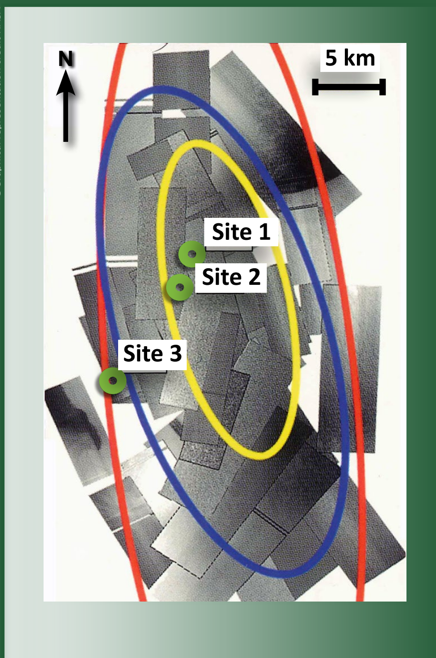
Geospatial Intelligence Review

An Analytic Tradecraft Journal

Spring 2017



Site Locations Compared to Predicted Landing Site Ellipses

A Note From the GEOINT Functional Manager

Directors of the National Imagery and Mapping Agency (NIMA) and the National Geospatial-Intelligence Agency (NGA) have used *Geospatial Intelligence Review (GIR)* to professionalize geospatial intelligence (GEOINT)—but many readers are seeing this journal for the first time. If *GIR* had a shortcoming it is that the journal was published only within classified channels.

Until now. I have directed that *GIR*, after 15 years in print, succeed in and with the open. It is time for the journal to leave its comfort zone.

The articles in this edition reflect several more specific reasons I am bringing *GIR* into the open: to publicize NGA's support to other agencies, to help inspire prospective talent, to teach some tradecraft, and to theorize about the profession's future.

- **Publicize.** NGA directly supports every member of the Intelligence Community and practically every agency in the US Government. Examples include humanitarian assistance, disaster readiness, response & recovery, and land reclamation. Ivar Svendsen and James Salacain explain how NGA's predecessor, NIMA, searched imagery for the lost Mars Polar Lander (the Amelia Earhart of space probes).

- **Inspire.** GEOINT encompasses dozens of disciplines, some of which are rather art like. John Macier—now a Senior Associate at Booz Allen Hamilton, Inc.—was in the US Army's National Ground Intelligence Center when he set out to understand the nature of imagery analysis. He concluded there was a small set of individuals who could perform image interpretation and intelligence analysis simultaneously.

- **Teach.** NGA analyst Greg Grohman explains the advantages (and some drawbacks) of a GEOINT mainstay: orthorectification (which processes monoscopic imagery to remove distortions of tilt, tilt-induced scale, and terrain relief). Greg has been crunching pixels and teaching analysts since before the Defense Mapping Agency reorganized under NIMA in 1996.

- **Teach some more.** Analysts in NGA have heard me say "GEOINT is new, but it's not new." Professors Kim Rossmo, Heike Lutermann, Mark Stevenson, and Steven Le Comber provide an example of what I mean. Spatial analysis is time-tested (these four authors use a case study from Nazi Berlin) but modern automated processing has greatly improved our capabilities.

- **Theorize.** John Oswald retired as the NGA Director of Analysis and Production in 2011 but continues to serve, writing "Geospatial Analysis: Origin and Development in NGA." John and coauthor Scott Simmons demonstrate that "retired" authors know a lot about how the profession came to be and where it may be heading.

GIR has come out so more professionals can join in the learning and teaching. There was a time when GEOINT advanced almost exclusively inside the US Government; advances now happen just as often outside government. This edition of *GIR* demonstrates what can be done by authors in academe and industry and by government analysts willing to succeed in and with the open.

Robert Cardillo
GEOINT Functional Manager

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Online Submissions: A draft article should be submitted in Microsoft Word Rich Text Format (.rtf). A draft must show classification and releasability of each paragraph and title. Graphics should be submitted as attachments to the text in JPEG (.jpg), or TIFF (.tif) format at 300 dpi. Submit a draft to: Mark.G.Marshall@nga.mil.

Mail Submissions: Send a CD to: *Geospatial Intelligence Review,* NGA Mail Stop S62-ATP, 7500 GEOINT Drive, Springfield, Virginia 22150.

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Articles

Articles

Book Reviews

Awards: An annual award is offered for the most significant contribution to the literature of geospatial intelligence submitted for publication in *GIR*. The award may be divided if two or more articles are judged to be of equal merit.

Unless otherwise announced from year to year, articles on any subject within range of *GIR's* purview will be considered for the awards. They will be judged primarily on substantive originality and soundness, secondarily on literary qualities. Current members of the editorial board are excluded from the competition but the board may choose to recognize coauthor(s) not on the board. The editorial board will welcome readers' nominations for awards, but reserves exclusive prerogative in the decision.

An Imagery Search for NASA's Missing Mars Polar Lander: Lost and Found?

By Ivar Svendsen and James Salacain

In 2002, Ivar Svendsen had 27 years of experience in imagery analysis and had worked in NASA's Space Shuttle program. His last assignment was at the National Imagery and Mapping Agency's (NIMA) Missile and Space Issues Branch.

In 2002, James Salacain had 15 years of experience in imagery science in support of the national imagery community.
E-mail address: salacain@nro.mil

Editor's note: Originally published in GIR *1 no. 2 (2002), the article subsequently received approval for public release; case #07053, 18 Nov 2006. The NASA investigation board eventually concluded that the lander likely crashed because its descent rocket engine quit firing due to a software error. The fallen lander has never been definitively located.*

Introduction

The Mars Polar Lander (MPL), one of NASA's new generation of small planetary explorer spacecraft, was developed between 1994 and 1998 and launched toward Mars by a Delta-II booster from Cape Canaveral, Florida, on 3 January 1999 (figure 1). The MPL arrived at Mars on 3 December 1999. It was programmed to enter the Martian atmosphere, to perform a soft landing, and to conduct a 90-day science mission about 800 km from the Martian South Pole. Unfortunately, after entry into the Martian atmosphere, the MPL was never heard from again.

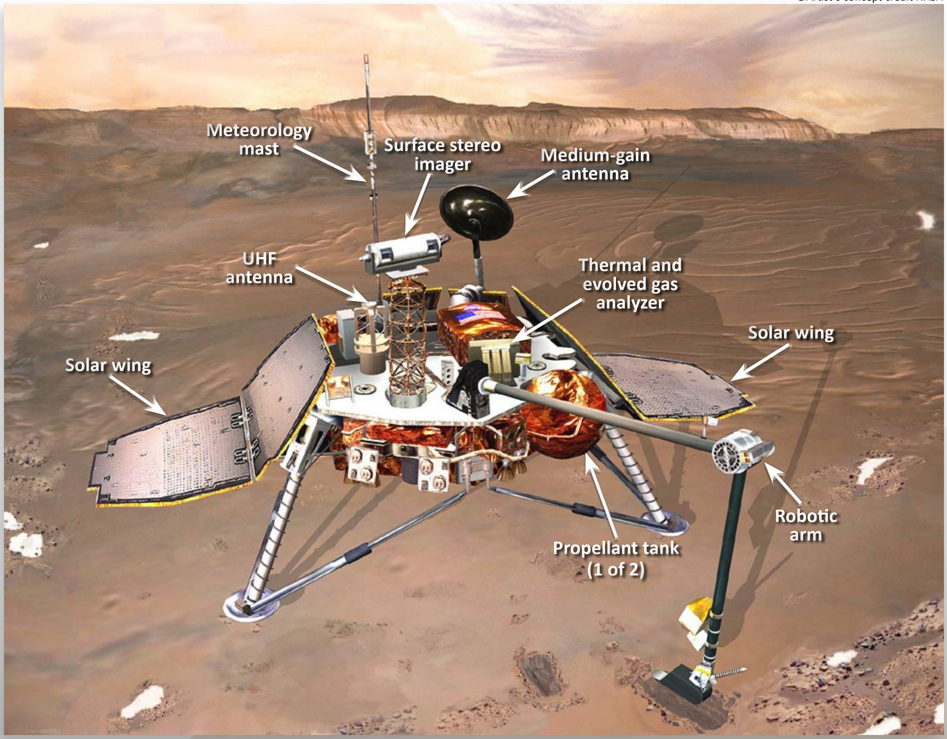


Figure 1. Mars Polar Lander Spacecraft[1]

Because the MPL did not have a telemetry transmission capability during atmospheric entry, no radio signals were sent back to Earth that might have revealed to investigators what went wrong. Overhead search imagery of the MPL landing site and surrounding area was acquired by the Mars Orbiter Camera (MOC) system onboard NASA's Mars Global Surveyor (MGS) spacecraft, orbiting Mars since 1997. In addition, imagery searches were subsequently conducted by the Jet Propulsion Laboratory (JPL) and by Malin Space Science Systems (MSSS), the primary contractor/operator of the MOC system on the MGS.

A NIMA team, at NASA's request, conducted a detailed search of the primary MPL landing area. The team identified three candidate sites that had pixel returns appearing to match the expected signatures of the lander and its associated landing hardware. These sites generally were arranged in a northeast-to-southwest orientation in the MPL landing area. Two of the three sites are within the western side of the ellipse predicted to have the highest probability as a landing site for the MPL, and the third site is southwest of these sites. The imagery signatures at the sites north and south of the central, or second, site suggest the presence of protective hardware associated with atmospheric entry. The imagery signature at the central site was assessed to be possibly associated with the MPL itself.

After the loss of the lander, NASA commissioned a blue-ribbon Mars Program Independent Assessment Team to examine the successes and failures of the Mars exploration program. This commission, with the assistance of JPL and Lockheed Martin Astronautics (LMA), concluded that the "most probable cause" of the MPL loss was the transmission of spurious signals from touchdown sensors on the lander's legs. These signals would have led to a premature shutdown of the MPL's descent engines, causing it to crash to the surface at 22 meters per second (50 mph) and be "destroyed."[2]

"Overhead search imagery of the MPL landing site and surrounding area was acquired by the Mars Orbiter Camera (MOC) system onboard NASA's Mars Global Surveyor (MGS) spacecraft . . ."

"A NIMA team . . . conducted a detailed search of the primary MPL landing area. The team identified three candidate sites that had pixel returns appearing to match the expected signatures . . ."

Partnership of Imagery Analysis and Imagery Science

The rationale stated by NASA for NIMA's involvement in the search for the missing MPL was to have NIMA provide imagery exploitation skills and techniques used for locating and identifying small manmade objects in terrestrial imagery, possibly identifying the MPL and its parachute in images taken of the Martian surface. From the outset, the NIMA search effort was intended to combine the "toolkit" and skills of imagery analysis with those of imagery science—so that the fusion of both disciplines might prove to be more effective than each discipline on its own. One NIMA imagery analyst and one NIMA imagery scientist partnered on this project. Using appropriate imagery analysis and imagery science tools, the team reviewed and analyzed the search imagery. The effort concentrated on finding any imagery evidence of the lander or its associated entry, descent, and landing (EDL) hardware such as the descent aeroshell and parachute objects that, in theory, would be barely detectable by the camera on the MGS (figure 2). An initial but incomplete NIMA search was conducted in early 2000 and a second, more thorough, search was done in late 2000. Analysis of the search findings was completed in early 2001, and the results are detailed in this article. Internal NIMA peer and management reviews of the search findings and associated analysis were completed in February 2001.

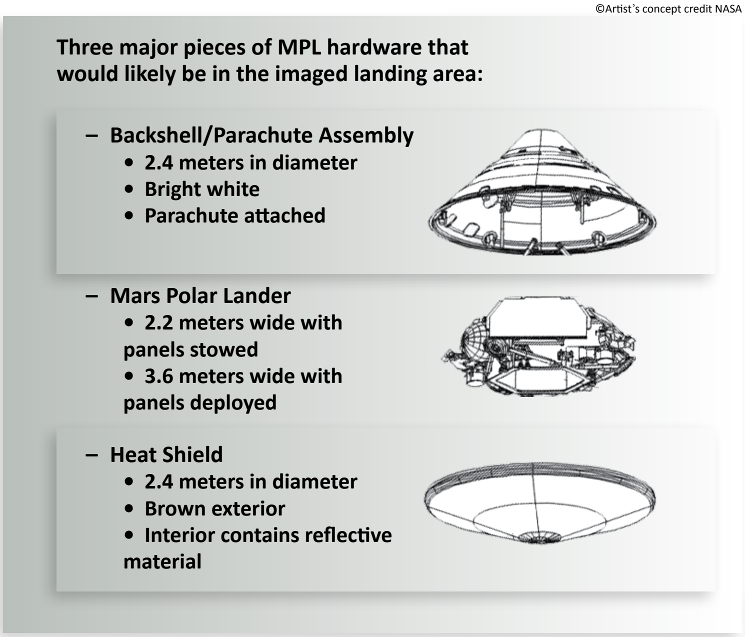


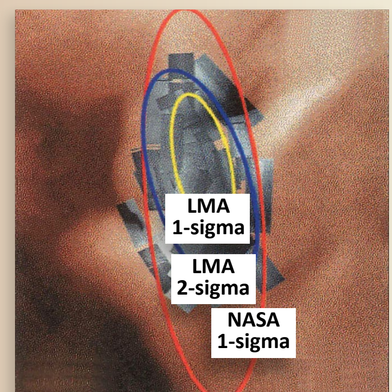
Figure 2. The MPL (Center, in Folded Flight Configuration) and Associated Atmospheric Entry, Descent, and Landing Hardware[1]

Search Imagery of the Landing Area

An imagery search of the most probable MPL landing site and surrounding area near the Martian South Pole was authorized by NASA and implemented by JPL and MSSS. The MGS acquired 40 MOC images between mid-December 1999 and early February 2000. These images and associated imagery support data were provided by JPL and MSSS to NIMA between January and May 2000. This imagery (shown in figure 3) covered an area of 667 square km, according to MSSS, and was centered at approximately 76 degrees south latitude and 165 degrees east longitude. The three ellipses that are overlaid on the search images in figure 3 depict the predicted landing zone of the MPL. The red, or outermost, ellipse shows the NASA 1-sigma prediction of the landing location.* The smaller blue and yellow ellipses show, respectively, the LMA 2-sigma and LMA 1-sigma predictions of the MPL landing area.

Along with the imagery, NIMA was provided ephemeris for each collected MOC image, detailing, among other parameters, the resolution of the image, the latitude and longitude of the image corners, and the angles defining the illumination and viewing geometry. A number of the image frames contained

Figure 3. Search Imagery Mosaic With Predicted MPL Landing Ellipses[3]



*The 1-sigma ellipse is a single standard deviation of the latitude and longitude errors around the predicted landing point. This ellipse represents the area where there is a 63-percent likelihood of the true location of the landing site. A 2-sigma ellipse represents two standard deviations and embodies the area where there is a 95-percent likelihood of the true location of the landing point.

data dropouts of indeterminate length; as a result, the corner geocoordinates could be used only as a rough starting point for registering the imagery. The resolution of the imagery dataset provided ranged from MOC system best (1.4 meters) to approximately double system best. The image quality of the data, a factor driven primarily by the atmospheric conditions at the targeted areas (figure 4), ranged from good (good dynamic range, low noise) to poor (low dynamic range, high random and patterned noise).

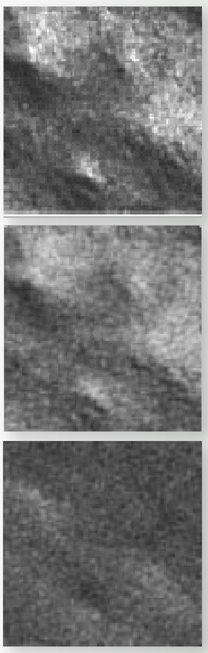


Figure 4. Examples of Good, Moderate, and Poor Quality Imagery of the Same Point on the Martian Surface

NIMA Imagery Search Methodologies

Initially, the NIMA search methodology was a conventional examination of the MOC imagery to find a signature indicative of the MPL parachute on the Martian surface. The 6-meter-diameter white parachute, the largest component of the MPL EDL system, should have contrasted sharply with the reddish Martian soil and provided the best hope of finding the MPL. MOC imagery of the landing area would have shown the parachute canopy at four pixels in size; repeated reviews of the search imagery for a signature indicative of the parachute found none.

An alternative approach was used to take advantage of the significant overlap in MOC search imagery coverage by averaging the images to reduce the noise and to improve the image quality. This technique allowed the random noise component in each of the constituent images to be cancelled out, thereby improving the dynamic range of the combined image set. An example of a block of image data generated using this technique is shown in figure 5. The figure shows the end result of combining seven images with different viewing orientations, resolutions, and qualities into a single combined product. In comparing the original images to the combined result, this technique showed some promise for improving the quality of the MOC image, thereby permitting better discrimination of the MPL parachute from the background soil.

"Initially, the NIMA search methodology was a conventional examination of the MOC imagery . . ."

Figure 5. Example of 5- by 5-km Block of Averaged Imagery

In the course of generating blocks of averaged image data for a detailed review, a particular location in one of the image blocks was noted as being unusually bright. The source of the bright return in the averaged image block was determined to have come from a single saturated (255-count) pixel in image M10-2177 at pixel coordinates (611, 3928). The signature at what we called site 1 was such a significant departure from the expected pixel values of the image that an examination of the remainder of this image was warranted (figure 6a).

Further examination of image M10-2177 revealed the presence of a second bright pixel site, known as site 2, at coordinates (1615, 3324). This site exhibited a pair of bright, but not saturated, pixels that were separated by a single, darker pixel, (figure 6b).

An examination of the rest of the MOC search image set turned up only one additional bright-pixel site, known as site 3, at coordinates (1571, 1069) in image M11-3986 (figure 6c).

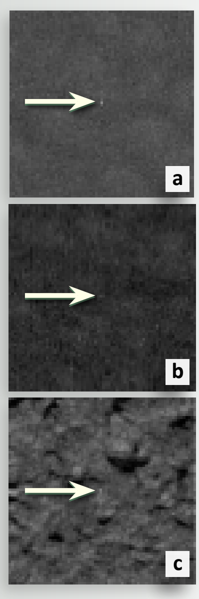


Figure 6.
a) Site 1,
b) Site 2, and
c) Site 3

Search Findings

Overview of Sites 1, 2, and 3

The locations of sites 1 through 3, relative to the predicted landing site ellipses, are shown in the mosaic of the MOC search images in figure 7. A closer view of the site locations, overlaid on the imagery, is shown in figure 8. The sites are aligned along a northeast-to-southwest orientation. Site 1 is about 3 km northeast of site 2 and both sites are located within the LMA 1-sigma ellipse. Site 3 is about 10 to 12 km southwest of site 2 and is just within the western edge of the LaRC 1-sigma ellipse. Sites 1 and 2 were discovered in image M10-2177, a 2.57-meter-resolution image best described as murky or hazy and exhibiting very little scene detail. Site 3 was identified in image M11-3986, a good-quality image with a resolution of 1.45 meters.

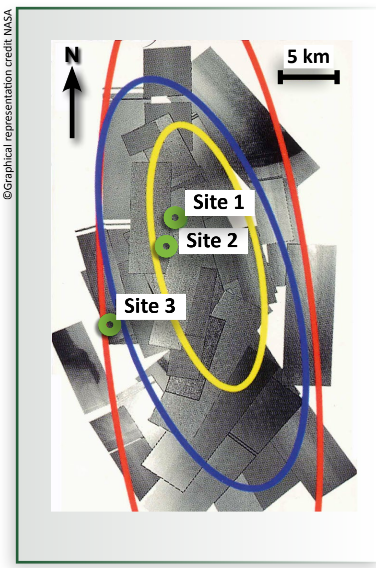


Figure 7. Site Locations Compared to Predicted MPL Landing Site Ellipses[3]

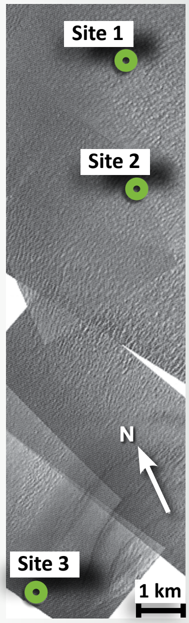


Figure 8. Closeup View of Site Locations

of the identified bright pixels significantly outside the expected image count range. Simple statistics dictate that 99.9 percent of the image pixel values should fall within three standard deviations of the image pixel value mean. The pixel values for the identified sites fall well outside this range and therefore cannot reasonably be considered within the normal range for the scene. The site 1 pixel is 18 standard deviations above the image mean; the two site 2 pixels are 9 and 6 standard deviations, respectively, above the mean; and the site 3 pixel is 7.3 standard deviations above the mean. An independent analysis performed as part of the internal NIMA peer review process also showed that the site 2 pixels, even though they are not as bright as the site 1 pixel in image M10-2177, are still significantly brighter than the distribution of the brightest

> *"Initially, an effort was made to characterize the pixel intensity values of the bright signatures at the three sites to understand their likely origin."*

Initial Characterization of Sites 1, 2, and 3 Signatures

Initially, an effort was made to characterize the pixel intensity values of the bright signatures at the three sites to understand their likely origin. Once that was done, an examination of various possible sources of these signatures was conducted.

Sites 1 and 3 were determined to be the brightest pixels in their respective images. Site 1 was saturated at 255 counts and site 3 at 173 counts. The brighter (220 counts) of the two site 2 pixels, if not for the presence of the pixel at site 1 in the same image, would have been the brightest pixel in the image. Figures 9 and 10 show some basic imagery intensity statistics for images M10-2177 and M11-3986. Visual examination of sites 1, 2, and 3 pixel counts, relative to their associated image histogram, shows all four

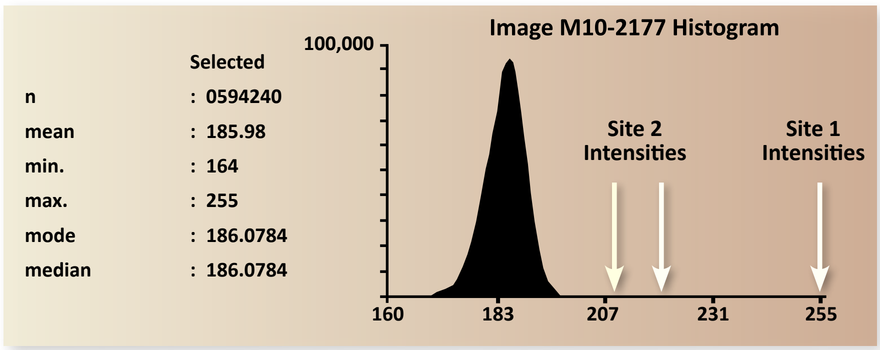


Figure 9. Image Intensity Count Statistics of Image M10-2177

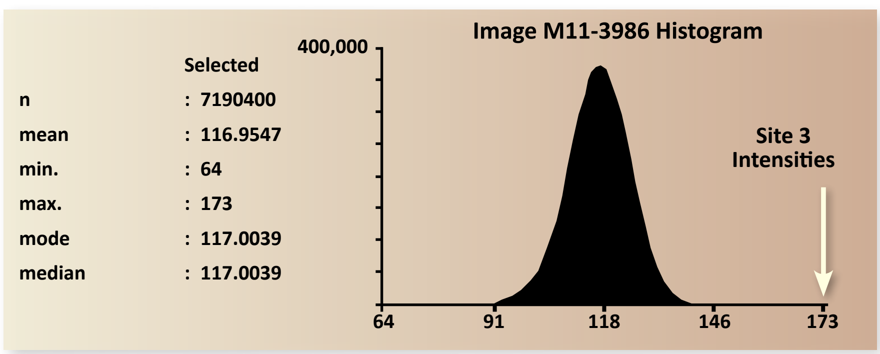


Figure 10. Image Intensity Count Statistics of Image M11-3986

“. . . the apparent causes of the signatures at the identified sites appeared to be reflected light or glints from some portion of the MPL EDL system and/or the MPL itself.”

pixels in that image. In fact, of the 40 MOC image scenes analyzed, the three sites were the only locations that exhibited this uncharacteristically bright response.

To identify sources of the bright pixels at all three sites, several possible causes of these signatures were reviewed and assessed. The sources that were considered tended to be binned into categories designated “natural in origin,” “imaging system noise,” or “possibly manmade objects” (for example, the MPL and related EDL system hardware).

Possible natural causes considered for the bright pixels included ice and glint from a natural object. A glint is a specular reflection of the sun on the surface of an object in the direction of the camera. Ice tends to be among the brightest features in some of the MOC images because it has a reflectivity much higher than that of the reddish soil of Mars and sends back a strong, reflected-light signature. However, ice, when present, tends to be many pixels in size and usually is observed in various locations within an image, commonly near ridge peaks or knobs and in shadowed areas. All four of the bright-pixel signatures at the three sites occur in locations that could be described as fully illuminated gullies. No similar occurrences of ice are apparent anywhere in the vicinity. On the basis of these factors, ice was discounted as a possible source of these signatures.

The possibility of glints from natural objects on the surface was also considered as an explanation for the source of the bright pixels at the three sites. For a natural object to generate a glint, it must have a surface that is sufficiently well polished so as to have a specular reflective quality rather than the more common diffuse, or Lambertian, quality. Although possible, it is unlikely for a natural object to develop a surface capable of generating a glint. Furthermore, natural forces tend to degrade the specular quality of surfaces through processes of pitting, chipping, or covering. In naturally arid regions on Earth without surface water or manmade materials, for example, glints are very rare. Natural glints, therefore, can be discounted as a possible source of the signatures seen at the three sites.

Other causes such as noise generated in the imaging system were also considered, including random noise and spurious noise. Figures 9 and 10 show the statistics for images M10-2177 and M11-3986 along with indicators for the count values of the bright pixels at sites 1, 2, and 3. An examination of the statistics for images M10-2177 and M11-3986 indicates that all of the bright-pixel signatures were believed to be far outside the realm of a possible random occurrence and were discounted as being attributable to normal random noise within the imaging system. However, spurious noise, or isolated noise, consists of artifacts generated within the camera’s electronics and can be attributed either to a source internal to the spacecraft such as a static electricity charge buildup and discharge or to an external source such as a cosmic ray. Although the possibility of spurious noise events at the sites cannot be ruled out, the coincidental appearance of spurious noise within the MPL primary landing site that also happened to emulate MPL-like imagery signatures was considered unlikely.

