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Evaluation of New Sensors for Emergency Management

Robert Bolus and Andrew Bruzewicz

August 2002

Abstract: Large-scale natural or technological disasters often require some level of government response to mitigate their effects. U.S. Army Corps of Engineers response actions may occur under Public Law 84-99 authorizing the Chief of Engineers to activate the Corps for emergency flood control and coastal shore protection or under P.L. 93-288 as work for the Federal Emergency Management Agency (FEMA). Regardless of the type of disaster, rapid image acquisition and analysis is an important initial source of information that can detail conditions over a wide area. The time interval (a few hours to a few days) during which imagery provides added value is exceptionally limited, because once ground observations are reliably available, the imagery only provides duplicate information. Therefore, a test was developed to evaluate how quickly proxy hurricane damage imagery could be acquired with an airborne sensor and orthorectified into digital products that could be posted on an FTP site for the Corps of

Engineers. Emerge, a company with sensors in the US, was tasked to acquire imagery with multiple ground sampling distances (GSDs) to determine the optimal pixel size for determining both cover on roofing and visibility of underlying rafters at new house construction sites and broad-leaf/narrow-leaf tree types in Lakeland, Florida. Emerge was also tasked to keep their response time interval within 12 hours from start of image acquisition to a finished geographic information system (GIS)-compatible product. The results were as follows: (1) Individual roof rafters were always distinguishable with 8-in. GSD and often with 1-ft GSD. (2) Wood covering vs. tarpaper and/or shingles was always visible with 1-ft and 8-in. GSD, and often with 2-ft GSD. (3) Neither spatial nor spectral analysis methods yielded tree type information, with the exception of palm trees. (4) Emerge demonstrated its capability to mount an emergency response collection from image acquisition to production of orthorectified frames within the 12-hr time frame.

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Technical Report
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August 2002

Prepared for
OFFICE OF THE CHIEF OF ENGINEERS

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PREFACE

This report was prepared by Robert Bolus, Physical Scientist, and Andrew Bruzewicz, Director, Remote Sensing/GIS Center, of the Engineer Research and Development Center (ERDC), Hanover, New Hampshire.

Funding for this work was provided by the U.S. Army Corps of Engineers under the Geospatial Research and Development Program for a work unit entitled *Integration of Digital Imagery and Evolving Technologies into Emergency Operations*.

Michael Brunett and Gerald Kinn of Emerge Company, Andover, Massachusetts, coordinated planning, logistics, and acquisition and processing of the imagery taken for this study. Gerald Kinn provided a contractor report and all data.

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TABLE

Table 1. Detection matrix for objects at various GSDs. 23

GLOSSARY

CIR	color infrared
DEM	digital elevation model
FEMA	Federal Emergency Management Agency
GCP	ground control point
GIS	geographic information system
GPS	global positioning system
GSD	ground sampling distance
IMU	inertial measurement unit
RGB	red, blue, and green
RSGISC	Remote Sensing/Geographic Information Systems Center
USACE	U.S. Army Corps of Engineers
UTM	Universal Transverse Mercator

Evaluation of New Sensors for Emergency Management

ROBERT BOLUS AND ANDREW BRUZEWICZ

1 OVERVIEW

Hazardous events

Some level of government response is often needed to mitigate the effects of large-scale natural or technological disasters. Disasters may include but are not limited to hurricanes, tsunamis, floods, ice jams, tornadoes, wildfires, earthquakes, volcanoes, landslides, drought, ice storms, and spills of hazardous materials. When tasked, the U.S. Army Corps of Engineers (USACE) provides equipment, personnel, and technical assistance as requested. The Remote Sensing/ Geographic Information System Center (RSGISC) has experience in contributing to response and recovery efforts. It can provide imagery, maps, the geographic map base, and geographic information system (GIS) coverages, and it can run GIS models for analysis before, during, and after an event for a synoptic look at present conditions and prediction into the future (Bruzewicz and Pokrzywka 1999).

Responsible agencies

Corps response actions may occur under Public Law 84-99, which authorizes the Chief of Engineers to activate the Corps for emergency flood control and coastal shore protection, or as work for the Federal Emergency Management Agency (FEMA) under P.L. 93-288 (1988). The FEMA work is often conducted in conjunction with other agencies, including the National Oceanic and Atmospheric Agency (NOAA), the U.S. Geological Survey (USGS), the Environmental Protection Agency (EPA), the Department of Energy (DOE), the Department of Transportation (DOT), the U.S. Fish and Wildlife Service (USFW), and the American Red Cross. Regardless of the type of disaster, rapid image acquisition and analysis is an important initial source of information that can detail conditions over a wide area. Before an adequate assessment of the extent and

severity of damage can be developed from direct observation, imagery can be made available and is useful in the collation of reports from scattered observers. Observation of the impact area is necessary for federal declaration of a disaster; for estimation of damage to residential, commercial, and government buildings and infrastructure; and for direction of the USACE and other agencies' emergency management response.

Emergency response

After an actual site visit by the FEMA administrator and/or a representative from the executive office, a disaster declaration may be made and the attendant federal assistance authorized. While the assessment is done either on the ground or by air, initial analysis and mapping from either satellite or aerial imagery can give impetus to the process. Conflicting or inaccurate ground reports can be resolved or rapidly dispelled by viewing overhead imagery, enabling a more accurate assessment of damage area extent and conditions.

Management efforts

Management of response and recovery missions requires knowledge of highway access to and from the affected area; of buildings being used as shelters; of warehousing; and of distribution points for water, ice, food, temporary roofing, and donated supplies. Sites are evaluated for the locations of temporary debris storage and sorting, generators, and temporary housing. Areas for containment of toxic materials can best be determined in conjunction with imagery and maps. Post-event imagery may be used both to improve mitigation efforts that always require wide-area observation of present conditions and to counter future threats.

Rapid image surveys

While the benefits that can be provided by imagery are well known, numerous difficulties have prevented the timely incorporation of image products into the group of technologies commonly used by emergency managers. There are time lags between identifying the impact zone and contracting for, acquiring, processing, and delivering the imagery to the end user. Post-processing delays exist that are necessary to project the imagery into map coordinates so that they can be entered into a GIS in conjunction with other geospatial data. The imagery must also be analyzed so the data becomes information. As a result, in many disasters, the potential for the use of imagery has been much greater than the benefit derived from it.

