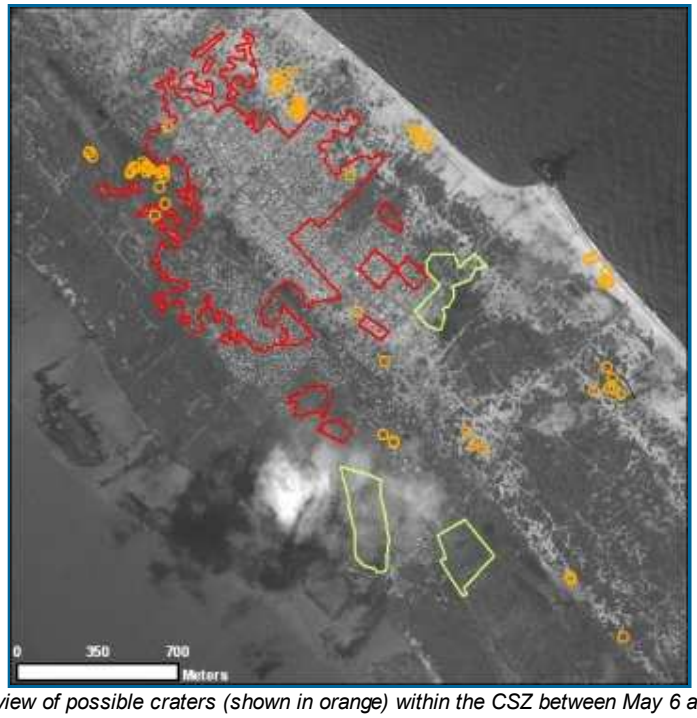
Circularity: Except at extremely oblique impact angles, the expended force of a surface burst is largely radially symmetric. As such, the resulting cavity will most frequently appear circular when viewed from above (Figure Four B - C). Natural formations such as sinkholes and karst formations, as well as numerous human excavations can also exhibit circularity, though irregular cross-sections are more common for all these features. When multiple and almost perfectly circular features occur in close proximity, they are more likely to have been caused by munitions.

Peripheral Ejecta: The impact of an explosive munition with the ground results in the rapid dispersal of ejecta throughout the surrounding area. Due to the aforementioned radial symmetry of the blast wave, in a surface burst this ejecta will frequently be circumferential to the resulting crater, though other orientations are possible. The excavated material may be obvious, or blend in with the surrounding terrain, depending on the reflective properties of the surface in question (Figure Four C). Very few natural or non-military events result in craters with circumferential ejecta, except in certain volcanic eruptions. In some explosions, so-called “rayed” ejecta are also visible, which take the form of multiple pronounced spikes of material radiating outward from the impact point. These rays can extend far further than the proximal ejecta blanket, sometimes by several orders of magnitude. Rayed ejecta are unique to impact events. Numerous examples of such ejecta were found in the imagery (Figure Four D and E).

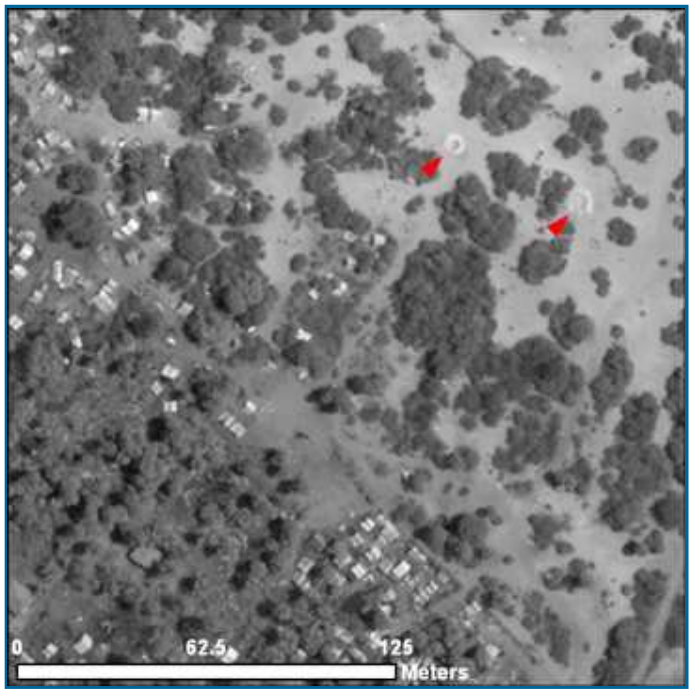
Diameter: Modern artillery systems come in standard calibers, and their munitions produce calibrated explosive yields, which combine to determine the diameter of the resulting crater. The appearance of numerous depressions of identical diameter can indicate repeated fire of the same artillery piece, or multiple guns of the same model, caliber, or munition. It is worth noting that this comparison is valid only between craters that form in the same soil type, as changes in soil types can affect the diameter of the resulting craters in unpredictable ways.