Thus, after having negated the most likely non-MPL sources of the signatures, the apparent causes of the signatures at the identified sites appeared to be reflected light or glints from some portion of the MPL EDL system and/or the MPL itself.

Detailed Analysis of Site Signatures

Of the three bright pixel signatures evident at sites 1, 2, and 3, the most intriguing was the twin-pixel signature at site 2. For that reason, the discussion in this section will first deal with a detailed analysis of the signature at site 2 and follow with an analytical treatment of the signatures at sites 1 and 3.

Site 2 Analysis

Site Description. Site 2 is within the western side of the ellipse predicted to have the highest probability of being the MPL landing site, LMA-1. This site was covered in four MOC images taken during the MPL search effort. The signature at site 2 consists of two bright pixels separated by a darker pixel. This twin-pixel signature at the site was seen on image M10-2177 at coordinates (1615, 3324). That same ground location in image M10-2187 is near coordinates (1971, 4560), on image M10-2295 near coordinates (1022, 4126), and on image M11-1713 near coordinates (310, 3667). However, identification of the same twin-pixel signature in each of these three latter MOC images was problematic because of the difficulty in performing the required tight registration of the different scenes at the individual pixel level, coupled with the varied illumination conditions and resolutions of the three images themselves.

MPL Configuration Pixel Size Comparison. A simple comparison of the size of the pixels in image M10-2177 and the two possible MPL configurations, shown in figure 11, suggests that the observed twin-pixel signature would not likely be produced by the terminal descent configuration but more likely by the postlanding configuration with deployed solar panels. However, because image M10-2177 was acquired with a significant off-nadir viewing angle, a more sophisticated examination of the two MPL configurations and the camera viewing geometry was warranted.

MPL Imagery Signature Simulation. A comparison was made of the actual site 2 signature with the simulated signatures of the MPL in its two possible configurations. Simplified, first-order camera simulations using three-dimensional (3-D) models of the MPL were created for this examination. The 3-D models incorporated the image viewing and illumination geometries, as supplied by MSSS, to simulate the collection conditions of image M10-2177. A scene model was set up using atmospheric assumptions consistent with the atmospheric scattering effects discussion, and the lander was placed on the ground at its intended azimuth orientation relative to north.

"... first-order camera simulations using three-dimensional (3-D) models of the MPL were created for this examination."

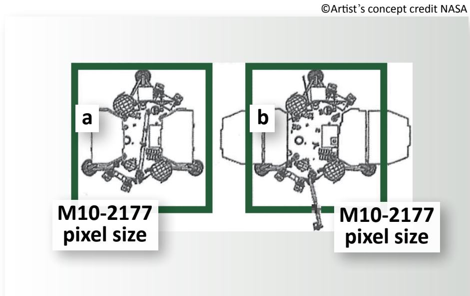


Figure 11. Size Comparison of MPL: a) Terminal Descent Configuration, b) Deployed Solar Panels Configuration[3]

The 3-D computer models of the MPL in both the terminal descent configuration and the postlanding configuration with deployed solar panels are shown in figure 12. These models were used to determine if the signature observed in image M10-2177 could have been created by one of these two MPL configurations. First-order simulations, consistent with both the optical- and focal-plane properties of the MOC, were then produced. The simulations accounted for the camera system's known scan, optical, and detector properties. Each simulation took into account 40 ways the MPL could have appeared to the MOC and also incorporated possible sampling variations that could have been created by the camera's imaging detectors.

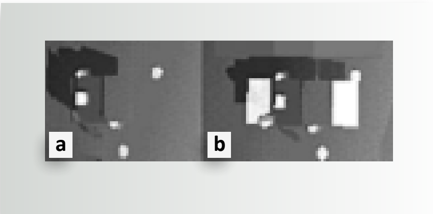


Figure 12. High-Resolution View of Simulated MPL: a) Terminal Descent Configuration, b) Deployed Solar Panels Configuration

The results of the first-order sampling simulations are shown in figure 13. Figure 13a shows the simulation that used the MPL terminal descent configuration, figure 13b shows a closeup of the image M10-2177 signature, and figure 13c shows the simulation that used the MPL postlanding configuration with deployed solar panels. In examining the MPL terminal descent configuration simulations, it was clear that in no instance was the twin-pixel signature evident in image M10-2177 able to be reproduced. In the MPL postlanding configuration simulations, however, the distinctive bright pair of pixels was observed in 16 of 40 cases attempted. These simulations demonstrate that not only is the observed twin-pixel signature consistent with the MPL but that—if the signature is indeed caused by the lander—the MPL is upright on the surface with its solar panels in the deployed position.

Orientation of Site 2 Twin-Pixel Signature. An assessment of the site 2 twin-pixel signature orientation was performed using two different methods. A "north-up," rectified projection showing the orientation of the twin signature at site 2 was initially created using image M10-2177 (figure 14a). Measurement of the signature orientation in this projection required sighting a line through the two bright

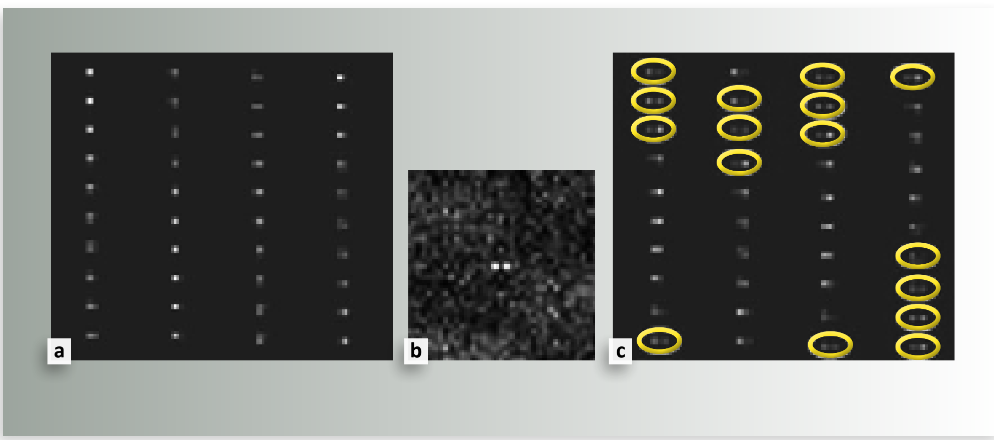


Figure 13. a) MPL Terminal-Descent-Configuration Sampling Simulation, b) Closeup of Image M10-2177 Signature, c) MPL Deployed-Solar-Panels-Configuration Sampling Simulation

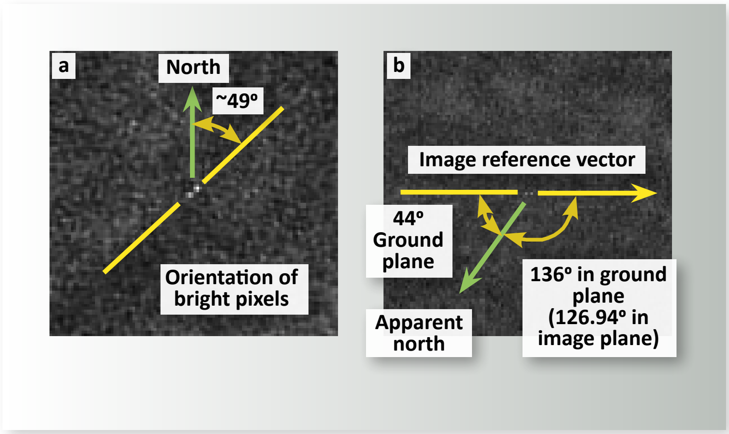


Figure 14. Site 2 Signature Orientation Assessment Using:
a) Rectified Image Method, b) Projective Method

pixels and measuring the angle of that line to north. The result showed that the two pixels fell along a line approximately 49 degrees east of north. However, taking into account that image M10-2177 has two data dropouts, the exact corner placement of the rectified image was considered suspect, and an additional method of assessing the signature orientation that would not be dependent on the geocoordinates of the image was employed.

The second method used in measuring the signature orientation made use of the fact that the two bright pixels at the site both fell in the same line of image data. The orientation of the site 2 signature was calculated by mathematically projecting a line of data onto the Martian surface and then measuring the angle of that line with respect to north. In the MOC ephemeris data, the angle to north in the image plane was stated to be 126.94 degrees, measured clockwise from a reference vector whose origin is in the center of the image and proceeds to the right. Taking into account the declination angle of the image and projecting the reference vector to the ground, an angle of 136 degrees was determined (figure 14b). Thus, the twin-pixel signature orientation was determined to be 44 degrees (the complement of 136 degrees) east of north. This angular measurement technique probably is the more accurate of the two methods because it is not dependent on the location of the image's corner coordinates.

The MPL was programmed to perform a "roll to landed orientation," about 40 seconds before landing, a maneuver that oriented its +X axis to an angle of 45 degrees (+/- 5 degrees) west of north orienting the MPL's solar panels to an alignment of 45 degrees east of north) to optimize both antenna and solar

> *"The process of identifying a common signature . . . involved performing a tight registration of all the images . . ."*

panel pointing. In comparing the intended MPL orientation, shown in figure 15a, to the site 2 twin-signature orientation calculated in the previous section, shown in figure 15b, the level of agreement is remarkable.

Collateral Imagery Coverage of Site 2. The existence of four MOC search images, or coverages, of site 2 allowed rectified subsections of each image to be created for overview and closeup review of the site locations. The process of identifying a common signature in the four target coverages involved performing a tight registration of all the images on the basis of common visible features and adjusting the registration at the location of the site to back out any errors due to relief displacement. The quality of this fine registration technique is dependent on the ability to locate small features (ridges, boulders, etc.) near site 2 in each of the images and using those features as the standard to guide the registration adjustments. The process of rectifying this imagery set made use of an interpolated, resampling function that had the effect of "blooming" the pixels and making the site 2 signature much larger than it was in reality. However, because of both the imprecise nature of registration at the individual pixel level and the small size of the MPL itself, the presence of the MPL in the collateral images could not be confirmed.

Reflectivity Simulation. To understand the expected MPL-ground contrast, a first-order camera reflectivity simulation was performed. This simulation required estimates of the MPL solar panel reflectivity and an estimate of the typical Martian surface reflectivity. An examination of photographs posted on the Internet that were taken during assembly and testing of the MPL provided a source from which the reflectivity of the lander's solar panels could be estimated (figure 16a). The light reflection of a worker's clean room garment from a solar panel in one photograph permitted an estimate of the panel's blue-light reflectivity (figure 16b). By measuring the intensity count values of the brightest part of the garment compared to that of the brightest part of the reflection in the panel, a blue-light solar panel reflectivity of approximately 30 percent was estimated for the MPL solar panels. Red and green reflectivity values were similarly estimated to

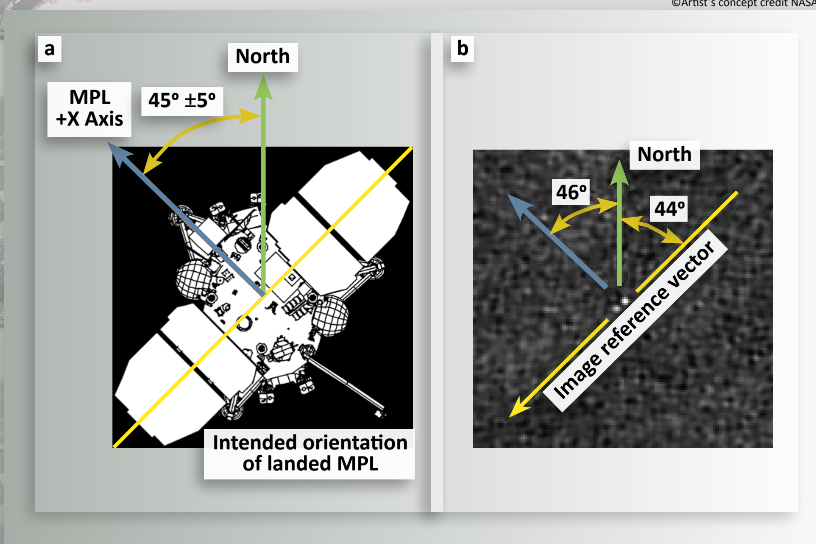


Figure 15. Comparison of: a) MPL Intended Orientation, b) Site 2 Measured Orientation

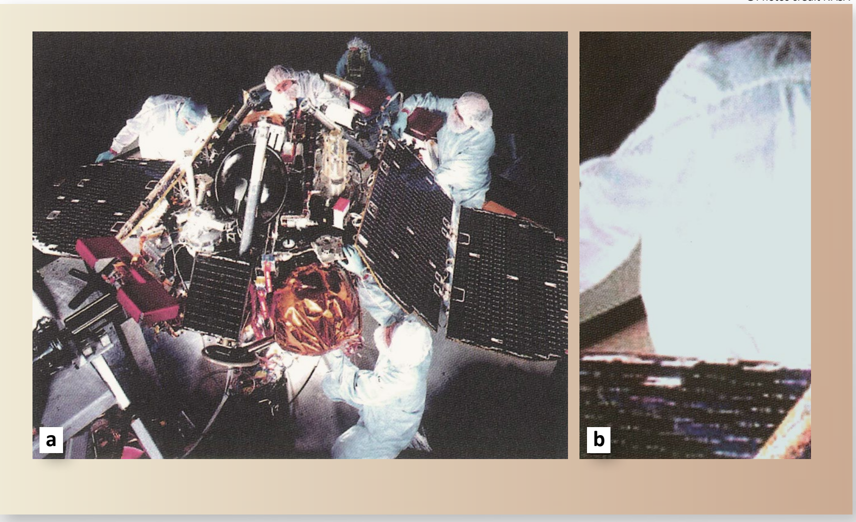


Figure 16. a) MPL During Assembly and Testing, b) Closeup of Garment Reflection in an MPL Solar Panel[3]

"A computer graphics application was used to create an MPL solar panel simulation model . . ."

be less than 1 percent. The Martian soil reflectivity estimate used in the simulation was derived from the Pathfinder measurements as shown in figure 17.

A computer graphics application was used to create an MPL solar panel simulation model with a 30-percent, blue-light-reflecting solar panel lying on a Mars-like surface with a red-light reflectivity of 20 percent, a green-light reflectivity of 5 percent, and a blue-light reflectivity of 1 percent. The atmospheric transmittance was adjustable so that the ratio of the red-to-blue transmittance could be altered to allow control over the amount of red that could be removed from the radiance by

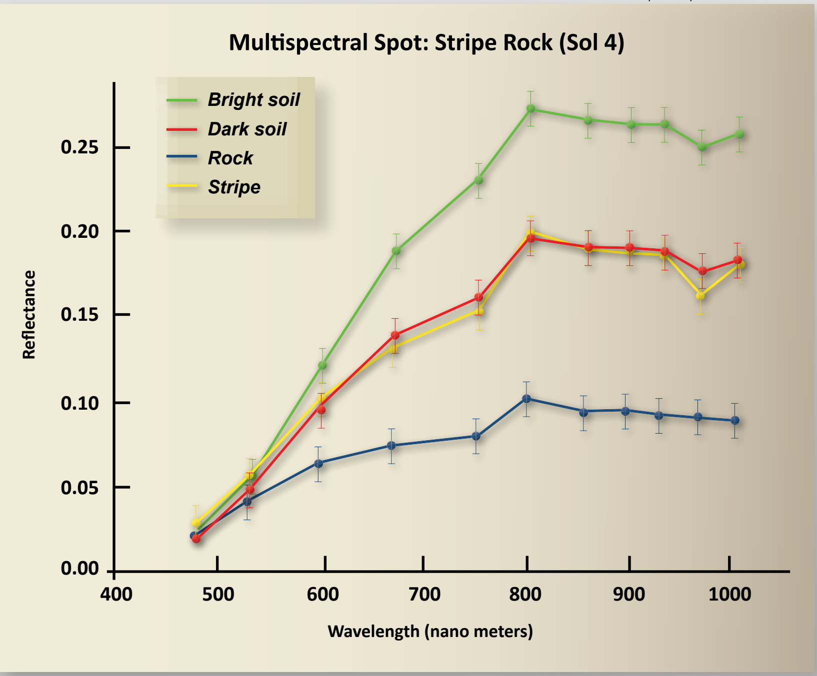


Figure 17. Soil Reflectivity Measurements From the Mars Pathfinder Mission[1]

atmospheric scattering effects as well as the amount that reached the camera. Figure 18 shows a series of five outputs from this simulation that depict, from left to right, an increasing amount of red scatter (or, in other words, a decreasing amount of red transmittance) relative to that of blue scatter. A 60-percent value, for instance, indicates the red transmission was 60 percent that of the blue transmission. Figure 19 shows a plot of the ratio of the solar panel count value to the surface count value for a range of atmospheric conditions. Evident in the results is that, with as little as a 15-percent reduction in red light transmission, the MPL solar panels would appear in imagery as brighter than their surrounding area. As the red-scattering effect of dust in the atmosphere increases, the brightness of the panels, with respect to the ground, increases. For situations where the red and blue scattering levels are similar, the panel-to-ground contrast is very low, indicating that it would be very difficult to distinguish the panels from the Mars surface background.

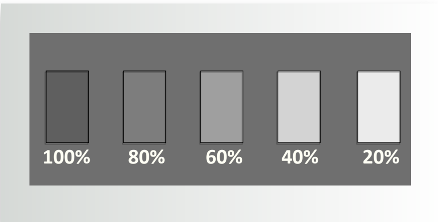


Figure 18. MPL Solar Panel/Mars Surface Contrast Simulations (Value Indicates Red-Blue Transmittance Ratio)

On the basis of these simulations, it is expected that the dark blue solar panels of the MPL would appear brighter than the Martian surface in the MOC images, and the panel/surface contrast would decrease as image quality improves. This trend appears to be consistent with analysis of the site 2 collateral images. As the quality of these images improved—or in other words as the level of atmospheric scattering in the illumination and MOC lines-of-sight decreased—the observed twin-pixel signature seen in image M10-2177 became increasingly difficult, if not impossible, to discern.

Conclusions. Site 2 is within the ellipse predicted to have the highest probability of being the MPL landing site, LMA-1. The twin-pixel signature observed in image M10-2177 is significantly bright with respect not only to the histogram of the entire image but also to the distribution of the brightest pixels in the image, indicating the source of the signature has a reflectivity inconsistent with natural surface features. Furthermore, the double "bright-spot" signature evident at site 2 was reproduced using a first-order camera simulation of a computer model of the MPL that is upright on the surface, in the orientation that the lander was programmed to attain, and with its solar panels in the open, deployed position.

©Graphical representation credit NASA

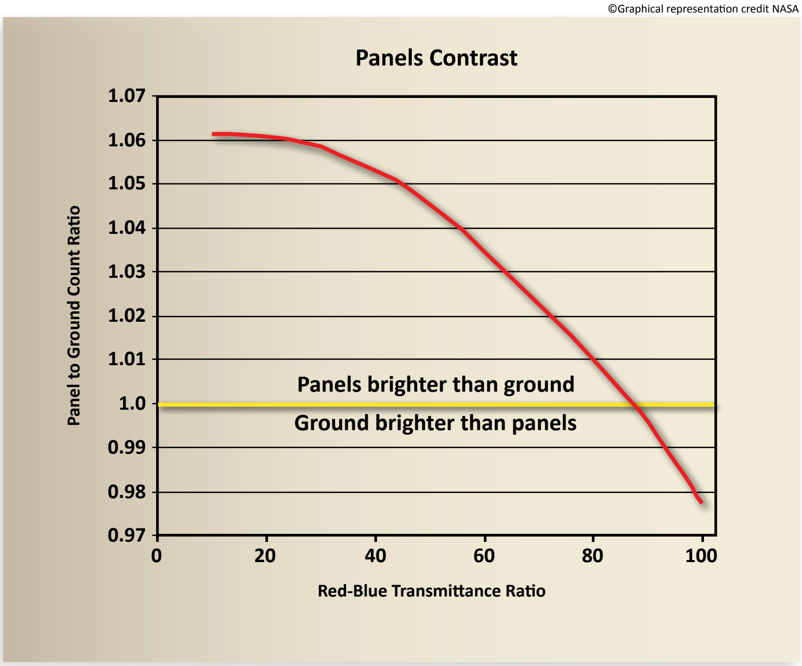


Figure 19. MPL Solar Panel/Mars Surface Contrast as a Function of Red-Blue Transmittance Ratio[1]

On the basis of these findings, we conclude that the MPL has possibly been located at site 2. If so, the lander is assessed to be sitting upright on the surface at the intended azimuth orientation angle and with its solar panels in the deployed position.

Site 1 Analysis

Site Description. Site 1 was the first candidate site identified in the MPL search effort and appears in image M10-2177 at coordinates (611, 3928). The site was also imaged in MOC images M10-2217 at coordinates (1026, 963) and M10-2652 at coordinates (1451, 5485). Closeups of site 1 in each of these images are shown in figure 20.

Given the 3-km separation of site 1 from the possible MPL landing site (site 2), site 1 was considered to be a possible landing location for the MPL backshell/parachute assembly (figure 21). During the MPL's atmospheric EDL phase, the backshell/parachute assembly and the MPL would have separated at an altitude of about 1.2 to 1.6 km. The backshell/parachute assembly would have rapidly lost lateral velocity (due to the loss of the MPL's mass) and would most likely have settled on the surface uprange, or north, of the lander itself. Although the backshell/parachute assembly would have landed fairly quickly, the resultant separation distance may have been due, in part, to drift resulting from atmospheric winds on the combined assembly after MPL separation.

The source of the saturated pixel signature at site 1 in M10-2177 was postulated, at first, to be a solar glint simply on the basis of the strength of the return. Further analysis, however, has shown that a saturated pixel can be produced by other means. Having observed that significantly bright pixels were created by the 30-percent-reflective solar panels in image M10-2177, the reflected return from an 80- to 90-percent-reflective backshell would easily push the pixel intensity count value above the saturation level.

"... we conclude that the MPL has possibly been located at site 2."

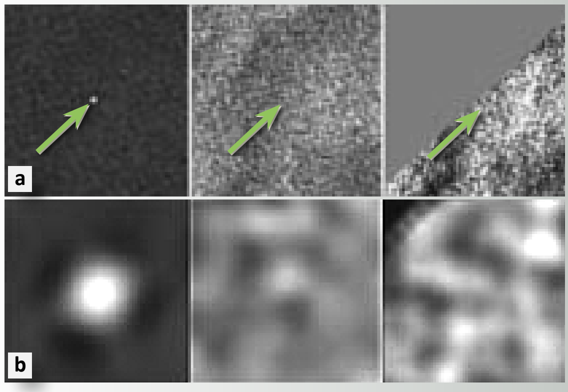


Figure 20. Site 1 in Images: a) M10-2177, M10-2217, M10-2652, b) Closeups of Site 1 in Each of the Images

©Photo credit NASA

Figure 21. MPL Backshell During Payload Integration[3]

> *". . . no conclusive evidence of a parachute has been identified on the imagery, . . ."*

A simulation of the backshell signature compared to the MPL signature is shown in figure 22. Here, the backshell is shown below the MPL for illustrative purposes. The image was adjusted via a linear stretch image-processing technique so that the ground would be shown at 185 intensity counts, the panels on the MPL would be adjusted to 209 counts (the more stressing case), and the resulting radiance of the backshell exceeded 255 intensity counts.

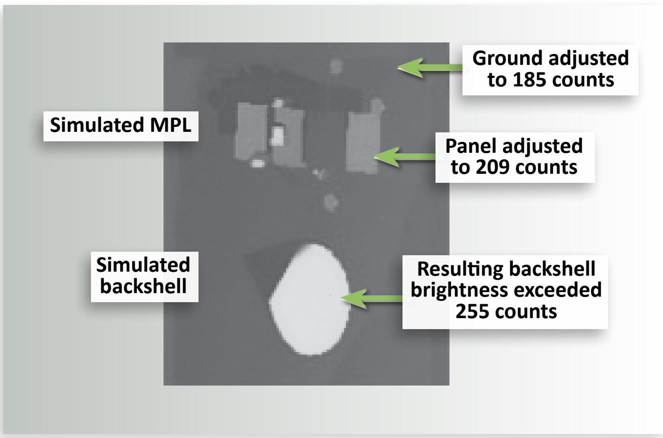


Figure 22. Relative Radiance Simulation of MPL vs. Backshell for Image M10-2177

The backshell as an equal reflector of both blue and red light should undergo a similar contrast reduction with clearer atmospheric conditions as was seen for the MPL solar panels. However, because the backshell is so reflectively bright, it would most likely be seen as brighter than the background. It should also be noted that in every image of site 1, there appears to be an object visible on the surface that is brighter than the background.

Parachute. The confirming observable of the MPL backshell would be the identifiable presence of the associated parachute in proximity to the backshell. After repeated reviews of the immediate surface near site 1, however, no conclusive evidence of a parachute has been identified on the imagery, although several possible features on the ground near site 1 have been postulated as possibly being the parachute. Figure 23 shows images of site 1 inscribed with an overlaid 25-meter-radius circle indicating the area in which a parachute must exist if site 1 is, in fact, the MPL backshell. Although several parachute candidate signatures are identified in the figure, this effort has been problematic and is left for further study. It is noteworthy that the Mars Pathfinder parachute was never identified on MOC imagery either. Perhaps the interaction of the parachute lying on the surface could be causing the signature to become indistinct.