Unfortunately, the time window for utilizing unique information extracted from imagery in the management of the response is narrow. For disasters in the continental United States, it is often a few hours to a few days.

Extent of damage

An additional significant issue relating to the use of commercial satellite sensors is the problem of acquiring imagery with adequate spatial resolution. Analysis of the imagery must lead to a reliable estimate of the extent and severity of the damage. On one hand, satellite systems have to be tasked to acquire an image and are only in position at cyclical intervals of several days. In the case of systems operating in the visible and near-infrared portions of the electromagnetic spectrum, cloudless weather conditions are required. Even then, most satellite imagery is of low resolution. Questions related to damage to infrastructure, critical facilities, roofs, and rafters cannot be answered even with the 1-m pixel size of the IKONOS satellite sensor. On the other hand, airborne film imagery, which can provide the detailed information (sub-meter pixel size) necessary for some USACE missions, is subject to delays due to the time required for scanning, digitizing, and geolocation processing.

Geospatial database

In seeking alternative image acquisition and processing techniques that would reduce the time from image acquisition to the delivery of a product that can be directly accessed by GIS software, the research team evaluated a digital imaging airborne system called EMERGE. This digital system provided the opportunity to obtain high spatial resolution imagery and eliminates both the time needed for photo processing and the scanning needed to create a digital file from film for entry into a geospatial database. Since the digital imagery was to become part of this mapped database, it had to be orthorectified. The vendor accomplished this in post-processing of the data by using ground control points (GCPs) and digital elevation models (DEMs) together with data about the sensor's attitude and position that was acquired concurrently with the imagery.

Limited time value

There is an exceptionally limited time interval during which imagery provides added value because once ground observations are reliably available, the imagery only provides duplicate information. A test was developed to evaluate how quickly imagery could be acquired with an airborne sensor and could be orthorectified into digital products that could be posted on an FTP site for the RSGISC. Emerge Company of Andover, Massachusetts, was tasked to acquire

imagery with multiple ground sampling distances (GSDs) to discover the optimal pixel size for determining damage both to roofing and to the underlying rafters. They were also tasked to keep their response time interval to within 12 hours from a requested start to a finished GIS-compatible product. The requirements and the results and conclusions are detailed in this report.

2 REQUIREMENTS

Ground sampling distance

The first requirement was based on a FEMA regulation that temporary roofing will not be installed unless more than 50% of the rafters are undamaged. So we asked the question: At what GSD can we tell from digital imagery if the roof rafters of a damaged building are substantially intact? The contractor was tasked to determine the GSD necessary to detect roof damage reliably.

Impact area

The second requirement had to do with the contractor's capability to collect a large volume of image data per day. Since the federal government does not become involved under the Federal Response Plan until the capabilities of the state and local governments have been overwhelmed for disaster assistance, areas affected by federally declared disasters are typically fairly large. Based upon damage swaths from previously declared hurricane disasters, somewhere between 30 and 150 square miles of area should be imaged. Based on tables of data volume versus square miles of coverage at 1-ft GSD, somewhere between 4 and 8 gigabytes of data will cover between 50 and 100 square miles of area. The contractor was tasked to collect 5 Gb of data.

Post processing

The third requirement was to test the contractor's ability to orthorectify up to 500 single frames of imagery in 12 hours or less, write them to CD-ROM, and post them on an FTP site. This number was derived from a table showing the maximum number of frames that could be collected in a day from a small Cessna-class aircraft. As already noted, images rapidly lose their value if they cannot be delivered in a mapped and analyzed format to the ultimate user in a timely manner. Since the digital images must be orthorectified before they can be combined with the other geospatial data, an essential component of a successful approach to incorporating digital imagery into the information stream is rapid processing of large volumes of data once the plane has landed.

Maps

A fourth requirement for this study was that a digital location map file be made at all collected resolutions, giving the nadir point of each image frame in

map coordinates with a frame identifier. This is a simple indexing system that allows the user to identify image frames corresponding to map base coordinate locations.

Orthomosaics

Although not a requirement, three-band composite orthomosaics were constructed after the exercise from the single frames acquired over each of the two areas flown. They were found to be of great value for rapid visual determination of potential damage locations and for selection of the corresponding image frames for detailed display.

3 EMERGE CAPABILITIES

Aircraft

Emerge Co. has a fleet of aircraft including a Cessna 172, a Piper Aztec, and a Canberra B6. They have ten sensor systems throughout the United States that are used to collect image data for commercial and governmental entities. Multi-purpose information can be provided to end users about various characteristics of the landscape such as agriculture, forestry, urban/rural land use, and utilities.

Nation-wide presence

Emerge also provides the potential to rapidly acquire imagery in any part of the country following a disaster. They have the capability to mount an emergency imagery response from flight plan to production of orthorectified image frames within 24 to 30 hours from notification of a request for disaster acquisition.

Image sensors

The digital camera system records 12 bits per pixel per band, providing a dynamic brightness range of 4096 levels. This allows a significant improvement in image brightness contrast over that provided by 8-bit collection systems, such as the mod-1 digital video systems. The improved contrast helps in the discrimination of bright objects against a bright background and the overall scene dynamic range from darkest object visible to brightest. Imagery can be collected in visual red, green, and blue (RGB) or red, green, and near-IR, called color infrared (CIR).

System camera/IMU/GPS

The EMERGE system is compact, transportable, and easy to install in and operate from small aircraft. A three-band Kodak DCS 460 digital camera with a 3072- by 2048-pixel readout is used to collect true-color images. A Litton LN200 strap-down inertial measurement unit (IMU) and a Novatel dual-frequency kinematic global positioning system (GPS) are used to collect the plane's position and motion data. Data from the GPS give the plane and camera's coordinate position as each frame is taken, and attitude data from the IMU permits projection of the center of each camera frame into ground coordinates when the data are post-processed. The three-axis IMU records the plane's attitude (roll, pitch, and yaw), enabling removal of distortion caused by the plane's not being level or not

flying parallel to the flight line. The GPS and IMU information, in addition to a DEM and ground control points (GCPs), enables Emerge staff to orthorectify the imagery into a post-processed GIS-compatible map product.