Bowl-shaped: The radial force of an explosive shell is not confined to a horizontal plane, and will most frequently result in a crater with smoothly sloping walls and a bowl-shaped floor. Steep-walled, flat-floored craters are more likely to be the result of natural subsidence or human excavation projects, although post-impact erosion and slumping can, in rare circumstances, cause a similar profile in impact craters. This attribute is identified through shadows cast by the crater, and is often very difficult to definitively ascertain.

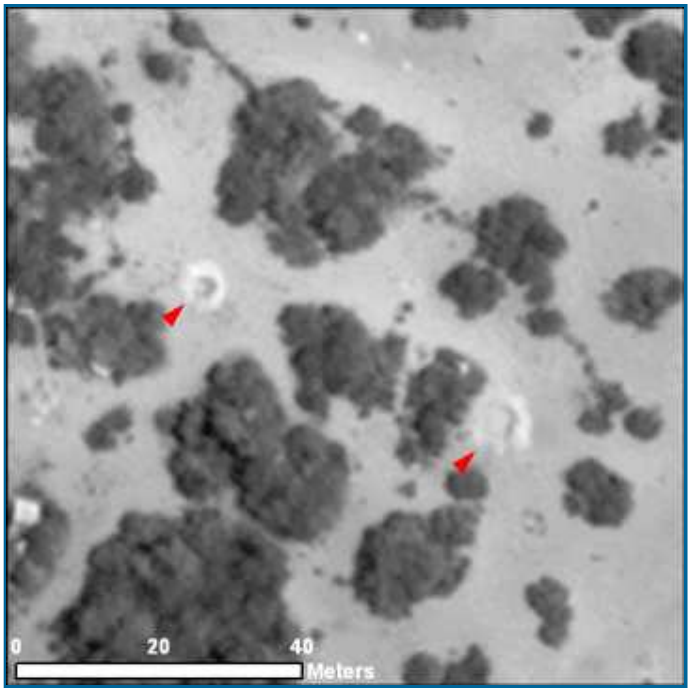
*Figure Four:* Crater formation within the CSZ between May 6 and May 10, 2009



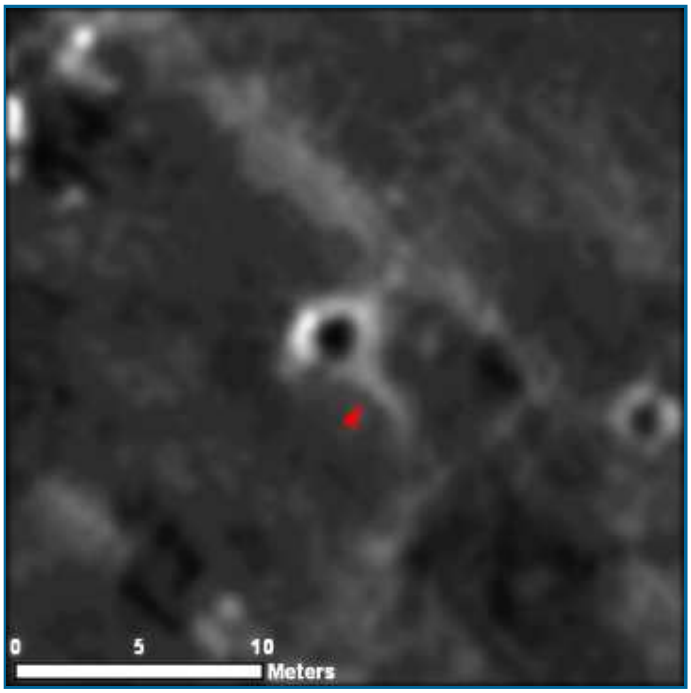

*A. An overview of possible craters (shown in orange) within the CSZ between May 6 and May 10, 2009. Image © 2009 DigitalGlobe*