Conclusions. The signature from site 1 may have been caused by the MPL backshell. This identification is consistent with the characteristics of the signature itself and its 3-km proximity to the MPL site (site 2). The reflectance of the site 1

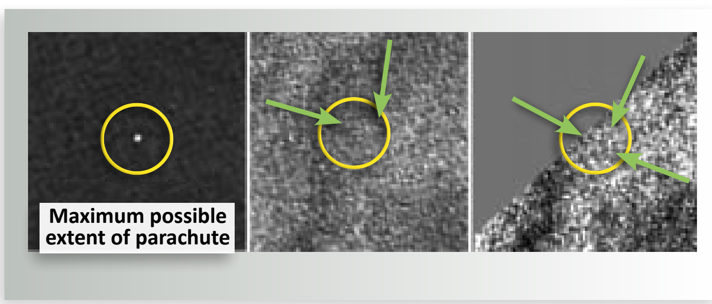


Figure 23. Images of Site 1 Inscribed with a Radius Equal in Size to the Maximum Length of the MPL Parachute With Shroud Lines (Arrows Indicate Possible Parachute Signatures)

signature is very high relative to that of the MPL solar panels at site 2 and may have been produced by an object such as the backshell with bright reflective surfaces. Identification of the parachute that was attached to the backshell, however, is thus far problematic. Difficulty in precisely locating the parachute within the immediate vicinity of the site 1 signature may be due, in part, to the parachute canopy's unusual shape or appearance on the surface. The lack of a parachute identification at this site prevents confirmation that the object at site 1 is indeed the backshell.

Site 3 Analysis

Site Description. Site 3 was identified in image M11-3986 at coordinates (1571, 1069). Unfortunately, no other image in the search collection set covers the site 3 location. Figure 24 shows a north-up rectified view of site 3 in image M11-3986. This image is very different from the image in which sites 1 and 2 were identified: it is near the MOC system's best resolution (1.45 meters), it has less haze, it has double the pixel intensity count range, and, consequently, significantly less noise. Site 3, for all these reasons, has an image quality higher than that of image M10-2177. The discovery of a bright pixel in this image immediately indicated that an unusual signature was at this site. As is seen in figure 10, the site 3 bright pixel signature—at an intensity of 173 counts—is 56 counts above the image mean or more than 7 standard deviations greater in brightness. Even though this pixel is not saturated, it is, nevertheless, a very bright signature and possibly is the result of a solar reflection, or glint, from a piece of reflective material.

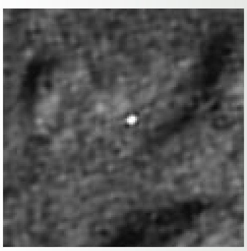


Figure 24. Site 3 in Image M11-3986

Possible Impact Point, Ground Scarring, and Surface Impression at Site 3. The glint-like signature at site 3 appears to have originated from within a shallow surface impression. An examination of that impression also revealed a nearby possible ground-scarring effect and a dark, circular area (figure 25). Because disturbed soil on Mars is thought to be tonally darker than undisturbed soil, it was hypothesized that the circular area might have been created by the impact of an object traveling at a high lateral velocity. The repetitive hash mark pattern of the scar-like feature begins from the vicinity of the possible impact point along a 222-degree azimuth heading then changes to a heading of 250 degrees and finally ends along a heading of 265 degrees, suggestive of an object being deflected by surface features. A detailed examination of the 180-meter-long, scar-like feature shows that the periodic breaks in the image could have been created by an object tumbling along the ground, or given their periodicity, the breaks could be artifacts formed as a result of image or postimage processing.

"The glint-like signature at site 3 appears to have originated from within a shallow surface impression."

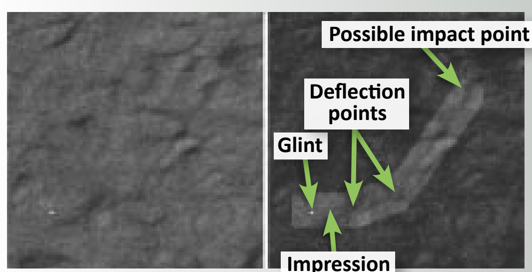


Figure 25. Examinations of Surface Impression and Possible Ground Scarring Near Site 3

". . . feature suggestive of an object that may have slid to a stop in soft or sandy soil."

If the linear feature is indeed an object-induced ground scar, its signature is notably different in appearance in the last section of travel than in the first section. The nature of the signature changed from darkened hash marks on the surface to a linear, impression-like feature suggestive of an object that may have slid to a stop in soft or sandy soil. The object appears to have come to rest some 40 meters from the beginning of this apparent linear impression. There is some indication that a smaller impression also continues about 10 meters beyond the observed glint signature. This smaller impression, furthermore, suggests one of two possible scenarios. The first would be that the moving object struck a ground feature and caused that feature to roll about 10 meters. Alternatively, and perhaps more likely, is that reflective material might have caused the glint-like signature in image M11-3986. Such material could have become detached from the original object and come to rest inside the ground impression left by the object as it slid to a stop.

The intensity of the site 3 pixel suggests the presence of manmade materials and the possible presence of a high-speed impact with subsequent ground scarring. It is deduced that a possible source of the observed signatures may have been the MPL heat shield. The heat shield should have separated from the MPL/backshell assembly at an altitude of about 8 km and at a lateral velocity of nearly 300 meters per second.

Analysis of Surface Impression. A simulation was performed to determine if the surface impression observed at site 3 was consistent with the convex shape of the MPL heat shield. A computer model of an MPL heat shield-like impression (convex side down) in the Martian surface was created. The impression was illuminated in accordance with the conditions at the time image M11-3986 was acquired, and the viewing geometry of image M11-3986 was also recreated. The resultant simulation is shown in figure 26, adjacent to a closeup view of M11-3986.

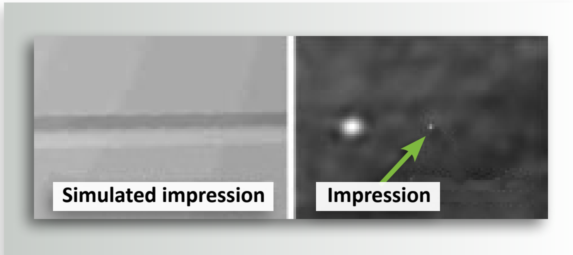


Figure 26. Simulation of MPL Heat Shield Impression Compared to Observed Site 3 Impression

Within the limits of image resolution, reasonable agreement is observed between the simulation and the surface impression in the image. The surface impression is difficult to measure, but it is not wider than 2 pixels. Given the 1.4-meter resolution of the image, the impression could not be wider than 2.8 meters. The observed surface impression could have been created by the MPL heat shield, since the MPL heat shield is 2.4 meters in diameter.

Possible Glint Source. A possible source of the site 3 solar reflection was identified on the inside of the MPL heat shield. A photograph of the MPL heat shield taken during payload integration revealed a relatively large amount of gold foil installed on the heat shield's interior concave surface (figure 27). This material, given its crumpled texture and reflective surface, is a ready source of solar reflections.

Azimuth Analysis. The entry azimuth of the MPL has been assumed, for the purposes of this study, to be due south or 180 degrees. The initial 222-degree azimuth of the possible ground scar at site 3 is at variance with this expected azimuth. Since the heat shield, after separation from the backshell, descends in an uncontrolled manner, dynamic forces acting on it could have caused a change in the direction of travel. It is also possible that the angle of ground slope at the impact location could have caused some deflection in the heat shield's direction of travel when it hit the surface. In either case, the direction of the possible ground scarring does not undermine the possibility that site 3 is the location of the MPL heat shield.

Conclusions. The intensity of the bright pixel at site 3 may be indicative of the presence of manmade materials. Given that the bright pixel is present in a high-dynamic-range image, it is possible that the source of the pixel is a direct solar reflection from a piece of specular material. The presence of a nearby, possible high-velocity impact site and possible ground scarring leading up to the glint, moreover, suggests that the source of the glint could be the MPL heat shield. Furthermore, the apparent ground impression leading up to the glint is consistent in size and shape with what would be expected from the MPL heat shield. Given these reasons, site 3 is believed to be the possible location of the MPL heat shield.

"The intensity of the bright pixel at site 3 may be indicative of the presence of manmade materials."

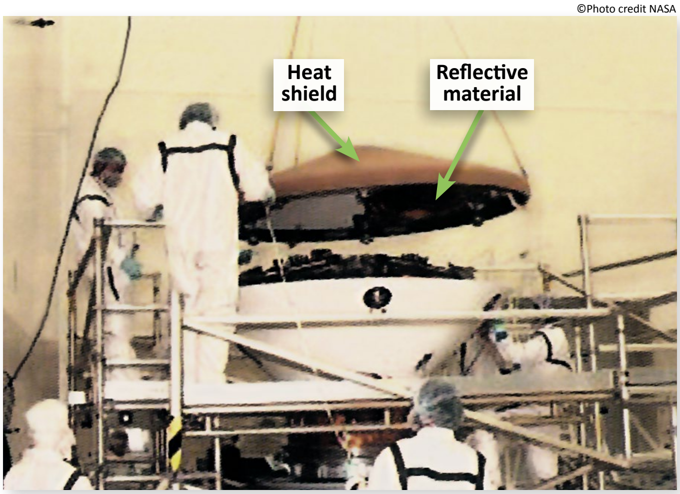


Figure 27. MPL Heat Shield During Payload Integration

Postulated MPL Atmospheric EDL Scenario

Given this study's conclusions concerning each of the three sites identified in the search effort, an EDL scenario was postulated that takes into account these sites and their possible MPL association.

"If the findings from the NIMA search effort are correct, an important and related conclusion is that the MPL failure likely occurred late in the lander's rocket engine-powered descent phase or perhaps even after landing."

In the side view of this postulated MPL EDL scenario (figure 28) and in the top view of this scenario (figure 29), the significant events of the EDL sequence are shown as they may have transpired. In figure 28, the heat shield should have separated from the MPL at an altitude of about 8 km with a lateral velocity of almost 300 meters per second that carried it the observed 10- to 12-km distance southwest of the MPL landing site at site 2.

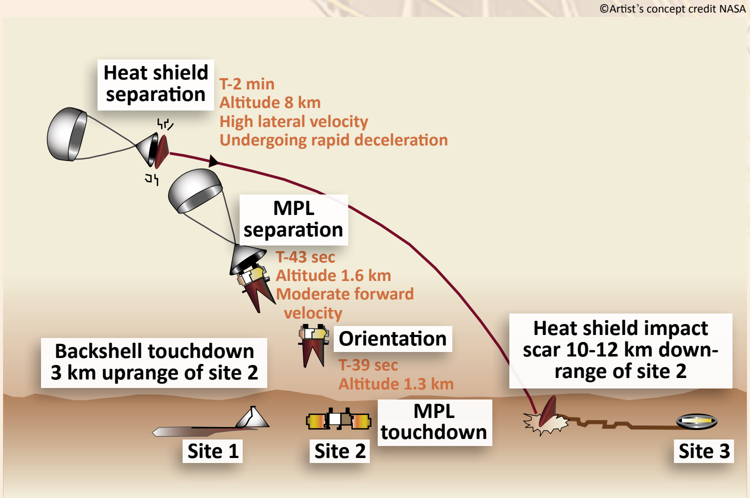


Figure 28. Postulated MPL EDL Scenario Based on Search Findings (Side View)[3]

The backshell, which should have separated from the MPL at an altitude of 1.2 to 1.6 km with a lateral velocity of under 80 meters per second, may have settled on the surface about 3 km uprange of the lander. In figure 29, these events are shown again but from a different perspective. The inferred 180-degree entry azimuth of the MPL is overlaid on the three known site locations. In this view, it is evident that the backshell may have drifted eastward (most likely due to wind conditions in the area) after separation from the MPL. The heat shield appears to have migrated southwestward (most likely due to dynamic forces) during its descent.

Implications of Search Findings

If the findings from the NIMA search effort are correct, an important and related conclusion is that the MPL failure likely occurred late in the lander's rocket engine-powered descent phase or perhaps even after landing. If so, an initial review of the potential EDL and postlanding failure modes postulated by the MPL failure investigation board (for example, JPL Special Review Board report, indicates that at least 80 percent of the major potential failure modes suspected as possible causes of the MPL loss can be ruled out.[2]

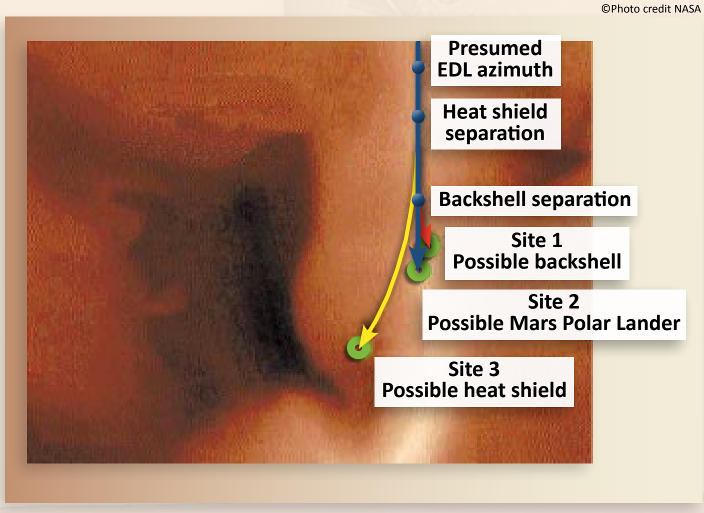


Figure 29. Postulated MPL EDL Scenario Based on Search Findings (Top View)[3]

Alternative View of Search Findings

The NIMA search findings were presented to NASA, JPL, and MSSS in March 2001. MSSS reviewed the findings in detail and stated that the bright pixel signatures identified by NIMA in the search images were more likely caused by spurious noise created by the power supply system in the MGS satellite than by MPL-related objects on the surface of Mars. MSSS indicated they observed similar noise patterns in other MGS images. Moreover, according to MSSS, the possible MPL-related hardware at the three bright-pixel sites NIMA identified would quite likely have been too small to be imaged by the camera system on the MGS satellite.

Postscript

Additional MGS images of the MPL landing site and surrounding area were acquired by the MGS satellite when lighting conditions at the polar site improved again in late 2001 and 2002. It was hoped that the additional MGS images might offer new or more definitive insights into the fate of the missing MPL. However, because of the lingering effects of a global Martian dust storm in 2001, the Martian atmosphere was hazier, and the newer images were consequently of lesser quality than the MPL search images taken in late 1999 and early 2000. As a result, the recent images did not add new information regarding the presence of the MPL or its associated EDL hardware.

NASA's Mars Reconnaissance Orbiter (MRO), currently in development, is scheduled to be launched toward Mars in 2005 and to begin orbiting the planet in 2006, taking very-high-resolution images of the planet's surface. The best of the MRO's images will be about 0.3-meter-resolution or about five times better than that of the best of the MGS images used in the MPL search. One of the targets of the MRO's powerful optics will be the MPL landing area, and images taken by the MRO of this site may help finally resolve the mystery of what actually happened to the MPL. If not, the MPL mystery may have to patiently await a final and definitive investigation by a future visiting astronaut on-site inspection team from Earth.

Notes

1. Jet Propulsion Laboratory, URL: www2.jpl.nasa.gov, accessed 2000.

2. Jet Propulsion Laboratory Special Review Board, *Report on the Loss of the Mars Polar Lander and Deep Space 2 Missions*, JPL D-18709, 22 March 2000. URL: www.nasa.gov/newsinfo/marsreports.html, accessed 2000.

3. National Aeronautics and Space Administration, URL: http://mars.jpl.nasa.gov, accessed 2000.

Defining Imagery Analysis

By John C. Macier

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Editor's note: Originally published in GIR *2 no. 1 (2003) with Department of Defense approval for public release case #95-S-3319, this article is an excerpt from Macier's 1995 Joint Military Intelligence College thesis. Many technological advances and geopolitical changes have occurred since, but the basic tenets of this work apply to today's tradecraft.*

Introduction*

What is a photographic interpreter? An imagery analyst? Are these different titles for those who perform similar functions, or do the titles reflect differences in function and in skill requirements? What is analysis? More than a matter of semantics, these questions weigh heavily on the ability of the US Intelligence Community (IC) to select, train, and effectively employ imagery exploitation professionals in a time of increasing demand and varied mission areas as personnel resources are being strained. As the Air Force's *Imagery Interpretation Handbook* states, "Ultimately, the image interpreter's report is dealing with [peoples'] lives."[1]

The titles used to name imagery exploitation professionals have developed haphazardly over the past 20 years, and intelligence officers and academics hold different definitions of image interpretation. For example, technology changes in the 1970s led the US Army to change the name for its imagery exploitation professionals from the long-used "photo interpreter" (PI) to "imagery interpreter" (II). But when the Army changed the name to "imagery analyst" (IA) in the 1980s, no corresponding amplification of analysis skills appeared in the imagery manual.[2] In academe, the most oft ascribed-to definition of image (or "photo" in earlier works) interpretation is specified by the American Society of Photogrammetry as "the act of examining photographic images for the purpose of identifying objects and judging their significance."[3] That emphasizes the aspect of judgment in a way that has analytic connotations within the intelligence profession.

In the intelligence business, it seems that everyone is known, or wants to be known, as an "analyst." People want to be called "imagery analysts" rather than "image interpreters" because of the positive connotations. However, they may or may not possess the necessary abilities, skills, and knowledge (ASK). At the same time, a misperception exists outside the profession that the imagery analyst is a minimally skilled support person.

*The author thanks the staff of the American Society for Photogrammetry and Remote Sensing for allowing him to use their private collection, and the staff of the National Photographic Interpretation Center (NPIC) Library for their assistance.

Findings

The processes of imagery interpretation and intelligence analysis, with their respective sets of abilities, skills, and knowledge, may be combined to create the distinct process that is imagery analysis. Figure 1 illustrates the imagery analysis paradigm. When an individual combines the skill sets of the image interpreter and the intelligence analyst, while still depending on imagery as the principal data source, he or she is then capable of producing imagery intelligence.

Imagery analysis requires strong interpretation abilities and strong analytic abilities. As figure 2 illustrates, strong interpreters with weak analytic ability will not become imagery analysts; neither will strong intelligence analysts with weak interpretative skills. People with neither skill should pursue another vocation.

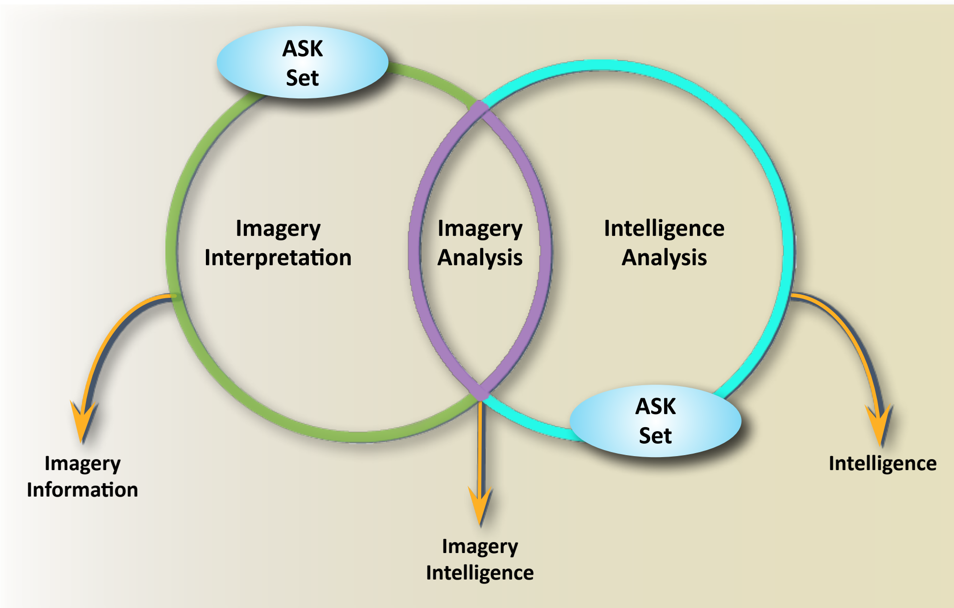

Figure 1. Imagery Analysis Paradigm

		Interpretative Abilities: Strong	Interpretative Abilities: Weak
Analytic Abilities	Strong	Imagery Analyst	Intelligence Analyst
	Weak	Imagery Interpreter	Alternate career choice

Figure 2. Profession Matrix Based on Abilities

Procedures

I arrived at these conclusions through researching published material, conducting personal interviews with intelligence professionals, and drawing on my own 20 years of experience as a cannon and rocket artillery systems imagery analyst with NGIC.

A wide variety of published material addresses image interpretation versus analysis. This material spans a spectrum from military training circulars to professional publications. Many textbooks on remote sensing contain a chapter relating to interpretation or analysis of imagery.

I interviewed about 30 people ranging across disciplines, experience levels, and subject areas.[4] Participants included analysts from these organizations:

- The National Air Intelligence Center, Wright-Patterson Air Force Base (AFB), Dayton, Ohio
- NGIC, Charlottesville, Virginia
- NPIC, Washington (DC) Navy Yard
- The US Army Intelligence Threat Analysis Center, [now part of NGIC] Washington Navy Yard
- The Defense Intelligence Agency, Bolling AFB, Washington, DC

In addition, I contacted people at the following:

- Canada Centre for Remote Sensing, Ottawa, Ontario
- Virginia Polytechnic Institute, Blacksburg
- University of Michigan, Ann Arbor

Interpretation and Analysis

Two Distinct Sets

Interpretation and analysis—as they relate to image exploitation—require two distinct sets of abilities, skills, and knowledge (figure 3). A person may possess one set without the other. Some people may not have the requisite aptitudes to develop the skills or knowledge a set requires. Some people may develop both sets, in either order.

Interpretation		Analysis
• Visual acuity • Perceptual and spatial flexibility • Stereovision	**Abilities**	• Capability to deduce • High reading comprehension
• Use of specialized equipment • Techniques of object, pattern, and activity identification and classification • Mensuration	**Skills**	• Use of analytic models • Research methods including conducting unbiased research • Use of data resources
• General geographic and cultural knowledge for area of focus • Sensor capabilities and limitations	**Knowledge**	• Developed political, diplomatic, cultural, and societal knowledge for area of focus • Intelligence disciplines and their strengths and weaknesses

Figure 3. Profession Matrix Based on Abilities

Interpretation

In its most basic sense, interpretation means to explain or elucidate.[5] Almost without exception, the intelligence officers interviewed identified imagery interpretation as merely answering "what?" According to most respondents:

- Identify objects
- Supply basic descriptions
- Generally provide limited information

This explanation was virtually unanimous despite the respondents' different experience levels.

Imagery interpretation embraces a spectrum of activities and specialized skills that relate to seeing information within remotely sensed data. These activities span the range from simplistic, such as differentiating manmade from natural features on high-resolution panchromatic imagery, to the highly complex, such as taking measurements on less interpretable radar imagery.

It is a myth that all people can look at a photograph with equal skill. As James Campbell writes in *Introduction to Remote Sensing*:

> "Few of us encounter difficulties as we examine family snapshots or photographs in newspapers, for example. Yet the art of image interpretation requires conscious, explicit effort not only to learn about the subject matter, geographic setting, and imaging systems in unfamiliar contexts, but also to develop our innate abilities for image analysis."[6]

Those who deny that interpretation is a skill fail to appreciate the challenges of conducting primary research concerning barely recognizable objects seen from unfamiliar vantage points.

Conventional intelligence analysts who think they are studying "imagery" are receiving secondary reproductions of original image research. These scenes are produced at a scale smaller than the primary image record, and the significant objects are already annotated on the print or electronic equivalent. The print, electronic or otherwise, requires no special equipment to view and has often benefited from enhancement to make it more understandable. Other analysts in the Community are surprised when they learn that image interpreters are not working with stacks of prints such as these.

The *Manual of Photographic Interpretation* acknowledges that most aerial perspective images contain objects that many people can identify and draw conclusions from. However, the manual also points out that the image interpreter often works on the threshold of recognition, and that it is by the interpreter's skill that "irrelevant obvious objects are ignored in favor of more subtle but significant [ones]."[3] Going one step further are radar imagery and infrared imagery, which to the uninitiated are even harder to interpret than electro-optical imagery.[7]

Campbell adds that remotely sensed images usually portray an unfamiliar overhead view.[6] Stephen Spurr, writing in *Aerial Photographs in Forestry*, elaborates, warning that familiar objects may not be recognized simply because they are viewed from an unfamiliar vantage point.[8]

A successful interpreter must apply skills and knowledge commensurate with the task assigned and the sensor—be it a 35-mm camera or multispectral imaging satellite. Image interpreters require skills and knowledge that include those shown in table 1.

Interestingly, although image interpreters refer to the "analytic" process of making an interpretation, this is not what the larger IC means when it uses the word "analysis." In interpretation, the primary focus and data source remain the imagery record.

Analysis

The dictionary defines analysis as "separation of an intellectual or substantial whole into its constituent parts for individual study," but in the intelligence profession the term carries a connotation that also presumes specialized knowledge or expertise.[5] According to the publication *A Consumer's Guide to Intelligence*, intelligence "analysts absorb incoming information, evaluate it, produce an assessment . . . and then forecast future trends or outcomes."[9] The skills of the intelligence analyst are so well understood that I will not add to the pages written on this subject but will point out that despite the variety of their topics, country analysts, political analysts, industrial analysts, economic analysts, and so on share a common set of abilities, skills, and knowledge.

Table 2 further illustrates the difference between the sets of abilities, skills, and knowledge needed for interpretation and analysis, by showing the difference between the source data and principal activity for two different tasks. The first task is very detailed; however, no element of the task requires information other than what can be interpreted using a satisfactory image. To accomplish the first task, the individual must use virtually every skill associated with imagery interpretation. The *Manual of Photographic Interpretation* contains the definitive review of interpretation skill, which need not be repeated here.[3] The result of this interpretation—the product—is information derived from the images. In the second task, the individual must call on a wide variety of sources to produce intelligence. The sources in the table are only representative, but the product of the second task is clearly "intelligence."