4 LAKELAND IMAGERY STUDY

Proxy hurricane damage

While an ideal test of the EMERGE capability would be to map areas during a real disaster, no events causing roof damage or hurricanes struck the East Coast of the U.S. during the time when this study was being conducted (October 2000 through September 2001). This necessitated the selection of a proxy location where it would be possible to observe features similar to those from hurricane or other wind damage that would result in the need for temporary roofing. To determine the number of houses that would receive temporary roofing, it is necessary to determine both whether the roof has been damaged and the status of the underlying rafters. After a ground reconnaissance, it was determined that active construction of new housing in the area of Lakeland, Florida, provided an acceptable analog to hurricane-induced roof damage. In this study, imagery was taken of sites with houses in all phases of construction, particularly houses with roof rafters intact but without plywood sheathing, with plywood sheathing but without tarpaper or shingle covering, and with tarpaper-covered roofs.

Location

Lakeland is located about 30 miles east-northeast of Tampa, Florida, in the vicinity of several freshwater lakes (Figure 1). Within the boundary of the city of Lakeland, two areas were chosen for evaluation of EMERGE imagery as a means of detecting roof damage and the status of roof rafters on partially completed buildings. Data were collected on 11 February 2001 over area 1 (4 sq mi) and on 12 February 2001 over area 2 (4 sq mi) (Figure 2).

Mobilization

Fifty-three frames (35 frames at 1-ft GSD, 12 frames at 2-ft GSD, and 6 frames at 3-ft GSD) were collected over area 1 on 11 February and over area 2 on 12 February. The demonstration exercise began each morning with acquisition of the data when the sky had cleared and ended by 5:00 p.m. with completely post-processed orthorectified image frames. From examination of this data, it was determined that imagery with resolution higher than that acquired was needed for reliable visual observation of individual roof rafters. Data were again taken over areas 1 and 2: on 28 March, 198 frames at 8-in. GSD and 70 at 1-ft GSD were collected, and on 30 March, 18 at 2-ft GSD were collected. The same construction sites were imaged as before, but some houses had been completed and some

new house starts had begun in those neighborhoods. Therefore, imagery at all resolutions is not available for comparison at each of the houses in the construction sites. Further details and a time line are given in the EMERGE report (Kinn 2001). As a benchmark, data acquisition took about an hour for the collection of the 53 frames in February and processing of the imagery with a 450-MHz machine took approximately 4 hours after landing. EMERGE determined that it would be possible to meet the requirement of 500 frames in 12 hr by a linear scale extrapolation, where they multiplied 50 frames by 3 (for three times as long as the 4 hours) and by 4 (for two machines that are twice as fast as the one they used).

Data acquisition

Data for 8 sq mi, flown twice at several resolutions, were collected. The volume was equivalent to that collected in a maximum daily mission for Cessna-

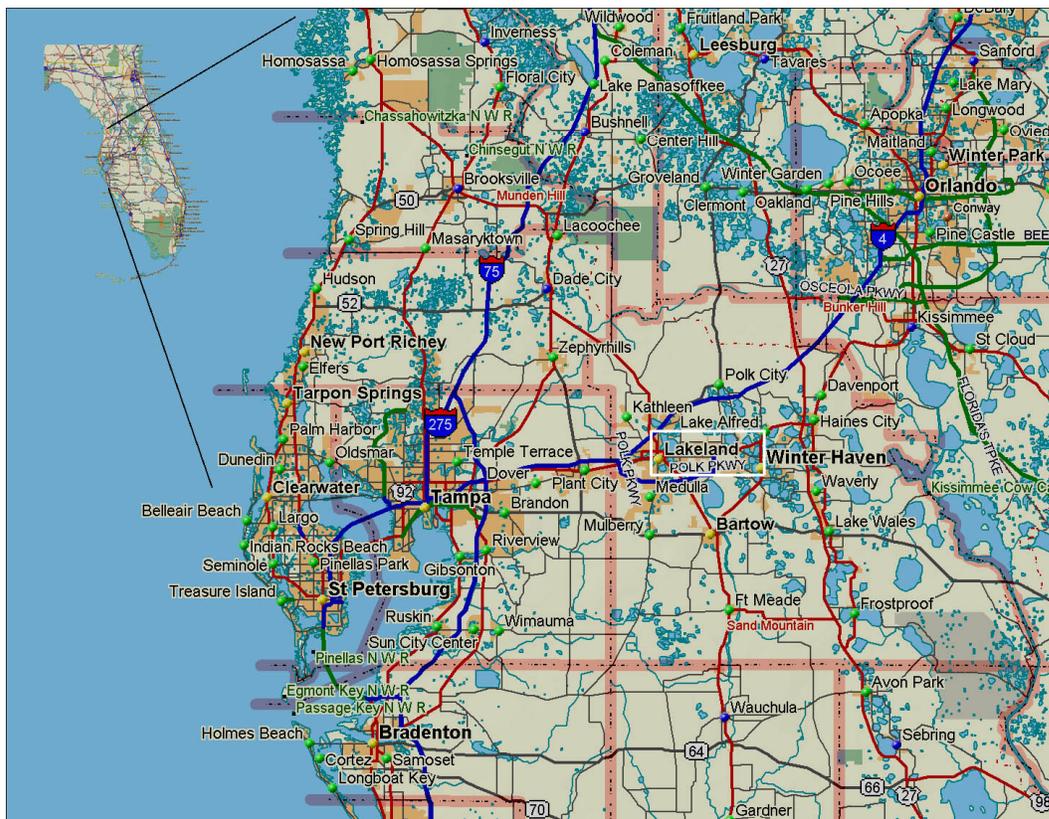


Figure 1. Location of Lakeland, Florida, study area (after Topo USA).