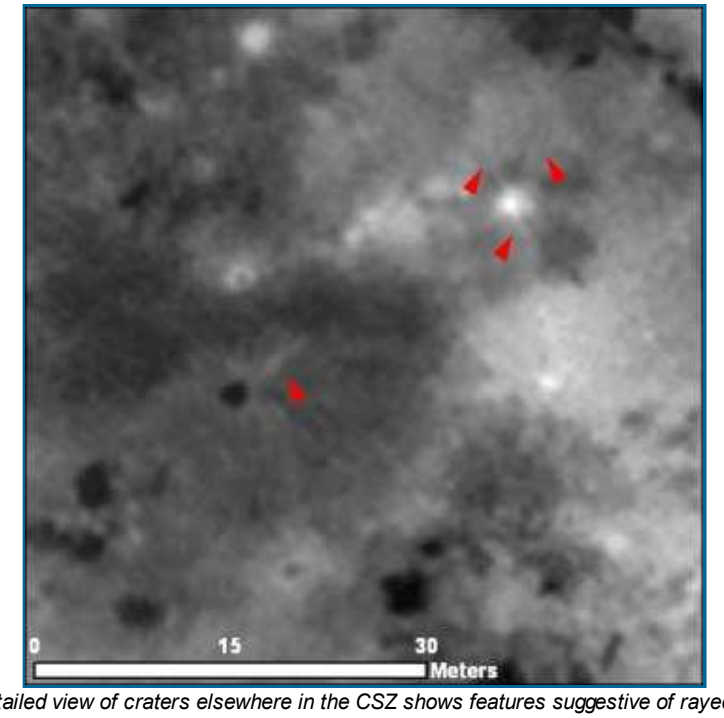

*B. New craters, indicated by arrows, have formed in close proximity to IDP areas. Image © 2009 DigitalGlobe*




*C. A detailed view of the newly-formed craters from Figure 4B shows features suggestive of circumferential ejecta. Image © 2009 DigitalGlobe*




*D. A detailed view of craters elsewhere in the CSZ shows features suggestive of rayed ejecta, indicated by red arrow. Image © 2009 DigitalGlobe*

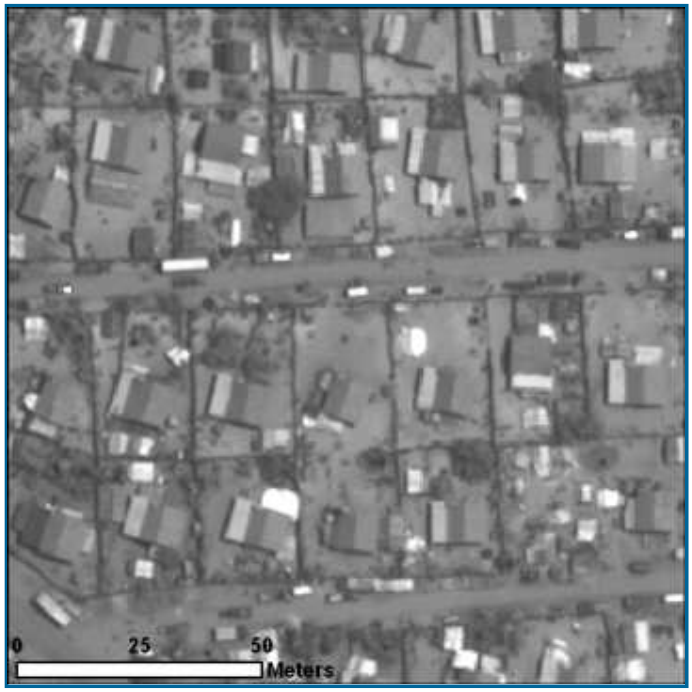



*E. A detailed view of craters elsewhere in the CSZ shows features suggestive of rayed ejecta, indicated by red arrows. Image © 2009 DigitalGlobe*