Table 1. An Image Interpreter's Needs

Skills	Knowledge
Identify and classify objects	Sensors and their physics
Identify and classify patterns and activity	The area of concentration (that is, geology, oceanography, military science, and so on)
Use interpretation equipment, including softcopy systems	The geographic region of interest
Correlate images to maps	Terrain analysis
Construct controlled and uncontrolled mosaics	
Mensurate manually and with a computer	

Table 2. Sample Tasks That Distinguish Activities of Imagery Interpretation and Intelligence Analysis

	Imagery Interpretation	Intelligence Analysis
Task	Provide detailed information on the Panagura City Suspect Nuclear Weapons Production Facility, including the following: • Rectified site plan drawn to scale 1:25,000 • Dimensions of all structures, including computation of floor space • Number, type, and dimensions (primarily height) of all physical security measures, including entry and exit points • Location and description of all vulnerable critical areas such as HVAC systems, communications antennas, support structures, and power distribution equipment • Estimate best ground-level observation point outside the facility Final product should be in hardcopy form, primarily text with annotated images, tables, and graphics best suiting a nonimagery audience	Provide an in-depth assessment of Panagura's nuclear weapons production capability, including IOC (initial operational capability) and FOC (full operational capability) forecasting
Primary Data Sources	• Imagery • Imagery-derived sources • Imagery-based sources	• Signals intelligence • Imagery • Human resource intelligence • Diplomatic communications • Media (open-source) reporting • Bills of lading • Trade agreements • Academic sources

Imagery Analysis

The processes of intelligence analysis and imagery interpretation, with their respective sets of abilities, skills, and knowledge, may be combined to create the distinct process that is imagery analysis (figure 1).

Image interpretation involves an analytic process based on interpretative skills. The intent is to "see" information using remotely sensed data. The focus of interpretation is the imagery record. Though the image interpreter may produce detailed, accurate reports rich in content, this reporting represents only *image-derived information*.

> *"Imagery analysis is conducted at a level beyond interpretation; analysis requires an additional set of abilities, skills,and knowledge."*

In contrast, national security intelligence analysis involves a different set of abilities, skills, and knowledge. An intelligence analyst draws on a broad spectrum of information sources—one of which may be image-derived information—to make an assessment. The output of the intelligence analyst's work, when properly executed, is *finished intelligence*.[9]

When an individual possesses and combines the image interpreter's set of abilities, skills, and knowledge with that of the intelligence analyst, while still depending on imagery as the principal data source, he or she is then capable of performing imagery analysis. This is not to say that an image interpreter does not use knowledge outside the image frame. The distinction relies on three factors:

- The individual's abilities, skills, and knowledge
- The nature and scope of the task
- The realization that the whole is greater than the image

Imagery analysis is conducted at a level beyond interpretation; analysis requires an additional set of abilities, skills, and knowledge. The distinction lies in adding the set of intelligence analysis abilities, skills, and knowledge to an existing interpretative set (not the reverse, a distinction discussed later). To accomplish this, the imagery analyst must exercise objectivity, use one or more recognized frameworks for analysis, and sort through the chaff to recognize the relevant information. Nearly all the intelligence officers the author interviewed associated the activity of judging the significance of objects with imagery analysis.

The imagery analyst will research a broader spectrum of data sources than will the interpreter and will apply them to the situation represented by the imagery record. To illustrate this breadth, the Air Force's *Imagery Interpretation Handbook* listed as subjects that improve interpretation "agronomy, botany, city planning, civil engineering, forestry, geography, geology, military science, physics, oceanography, and photogrammetry."[1] Campbell, writing in *Introduction to Remote Sensing*, adds computer science, biology, hydrology, business, and statistics to the list.[6] Few working analysts possess significant backgrounds in all of these areas, but as the *Imagery Interpretation Handbook* states, "the interpreter must continue to study . . . to maintain or improve his proficiency."[1]

One moves into the realm of imagery analysis when the output requires consideration of more information than only what is recorded on the imagery. From the early use of imagery, analysts have recognized that they must seek out and "utilize effectively information from other sources."[1] Bringing together seemingly disparate pieces of information allows the imagery analyst to see things in the image that might not otherwise be evident, resulting in original conclusions and forecasts. Imagery analysis results in a convergence of evidence that is *imagery intelligence*.

Do It Well

Imagery analysis comes easier to some than to others. Selecting the best-qualified candidates and helping them develop the needed abilities, skills, and knowledge are important to achieving competent and professional imagery analysts who enjoy the work they do and do it well.

Selection

The profession recognizes several qualifications by which candidates for image interpretation jobs should be judged. Three qualities that appear most often in texts are imagination, patience, and the power of observation, as noted by Thomas Lillesand and Ralph Kiefer in *Remote Sensing and Image Interpretation*.[10] Spurr, writing in *Aerial Photographs in Forestry*, emphasizes the quality of judgment. Eugene Avery, author of *Interpretation of Aerial Photographs*, includes high perceptual capacity and motivation.[8,11] Obvious qualities such as visual acuity, the ability to synthesize stereovision, and color vision also are necessary.

Unfortunately, agencies do not carefully qualify interpretation candidates. Some organizations require only the ability to see. Other organizations subject candidates to a minimum of tests, such as stereovision evaluation and perhaps a spatial orientation evaluation. Few organizations administer rigorous tests such as those identified in the *Manual of Photographic Interpretation*:

- Object completion
- Closure
- Figure analogies
- Picture integration
- Position orientation
- Logical reasoning
- Problemsolving[3]

Some agencies tend to hire prospective interpreters based only on their having completed a four-year degree regardless of subject area—a practice that does not ensure the new hires will be well-suited to do imagery analysis. The results have the potential to be, and sometimes are, costly and frustrating to the individual and the organization alike. An agency will attempt to train as an image interpreter an English major with limited spatial orientation abilities who cannot synthesize stereovision. In a training environment that practices the 90-90 rule (90 percent of the students get grades of at least 90 percent) and no student fails, there is great potential for allowing inappropriate individuals into the career field.

In conjunction with proper screening, assessing a candidate’s abilities to interpret and analyze imagery according to the model in figure 2 can help to predict his or her likely success in an intelligence profession. Agencies willing to accept an image interpretation candidate solely on the basis of normal visual acuity and completion of a college degree are not assured the candidate will develop into a successful image interpreter.

“. . . agencies do not carefully qualify interpretation candidates.”

Development

Whether working in civilian or military imagery analysis organizations, imagery analysts likely will follow the same sequence in their development (figure 4). In all cases, subject area knowledge is the foundation on which a person builds image interpretation skills and knowledge.

Campbell, in *Introduction to Remote Sensing*, emphasizes the requirement for fundamental subject knowledge, even before remote sensing training, when he quotes supervisors saying "you can make a geologist into a good photo geologist, but you cannot make an image interpreter into a geologist."[6] This is not to say that every geologist will make a good photo geologist, but a person without subject knowledge cannot become an imagery analyst in that topic. In intelligence, the baseline subject often is military science.

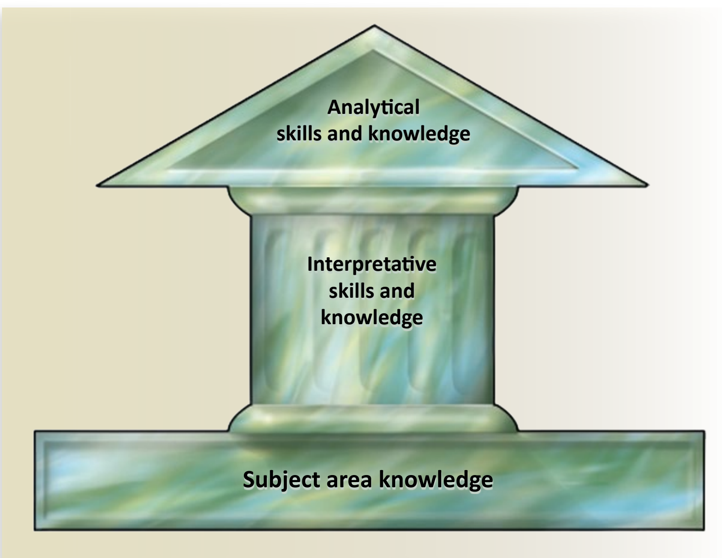

Figure 4. Building Blocks for Imagery Analysts

After an analyst gains the basics of subject knowledge, the road to imagery analysis begins with skilled image interpretation.

In the military, the US Marine Corps best follows this model. The Marines believe that each member is a Marine first and an occupational skill practitioner second. To ensure qualification in the basic subject, all Marine recruits must serve their first tour in a combat or combat-support specialty. Upon reenlistment, a Marine may take the second step in the model by choosing to pursue the image interpretation career field. Potential Marine interpreters must have attained the grade of E-5 and have been screened for both mental and visual abilities. Those interpreters who go on to excel as intelligence analysts deserve to be called imagery analysts.

Conclusions

The skill of image interpretation underpins both image interpretation and imagery analysis. It is a myth that all people can interpret with equal skill. A person who wants to be an imagery analyst must first become a skilled interpreter, and the bulk of work in the profession is image interpretation, but interpretation yields only *image-derived information* that answers "what?"

The phrase "imagery analyst" has a distinct meaning, and not all image interpreters are imagery analysts. When an individual combines the abilities, skills, and knowledge of both imagery interpretation and intelligence analysis, he or she becomes an imagery analyst. Imagery analysis is also distinguished from interpretation by the broad scope of the resultant intelligence product and by the inclusion of nonimagery information in the effort to explain what is visible in the imagery, resulting in *imagery intelligence*.

Imagery analysis is an alternative to conventional intelligence analysis, but not a replacement. The imagery analyst can accomplish intelligence analysis of visible topics; however, there are many questions imagery cannot answer, regardless of the analyst's skill.

Imagery analysts should feel at home in those organizations that conduct scientific and technical research, produce intelligence estimates, and study long-range problems such as nuclear proliferation, terrorism, and environmental issues, to name a few.

Imagery departments and agencies would do well to adopt the training model that starts with subject knowledge, adds interpretation skills, and culminates in analytic skills. People who wish to work as imagery analysts should first go through a battery of tests to ascertain both their interpretative and analytic abilities. Those who do not have a military background should learn basic military science, then begin imagery interpretation training.

Notes

1. Department of the Army, Technical Manual 30-245, Naval Air 10-35-685, Air Force Manual 200-50; December 1967. *Imagery Interpretation Handbook*, Vol. 1, pages 1-5.

2. Department of the Army, *Soldier's Manual*, Skill Level 1, [Military Occupational Specialty] MOS 96D, STP 34-96D1-SM, November 1987, pages i–B-1.

3. American Society of Photogrammetry (ASP), *Manual of Photographic Interpretation*, Washington, DC: ASP, 1960, pages 129-130.

4. Between 19 March and 19 April 1995 the author interviewed the following people:

   - Imagery analyst SSgt., US Army, National Ground Intelligence Center (NGIC)
   - Senior imagery analyst, NGIC
   - Imagery analyst, National Air Intelligence Center (NAIC)
   - Imagery analyst Sgt. 1st Class, US Army, Defense Intelligence Agency (DIA)
   - Imagery analyst, NAIC

- Technical intelligence analyst, NGIC
- MSgt., US Air Force
- Senior imagery scientist, NGIC
- Imagery analyst, DIA
- Imagery analyst, NAIC
- Imagery analyst, NAIC
- Technical intelligence analyst, NGIC
- Senior imagery analyst, NGIC
- Image interpreter SSgt., US Air Force
- Imagery analyst, NAIC
- Imagery analyst Spc., US Army, NGIC
- Imagery analyst, NAIC
- Imagery analyst, NPIC
- Imagery analyst, Intelligence Threat Analysis Center
- Imagery analyst, NPIC
- Imagery analyst, NGIC
- Signals intelligence analyst, National Security Agency
- Imagery analyst, NAIC
- Imagery analyst, NAIC
- Robert Ryerson, Canada Centre for Remote Sensing
- Imagery analyst, DIA
- Imagery analyst, NAIC

5. *Webster's II New Riverside University Dictionary*, USA: Houghton Mifflin Company, 1984, s.v. analysis interpret, and interpretation.

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7. Avery, Thomas E. and Graydon L. Berlin, *Interpretation of Aerial Photographs*, 4th ed., New York: Macmillan Publishing Company, 1985, page 148.

8. Spurr, Stephen H., "Photogrammetry and Photo-Interpretation," *Aerial Photographs in Forestry*, 2nd ed., New York: The Ronald Press Company, 1960, pages 233, 247.

9. Central Intelligence Agency, PAS 95-00010, July 1995. *A Consumer's Guide to Intelligence*, pages 4-5.

10. Lillesand, Thomas M. and Ralph W. Kiefer, *Remote Sensing and Image Interpretation*, 2nd ed., New York: John Wiley & Sons, 1979, page 149.

11. Avery, Eugene T., *Interpretation of Aerial Photographs*, 2nd ed., Minneapolis, Minnesota: Burgess Publishing, 1968, page 288.

Perspectives on Orthorectification

By Gregory Grohman

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Introduction*

Generating remotely sensed geospatial intelligence (GEOINT) has become increasingly bewildering because of the many sources of imagery that are at an analyst's disposal. Analysts can use reflected panchromatic, multispectral (true or false color), hyperspectral, active radar, and other phenomenological imagery.† Also, different platforms (satellite or aircraft) and different passes (orbital or flightline) can change the capability and appearance of the images they capture. Finally, the images will likely not line up once they are imported into an electronic light table (ELT) for exploitation.

One way to make exploitation less challenging is to use orthorectification to make images spatially consistent. Orthorectification processes monoscopic imagery to remove distortions of tilt, tilt-induced scale (where objects of the same size are not equal on the image due to obliquity), and terrain relief. These distortions are typical in remotely sensed imagery. While orthorectification solves many problems, analysts must beware of some pitfalls.

Rectifying Monoscopic Images

Raw monoscopic images delivered to a geospatial exploitation workstation contain inherent characteristics that adversely affect exploitation. To some extent, all images are taken from a nonorthogonal (tilted) angle, so terrain relief affects the way features appear on an image.

Resampling can compensate for adverse image characteristics by arranging the image's pixels into a new grid.‡ In its simplest form, resampling takes the digital numbers of the pixels from one grid and places them on another grid of different size or orientation.§ Resampling can rotate an image, change a projection, reset the size of the pixels (changing the ground sample distance), or enhance the pixels through image sharpening. Image compression (removing nonessential data to reduce the size of a file) is a form of resampling.

There are numerous resampling options. If the analyst chooses, the algorithm will simply use the digital number

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†Tilt and tilt-induced scale are related but vary based on the altitude of the sensor.

‡A grid is a network of uniformly spaced lines intersecting at right angles forming an array of equal size square cells arranged in rows and columns used for position referencing on the Earth's surface.

§A pixel is the smallest component of an image. Each pixel in an image is represented by a digital number for brightness information.

of the pixel nearest the spot it is filling in the grid. This is called nearest neighbor resampling. Other resampling options, such as bilinear interpolation or cubic convolution, take into account surrounding pixels' digital numbers and combine them to generate an enhanced image. Nearest neighbor is the only resampling that does not alter the digital number values in the original data, so if analysts plan to perform spectral analysis on a resampled image they should use nearest neighbor resampling.

Orthorectification is one of two common forms of resampling analysts use to rectify monoscopic imagery (the other form is plane-rectification). Orthorectification can be more useful than plane-rectification because orthorectification removes both tilt and terrain effects. Orthorectification does this by incorporating a digital elevation model (DEM) of the Earth's surface, whereby each pixel is mathematically placed onto an orthogonal grid.** The DEM is necessary for orthorectification.

Orthorectification makes each pixel appear as though it had been acquired at an elevation angle of 90 degrees and from an infinite distance from the scene. Every location on an orthoimage appears as though the observer were looking straight down—similar to viewing a map. analysts can rotate an orthorectified image to place north at the top like a map.

The frames in figure 1 demonstrate how orthorectification can remove terrain effects. Before orthorectification, in the frame on the left, the straight path of a powerline appears to wiggle as the line crosses hills and valleys. After orthorectification, in the frame on the right, the powerline appears straight.

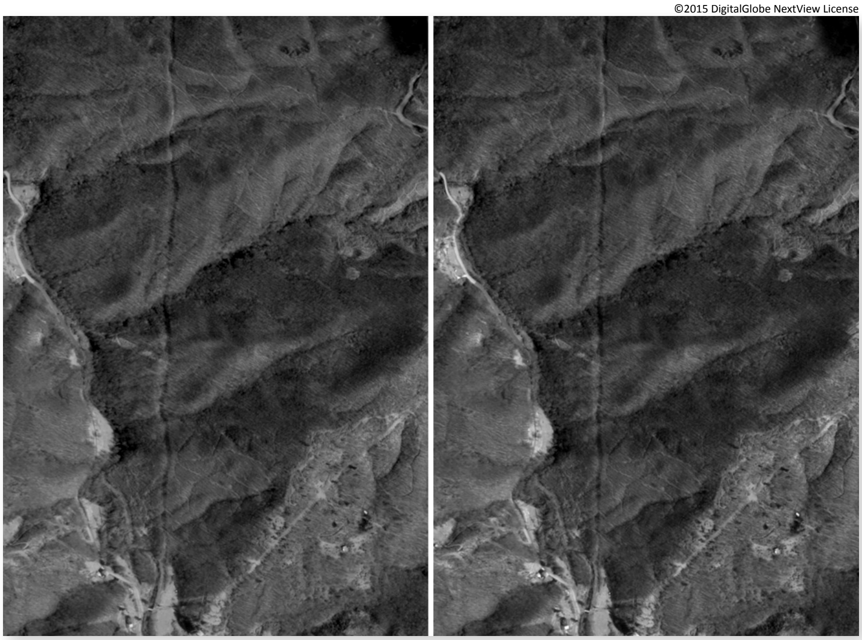

Figure 1. Terrain Effects Wiggle the Path of a Powerline (left); Orthorectification Straightens the Path (right)

**An orthogonal grid that is set on the ortho-image plane, parallel to the projection grid, and independent of topographic features.

Advantages of Orthorectification

There are many advantages to orthorectifying imagery, as demonstrated in figure 1. Orthorectification allows analysts to measure features on monoscopic imagery without the need for a stereo pair. Distances, angles, and areas can be measured directly on an orthorectified image, which can also be interpreted as any other aerial photograph. Orthorectified images, also called orthos, provide a map-like base usable for situational awareness and scene visualization for:

- Operational planning
- Change detection
- Time sequence
- Feature extraction
- Spectral analysis for automated land cover classification

Orthorectification requires sensor models and algorithms, but exploiting a resulting ortho requires no sensor model, making these images easy to import and adapt to a variety of uses. Because the software manipulates an ortho like a map, the only information software packages require are the corner coordinates, pixel size, and projection—much less metadata than that required to display and exploit a stereo pair.

Stereoscopic Exploitation

Two features of stereo imagery are highly prized for complex exploitation: 3-dimensional (3-D) viewing and accurate measurements. But only a small fraction of electro-optical imagery (from all sources) is tasked for stereoscopic collection, and stereoscopic exploitation requires two stereo-fusible images with appropriate collection geometries, specialized exploitation software, support data, and viewing hardware. This can make stereoscopic exploitation cumbersome and expensive.

A Disadvantage of Orthorectification: Errors

Two Sources of Errors

Despite its advantages, orthorectification can have inaccuracies that analysts should understand. Two major sources of errors contribute to these inaccuracies: image bias and the interaction between the errors in the DEM and the sensor's look angle. In some cases, an error source can be corrected, in others—such as an extreme geometry—there is nothing to be done.

Image Bias

Horizontal image bias occurs when software reads a raw image's ephemeris data and interprets the location of the image some distance from the ground truth. Figure 2 illustrates how image bias can displace objects in an image. In the figure, color represents objects' ground truth locations; gray represents an image bias offset.[††]

Image scientists can reduce horizontal image bias by registering an image. They do this by identifying ground control points of known accuracy within a scene and matching these to corresponding places in the image. Image scientists also call this geopositioning or correspondence determination. Registering does not require a DEM but does require control points/

[††]In this article, ground truth will refer to either a horizontal or vertical reference position established through a global positioning system survey or other photogrammetrically derived value.

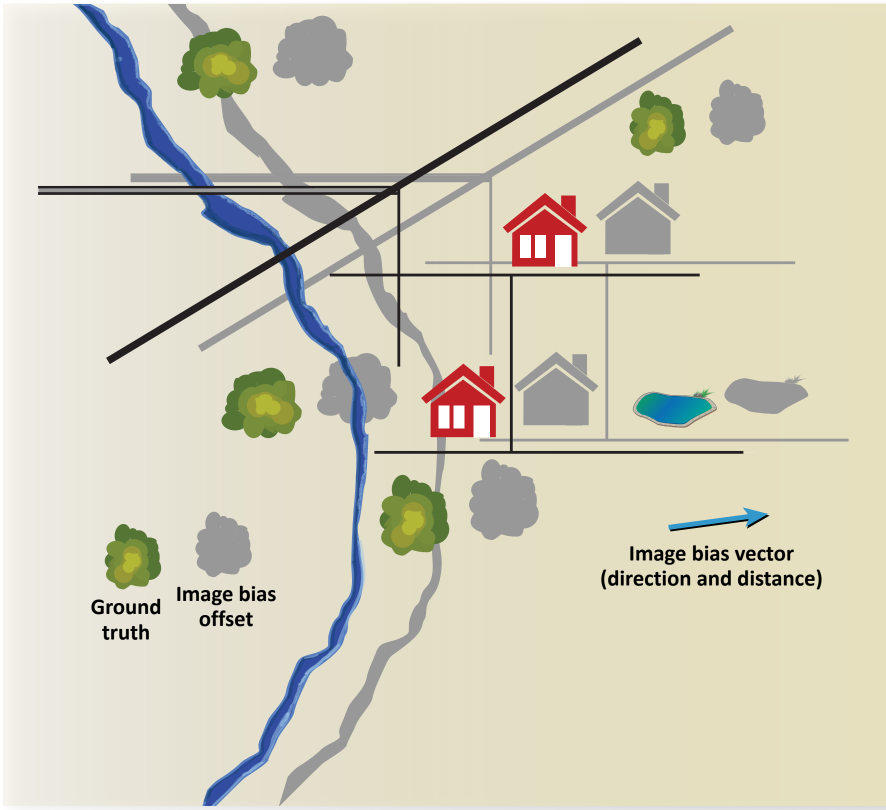

Figure 2. Image Bias

sources with better location accuracy than the initial image had—or you risk making the image bias even worse.

Look Angle-DEM Interaction

Look angle-DEM interaction refers to the way the look angle, in conjunction with the properties of the DEM, affect resampling. It is important to know that the look angle will be relatively consistent throughout an image collected from space because of the great distance from sensor to target; on airborne imagery, the look angle is less consistent due to the much lower flying altitude. This article will later explain how orthorectification is extremely sensitive to the difference between the true ground elevation and the DEM, and that the look angle is key. Complicating matters, every DEM will contain some errors in elevation representation. Many of the interpolated straight lines connecting a DEM's elevation posts (the discrete elevation points that form a grid for the

DEM) will be above or below the true ground elevation (figure 3). The mismatch between the interpolated lines connecting a DEM's elevation posts and true ground elevation leads to erroneous pixel placement in that vicinity when analysts resample the image's pixels into a new orthorectified image (figure 4).

Analysts must consider both the direction and magnitude of these errors. The direction of the DEM-induced errors in an orthoimage will be determined by whether the DEM is above or below the true ground elevation for each pixel. If the DEM is above the true ground elevation, the pixel will be displaced toward the sensor; if the DEM is below the true ground elevation, the displacement will be away from the sensor. The differences between the DEM and ground truth elevations determine the magnitude of the DEM-induced horizontal errors as driven by the off-nadir angle of the sensor.

A DEM error will cause smaller or larger horizontal errors in an ortho depending on the sensor's look angle. As the collection elevation approaches 90 degrees (perpendicular above the image) the DEM's contribution to the total error will get smaller. If the sensor was nearly overhead there would be smaller errors; if the look angle was more oblique there would be larger errors. The table shows how the horizontal error increases as imagery is acquired at increasingly oblique angles. For example, at 26 degrees off-nadir (a sensor elevation look angle of 64 degrees above the horizon), a 12-meter error between the DEM and the true ground elevation results in a 6-meter horizontal error (2:1).