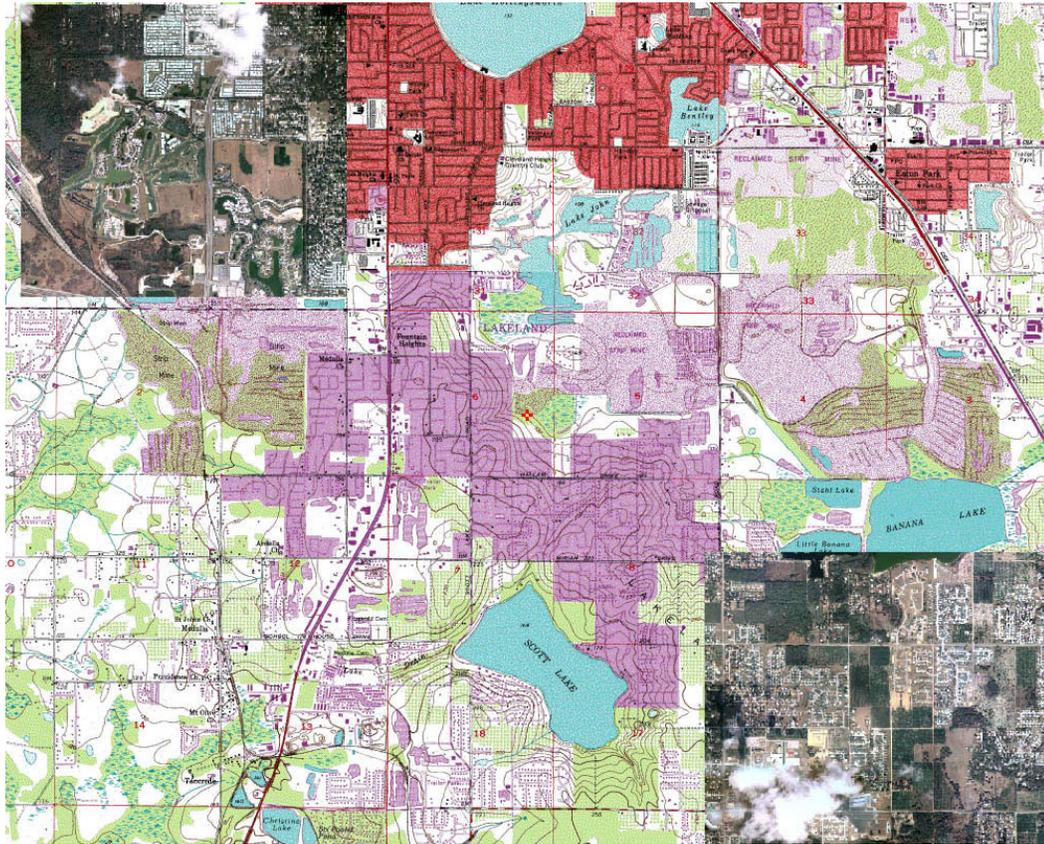


Figure 2. Area 1 (lower right) and area 2 (upper left), overlaid on topo map (after TopoZone).

class aircraft at 1-ft GSD, an end lap of 20%, a side lap of 30%, and an area of 60 sq mi. This equivalent large data set volume for a single-day collection amounted to approximately 5 Gb.

Data processing

The pixel sizes were measured in meters, and the frames were formatted into geoTIFF and JPEG format, written to CD-ROM, and placed on an FTP site that enabled end-user acquisition from any Internet-accessible location. Digital location map files were also made available. All data were rectified into Universal Transverse Mercator (UTM) zone 17 coordinates using the WGS 84 spheroid and datum. The study revealed the level of detail visible in the 3-, 2-, and 1-ft and 8-in. GSD mapped images.

5 IMAGERY EVALUATION

Area 1 sites

Sites 1, 2, and 3 are located in the area 1 mosaic, constructed using 3-ft GSD imagery, as shown in Figure 3. The state of roof conditions will be examined from the high-resolution imagery for sites in area 1 that have been designated with a yellow boundary marker. Site 1 has a house with exposed roof rafters, and site 2 has a house with plywood roof sheathing in place that is mostly covered with tarpaper. Site 3 has a house with exposed roof rafters, but the electronic camera sensors saturated as the image was acquired. Saturation is a problem in image acquisition that occurs when the gain is set too high for the target of opportunity. In these images, the rafters were at the white end of the brightness range and sometimes disappeared into the uncovered concrete substructure of the building, which was also bright. This resulted in permanent data and detail loss at the white end of the brightness range.

House roof rafters

Figure 4a shows site 1, a house under construction with exposed roof rafters in the lower right corner of the image, at 2-ft GSD. The detail is barely sufficient to distinguish individual roof rafters at this GSD. At both 1-ft GSD (Figure 4b) and 8-in. GSD (Figure 4c), however, the same site shows sufficient detail and resolution to distinguish individual rafters. .

Tarpaper/shingles/plywood

Figure 5 shows site 2 at 8-in. GSD. A new house without roof shingles is to the left of the center of the image. Part of the roof is covered with tarpaper and part is covered with plywood. Resolution and detail are not sufficient to detect the edges of the tarpaper or shingles that would distinguish one from the other. The tarpaper strips are 3 ft wide by as long as the roof is wide, and the shingles are 3 ft wide by 1 ft high. Contrast between the roof covered with tarpaper and that sheathed with plywood, however, is visible at this and greater GSDs.

Saturation problem

Figure 6 shows site 3 at 1-ft GSD. A new house in the middle of the image is under construction, but due to sensor saturation at the high end of the intensity (or brightness) scale, individual roof rafters are obscured. This is because bright