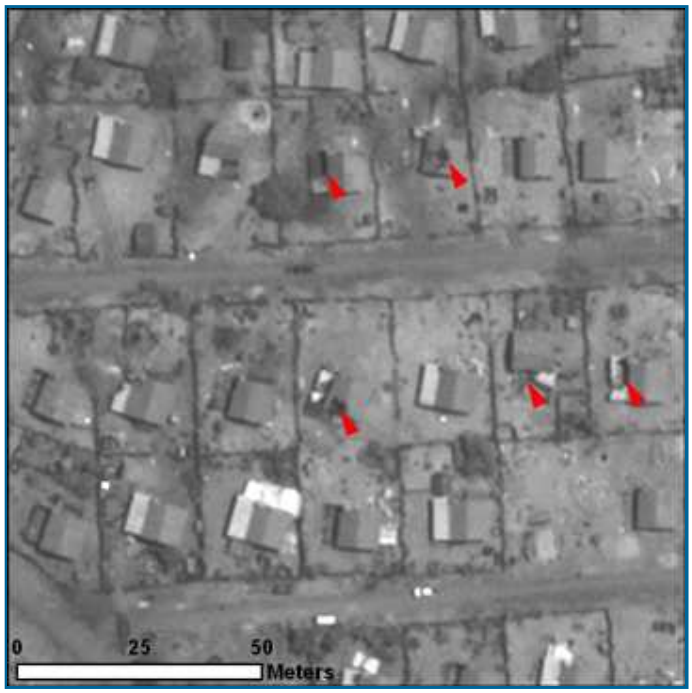
## Destroyed Permanent Structures

The status of permanent structures in the southern portion of the CSZ was also evaluated by AAAS using imagery from May 10 and prior. Damage to permanent structures is perhaps indicative of significant use of explosive shells, as these structures obviously would not be moved in the manner that IDP shelters often are. Evidence of destroyed permanent structures is commonplace and unambiguous in the May 6 imagery when compared to the images from previous dates. Dozens of structures have clearly been damaged or destroyed by May 6, with remains of the structures and concomitant debris visible (Figure Five). Numerous other structures bear markings consistent with burning or damage from weapons fire, such as blackened exteriors or holes in the rooftop. These roofless buildings were initially interpreted as possible evidence of shelling or burning. However, on-the-ground photos taken immediately after the conflict instead indicate widespread removal of rooftops, which were composed of sheet metal, for use in constructing shelters throughout the area.

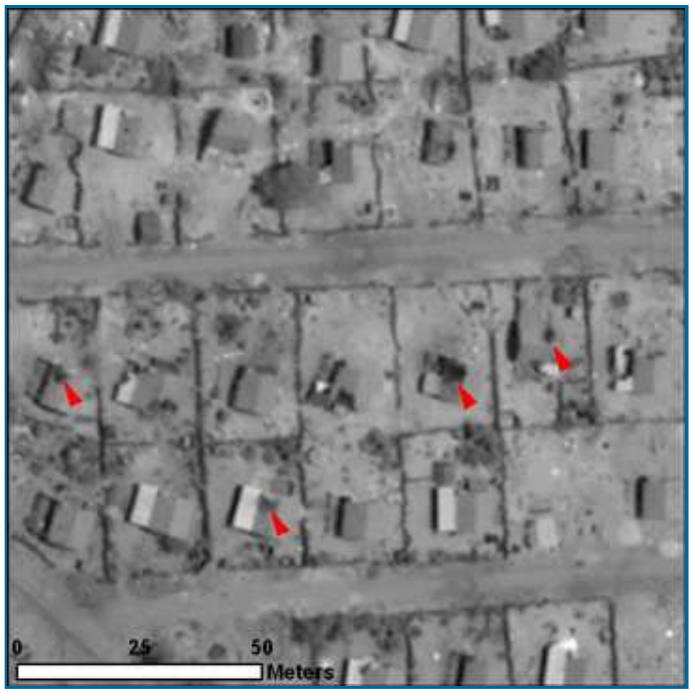
*Figure Five:* Damage to permanent structures within the CSZ, between April 19 and May 10, 2009




*On April 19, 2009 (above), intact permanent structures are visible in the CSZ, along with numerous outbuildings. Image © 2009 DigitalGlobe*




*By May 6, 2009 (above), several of these structures had sustained substantial damage (indicated by red arrows), and most outbuildings had been removed. Image © 2009 DigitalGlobe*




*By May 10, 2009, other structures had sustained damage (indicated by red arrows). Image © 2009 DigitalGlobe*

Permanent structures within the southern area of the CSZ also suffered observable damage in the period between the May 6 and May 10 images. Again, as in the May 6 image, numerous structures had their sheet metal rooftops removed, most likely to construct or repair shelters throughout the CSZ. Excluding roofless structures, 21 permanent structures have sustained visible damage in the period between May 6 and May 10 within the southern area of the CSZ. A cluster of these damaged structures is shown in Figure Five.