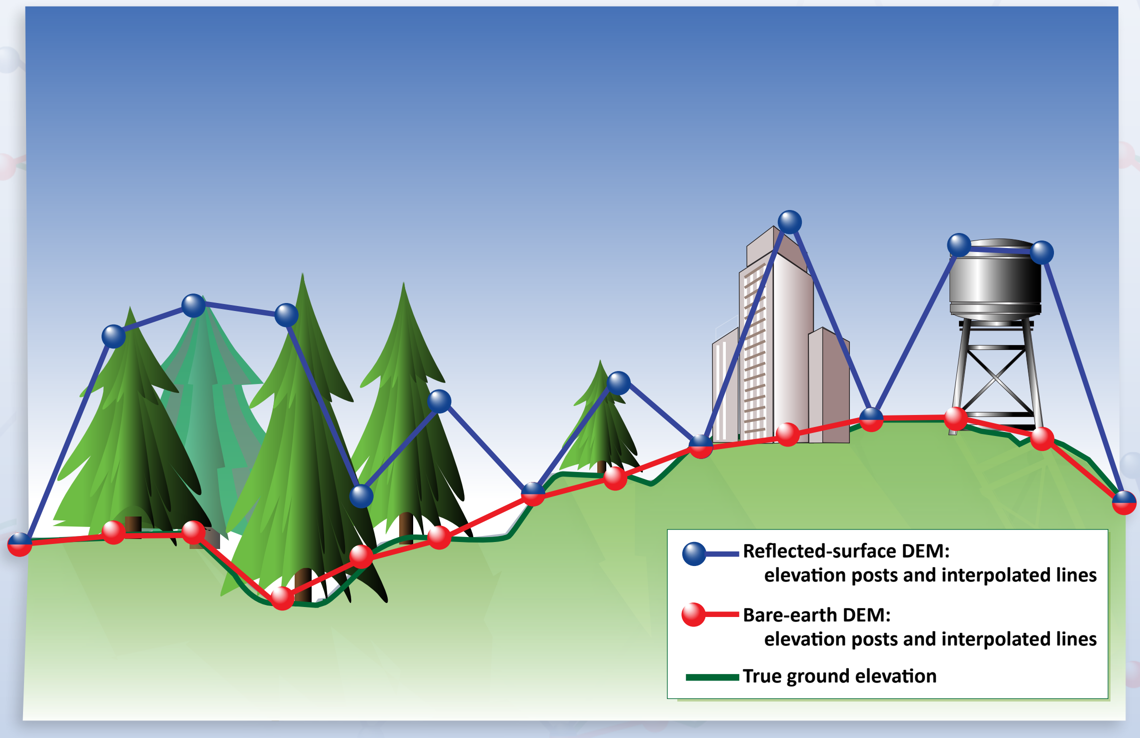

Figure 3. Differences Between Two Types of DEMs and True Ground Elevation (Cross Section)

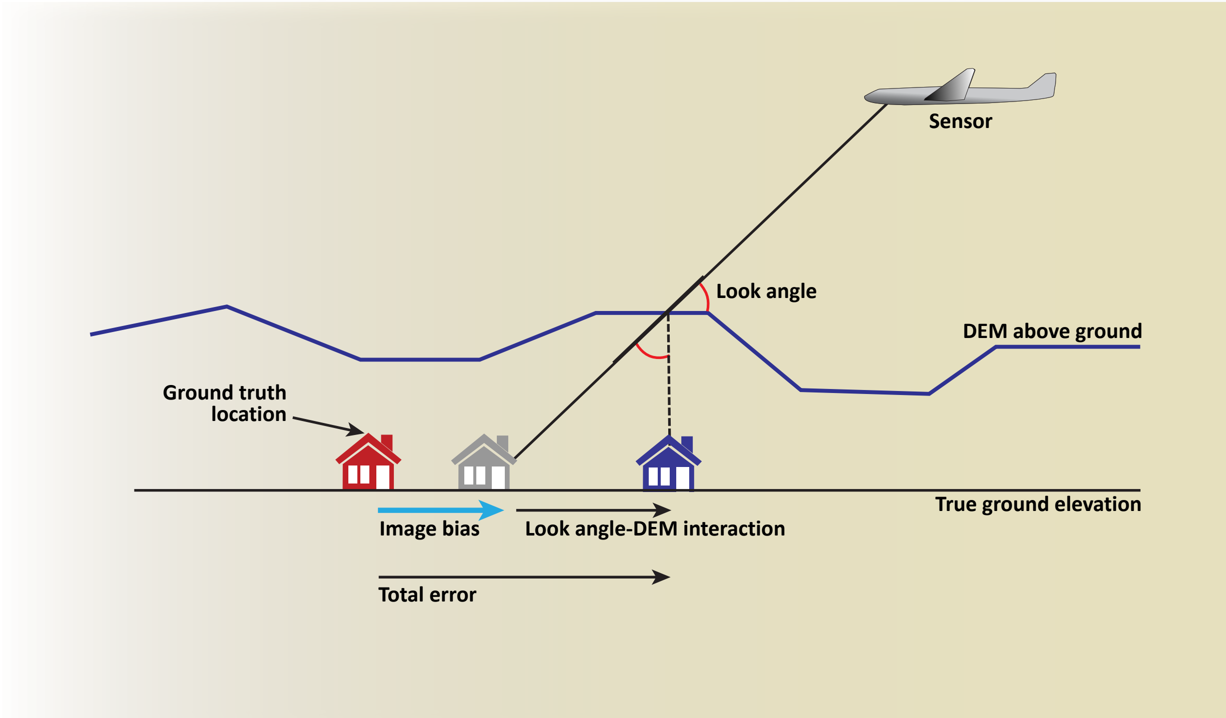

Figure 4. Image Bias + Look Angle-DEM Interaction = Total Error (Cross Section)

Table. Round-Number Error Ratios at Selected Off-Nadir Values

Degrees Off-Nadir	Sensor Look Angle	Ratio of DEMΔ to Horizontal Displacement
0	90	No displacement
14	76	4:1
26	64	2:1
45	45	1:1

The vector math combination of the two sources of errors is complex. Figure 5 shows how the direction and magnitude of errors can vary. The DEM errors can be projected on a line that points directly toward (and away from) the sensor and the known image bias (a location image scientists call the "bias point"). On the right side of figure 5, the black arrows coming from the red ground truth location illustrate error caused by a DEM that is either below or above the true ground elevation. The histogram in figure 5 illustrates that 90 percent of the horizontal errors caused by the interaction between the look angle and the DEM will fall within the middle 90 percent portion of the histogram which defines the linear error 90 percent (LE90). Even so, some DEM elevations will be well above or well below true ground elevation (represented as error vectors pointing to the tails of the histogram). Image scientists call this variety the "DEM error spread."

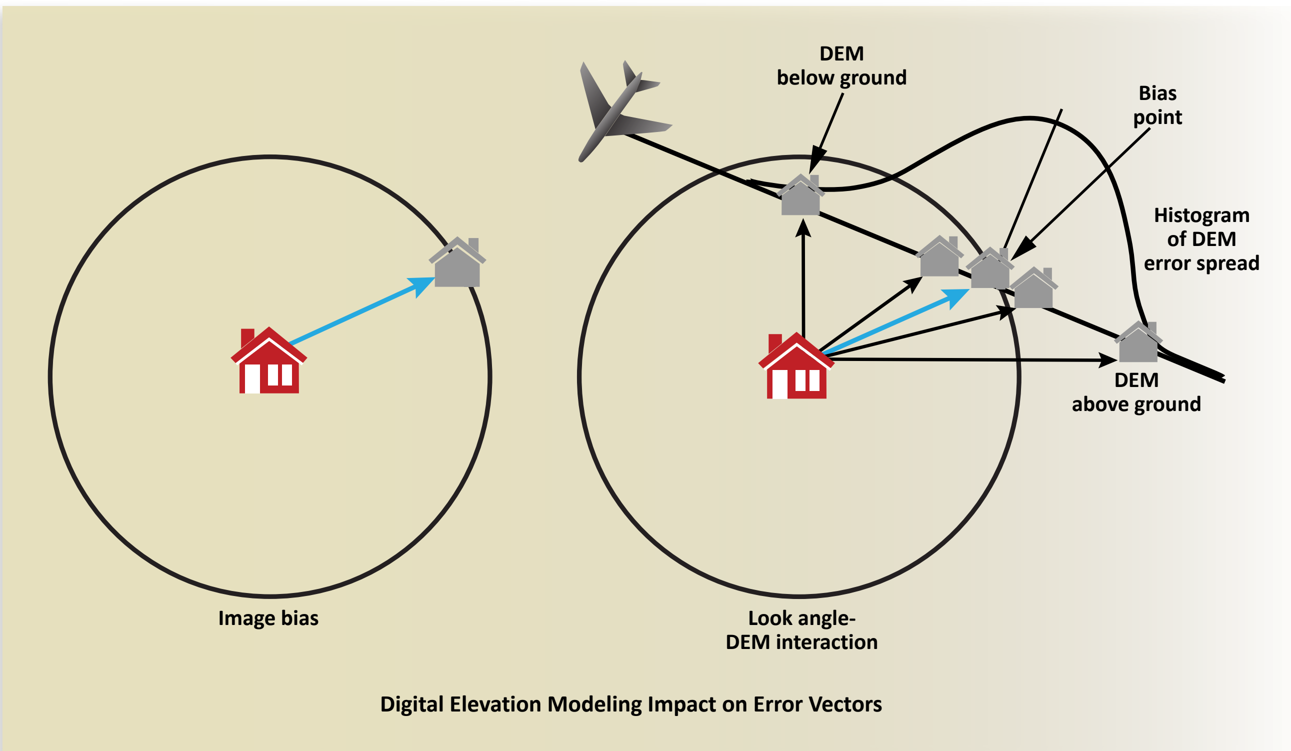

Figure 5. Vector Math Combination of Image Bias + Look Angle-DEM Interaction

Orthoimage Accuracy Rating

The look angle interacting with the DEM errors makes it difficult to assign an overall accuracy to an ortho. While the sensor look angle may vary slightly from pixel to pixel, the accuracy of a DEM at a particular location is less predictable. The result is that the total error caused by the look angle-DEM interaction can be different for each pixel. Theoretically, no two pixels will be off by the same distance and direction.

In an ortho the total errors are dynamic and unpredictable—distributed across the product in a random fashion. Figure 6 shows the error vectors at 27 check locations in one ortho. The left side of the figure shows look angle-DEM interaction errors—that fall toward or away from the sensor depending on whether the DEM was above or below true ground elevation at the check location. The total errors (image bias + look angle-DEM interaction) on the right side of figure 6 are even more variable.

"... total error caused by the look angle-DEM interaction can be different for each pixel."

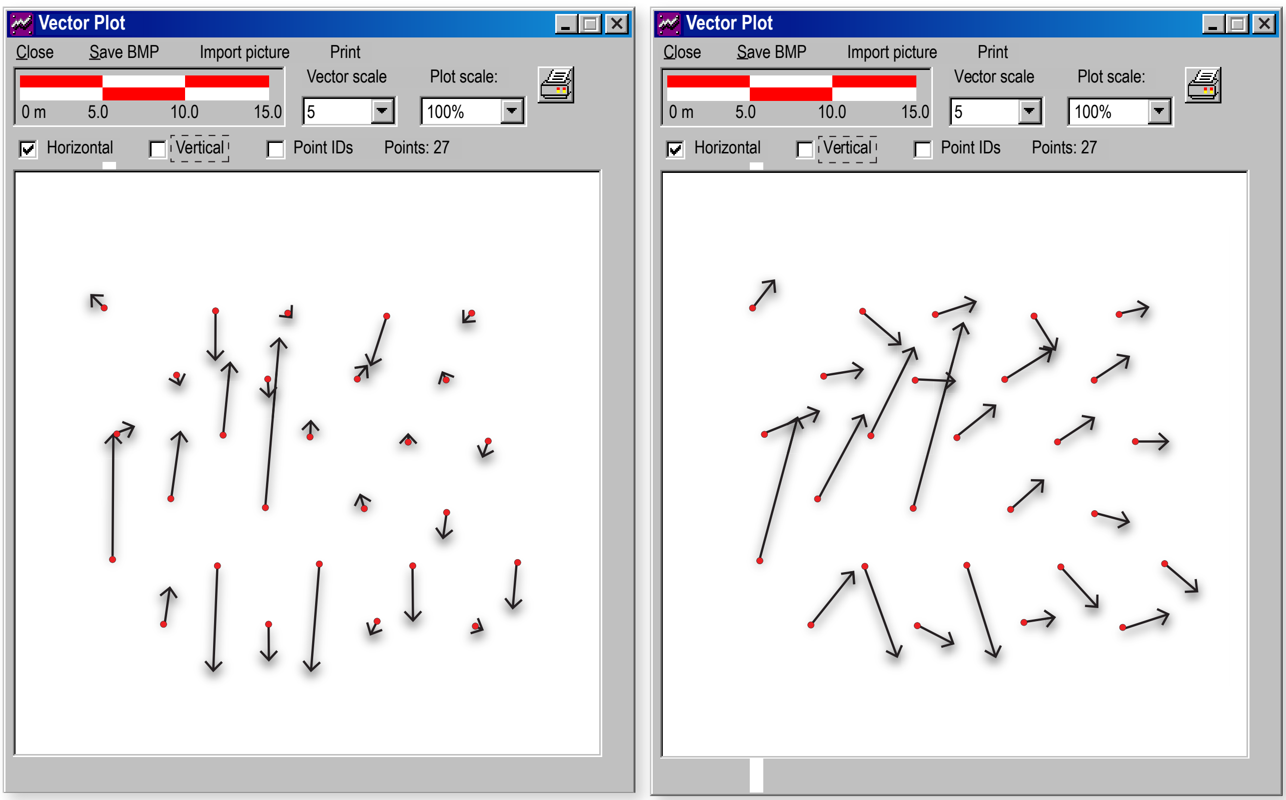

Figure 6. Look Angle-DEM Interaction Errors (left) and Total Errors (right)

Because of the complexity of the two error components—every pixel can have a different error—it is difficult to place a single horizontal accuracy value on an ortho. The goal becomes determining a radial error that would contain 90 percent of the pixel displacements, irrespective of direction. Image scientists express this as circular error, and CE90 means there is a 90-percent chance a given pixel is horizontally displaced inside that named accuracy. Conversely, up to 10 percent of all pixels can be outside the named accuracy. So an ortho may contain small pockets with large errors, and measurements in these areas may have horizontal errors significantly higher than those indicated by the CE90 value.

DEM Considerations

Two DEMs

The analyst must address certain DEM factors such as the best DEM type to consider for the ortho and if the post spacing (distance between discrete elevation points on a grid) is good enough. The decisions depend on the intended uses of the orthoimage being generated using the DEM. Irrespective of post spacing, two distinctly different types of DEMs exist, and they will have different impacts on an orthoimage. The first type of DEM is the "reflected-surface" in which the tops of visible objects determine the DEM elevation. The second type is a ground-surface, or "bare-earth" DEM in which the posts are at ground level (if it was not covered by vegetation or buildings). Figure 3 on page 40 illustrates the difference between reflected-surface and bare-earth DEMs.

Reflected Surface DEM

Radar, "first-return" light detection and ranging (LIDAR) systems, and autocorrelation of electro-optical stereo imagery (which is by far the most common), will generate a reflected surface DEM. In the jargon, image scientists call reflected surface DEMs "digital surface models," or DSMs. During orthorectification, the reflected surface DEM will "stand up" tall objects. This makes the top of the tall object appear directly over the bottom of the object. On an image that is not orthorectified, a tall object imaged from an oblique angle will appear to lean away from the sensor, and analysts must rotate the image to view the object "up-is-up." Standing up a tall object in an ortho allows the analyst to see how the object appears from directly above.

Any horizontal offset between an image and a reflected-surface DEM is particularly problematic with DEMs that have very high resolution, such as a 1-meter LIDAR DEM. The buildings in the center of figure 7 are poorly aligned with the high-resolution DEM. As a result, there is considerable smearing around the edges of the tops of the buildings. Note the wavy building edges as well as the streaks left behind as the parts of the building appear to be “left on the ground.”

An additional risk is that a DEM was often produced years before an image is recorded. Between these two events, many objects may have been subtracted or added. The posts in the DEM will conform to objects that are no longer present or represent an elevation before an object occupied a location. The upper left portion of figure 7 contains a light-colored S-shaped object. This is a vehicle that appears warped because a large tree, present when the DEM was produced, had been cut down before the sensor recorded the image.

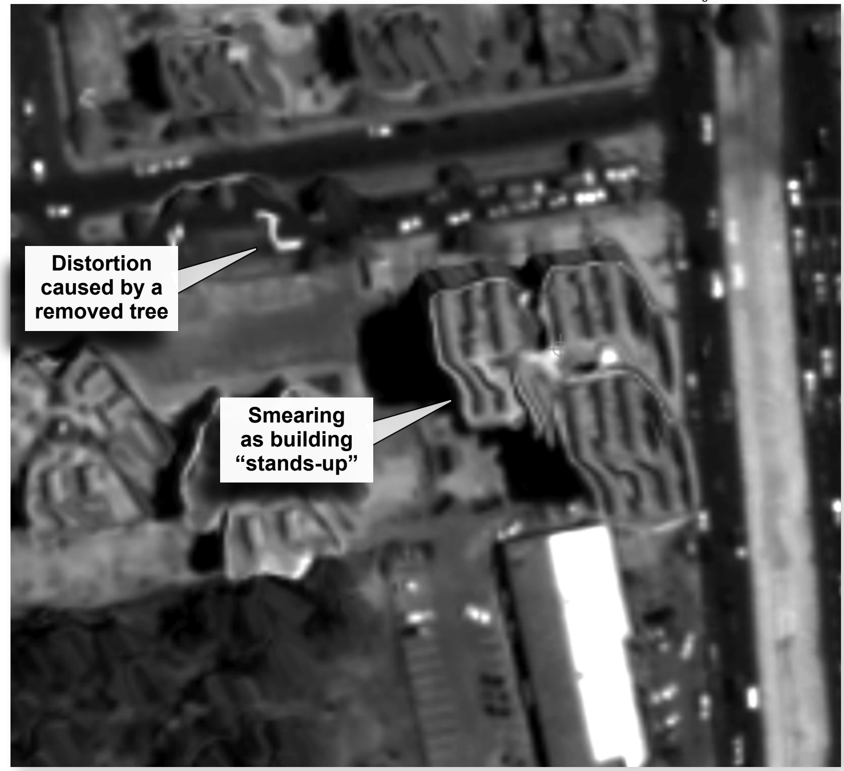

Figure 7. Problems With a High-Resolution LIDAR DEM

In urban areas or when dealing with manmade objects, the elevation posts of the DSM must be no more than 1 meter apart. Sometimes called a “feature-level” DEM, the DSM must be able to adequately represent objects in 3-D and any unevenness in the edges of tall objects, like a building top that is at an angle with the DSM grid, will be adversely affected in the ortho. A registration difference of as little as 1 meter will cause distortions or artifacts (signatures in imagery not indicative of ground truth). Tall objects may shed parts of their tops and leave them on the ground, and ground features may appear on top of tall objects. One reason figure 7 looks as distorted as it appears is because it was produced with an approximately 2-meter offset between the LIDAR DEM and the image.

Bare-Earth DEM

Moving the elevation posts from the tops of buildings or trees to ground level results in a bare-earth DEM. In the jargon, image scientists call bare-earth DEMs "digital terrain models," or DTMs. A bare-earth DEM is a continuous surface model of where the terrain would be if all features above ground level were removed. This takes extra work but the bare-earth DEMs make for excellent positioning of ground features in an ortho. Also, the bare-earth DEM warps tall objects less than the reflected-surface DEM does because

Digital Terrain Elevation Data

After choosing between a reflected-surface DEM or bare-earth DEM, the next consideration is the post density of the digital surface. This is established by setting the distance between each measured elevation spot, or post. If the analyst is using a digital terrain elevation data formatted DEM, the post spacing is called the DTED level. Different DTED levels have different arc-projected post spacings. For example, DTED level 0 has a post every 30 arc seconds, or roughly 1 km. DTED level 1 places a post every 3 arc seconds. This puts the posts about 90 meters apart at the equator and 78 meters apart at 33 degrees latitude. DTED level 2 places posts 1 arc-second apart—approximately 25- to 30-meter spacing. A surface produced with anything worse (coarser) than the post spacing in a DTED level 2 will likely not capture the ground characteristics sufficiently for high-resolution images.

Generally speaking, adding more posts beyond DTED level 2 does not significantly increase accuracy or improve the quality of an ortho. DTED level 3 places posts every .4 arc seconds apart—approximately 10- to 12-meter spacing. This increases the DEM's file size but it does not correspondingly improve an ortho's accuracy. DTED level 3 may even add artifacts because taller objects are not well captured or represented in the DSM (and most level 3 DTEDs are DSMs). Picture a single post on top of a building, which would make the DEM look like a pyramid there, and the ortho of that building would be badly deformed. The larger number of posts may also slow processing. DTED level 3 contains nearly six times more posts than DTED level 2 over the same ground footprint, but the resultant orthos are not six times more accurate.

as we saw, standing up buildings is difficult to achieve cleanly. Tall objects do not appear to stand up in a bare-earth DEM so the tops of tall objects have poor geometric accuracy. The taller the object, the worse its horizontal accuracy in the resulting ortho.

Recognizing Errors in an Orthoimage

Orthos are inappropriate for targeting unless the analyst closely monitors image registration and DEM accuracy. Artifacts and distortions such as those in figure 7 are often identifiable and unmistakable—but not always. Even when an ortho looks completely normal, image bias can make it horizontally inaccurate. If the image bias is large enough, the image and DEM will not be aligned. The result is as bad as using an inferior DEM. As an example, if the image location of a hilltop is not aligned with the DEM, a structure on top of the hill will orthorectify away from its true location. The DEM values at the hilltop will be lower (farther down the slope) than the true ground elevation. This can be difficult or impossible to detect without ground truth, while flatter locations in the same ortho may look just fine.

The potential for horizontal errors and artifacts exists any time a DEM and image are misregistered. In figure 8, the high-resolution DSM and the air traffic control tower are misaligned. After analysts generated the ortho, the tower still appeared to lean. The situation gets worse when the DEM post spacing is denser or when image obliquity increases.

"Orthos are inappropriate for targeting unless the analyst closely monitors image registration and DEM accuracy."

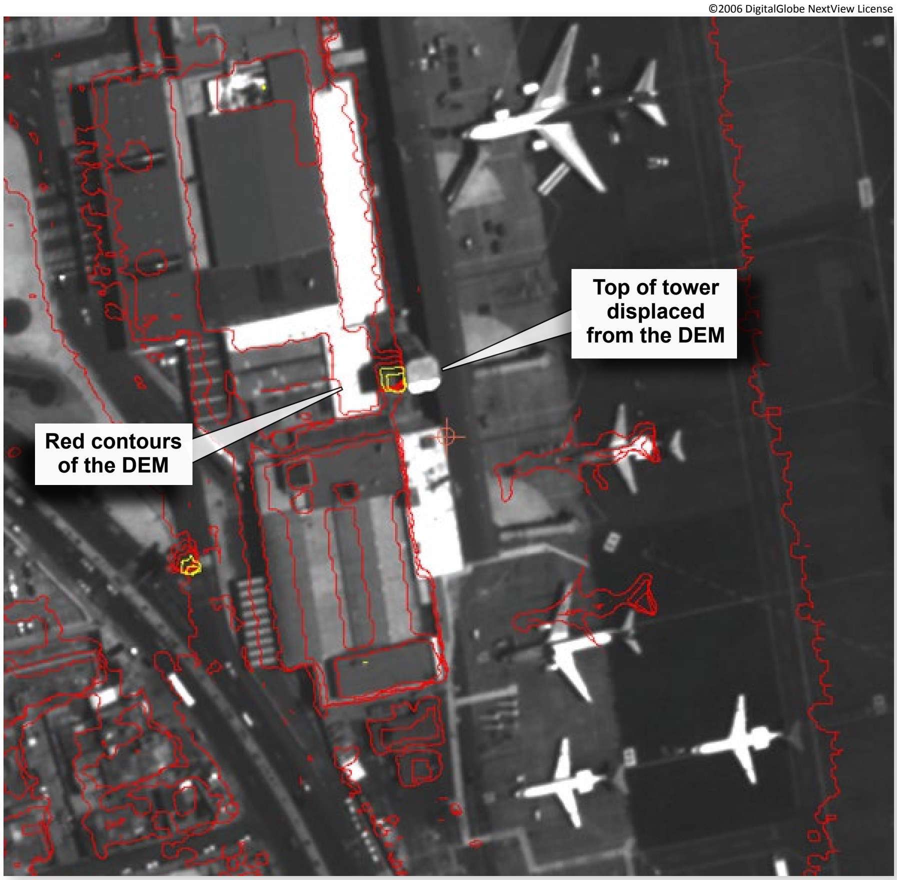

Figure 8. Misregistered Image and LIDAR DEM

Figures 9 and 10 demonstrate another example of errors analysts can observe in orthos. Collected by a commercial satellite at an elevation angle of 77 degrees, the image of the rows of buildings in figure 9 appears straight prior to orthorectification. Because of a poor DEM, the orthorectification process shown in figure 10 warps the buildings. In this case, the DEM contained a pocket of bad posts (known as noise) when compared to ground truth. This is not only distracting, it can affect the relative accuracy of any measurement taken from the damaged ortho. In this case, the analyst should opt for a higher quality DEM. If the warp were not so obvious, there could be issues, as the analyst might not know the errors are even there.

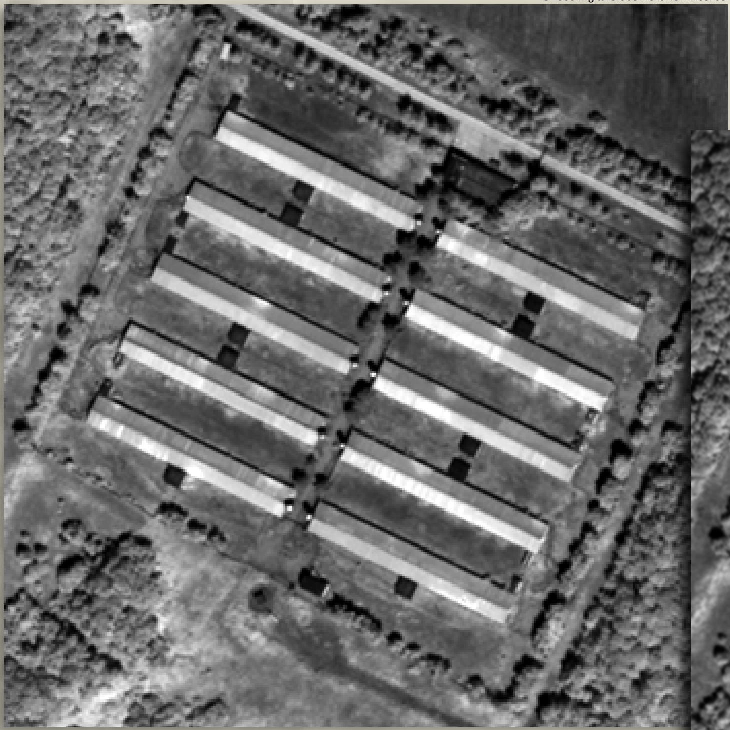

Figure 9. Buildings Before Orthorectification

Figure 10. The Same Buildings After Orthorectification With a Bad DEM

Figure 11 shows what high-frequency noise in a DEM looks like. The figure is a commercial satellite image of Baghdad International Airport. The image is draped over a reflected-surface DEM built with shuttle radar topographic mission (SRTM) level 2 data. The high-frequency noise bumps in the DEM are easier to see from the side.

To demonstrate this noise impact on an ortho, a test was performed using this SRTM data. Test site 1 is the end of a paint stripe. At test site 1 the DEM is higher than the true ground elevation by 17 meters. At test site 2 (another stripe) the DEM is below ground elevation by 11 meters. Note how these differences result in bumps on the ortho of a straight and level runway. Errors such as these result from radar energy bouncing away from the sensor, making for a weaker, less accurate, return. This is common in SRTM data near airfields and large, flat, grassy areas. Because of this undesirable characteristic, SRTM is not the orthorectification surface of choice, but over the vast majority of the globe, SRTM may be the only option.