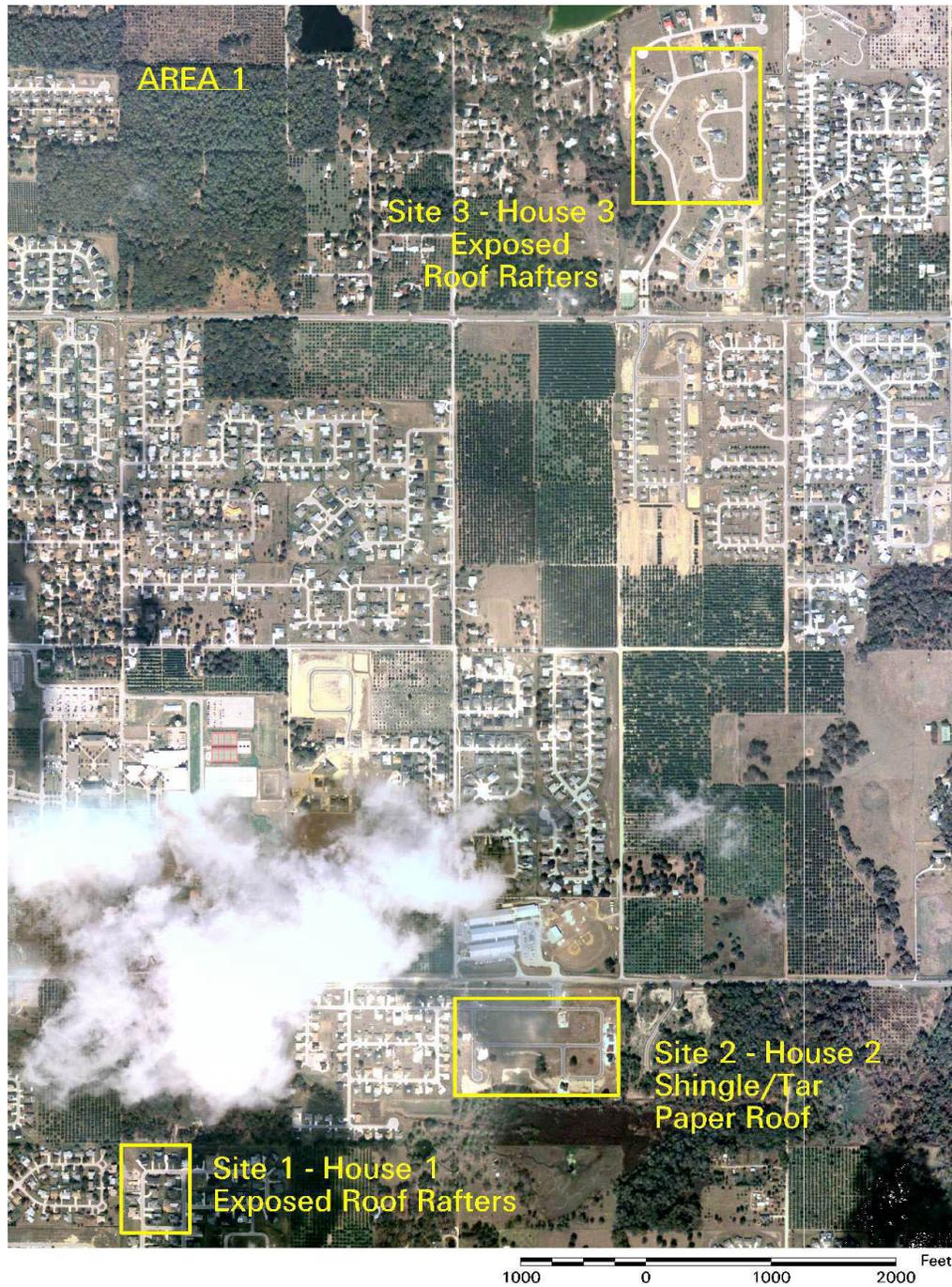


Figure 3. Area 1 mosaic: Location of house construction sites 1, 2, and 3.

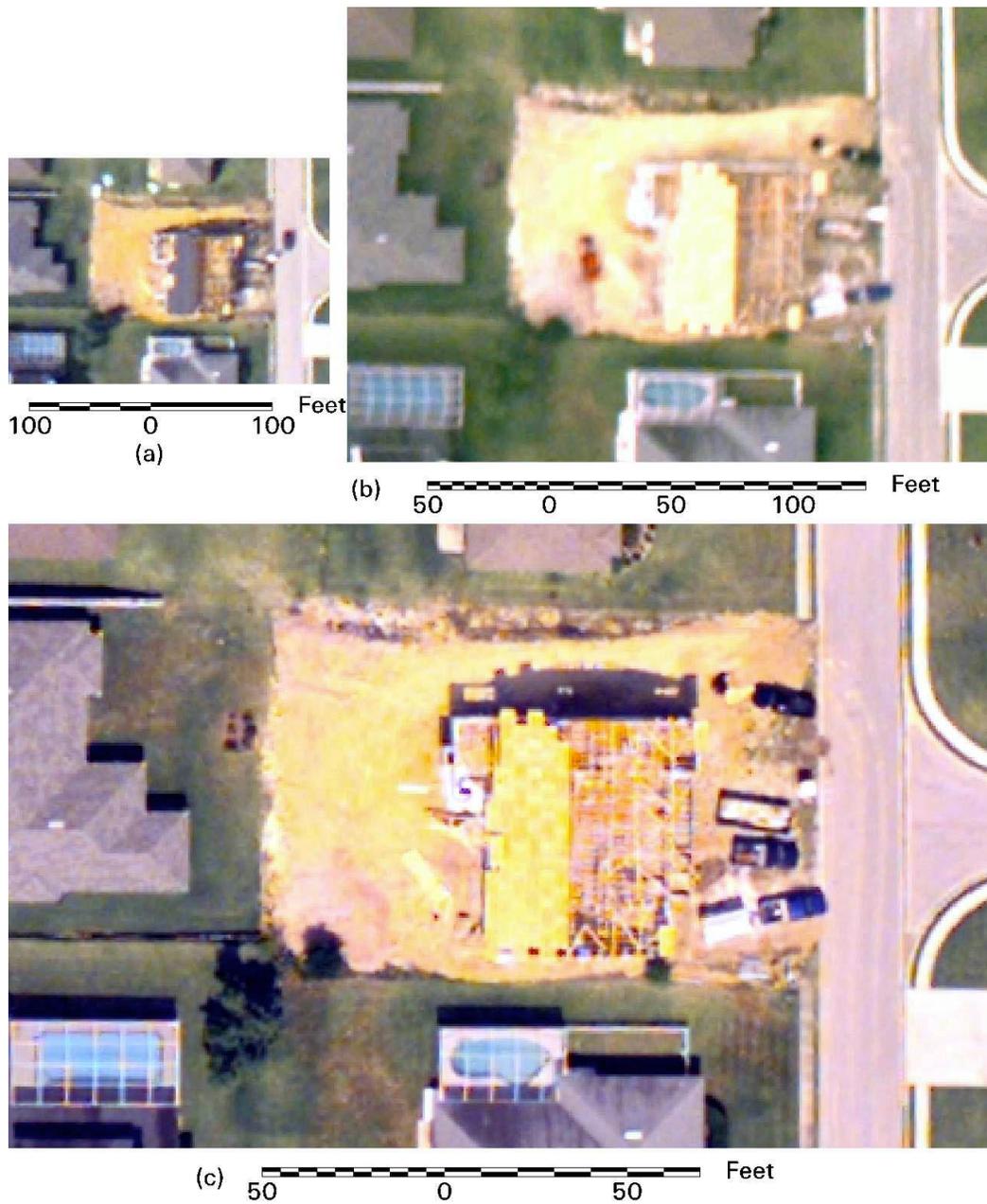


Figure 4. Site 1: House at (a) 2-ft GSD, 30 Mar 2001 (rafters not visible); (b) 1-ft GSD, 28 Mar 2001 (rafters visible); and (c) 8-in. GSD, 28 Mar 2001 (rafters visible).