## Examination of Gravesites

Three apparent gravesites were visible within the CSZ, one in the southern area and two in the northern. Graveyards were found during the initial review of the satellite imagery, but were only definitively identified when AAAS reviewed photographs taken immediately after the conflict. AAAS counted the growth in graves at all three sites over time, using all imagery up to and including the image gathered on May 24. It must be noted that graves analysis is problematic with satellite imagery. In addition to the sites

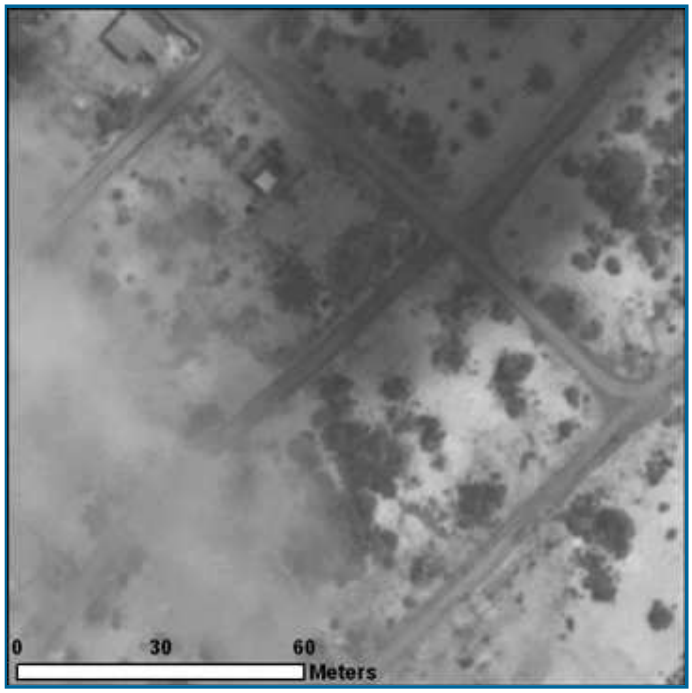
described below, it is likely that other graves were dug individually, in smaller groups, and/or under vegetation, and completely unmarked, which would have hidden them from view of the satellites.

The southernmost graveyard lies close to the IDP area reviewed above, and appears at some point between April 19 and May 6, as shown in Figure Six. Individual graves are visible and appear to cast distinct shadows in the May 6 satellite image, suggesting mounded burials. IDP shelters also appear in the immediate vicinity of the graves during the same period. Visual inspection of the imagery identified the appearance of 148 probable graves at this location between April 19 and May 6. However, given the size of the graves and quality of imagery, it is likely that not all graves present at that time are visible in the May 6 image due to blurring and effects of shadows. As this graveyard was quite regular and orderly in its layout, AAAS also estimated a count of individual graves based on an estimated width of fifteen burials per row. Using this method, 195 graves are estimated to be at this location as of May 6.

In the image acquired May 10, the southernmost graveyard seems to have expanded substantially. As illustrated in Figure Six, terrain to the southwest of the site appears to have been cleared, and a number of new graves are apparent. Inspection of the imagery for May 10 indicates that 77 new burials likely occurred since May 6. Notably, five graves occupying the south-westernmost corner of the expanded graveyard appear substantially darker and wider than their neighbors, possibly indicative of burials planned or in-progress at the time of image acquisition.

The latest image to cover this southernmost graveyard was acquired on May 24. When compared to previous imagery, it is clear that temporary structures have been cleared from the lot northwest of the original site (Figure Six). In their place, a number of new burials appear to have been created. Because this image was taken by a different satellite than the previous two, altered viewing geometry and illumination conditions made a direct comparison with the earlier imagery difficult. Based on the established density of interments and the area covered by the expanded burial ground, however, an estimate of 70 additional graves is likely. This brings the total of the estimated burials at this southernmost graveyard to 342.

*Figure Six:* Formation of a probable gravesite in CSZ




*A. On April 19 roads are present, but the area is mostly deserted. Image © 2009 DigitalGlobe.*

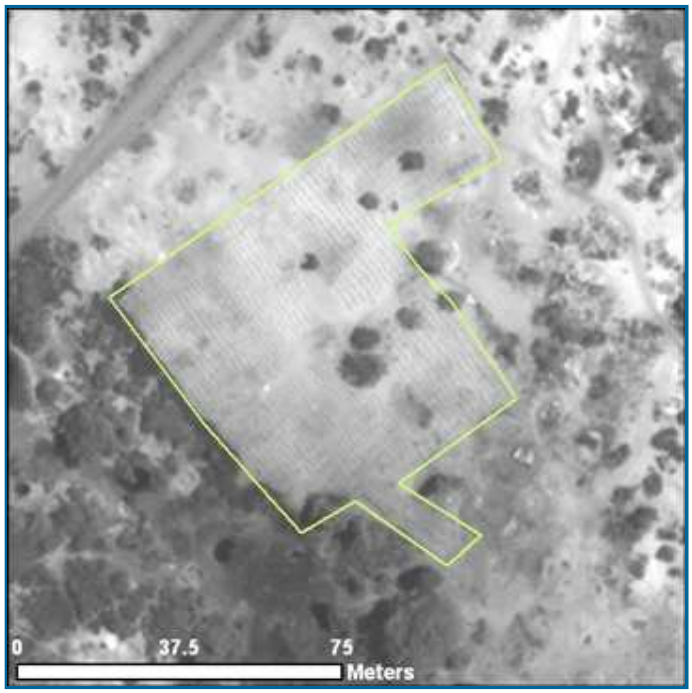

*B. By May 6 numerous probable IDP structures are present, along with a graveyard (outlined in red) containing an estimated 195 burials. Image © 2009 DigitalGlobe.*