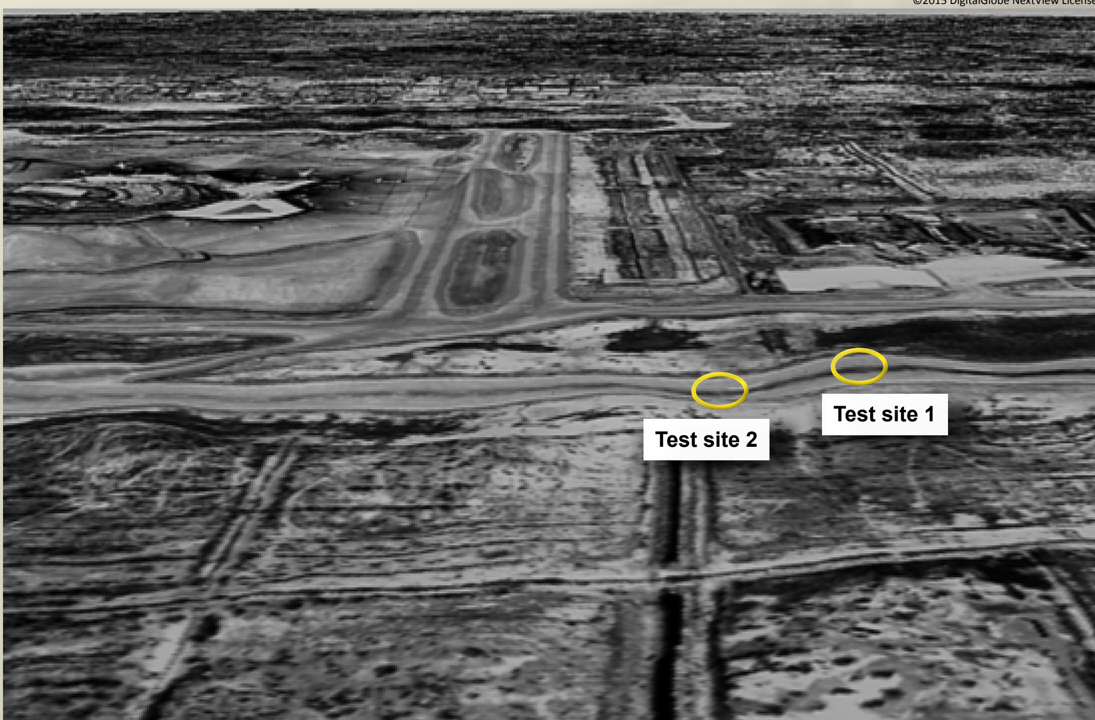

Figure 11. Commercial Imagery Draped Over a DEM Produced From SRTM Data

Figures 12 and 13 are examples of variable error common when using high-frequency noise DEMs like SRTM. The figures show the same two test sites at Baghdad International Airport. The ground truth location of test site 1 is the center of the red box in figure 12. The white cursor in the figure shows the location of test site 1 on the ortho. The location is incorrect by 16.26 meters at an azimuth of 190.58 degrees (south-southwest).

The ground truth location of test site 2 is at the center of the red box in figure 13. The white cursor in figure 13 shows the location of test site 2 on the ortho. The location is incorrect by 10.21 meters at an azimuth of 341.5 degrees (north-northwest).

The directions of the errors in figures 12 and 13 are meaningful. The location of the DEM surface (above or below true ground elevation) dictates the direction of the horizontal error during orthorectification. At test site 1 the DEM was above the true ground elevation. At test site 2 the DEM was below the true ground elevation. These error directions indicate the sensor was almost due south of the runway when it acquired this image. The errors do not align exactly because of a small amount of image bias to the west.

Figure 12. Error at Test Site 1

Figure 13. Error at Test Site 2

Mitigating Errors in an Orthoimage

Registering

Analysts working with large horizontal image bias can make corrections by registering the image using higher quality ground truth locations. This technique can help align the image and the DEM because improving the horizontal positioning of the DEM is usually not an option. In cases where the DEM is of insufficient density or type, it can often be corrected or a new DEM may be requested. Although the look angle of the oblique image cannot be changed, if the angle is causing unsatisfactory results, the analyst can request another, more orthogonal image.

Layering

At the beginning of this article, the author described how multiple imaging phenomena could be a challenge. But after fixing errors in the raw imagery, having multiple images and multiple types of images of the same area can be an advantage. After images from different sources have been orthorectified, analysts can layer them in a geometrically consistent manner. Also, when standing up a tall object on an ortho results in “empty” areas that were obscured by the tall objects in the oblique image, analysts can fill these empty areas with imagery taken from another angle. Figure 14 illustrates how one source can be used to fill voids in another source, in this case using orthorectified radar imagery to fill a panchromatic electro-optical imagery obscuration. Such layering might distract a new analyst (and the shadows are a challenge) but the information is properly positioned and the result is a product free of cloud cover.

Conclusion

In summary, orthos are a form of resampling that can compensate for adverse characteristics of oblique images. Orthoimages are photomaps that do not contain the scale, tilt, or relief distortions that characterize unprocessed remotely sensed imagery. Orthos can be interpreted like any air photo, but distances, angles, and areas can be measured directly without further processing. These characteristics make orthoimages especially useful for exploitation.

Producing an ortho permanently burns random, variable horizontal errors into the product. The horizontal errors are neither modelable nor removable. The majority of each pixel’s horizontal placement error will be a combination of the interplay between image bias and the interaction between look angle and a DEM.

Orthorectification requires DEMs, and all DEM surfaces will have errors. The reflected-surface DEM uses the tops of visible objects to determine the DEM

Figure 14. Layering Electro-Optical and Radar Imagery

elevation and can poorly represent above-ground objects (unless the post spacing is very small). The bare-earth DEM is harder to construct but places the posts at ground level, where the final ortho product looks much like the original image.

The total error caused by the look angle-DEM interaction (combined with image bias) can be different for each pixel. This means orthos are inappropriate for targeting or for sources of ground-control points (unless the analyst closely monitors image registration and DEM accuracy). Because of the complexity of the two error components, the goal of an ortho-rectified image's accuracy statement is to determine a radial error that would contain 90 percent of the pixel displacements.

The task for an analyst who intends to generate an ortho is to minimize these errors to the degree possible. Two options are to register the image or to improve the DEM. Registering the image will still leave the look angle-DEM interaction errors. While the variety of the error sources is daunting, most ortho errors are often relatively small.

GEOINT, with its expanding demand for layered information, benefits greatly from orthorectification. Intelligence and information can be easily derived from orthorectified images that are all stacked in a spatially accurate way. In addition, orthorectified imagery can be generated from multiple remote sensing sources, helping gain a better familiarization of an area of interest through different sensor properties and look geometries. With multitemporal, multispectral, and multisensor (aircraft and satellite, electro-optical and radar) stacked orthorectified imagery, a clearer picture of ground features, changes, and activity patterns can be revealed.

Reference

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Geographic Profiling in Nazi Berlin: Fact and Fiction

By D. Kim Rossmo, Heike Lutermann, Mark D. Stevenson, and Steven C. Le Comber

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Editor's note: The authors of this article investigated how geographic profiling might be applied to analysis of minor terrorism-related acts such as theft and antigovernment graffiti to help locate terrorist bases before more serious incidents could take place. The authors illustrate the methodology's effectiveness by examining the historical case of Otto and Elise Hampel, who distributed hundreds of anti-Nazi postcards in Berlin during World War II.

The authors demonstrate that specialized analytic methods can be applied to problems with similar characteristics. Cross-domain methodology borrowing clearly works.

Not all terrorism-related events can be directly analyzed using geographic profiling. The choice of location for some acts, especially major ones, can be driven by factors other than opportunity, for example, by symbolism or the expected impact. This article deserves consideration because geographic profiling has been successful in the analysis of a wide variety of crimes and other incidents. Originally published in GIR *12 no. 2 (2014), the article is approved for public release, #15-287.*

Introduction*

This article shows how the Gestapo [German security police] employed the basic ideas of geographic profiling during World War II. Geographic profiling analyzes the locations of connected incidents to determine the most probable area for an offender's "anchor point" (usually a home, but sometimes a workplace). This Gestapo investigation formed the basis of a classic German novel, *Alone in Berlin*, about Otto and Elise Hampel, who had distributed hundreds of anti-Nazi postcards during the war.

We used modern geographic profiling methods to analyze the postcard and letter dropsites in the Hampel case and show that the technique successfully and quickly prioritized the area that contained the Hampel's Berlin apartment. Modern geographic profiling accomplished this after just 35 of the 214 incidents the Gestapo recorded before arresting the Hampels. This study provides empirical evidence to support the idea that analysis of minor terrorism-related or subversive acts such as theft and antigovernment graffiti can help locate terrorist bases before more serious incidents occur.[1]

*The authors thank the *Bundesarchiv* [National Archive], Berlin, for access to the files and thank colleagues at Queen Mary University of London and Texas State University, especially Jonathan Allen, Richard Nichols, and Yannick Wurm, for helpful comments. The authors are also indebted to K.A. Lankheit for his help locating the original Gestapo files, to T. Gegeny for granting temporary access to Dr. Gruyter's historical online resource, and to M. Kuhnke for additional historical information.

Cases of serial crime such as murder, bombing, and arson typically involve large numbers of suspects. For example, the Yorkshire Ripper investigation in England generated over 268,000 suspects.[2] Suspect prioritization and information management are therefore critical for major investigations. This is also true in counterterrorism investigations; as of December 2012, the US Government's terrorist watch list contained the names of over 875,000 individuals.[3]

Geographic Profiling

Geographic profiling is a frequently used method of prioritizing long lists of suspects. The technique was developed in the early 1990s to analyze the locations of a series of connected incidents to determine the probable area of an offender's anchor point.[4] Geographic profiling does not provide an "X" that marks the spot; rather, it is an information management and suspect prioritization method. The technique has been successful in criminal investigations and is now used routinely by law enforcement agencies around the world. More recently, it is being applied to military, biological, and epidemiological data.[1,5,6,7,8,9,10]

The methods underlying geographic profiling depend on the integration of two concepts: distance decay and the buffer zone.[4,11,12] Distance decay reflects the fact that most crimes take place relatively close to the offender's anchor point; for example, 70 percent of serial arsons are within 2 miles of an arsonist's residence.[13] The buffer zone is an area around the offender's anchor point in which offenses are less likely to occur, partly because of an increase in detection risk related to reduced anonymity and partly because the number of opportunities increases with the distance from the anchor point. The combination of these opposing effects produces a probability distribution that resembles a volcano with a caldera; the likelihood of incidents increases with distance up to the limit of the buffer-zone radius and then decreases or "decays" with distance.

Geographic profiling uses this buffered distance-decay function to determine the offender's probable anchor point within the area of interest. The profile produces an offender base probability surface ("jeopardy surface") from the point pattern of the incident locations.[4] When a jeopardy surface is overlaid on a map of the search area, the result is a geoprofile. Locations are then prioritized by their position on the geoprofile.

The Gestapo Investigation of Otto and Elise Hampel

Given that geographic profiling was not developed until the early 1990s and requires sophisticated computer software, it was surprising to discover the Gestapo's investigation of the Hampels used the concepts of distance decay and buffer zone. In *Jeder Stirbt für sich Allein* (a novel written by Rudolf Ditzen in 1947 under

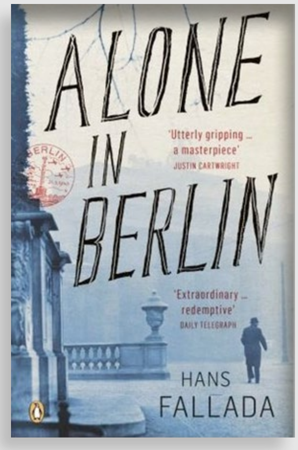

Figure 1. *Alone in Berlin*[14]
© 2009, Penguin Books, London

the pen name Hans Fallada), published in English as *Alone in Berlin* (figure 1), the writer describes the police search:

> "The dust-coloured man had pulled out a streetmap of Berlin and pinned it on the wall. Now he stuck in a red flag, exactly over the office block in the Neue Königstrasse. 'You see, this is all I can do for the moment. But over the next few weeks, more and more flags will go up, and where the density is greatest, that's where our hobgoblin will be found. Because over time he will wear out, and he won't want to go all that way to drop one of his postcards.'
>
> "The inspector led the gentlemen back to the map, and, speaking in a whisper, showed them how although there were flags evenly sowed all over the area north of the Alex [the Alexanderplatz], one little area had none at all.
>
> " 'And that's where my Hobgoblin [sic] lives. He doesn't drop any cards there, because he is too well known; he would have to worry that a neighbour might see and identify him. It's a little working-class enclave, just a couple of streets. That's where he lives.' "[14]

Fallada's novel, which Primo Levi† called "the greatest book ever written about German resistance to the Nazis," is based on the case of Otto and Elise Hampel. After Elise's brother was killed in France, the Hampels began leaving postcards in apartment buildings around Berlin, denouncing the Nazis (figure 2). Roughly translated, the card in figure 2 says "Free Press! Continue with the Hitler [?] system and the common soldier Hitler and his gang will plunge us into the abyss! This Hitler Goring Himmler Goebbels gang is for Germany only a death chamber." After a tip from an informant, the Gestapo arrested the Hampels in October 1942 (figure 3). They were tried, found guilty, and executed in Plötzensee Prison in 1943.

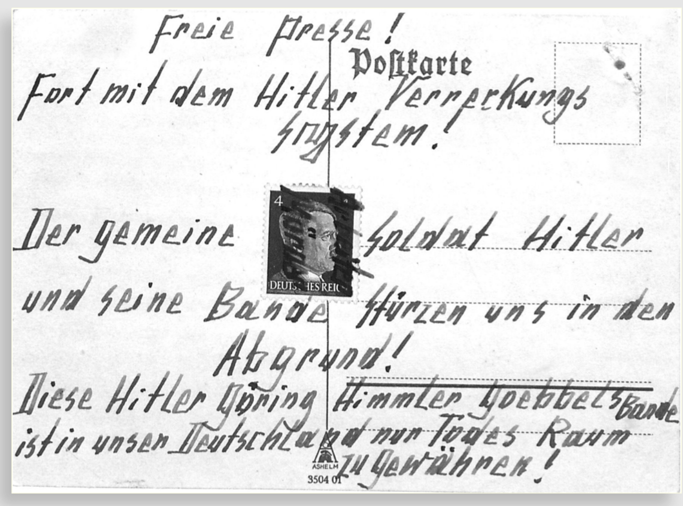

Figure 2. Hampel Postcard

†Levi, an Italian scientist and writer, wrote *Survival in Auschwitz* about his year in that concentration camp.

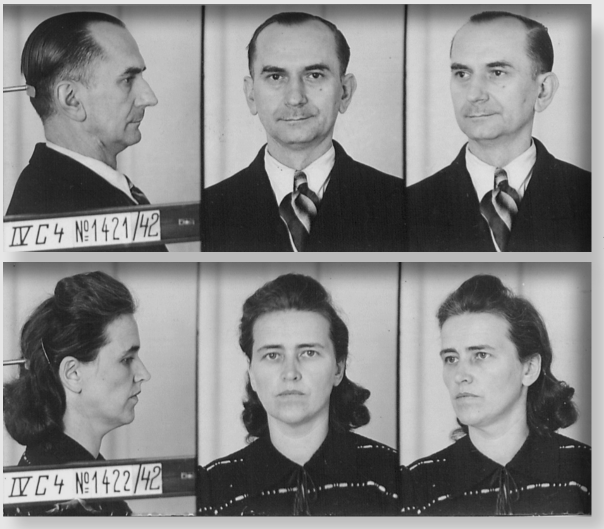

Figure 3. Otto and Elise Hampel

The concepts of distance decay and buffer zone were clearly used in the actual Gestapo investigation led by a *Kriminalsekretär* (Detective Sergeant) Püschel:

> "*Hauptverbreitungsgebiet ist nach wie vor die Gegend des Wedding, vor allem die Strassenzüge beiderseits der Müllerstr. Die Fundorte der Hetzschriften lassen nach wie vor nur den Schluss zu, dass der Hersteller bezw. der Verbreiter nur in der Gegend der Müllerstr, etwa in Höhe der Brüsseler und Amsterdamer Str. wohnen kann.*"‡

> "[The main focus of distribution remains the area around Wedding, particularly the streets on both sides of Müller Strasse. These sites at which the inciteful writings were found still suggest that the author or distributor must live in the vicinity of Müller Strasse, probably between Brüsseler and Amsterdamer Strasse.]"

After Otto Hampel was identified as a suspect, Püschel noted the existence of what we would now call a buffer zone around the Hampels' apartment:

> "*Die Überprüfung der Vorgänge in Bezug auf die Fundorte und die Person Hampel ergab, dass in Wohngrundstück des Hampel derartige Karten nicht gefunden worden sind. Dagegen sind früher einmal die nächsten beiden Eckgrundstücke Thriner Str. 46 und 48 mit derartigen Hetzschriften belegt worden.*"

> "[Further enquiry into possible connections between retrieval sites and Hampel revealed that no such cards were found on the premises he is living on. However, cards have been retrieved from neighboring corner properties 46 and 48 Thriner Strasse.]"

> *"The concepts of distance decay and buffer zone were clearly used in the actual Gestapo investigation . . ."*

Geographic Profiling: *Alone in Berlin*

For this study, we digitized and geocoded the 214 addresses at which the Gestapo had found a postcard or letter between 2 September 1940 and 16 September 1942. The Gestapo records subdivide

‡German language passages are from police file number *Stapo IV* A 1 c, 25 September 1942.

the 214 locations into seven bands (volumes) in the order in which the cards or letters were discovered (figure 4).

4

Hetzschrift "F R E I E P R E S S E"

Band III.

Nr.	Tag	Zeit	O r t	Art
61.	12.4.41		Hausburgstrasse 10	1 Karte
62.	12.4.41		Fritz-Schulz-Str. 41	1 Karte
63.	14.4.41	13,00	Hagelberger Strasse 9	1 Bogen
64.	14.4.41	13,00	Gross-Beeren-Str. 36	1 Bogen
65.	15.4.41	16,00	Fritz-Schulz-Str. 41	1 Karte
66.	20.4.41	12,45	Jasmunder Strasse 15	1 Bogen
67.	27.4.41		Seestrasse 57	1 Bogen
68.	27.4.41	15,15	Wendenstrasse 2	1 Bogen
69.	23.4.41		Hennigsdorfer Str. 3	1 Karte
70.	1.5.41	18,30	Wittstocker Strasse 25	1 Bogen
71.	4.5.41	19,45	Wagnitzstrasse 41	1 Bogen
72.	5.5.41	14,15	Brunowstrasse 53/54	1 Bogen
73.	11.5.41	11,00	Linarstrasse 2	2 Karten
	11.5.41	12,00	Wildenowstrasse 3	1 Karte
74.	14.5.41	8,00	Müllerstrasse 34 a	1 Karte
75.	15.5.41		Glasgower Str. 7	1 Karte
76.	15.5.41	18,30	U-Bahn Alexanderplatz	1 Karte
77.	15.5.41	21,00	Luxemburger Strasse 2	1 Karte
78.	16.5.41		Bahnhofstrasse 13	1 Bogen
79.	17.5.41		Wiesenstrasse 44	1 Karte
80.	17.5.41	16,00	Müllerstrasse 145	1 Karte
81.	18.5.41	12,30	Wiesenstrasse 22/23	1 Karte
82.	18.5.41		Treskowstrasse 32	1 Bogen
	18.5.41		Schulstrasse 5	1 Bogen
83.	19.5.41	18,30	Wittstocker Str. 25	1 Bogen
84.	20.5.41	21,00	Utrechter Strasse 28	1 Karte
85.	21.5.41	21,30	Barfusstrasse 18	1 Karte
86.	26.5.41	11,30	Schererstrasse 7	1 Bogen
87.	26.5.41	20,00	Wichertstrasse 10	1 Bogen
88.	26.5.41	20,45	Wichertstrasst 7	1 Bogen
89.	27.5.41	20,00	Müllerstrasse 151	1 Karte
90.	5.6.41	20,45	Rykestrasse 37	1 Bogen

Kopie aus dem Bundesarchiv

The addresses were analyzed using the software Rigel (ECRI Canada), which is based on the criminal geographic targeting algorithm.§ Ten incidents that could not be associated with a precise location were excluded from the analysis. (For example, incident number 181 was assigned only to the Wedding neighborhood.)

Figure 4. Incident Locations 61 Through 90 in Volume III

We used historical maps from the online *Berlin City Map Archive* at URL: http://www.alt-berlin.info/ to identify locations on a modern map, then further verified the locations by a site visit to Berlin. Figure 5 shows the residences of the Hampels and their relatives. Red dots mark the incident locations in this frame where the Gestapo recovered anti-Nazi postcards or letters.

The modern Berlin street layout closely matches that of World War II maps and, surprisingly, many of the original buildings are still in existence. Figure 6 shows a

©Environmental Criminology Research, Inc. (ECRI) Canada, Google Maps

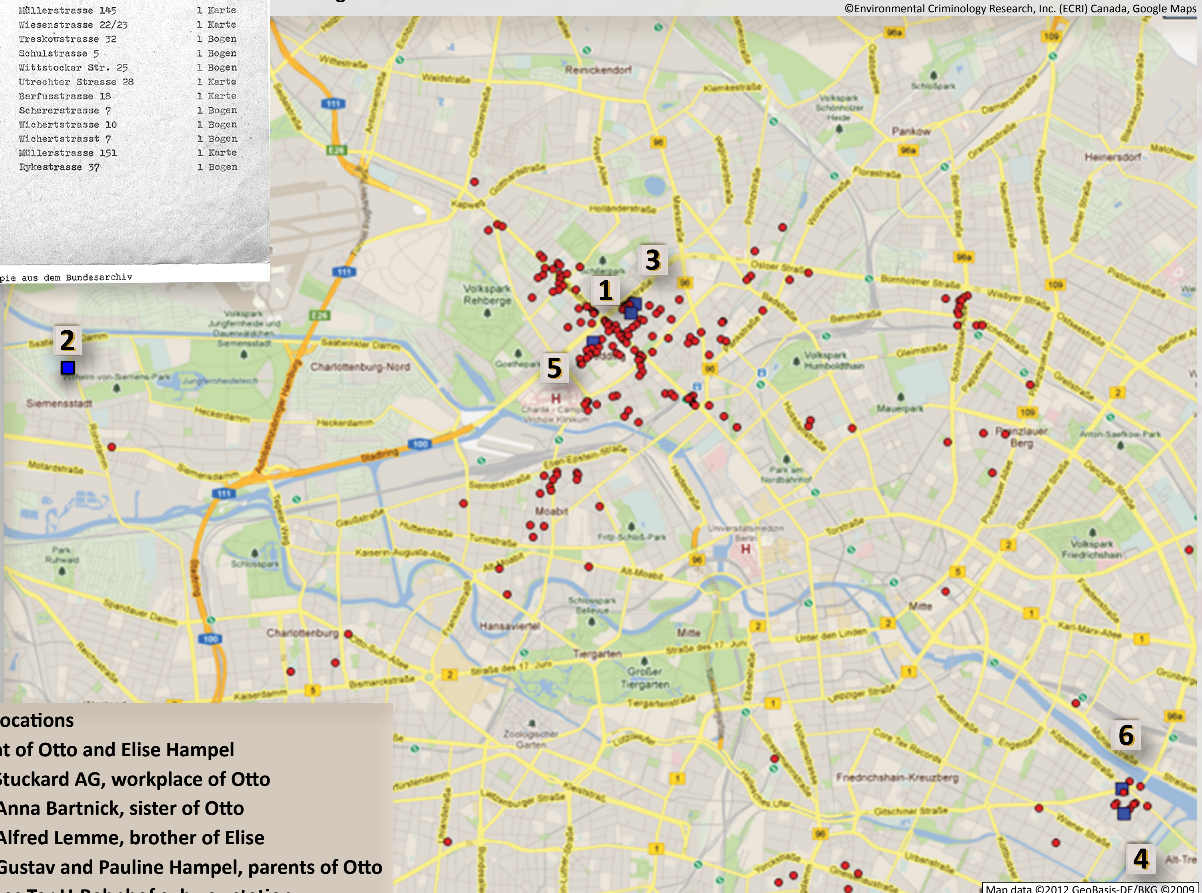

Figure 5. Central Berlin, Depicting 207 Incidents in the Hampel Case

§ The authors describe this in detail in *Geographic Profiling*.[4]

typical location (incident 64), where a one-page anti-Nazi letter was recovered from an apartment building at Gross-Beeren-Strasse 36, in the Kreuzberg district, on Monday, 14 April 1941. The Gestapo listed incident 64 in figure 4 (on page 58).

We prepared a geoprofile for each temporal volume separately, a geoprofile for all 214 incident locations (the base case), and a geoprofile from which duplicate addresses had been removed (table). The performance of a geoprofile can be measured by the hit score percentage (HS%), which is the proportion of the area covering the incidents that must be searched before the offender's anchor point is located. The HS% is equal to the target area divided by the hunting area; the target area is the size of that search area, and the hunting area is the rectangular area encompassing all the analyzed incident sites (equivalent to the area of interest). HS% is a measure of the

Figure 6. Incident Location 64, Gross-Beeren-Strasse 36 Entrance (Left) and Interior Where a Letter Was Found (Right)

Table. Incident Locations, Hit Score Percentages, and Target and Hunting Areas (in Square Miles) for Nine Geoprofiles

Geoprofiles	Incident Locations	Hit Score %	Target Area	Hunting Area
Volume I 2 September 1940 to 11 March 1941	35	0.38%	0.13	34.14
Volume II 12 March 1941 to 6 April 1941	33	0.16%	0.13	82.60
Volume III 12 April 1941 to 5 June 1941	32	0.15%	0.22	144.60
Volume IV 4 June 1941 to 24 August 1941	33	3.03%	0.40	13.22
Volume V 31 August 1941 to 28 December 1941	34	0.05%	0.012	24.37
Volume VI 1 February 1942 to 30 May 1942	35	0.43%	0.19	43.78
Volume VII 12 July 1942 to 16 September 1942	12	0.92%	0.50	54.18
Total Incident Locations (Base Case)	214	0.08%	0.12	146.44
Unique Incident Locations	172	0.11%	0.16	146.78

ability of a geoprofile to prioritize suspects: the smaller the HS%, the more accurate the geoprofile. We would expect a hit score of 50 percent from a nonprioritized search.