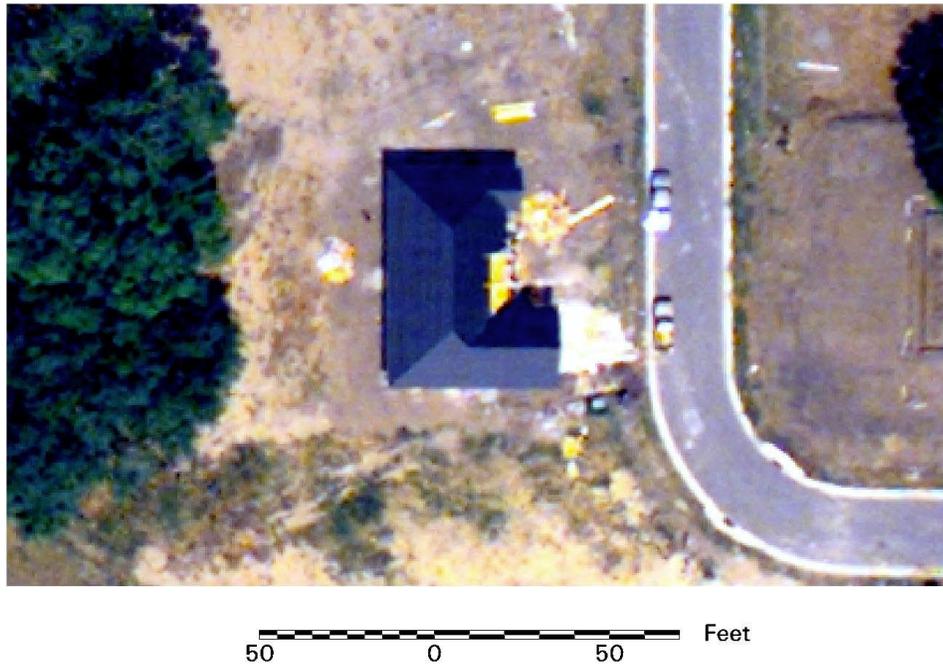


Figure 5. Site 2: House at 8-in. GSD, 8 Mar 2001 (tarpaper roof).

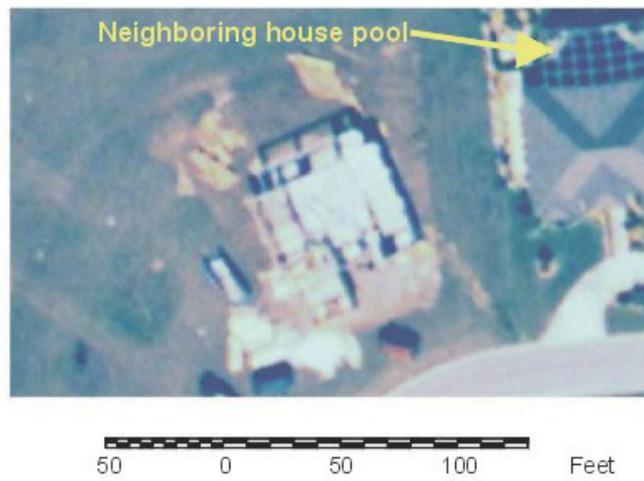


Figure 6. Site 3: House at 1-ft GSD, 12 Feb 2001 (in saturation).

rafters appear over bright interior concrete subflooring, and both are in or near saturation. Note that pool-house rafters over the swimming pool, visible on the neighboring house, are easily distinguishable due to the contrast of the dark blue of the pool with the white rafters. The status of individual rafters may not always be determined during new construction with 1-ft GSD where there is limited contrast between the rafters and the underlying flooring. Contrast between the blue water and the white pool-house rafters, however, suggests that where construction has been completed and subsequent roof damage has occurred, there may be sufficient contrast to distinguish rafters from the floor-covering material below them. This may enable successful determination at 1-ft GSD of whether the rafters are substantially intact.

Area 2 sites

The area 2 mosaic (Figure 7) shows the remaining two sites, designated by a yellow boundary marker. Site 4 showed various stages in the construction of a commercial building, from land clearing to foundation pouring, from wall and roof framing to partial plywood roof sheathing, and from plywood and tarpaper roof covering to finished shingled roofing. Site 5 is located in a sports-complex region that contains a mix of vegetation types, including grasses, bushes, and trees.

Commercial building rafters

The roof rafters and plywood sheathing of the new building at site 4 are visible at all three resolutions with, as expected, the most detail at 8-in. GSD. When the GSD is larger than 8 in., it is difficult to distinguish individual rafters, but that may be an artifact of new construction (see Conclusions, below). Figure 8 shows images of the exposed roof rafters at site 4 within area 2. The figures progress from coarse (2-ft) to medium (1-ft) to fine (8-in.) GSD images.

Scatter plots

An image-processing approach that might lead to an automatic process of distinguishing between intact roofs and damaged roofs was also attempted. Scatter plots of band 1 (visible red) vs. band 2 (visible green) of a roof under construction and a completed, intact roof were displayed with ENVI (ENVI 2000). The plot for the roof under construction (proxy damaged roof) was expected to show more variability in reflectance due to chaos (a plethora of colors) than the intact roof. The intact roof was expected to show only a relatively invariant color-tone because of the single-color shingles and brightness