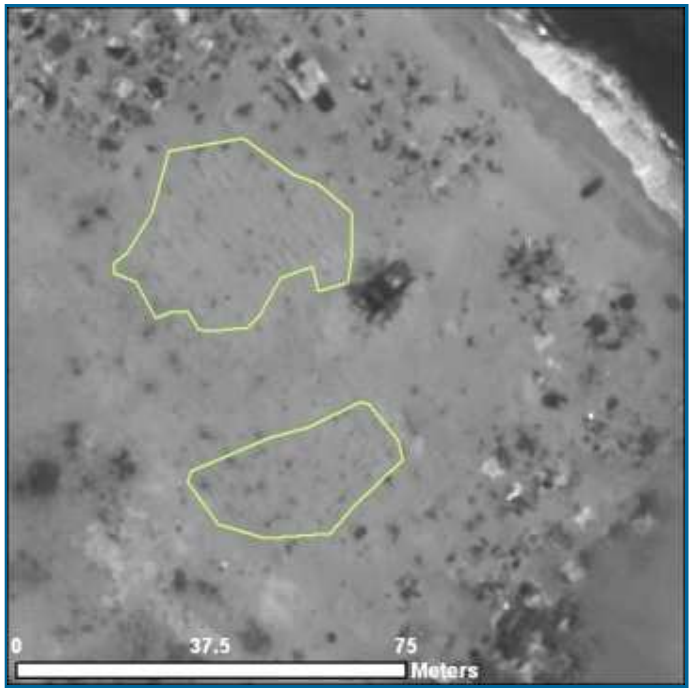

*C. By May 10 the graveyard has expanded substantially. Image © 2009 DigitalGlobe.*


*D. By May 24, an area across the street has been cleared and is also being used for interments, bringing the total to 342 graves (estimated) at this location. Image © 2009 GeoEye.*

The second graveyard identified in this study was located approximately 3.6 kilometers northwest of the previously described location. The layout of graves was very similar to the previous site, consisting of evenly-spaced rows and columns. Its scale however, is far larger than the first, as illustrated in Figure Seven. First identified in imagery from May 6, this site consists of an estimated 960 graves on that date. Unlike the first site, this graveyard exhibits no signs of growth between May 6 and May 10, nor between May 10 and May 24. One noteworthy characteristic of this site is that it was identified in media reporting as belonging to the LTTE. While AAAS has no way to substantiate this statement, the similarities between this site and previous, southernmost graveyard may indicate a common origin.

*Figure Seven:* Graveyards in Northern Section of the CSZ






*A large graveyard (top), containing an estimated 960 burials, is visible in the CSZ on May 6. Another more chaotic cemetery (bottom) is barely visible nearby. Unlike the graveyard further south (shown in Figure 6), neither of these exhibit signs of growth. Image © 2009 DigitalGlobe*

The final graveyard analyzed by this study was located 4.3 kilometers northwest of the second graveyard, and almost 8 kilometers northwest of the first gravesite described above. Identified in media reports as being a burial ground for civilians, this location differed substantially from the others in its organization and size. Unlike the rigid pattern of the previous two sites, the layout of this area was much less regular. As shown in Figure Seven, apparent burial mounds were scattered throughout the area. These mounds were also less regular in their individual shapes than those at previous sites, which rendered their identification difficult in the available imagery. In total, 44 burials were identified at this site on May 6, with no changes observed between May 6, May 10, and May 24. Again, the irregularity of this site made counting of the graves very difficult, and many graves are undoubtedly not visible in the imagery.