Figure 7 shows the frequency of incidents of recovered postcards and letters by distance from the Hampel apartment, overlaid with a kernel density curve. The distribution exhibits both distance decay and a buffer zone. Figures 8 and 9 show the jeopardy surface (three-dimensional) and the geoprofile (two-dimensional), respectively, produced from the analysis of the incident data. Probability of offender anchor point is indicated by both color and height in figure 8 and by color in figure 9. For example, areas in red or orange have a higher probability than do those in gray or purple.

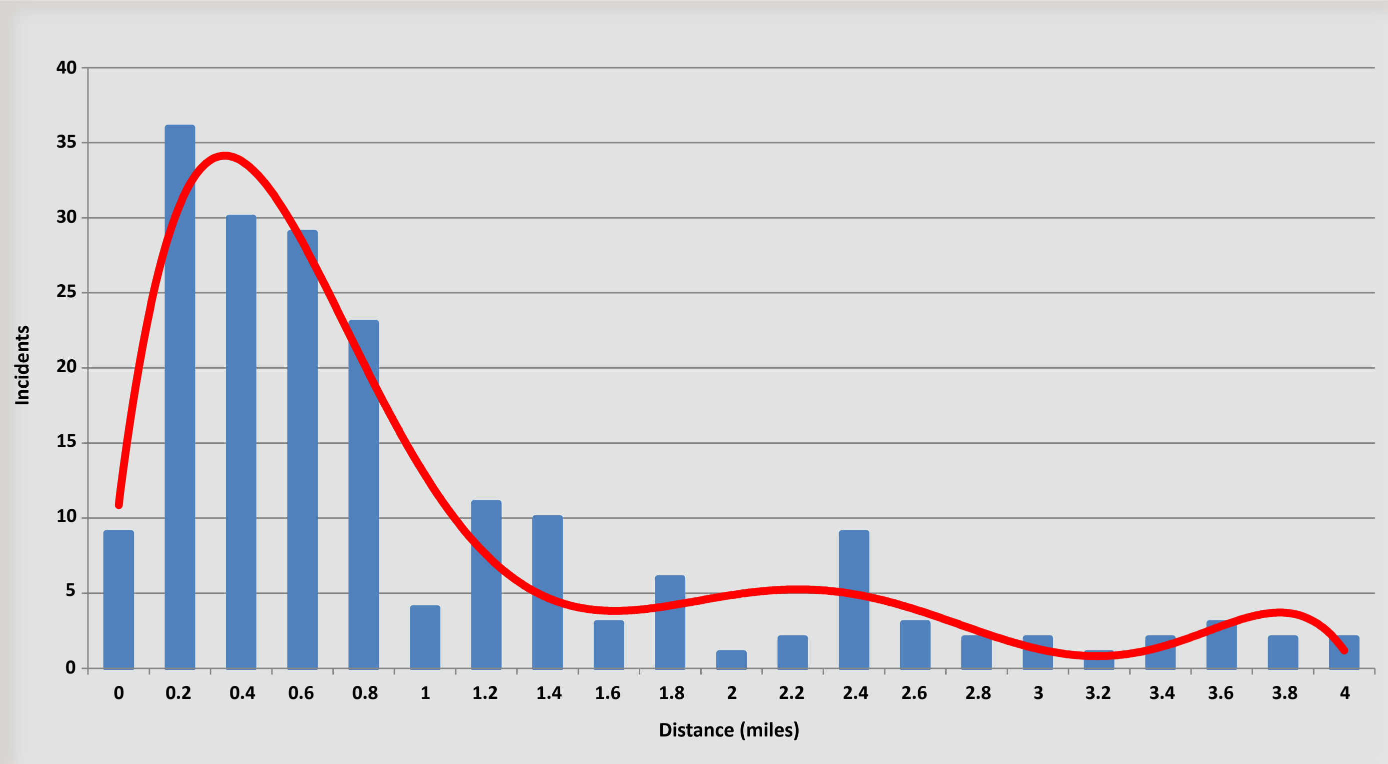

Figure 7. Frequency of Incidents by Distance From the Hampel Apartment

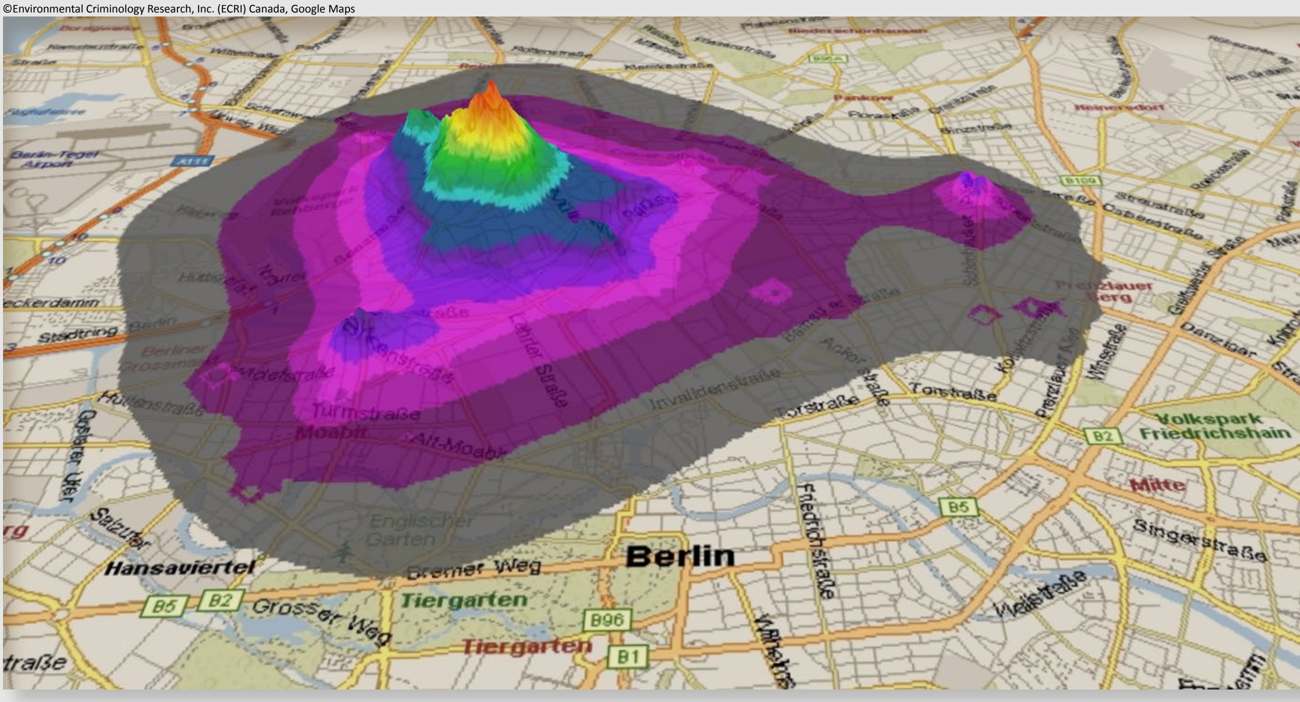

Figure 8. Hampel Base Case Jeopardy Surface (Three-Dimensional)

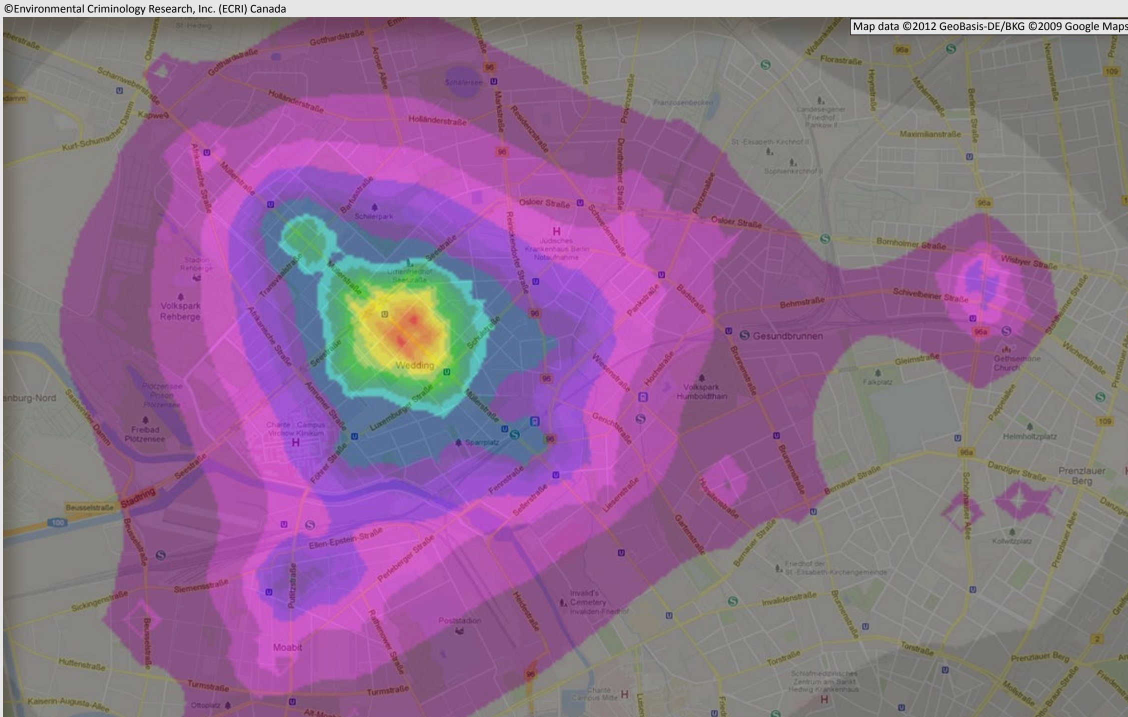

Figure 9. Central Area of Hampel Base Case Geoprofile (Two-Dimensional)

“. . . the data would have been sufficient to prioritize the Hampels’ apartment as early as March 1941 had the Gestapo used modern techniques. ”

On the basis of the analysis of all 214 incident locations, the peak of the geoprofile—hence the most likely location for the offender’s anchor point—includes Amsterdamer Strasse 10, the Hampels’ apartment. Amsterdamer Strasse 10 appears in the top 0.08 percent of the geoprofile (a 500-fold improvement from a random search). The map in figure 10 shows the Hampel apartment and the homes of Otto’s parents and sister superimposed over the peak 0.1 percent of the 214-incident (base case) geoprofile.

Remarkably, the data would have been sufficient to prioritize the Hampels’ apartment as early as March 1941 had the Gestapo used modern techniques. In the geoprofile based on the 35 incident points in the first volume (2 September 1940 to 11 March 1941), the Hampels’ apartment is found in the top 0.4 percent of the geoprofile (table on page 59).

The addresses of other Hampel family members also had a high HS%. Otto’s parents, Gustav and Pauline Hampel, lived close to Otto and Elise (HS% = 0.09%), as did Otto’s sister, Anna Bartnick (HS% = 0.19%). Elise’s brother, Alfred Lemme, lived in Falkensteinstrasse until July 1942 (see figure 5, page 58); his home fell on a secondary peak southeast of the main peak (HS% = 2.28%).

Secondary peaks were near other relevant locations (see figure 5, page 58). These include the stations at S-Bahnhof Schönhauser Allee and Schlesisches Tor U-Bahnhof (HS% = 2.89% and 4.96%, respectively), suggesting these were routes used by the Hampels between their apartment and Alfred Lemme’s home. In contrast, the incident location where Otto left only one note near his workplace at Siemens Stuckard AG did not rank high in the geoprofile.

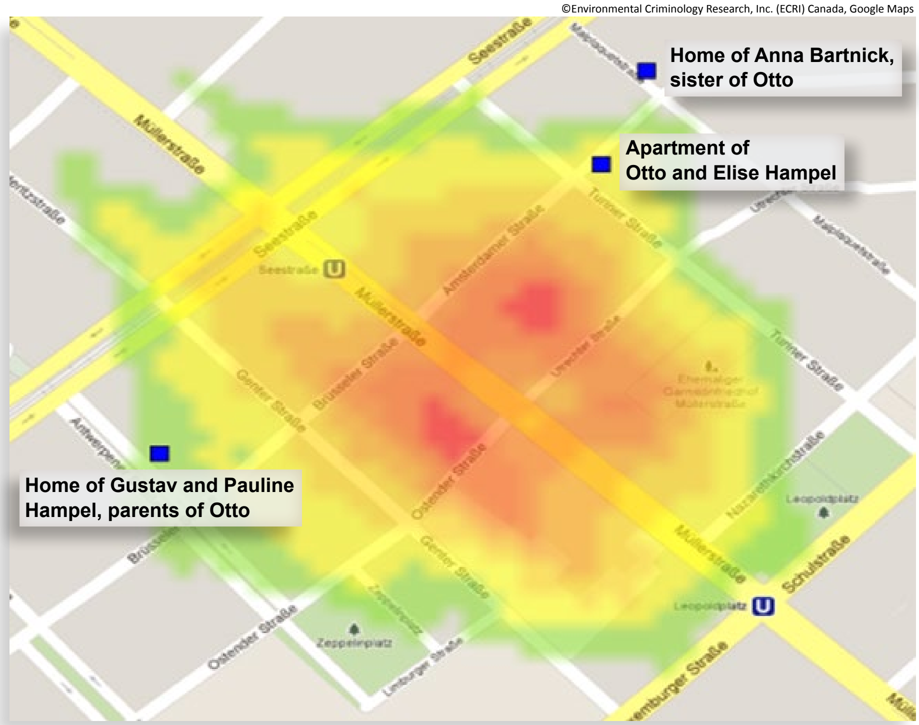

Figure 10. Closeup of the Top 0.1 Percent of the Hampel Base Case Geoprofile

Discussion

Beyond its historical interest, the present analysis of the Hampel case demonstrates the potential of geographic profiling in similar situations today. The problems that faced the Gestapo have parallels in modern counterterrorism investigations and counterinsurgency efforts, which must also deal with information overload challenges.[1,3,10] This is exactly the problem geographic profiling is designed to address by prioritizing large lists of suspects in a meaningful way.

The algorithm is robust and generalizable. The model parameters we used to analyze World War II insurgency are the same as those used for modern serial murder and rape investigations, studies of animal foraging, and identification of malaria epidemic outbreak sources.[4,5,6,7,8] Model generalizability is an important characteristic in geospatial analysis as it provides confidence in the application of a technique in new and unique situations and in a variety of domestic and foreign environments.

The focus provided by a geoprofile is significant, providing an area small enough for a variety of suspect- and area-based investigation strategies.[4] Though most of the incident locations in the Hampel case were in the highly dense Wedding area of the Mitte borough of Berlin, the Hampels distributed their postcards over 150 square miles—44 percent of Berlin's total area. Therefore, the HS% of 0.1 covers approximately 0.15 square miles. Even in that small an area, there are over 2,500 people in almost 800 households (based on estimates of the current Berlin population density and household size).

Modern geographic profiling methods are a considerable improvement on the original investigation. Despite the Gestapo's reputation for ruthless efficiency,[15] two years and 214 incidents passed before the Gestapo arrested the Hampels. Of particular interest is how quickly the geoprofile narrowed in on the Hampels' apartment; after only 35 incidents (16 percent of the total of 214 incidents), their apartment could be found in less than one-half of one percent of the area of interest. This geographic focus would have been possible as early as spring 1941, a full 18 months before the arrest of the Hampels in the fall of 1942.

Although much attention is typically focused on major attacks—bombings, kidnappings, hijackings—certain terrorist or insurgent organizations may engage in low-level seditious activities similar to the Hampels' campaign. The activities may include theft, vandalism, antigovernment graffiti, leaflet distribution, or banner posting.[1,16,17] Rossmo and Harries[1] suggest that the creation of geospatial databases of terrorism-related graffiti could help locate terrorist support bases before more serious incidents occur, and the *Alone in Berlin* study provides empirical support for this suggestion. Of course, in this particular case, our sympathies are with the insurgents (figure 11).

Figure 11. Berlin Memorial to Otto and Elise Hampel

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Geospatial Analysis: Origin and Development in the National Geospatial-Intelligence Agency

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An Exciting and Critical Time

This is an exciting and critical time for geospatial analysis. GA today is not what its forefathers envisioned; what it will be tomorrow will be based largely on changing world conditions and the imagination of practitioners. The convergence of new ways of thinking about problems, new technologies and methodologies, an abundance of new sources, continual progress in the establishment of national and global data standards, and our own creativity will be the only limiting factors.

> *"More than the mechanics of operating a geographic information system (GIS), GA is about answering questions."*

In the article, the authors first give their perspective on the definition of geospatial analysis. Subsequent sections explain how GA evolved as a tradecraft in the National Imagery and Mapping Agency (NIMA) and NGA and the resulting profession and process. The last sections list fundamental issues with GA and estimate what lies ahead.

The article is not conclusive, but open to interpretation and discussion. The conversation and the tradecraft do not end here; an event, technology breakthrough, change in practices (analytical methodologies), and/or new data sources may collectively or individually change the future of this discipline.

What is GA?

Definitions of "geospatial analysis" vary, even within the geospatial community. Many agree that geospatial analysis is an emerging discipline that brings data and information into a spatial and temporal context. GA visually portrays, integrates, and correlates diverse georeferenced information found in text, images, and databases, while also applying statistical techniques. GA can identify trends and patterns not discernible in unformatted data.

One reason definitions vary is that GA crosses disciplines. More than the mechanics of operating a geographic information system (GIS), GA is about answering questions. GA provides insight into economics, business, agriculture (farming and illicit drugs) and migration, military (peacekeeping and war planning), and political, social, and cultural developments. GA also plays a significant role in planning for and recovery from environmental and manmade disasters.

Another reason definitions vary is that open-data sharing and the integration of broad sets of technology have led to the emergence within GA of distinct disciplines such as:

- **Human geography** is an evolving discipline that builds on physical and cultural geography and also uses other geospatially referenced sources. Human geography provides tribal, religious, economic, political, and cultural understanding. This gives policymakers, aid workers, and military personnel information to support decisions on diplomatic, policy, and military predicaments.

- **Quantitative geography** as a study began in the 1950s as an effort to apply scientific methods to geography and provide meaningful analysis of georeferenced data. Quantitative geography now benefits from advancements in database-driven GIS with robust statistical tools. These developments allow geospatial analysts to assess complex problems on full-scale models over space and time. Other advances led to a greater role of spatial statistics and modeling in geography by integrating the disciplines of physical and human geography.

- **Social media** can provide aggregated insights into the sentiment of populations according to georeferenced chatter about regional political and socioeconomic changes. Social media such as tweets provide information on changes to the physical environment such as describing a new facility. Most people visit YouTube for fun, but YouTube video also provides situational awareness of events such as natural disasters, terrorist activity, and civil unrest. As more people carry digital cameras or smartphones they record and geotag more events.

- **Volunteered geographic information** (VGI) sites such as OpenStreetMap[1] and Wikimapia[2] provide real-time, on-the-ground information on changing commercial, cultural, and transportation features and attributes not discernible on airborne or satellite sensors (for example, storefront mosques or hospital trauma units). This data layer is timely and has a high level of accuracy because of the self-correcting nature of crowdsourcing. These data can be combined and manipulated—both historically and in real time—to anticipate and potentially predict events. Figure 1 on the next page compares VGI in OpenStreetMap to the official Digital Vertical Obstruction File (DVOF).*

*The scene in figure 1 around Dubai International Airport covers 265 km^2. The DVOF specifies 120,371 obstructions in this area. VGI provides 39,667 potential additional obstructions in the same area.

Figure 1. Vertical Obstructions From OpenStreetMap (pink) Compared to Vertical Obstructions in the Official DVOF (yellow)

The Evolution of GA in NIMA and NGA

NIMA, and to a greater extent NGA, experienced a major evolution in GA. The agency tradecraft changed from cartographic specialists relying on limited datasets to groups of multidisciplinary teams working with content from widely varying sources. New technologies and huge amounts of diverse data gave government analysts new abilities to address global, national, and local needs.

Academe and industry had been combining GIS and remote sensing to address commercial activity, agriculture, emergency services, and urban planning. Government imagery and geography professionals also recognized the potential benefits. Inside NIMA, senior managers like Robert S. Zitz, Irvin Buck, and Roberta (Bobbi) E. Lenczowski set geospatial analysis in motion—but at a faster pace and with greater complexity than in the private sector. NIMA had the power of sources, technologies, and tradecraft found only in the Intelligence Community (IC) and Department of Defense. Despite these advantages, NIMA managers knew it would not be easy to change decades of intelligence and cartographic culture.

National Imagery and Mapping Agency

The National Defense Authorization Act for Fiscal Year 1997 established NIMA on 1 October 1996. The creation of NIMA followed more than a year of study, debate, and planning by the Defense, Intelligence, and Policymaking Communities (as well as Congress) and consultations with customer organizations. NIMA centralized responsibility for imagery and mapping. The new agency was a diverse mix of talent and expertise from the imagery, mapping, and information collection elements of the Central Intelligence Agency, the Defense Intelligence Agency, the Defense Mapping Agency, the National Photographic Interpretation Center, and the National Reconnaissance Office. In the 1990s, Congress and the IC were driven to reduce costs and improve efficiencies in the exploitation of national technical means.[3] The decision to form NIMA was based on the premise that imagery was the resin that joined the diverse missions of these agencies. However, each agency tasked, enhanced, extracted, and exploited image data for different purposes—and in a way that was not well integrated among the agencies.

NIMA's first effort to formalize GA was part of a program called Workforce 21 (1998-2001). This program established occupations to accomplish NIMA missions, developed a performance-based pay system, and converted the General Schedule pay scale to a banding pay scale. Workforce 21 specified the skills, training, and education required for NIMA's tradecrafts including one known, for the first time, as "geospatial analysis." Unfortunately, Workforce 21 coincided with Congressional pressure to downsize, which led to the elimination of cartography as a work role (cartography was to be outsourced, but NGA later reversed this decision).† Even after Workforce 21, geospatial analysis remained largely misunderstood until NIMA became NGA.

Four things influenced the transition from NIMA to NGA. The Independent Commission on the National Imagery and Mapping Agency published its recommendations in 2000 (figure 2). James R. Clapper, Jr., Lieutenant General, USAF (Ret.) became Director of NIMA in 2001. Terrorists destroyed multiple targets inside the US on 11 September 2001. Academe began graduating a steady supply of students with degrees in GIS-related disciplines.

†One finding of the Commission: "D/NIMA appreciates the need to bolster long-term imagery analysis and plans to transfer 300 NIMA positions (60 per year, 2001-2005) from cartography to imagery analysis, all of whom would remain in the Washington, DC, area to support Washington customers and rebuild NIMA's long-term analysis capability."[4]

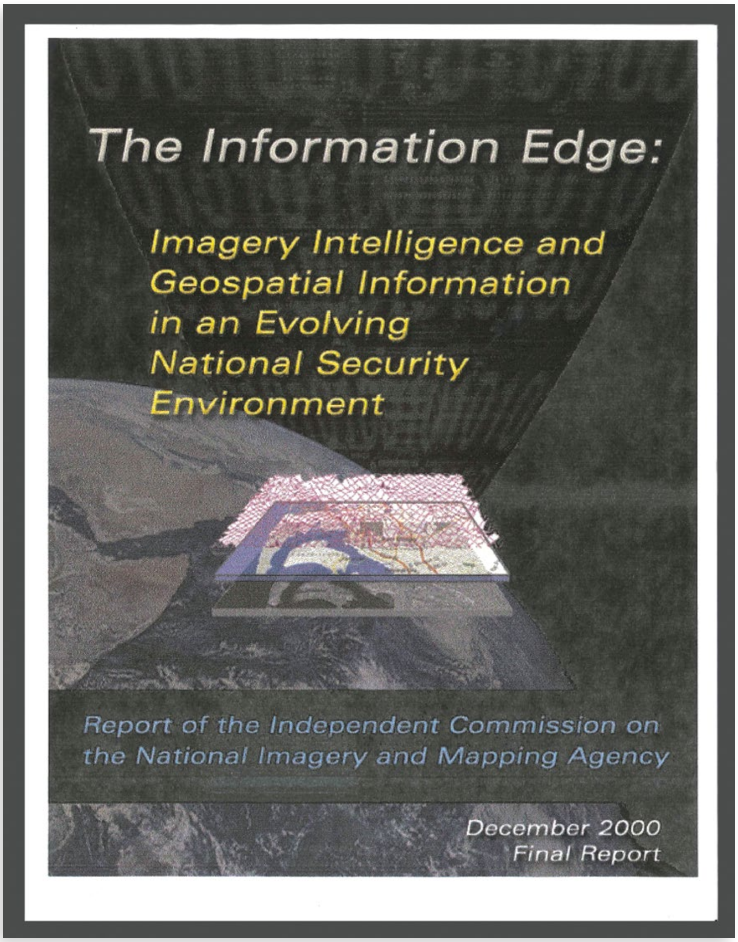

Figure 2. Independent Commission on the National Imagery and Mapping Agency[4]

In 1999 Congress requested the Director of Central Intelligence and the Secretary of Defense to form a commission to review NIMA, the national security environment, and US doctrine. In December 2000 the NIMA Commission concluded that, although progress had been made, the promise of converging mapping and imagery exploitation into a unified geospatial information service had yet to be realized. NIMA continued to experience "legacy" problems, both in systems and in staff. Admittedly, these problems were not of NIMA's making—it had inherited two disparate cultures, an expanding mission, and inadequate resources.[4]

Clapper became the third Director of NIMA on 1 September 2001. He emphasized the geospatial principle that everyone and everything can be referenced to the Earth in space and time. This perspective recognized the potential of geospatial analysis to solve myriad problems that had previously gone unanswered or for which conventional methods could not deliver timely results.