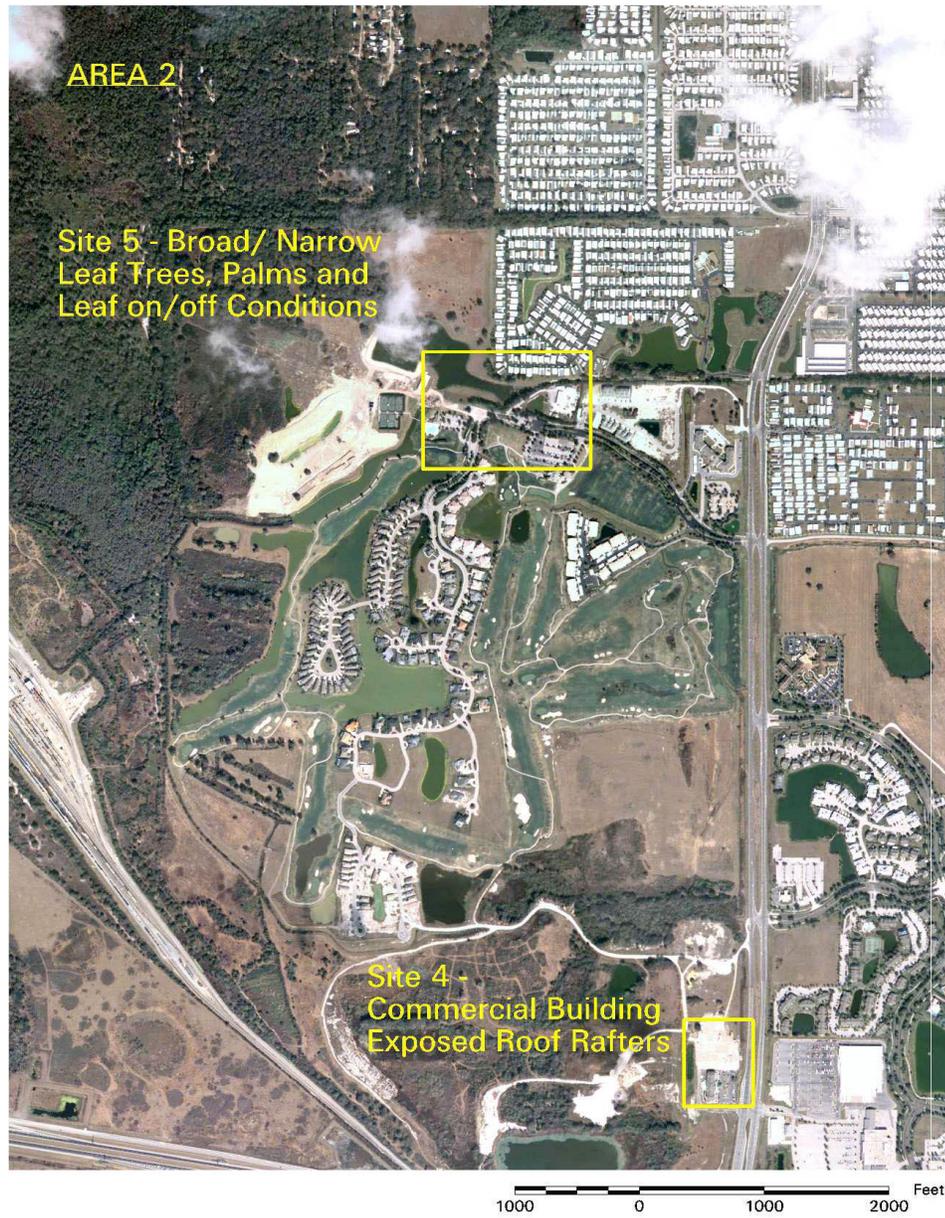


Figure 7. Area 2 mosaic: Location of building sites 4 and 5.

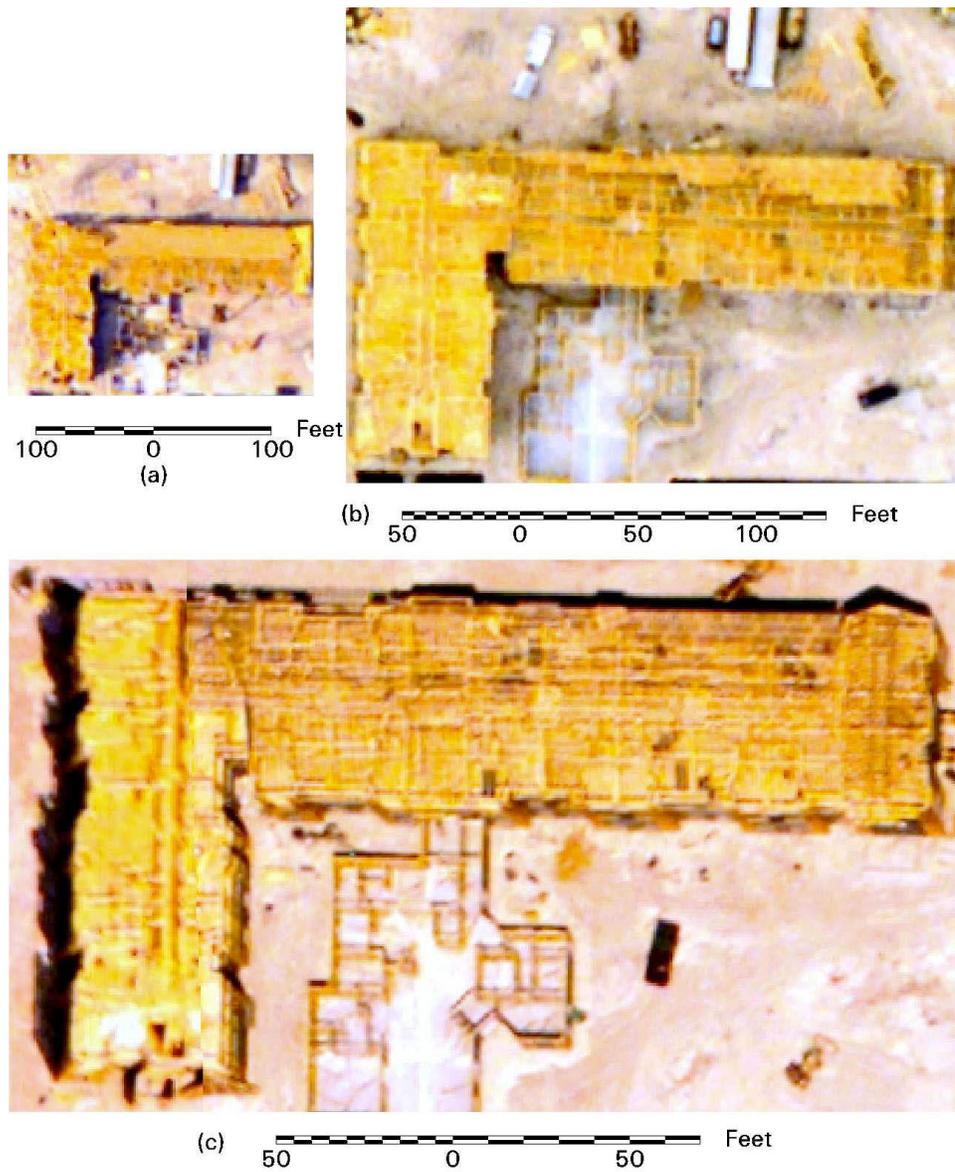


Figure 8. Site 4: Building at (a) 2-ft GSD, 30 Mar 2001 (rafters barely visible); (b) 1-ft GSD, 28 Mar 2001 (rafters visible); and (c) 8-in. GSD 28 Mar 2001 (rafters visible).