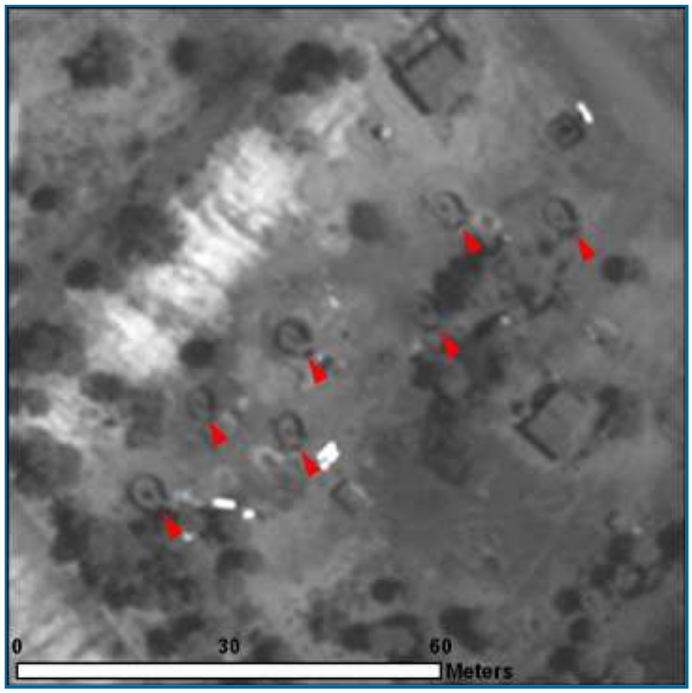
In all three gravesites reviewed, a total of 1,346 likely graves are estimated to be in the imagery by May 24, 2009. The majority of the graves were present by May 6, with little change after that except in the southernmost graveyard. The southernmost site grew an estimated 28% between May 6 and May 10, and grew another 20% between May 10 and May 24.

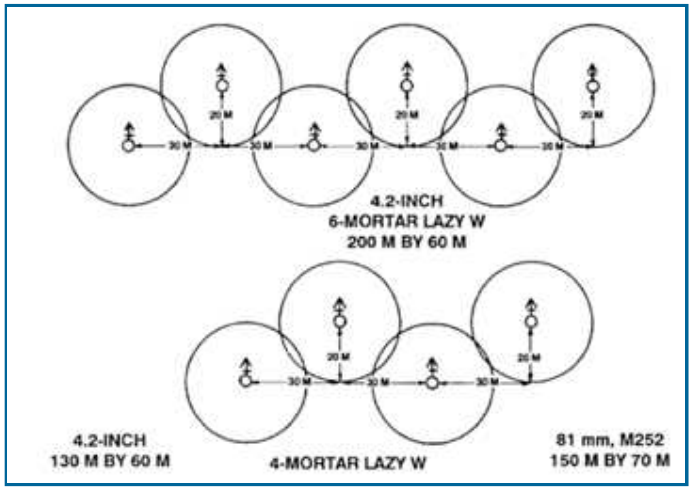
## Possible Artillery and Mortar Positions

In addition to the analysis described above, AAAS reviewed the entirety of the CSZ and a swath of surrounding territory for possible indications of artillery and mortar positions. This analysis extended northwest, west, and southwest from the CSZ for approximately nine kilometers, excluding ocean and lagoon areas. While this analysis sought to locate artillery positions, it should be noted that various artillery pieces in use by the Sri Lankan Army have ranges well beyond nine kilometers. Unfortunately, budgetary constraints do not allow analysis of all potential artillery sites at present, and it is unlikely sufficient imagery exists for a complete review. For this portion of the analysis, only the May 10 image was used, and was compared with the image from May 2005, on GoogleEarth. Features in the May 10 image with a configuration that possibly denoted military origin were flagged for review by an outside consultant with more than five years of experience interpreting imagery for the United States Marine Corps.

Numerous features outside of the CSZ were identified that bear resemblance to mortar positions, based on comparisons with a United States Army Field Manual (FM 7-90 Tactical Employment of Mortars). Specifically, 17 possible mortar locations were identified in the area surrounding the CSZ. One of these sites is arrayed in a formation referred to as the "Lazy W" by the US Army Field Manual (Figure Eight; FM 7-90 Tactical Employment of Mortars), while another might include a "Six Star" formation (Figure Nine; FM 7-90 Tactical Employment of Mortars). Most of the sites are simply in a parallel or single line formation, and are oriented both towards the CSZ and surrounding roads. Note that no mortar tubes are visible in the imagery, preventing conclusive identification of the sites as mortar positions. Given the average distance of these suspected mortar sites from the CSZ, it can be extrapolated that any mortars therein would likely be up to 120 mm in size, based on ranges of such weapons publicized in the US Army Field Manual (FM 7-90 Tactical Employment of Mortars). While it is not possible to conclusively identify such sites based on image analysis alone, their locations bear noting for possible further investigations. None of the sites reviewed showed indications they were occupied by heavy artillery pieces, which are generally readily identifiable in such imagery unless camouflaged.