The terrorist attacks on 9/11 accelerated change throughout the IC, including NIMA. The new focus on an unconventional, nonstate adversary that was less susceptible to traditional problemsolving called for different methods. GA could make new kinds of contributions.

By 2001, more new analysts were arriving with formal degrees in GIS-related disciplines, and in 2003 NGA added GA-related training to its analyst basic course. In the Geospatial Intelligence Training Program, geospatial analysts (and all NGA analysts) now learned principles of problemsolving, collaboration, imagery analysis, GIS applications, and cartography.

The integrated use of GIS tools, photointerpretation, and multiple intelligence sources such as human intelligence and signals intelligence expanded the limits of what was achievable in the isolated domains of imagery analysis and cartography. In addition, the move from hardcopy to softcopy production facilitated open and multisource harvesting and fusion. During his tenure as Director for Analysis, the author saw GA begin to assist in analysis, bringing an additional skillset and context to address the overall intelligence requirements. These reports were not always limited to imagery observations. They included non-imagery-derived georeferenced information and added context to the analysis. By 2005 GA had become the second largest analytic profession in NGA (after imagery analysis).

The Profession and Process of GA

GA is both a profession and a process. The profession requires analysts to present knowledge appropriately to decisionmakers for specific purposes. The process requires analysts to identify, collect, store, and manipulate georeferenced data and related information using critical thinking, reasoning, and analytic methods.

> *". . . more new analysts were arriving with formal degrees in GIS-related disciplines . . . "*

Today, geospatial analysts enter the profession with education and training in diverse specialties. Many studied GIS, imagery analysis, cartography, geography, remote sensing, imagery science, and/or geodetic science. Other backgrounds include geology, international studies, safety of navigation, aerospace, chemistry, biology, history, anthropology, statistics, engineering, political science, forestry, meteorology, agriculture, nuclear power, and petroleum exploration.

The profession has advanced to the stage where government and industry are collaborating to develop certifications for GA tradecraft. These programs will document the skills, knowledge, and competencies of the individual analyst, with obvious advantages for hiring and assignment decisions (especially during crisis surge). The data from certifications will also help drive curriculum and tool development.

Geospatial analysts call their processes "workflows" and these are critical to their tradecraft. Once the GA frames a question, he or she develops a workflow that encases the problem. The workflow includes data and information, tools and applications, geospatial analysts and other kinds of experts (collaborators).

Technology has come a long way in developing tools and applications to support GA. What once required the manipulation and integration of many tools can now be achieved with single software applications. Advanced geostatistical analysis tools are now incorporated into GIS software and provide expert systems to lead the users to statistically valid results. The advent of background, server, and cloud-based geoprocessing services has largely removed the tedium of waiting on intermediate geoprocessing calculations in an analytic workflow. One example of interoperable design is the Open Geospatial Consortium standards that allow users to publish data that can be saved as an Open Web Services Context document to be shared with others.

In contrast to the 1990s, geospatial analysts now arrive with process experience. Newly hired analysts have already used computer applications and diverse data to solve real-world problems during their training and education. Some "new" analysts have served previously in combat or worked in other fields that require accurate and current data.

Issues in GA

Geospatial analysts will continue to be challenged by new technologies, more complex problems, and reduced timelines. Different kinds of data are transforming workflows. Access to good data has always been decisive, but it is more about content than databases. In addition to the data, GA depends on analyst experience. Collaborative teams outperform individual analysts.

Access to the right data, current data, and accurate information have always been the tall poles in the tent. Access to more data and information is both a blessing and a curse. Many sources of data may apply to an area of interest, and the currency, completeness, and even the pedigree of these data vary from excellent to nonexistent. Some data and information will inevitably be inaccurately positioned or presented on more than one datum. Some metadata are not tagged geospatially, are not presented in consistent formats, or are missing altogether.

Even when data are current and accurate, direct access and static databases are no longer the only sources of these data. The increasing volume of imagery, video, and other sources results in new workflows to accommodate streaming data (for example, via JPEG 2000 Interactive Protocol), automated data reduction, and change detection-based tipping and queuing. Analysts must evolve workflows to accommodate new data sources and new processing methods.

Accordingly, where geospatial analysts once talked mostly about "databases" the conversation now emphasizes "content." Content is now more diverse and wide ranging than tightly organized feature data in a specific schema. Content may have no fixed structure and may be variably geoenabled. Unstructured content can mix truth with hearsay in nonobvious ways.

GA is data driven and fact based but also depends on analyst experience and insight. One example is a spatial analysis used to predict civil unrest in South Africa by georeferencing social media that aggregate regional changes in sentiment (figure 3). Most of the hotspots of aggression correlated with agitated communities, but a nonsocial scientist observed that the red "S" shaped area in the lower center of the map more likely corresponded to drivers in heavy traffic on major freeways than to instigators of civil unrest. The geospatial analyst must not become trapped in

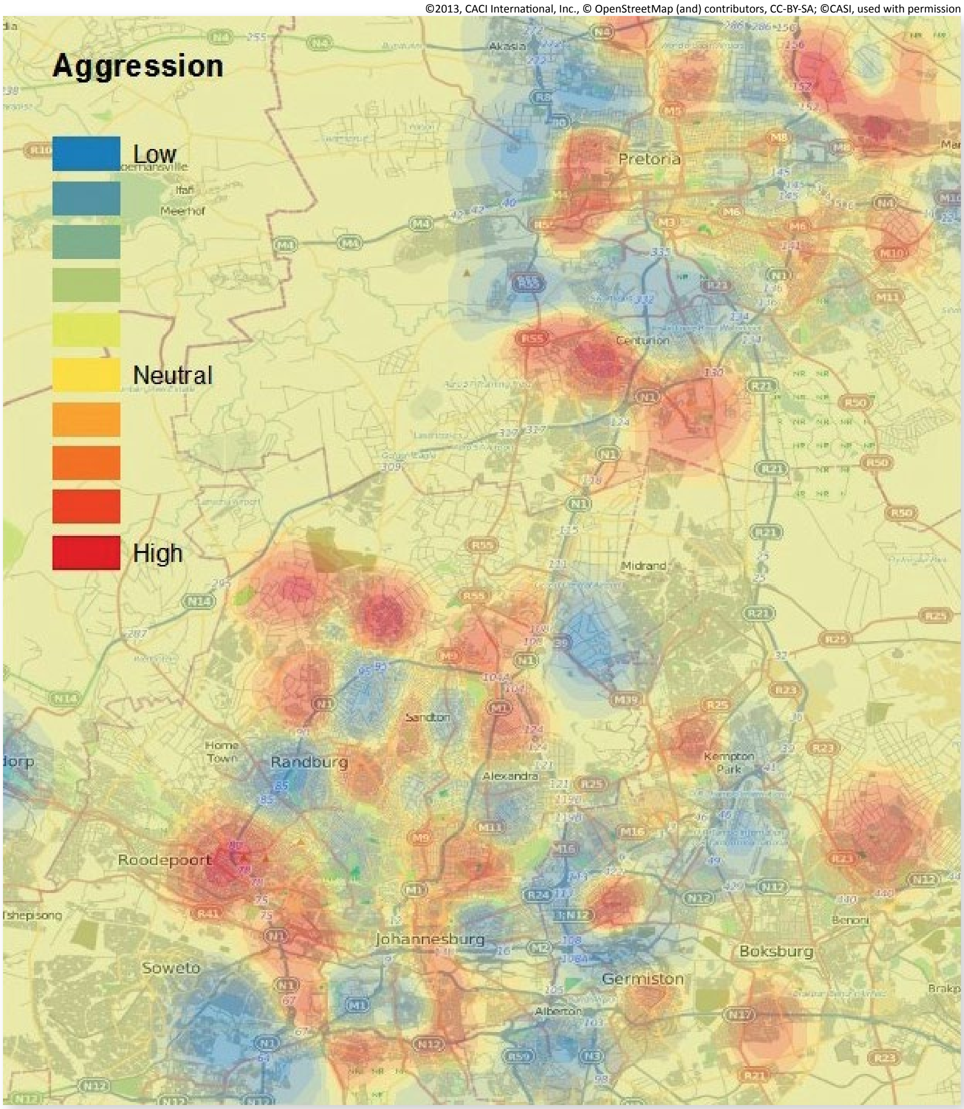

Figure 3. Civil Unrest in South Africa From a Sentiment Analysis of Twitter Messages[5]

the comfort zone that accepts all data as truth. There is never enough data and information for a decisive result. Geospatial analysts gain experience and insight over time, learning by doing.

As demonstrated in the civil unrest example, collaboration outperforms the individual "Renaissance Man," especially when data are complex and indirect. Generalists no longer rule; there are too many skills for one analyst to acquire, too many things for one analyst to know. When faced with a complex problem the geospatial analyst needs to work with specialists outside his/her area of expertise. For any geospatially related workflow, this includes planning, determining requirements, collecting, exploiting and analyzing the data, and communicating the results. Although the geospatial analyst may create the integrated visual components, other experts collaborate in the analysis.

The Future of GA

In five years we may hardly recognize the duties of a geospatial analyst. The way analysts discover, collect, and use geospatial data will change—and even accelerate—at a rapid rate. The workflows of GA will continually improve, in terms of both improved fidelity of derived information and access to new technologies.

> *"GA will evolve into subdisciplines with clearly defined practice areas in their own right."*

GA will evolve into subdisciplines with clearly defined practice areas in their own right. Many practices expand as they become enabled by new technology and new types of data. GA is akin to a cookbook that can support diverse applications using the same basic ingredients. Many disciplines require a foundational layer of the natural features and positional references to the Earth's surface, then add their own data sources to complete their recipe.

The geospatial analyst of the future will need to sift through enormous amounts of data and poorly structured sources. This will require an ability to vet information using automated validation and metadata change detection. Algorithms that identify changes in known features and attributes must be able to validate changes using reliable sources.

Technology and the availability of data may advance more quickly than our expertise will allow us to best exploit new capabilities. Content and tools will straddle classified and unclassified environments and will perform as though they have an innate "knowledge" of where they are being used and for what purpose. Only the appropriate data will be accessible and only the proper functionality will be enabled for each task. The content will be "smart" enough to automatically rescale.

Consumer applications will begin to dominate where the needs of the warfighter once drove the evolution of GA. The general public already uses navigation devices that dynamically alter directions to compensate for traffic. This fusion of foundation data (the street database) and dynamic content (traffic reports in many formats) is the tip of the iceberg. It may not be long before mobile devices perform a cost benefit analysis to optimally route trips on the basis of our shopping list, travel time, fuel costs, item prices, and schedule convenience. Free to most users, applications such as OpenStreetMap, Wikimapia, and Google will compete with the US Government to provide content. Figure 4 shows screenshots of the images that result from a Google search for "geospatial analysis."[6]

Mobile devices will become a one-stop shop, even for government analysts. Devices will provide communications (telephone/internet/social networks), photography (cameras/videos), geolocational functions (navigation, location-based information), various business applications, music, and so on. Through cloud computing and specialized applications, data layers become easily accessible. Soon enough, the government geospatial analyst will operate in an environment parallel to that of the general public with instantly available commercial imagery and web-based mapping sites.

Figure 4. Samples of Google Searches for "Geospatial Analysis"

Devices will "learn" and integrate our daily habitats and routines, providing information even before we request it. The Ozone Widget Framework (a web-based platform that allows users to easily access online tools from one location) and other environments for focused applets will be a bridge to the future, but mobile apps will soon be so flexible that analytical processes will be updated and results disseminated on the fly, without human intervention. The expression "There's an app for that" will become "the app knows what you want before you do."

Conclusions

Vast holdings of geospatial information and access to advanced technology are no longer the exclusive province of government professionals. GA has become an interactive process that includes any individual who resides on the virtual grid. Some nontraditional areas of study already produce professionals with a keen understanding of how to use geospatial data. As the tradecraft evolves, industry and government will drive technological research that will make aspects of this discipline easier to use by an expanded customer base.

Commercial applications will force the tradecraft into new directions. Location-based capabilities, small satellites, unmanned aerial vehicles, sophisticated sensors, enhanced data processing and storage, driverless cars, and VGI will all affect GA tradecraft and are being developed at different speeds. The Department of Defense approach might best embrace rather than compete with these fast-moving trains and develop complementary solutions for government and military requirements.

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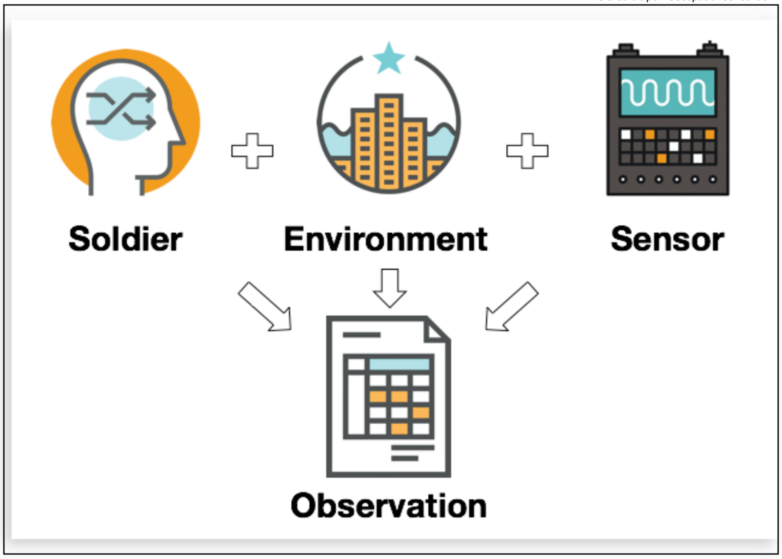

Figure 5. Soldiers and First Responders Will Operate or Carry Sensors That Collect Highly Reliable Data That Can Address Broad Requirements

To remain in the forefront of GA, organizations must advance and integrate technologies and incorporate alternative data sources. Areas that require attention include:

- Discovering, harvesting, and ensuring open-source data and information are fit for use (valid).
- Emphasizing nontraditional sources such as VGI, social media, citizen-as-sensor (or soldier-as-sensor), dynamic databases of natural phenomena (weather, stream gauges, aquifer levels, drought conditions, etc.).
- Establishing secure mobile devices for military and first responders to exchange data and information from users to a central server (figure 5).
- Leveraging databases and information services to increase integration and interoperability (by implementing consistent standards, schemas, and formats).
- Exploiting and integrating the diverse national and commercial sensors that span the electromagnetic spectrum.
- Understanding and accessing the proliferating small imaging satellites and unmanned aerial vehicles that are increasing persistence at reduced cost.
- Increasing GA training while maintaining cartographic, geodetic, and photogrammetric science expertise. The GA discipline benefits the IC but does not replace traditional tradecrafts.

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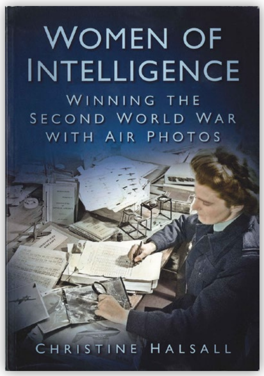
Women of Intelligence: Winning the Second World War With Air Photos

By Christine Halsall

***Reviewed by* Jack O'Connor**

Jack O'Connor recently retired as the National Geospatial-Intelligence Agency Chief Learning Officer. His latest work is NPIC: Seeing the Secrets and Growing the Leaders, *Alexandria, VA: Acumensa Solutions, 2015.*

Any practicing analyst who cares about tradecraft should read this book. It shows the enduring challenges of working with imagery as well as the stamina and resilience needed by photointerpreters to meet the challenge of providing combat and strategic support in an entirely analog world. The book recounts the history of the Royal Air Force (RAF) Photographic Interpretation Unit housed at a mansion at Medmenham and which became the Joint Allied Central Interpretation Unit, when the United States joined the War in Europe. This mansion, near Henley-on-Thames in Buckinghamshire, England, was the location of some of the most famous photointerpretation carried out during World War II, and it was also where the US Navy sent its officers before Pearl Harbor to begin to learn about the latest British advances in photointerpretation.



Women of Intelligence: Winning the Second World War With Air Photos

By Christine Halsall

© 2012
Spellmount, The History Press, Gloucestershire, UK
192 pages

The book outlines the British investment in photointerpretation, which had been initially driven before World War II by an Australian, Sidney Cotton. Cotton was an innovator in aerial photography who covertly photographed many German facilities until his last flight from Germany to England on 27 August 1939, four days before the War in Europe began.

Cotton created the three-phase model of exploitation, and, as the RAF had only one photointerpreter and a number of "photo-readers" in the summer of 1939, he brokered a working arrangement with a Canadian-owned aerial survey company that owned a Wild A-5 comparator, a Swiss-made instrument that could take more precise measurements from photographs taken by a Spitfire aircraft. At that time, the RAF did not own an operational Wild comparator.

As important as his technical contributions were, Cotton's employment practices had a greater impact on the war. Cotton recruited women as photointerpreters because he thought they had greater patience, attention to detail, and persistence than did men with comparable training. Halsall's book details how a number of capable women, some with unique and valuable skills, were recruited into the Photo Interpretation Unit, and how they were able to make some of the most significant intelligence contributions toward the Allied victory in Europe. One of the strengths of Halsall's book is how she captures the eclectic backgrounds of the female photointerpreters. The group included art students, archaeologists, aircraft enthusiasts, a confectioner, and a former actress.

Halsall is a volunteer at the Medmenham Collection, the British national archive of photographic interpretation history. She thoroughly researched the published and unpublished records and memoirs in the collection, and, more importantly, she obtained oral histories of the now aged workforce, both British and American, who worked at Medmenham.

The cultural history that she has compiled about the work of these women is important for two reasons. Many of the narratives describe tradecraft and skills that automation has since accelerated but which then had to be done manually. Developing photographs, using a slide rule to determine scale, arranging stereo pairs, correlating maps and film, indexing, mosaicking, and enlarging images were all manual processes that added time to the significant challenge of photointerpretation.

The second reason the book is important as a cultural history is that Halsall describes the challenges of photointerpretation with famous examples. The efforts involved in targeting for the Normandy invasion, defeating denial and deception at German shipyards and radar sites, assessing damage on strategic bombing raids, and planning for the Dam Busters raid on the Moehne Dam outline the criticality of the women's contributions and the timelines and conditions under which they were made. Other famous examples such as the work on the German jet aircraft testing and construction programs, and the V-1 cruise missile and the V-2 ballistic missile test and deployment programs, illustrate challenges that remain today for geospatial analysts. In her work on the German jet aircraft and missile programs, Constance Babington Smith was unable to obtain collateral information that she later learned was available to other analysts. World War II interpreters faced collection challenges of balancing urgent operational priorities and strategic national issues in the search for V-1 launchsites in Normandy and western France while the Normandy invasion planning was ongoing. The pressures of time, working with imagery of insufficient resolution, and having to make risky calls are all described well in this short book.

The book is chronologically organized, and this organization reflects a focus on the European theater. Although the photointerpretation efforts in the Pacific theater were increasing in late 1944 and early 1945, the level of resources and effort on the part of the British was not nearly as large as that in the European theater. The chronology reinforces the criticality of the women photointerpreters to the war effort. The scarce skills of mapmaking, the familiarity with aerial photography, the ability to render what was seen, and the curiosity and tenacity to pursue a find through hundreds of photographs and remember what was seen on each one, were not plentiful enough in the male population. After the Normandy invasion, when the male photointerpreters were moved forward to work on tactical exploitation, the roles of the women at Medmenham became even more important.

Book Review

Mapping the Nation: History and Cartography in Nineteenth-Century America

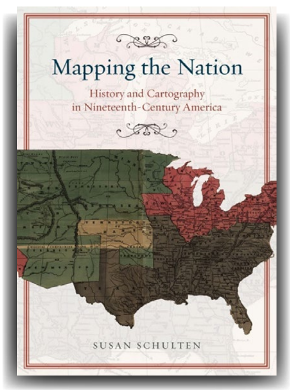
By Susan Schulten

***Reviewed by* Joseph Caddell**

Joseph Caddell is the Arthur C. Lundahl Chair for Geospatial Intelligence at the National Intelligence University.

In *Mapping the Nation: History and Cartography in Nineteenth-Century America*, Susan Schulten crafts a masterful narrative of the emergence of thematic mapping and the growth of cartography in the 1880s into realms beyond physical and political geography. Schulten, a professor of history at the University of Denver, previously explored America's relationship with maps from a cultural studies angle in her 2001 work, *The Geographical Imagination in America, 1880-1950.* In *Mapping the Nation*, Schulten takes a more conventional, historical approach to detailing the emergence and impact of maps that went beyond plotting topography and borders. She lays out the history of mapping disease, climate data, census information, and other natural and social topics that yielded new relevance when considered geographically.

Although the broad outline of the history of cartography in America has been told in a variety of works—piecemeal—*Mapping the Nation* tells a single, coherent, story of the impact of cartographic thought on topics less literal than ridgelines and county borders. "[T]hese maps," argues Schulten, "are easily overlooked for precisely the reason that they are distinct: they were adopted as tools to make sense of particular kinds of information. Only in retrospect can we see a pattern in which maps began to go beyond descriptions of the landscape in order to synthesize and analyze information." Schulten continues:



Mapping the Nation: History and Cartography in Nineteenth-Century America

By Susan Schulten

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University of Chicago Press
Chicago, IL
264 pages

> "We know much about the role of maps in exploration, for scholars have been captivated by the drive to represent topography and political boundaries with increasing precision. Yet despite the attention given to physical maps of the West, the frontier, settlement, and land use, comparatively little has been paid to the equally monumental shift in cartographic thought. Simply put, in the ninteenth century, Americans discovered that maps could help organize and analyze information. While historians routinely characterize this as an era of expanding knowledge, my concern is the cartographic form that this knowledge took."

Schulten ably details this cartographic form of expanding knowledge in several contexts. In the field of medicine, she builds on Dr. John Snow's famous 1854 map of a cholera outbreak in London—probably known to many (if not most) in the geospatial intelligence profession—by devoting an entire chapter to "Disease, Expansion, and the Rise of Environmental Mapping," and placing a heavy focus on epidemiology mapping in Europe and America from the 1810s to the 1850s.

Perhaps most relevant to the National System for GEOINT/Allied System for GEOINT (NSG/ASG) audience is Schulten's examination of the role of geographic information as a tool for informing senior policymakers of socio-political realities. Schulten grounds her discussion of political thematic mapping in the movement to abolish slavery before and during the American Civil War. Her chapter on "Slavery and the Origin of Statistical Cartography" centers on the story of the 1860 Coast Survey map (figure 1), a cartographic product that projected the density of slave populations in the upper and lower south as a function of geographic location. As Schulten details, President Lincoln consulted this map in his deliberations over the question of limited or complete abolition in 1861

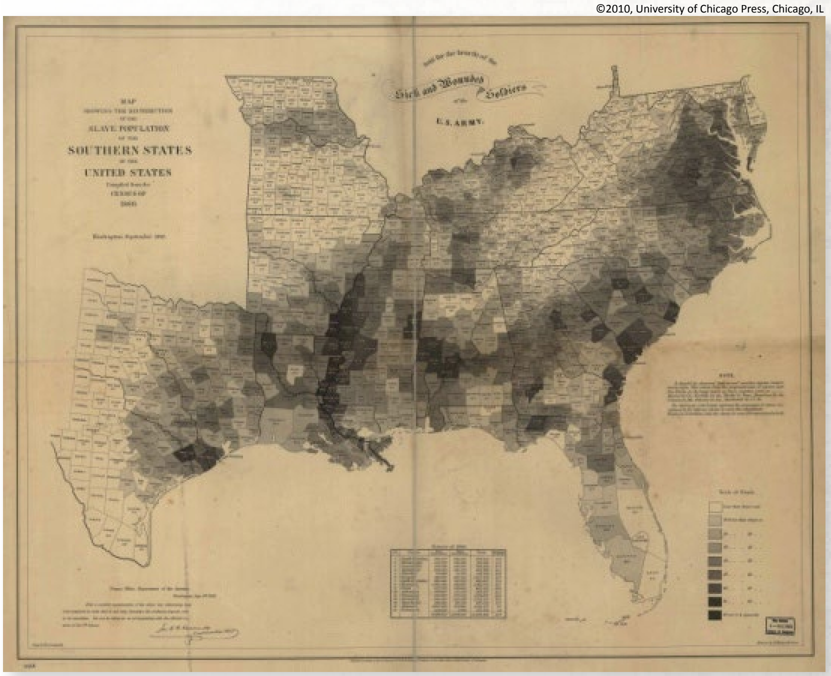

Figure 1. Coast Survey Map of Slave Population in the Southern States, 1860, Schulten, page 121, US Senate Collection

and 1862, and the map helped guide his decision to issue the Emancipation Proclamation. The 1860 Coast Survey map illustrated a sociopolitical reality, helping Lincoln understand where Southern slavery was most prominent, how partial or full emancipation might advance Union war aims, and where positions of Union armies in the field were best suited to eradicating slavery. This map so influenced Lincoln in his thinking that, as Schulten describes, it is prominently displayed in Francis Bicknell Carpenter's painting of the *First Reading of the Emancipation Proclamation of President Lincoln* (1864), a large oil-on-canvas work that hangs in the United States Capitol (figure 2).

Mapping the Nation is built on a broad foundation of primary and secondary sources and extensively cited with detailed endnotes. Perhaps most impressively, the book contains 47 beautiful illustrations that include thematic maps, navigational charts, statistical data overlays, and other examples of period cartography.

Available in paperback and reasonably priced, this book is an essential part of any geospatial intelligence officer's core library. *Mapping the Nation* is as much a history of geospatial intelligence as any book on Lewis and Clark or the Cuban Missile Crisis and deserves close attention from the profession.

Figure 2. Reading of the Emancipation Proclamation—Note the 1860 Coast Survey Map at Lower Right, Schulten, page 120, Geography and Map Division, Library of Congress