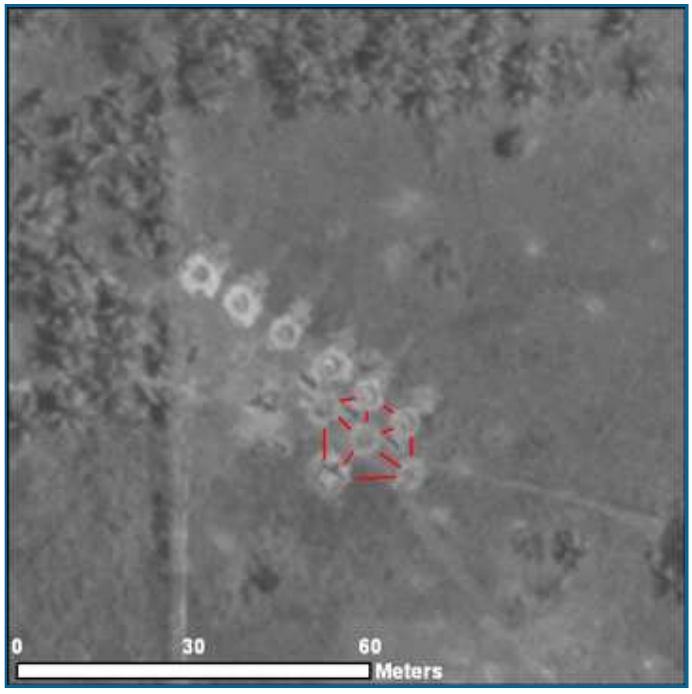
*Figure Eight:* Probable mortar emplacements surrounding the CSZ




*Numerous possible mortar emplacements are located throughout the area of the CSZ. One such emplacement (top), is arrayed similarly to the 'Lazy W' formation detailed in a US Army Field Manual (bottom; FM 7-90 Tactical Employment of Mortars). Image © 2009 DigitalGlobe.*

*Figure Nine:* Probable mortar emplacements surrounding the CSZ



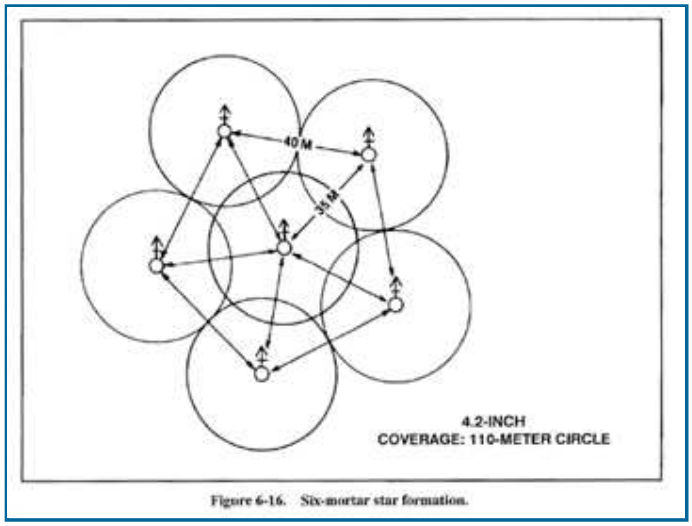




Figure 6-16. Six-mortar star formation.

*This possible mortar position (top) is arrayed similarly to the 'Six Star' formation, as detailed in a US Army Field Manual (bottom; FM 7-90 Tactical Employment of Mortars). Image © 2009 DigitalGlobe.*

## About the Imagery

Since 2000, commercial satellite operators have acquired high-resolution imagery around the world, largely in response to customer requests. Once imagery is acquired from a satellite, it is then added to the companies' archives and generally made available for resale. One image source used in this analysis was the Ikonos satellite, operated by the GeoEye corporation. Ikonos has a multispectral sensor with one meter panchromatic resolution and has been in operation since 1999. A second satellite from GeoEye is GeoEye-1, with 50 centimeter non-governmental panchromatic resolution and 1.65 meter multispectral resolution. Another satellite utilized was QuickBird, operated by DigitalGlobe, which has 60 centimeter panchromatic resolution and two meter multispectral resolution, which became operational in 2002. Lastly, DigitalGlobe's WorldView satellite, which provides 50 centimeter panchromatic imagery, was used extensively. Note that only the US Government can direct WorldView to acquire imagery, but once such imagery is obtained it is made available for public use via the DigitalGlobe archives.

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*(site updated 8/10/2009)*