differences due to shadowing (Lunetta 1998). These expectations were supported in the resulting scatter plots that were nondirectional bright-end clusters (denoting damaged or under-construction roofs, shown in green) and dark-to-bright linear clusters (denoting intact roofs, shown in red), respectively (see Figure 9). The scatter plots suggest an automated approach to counting the damaged house roofs, given that the locations of the buildings are known ahead of time and that monochrome shingles are used on house roofs. The automated process would require counting all the abnormal roof scatter plots within the damage swath using a pre-existing GIS coverage of all roofs as a mask. This technique is not expected to work in areas with roofs that have multicolored shingles where the spatial color changes are larger than a pixel size.

Sun angle

The angle of the sun with respect to the local vertical makes a difference in the detail seen in the imagery. As noted above, the effects of shadowing increase the length of the linear scatter plots taken of intact roofs. The length is directly related to an increase in visible detail due to scene contrast. Assuming that the imagery is taken with a sensor that is pointing near nadir, if there is a medium sun angle, the sensor will “see” both lighted and shadowed portions of objects at discrete sites within an area. Our study has revealed that 2-ft, 1-ft, and 8-in. imagery is useful for roof damage assessment and so should be taken with medium sun angle when possible. The 3-ft imagery is primarily used as a location tool. It is best taken with an overhead sun angle where maximum illumination of an entire area is the goal.

Broad leaf/narrow leaf

Additional analyses were carried out on the EMERGE imagery of Lakeland, Florida, to evaluate its capability for discriminating vegetation. At site 5 in area 2, we evaluated the discrimination between broadleaf and narrow-leaf (ever-green) tree species. It was found that neither spectral nor spatial resolution was sufficient to permit this distinction. However, the presence or absence of leaves (leaf on/leaf off) was found to be visibly distinguishable, as the deciduous trees were bare when the imagery was acquired in February and fully leafed out in the March scenes. Palm trees were always visibly identifiable by their distinctive fronds in the 8-in. GSD imagery.

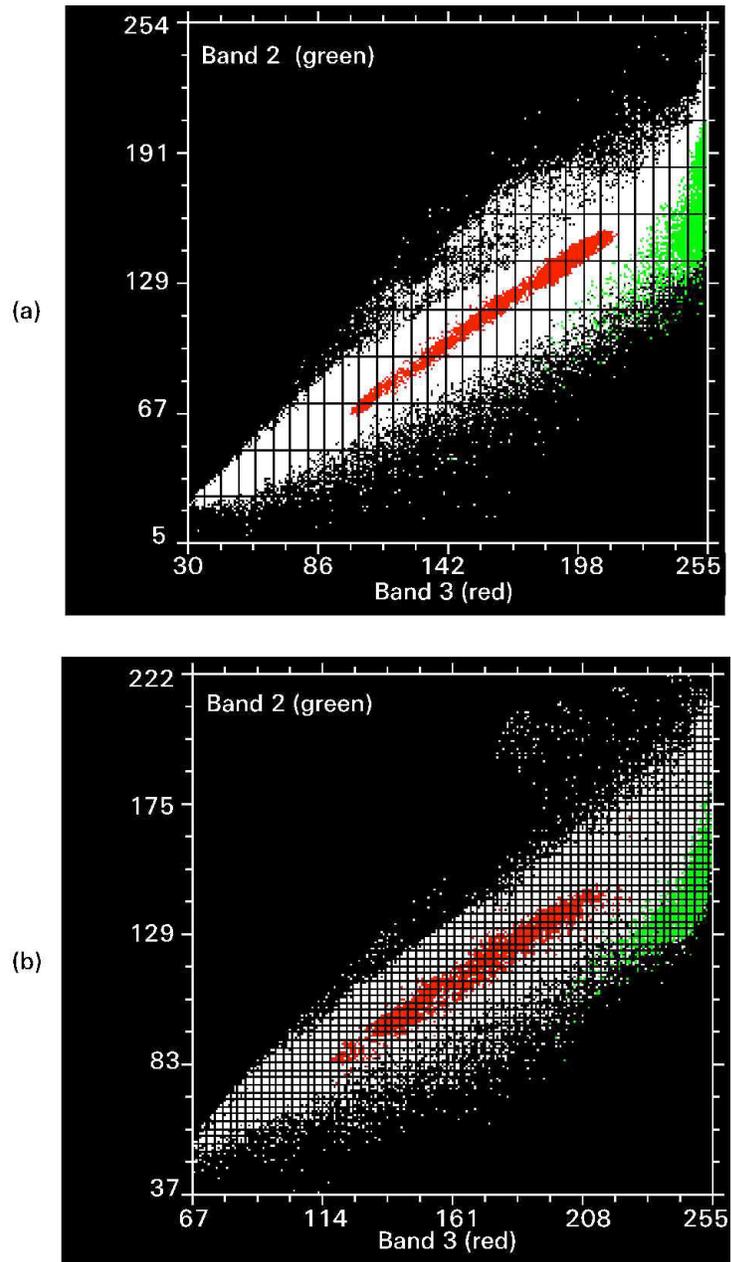


Figure 9. Scatter plots of band 2 vs. band 3. Red indicates intact roof, and green is roof under construction at (a) 8-in. GSD and (b) 2-ft GSD.

Leaf on/off and palms

Figure 10 shows site 5 with broadleaf and evergreen trees at 1-ft and 8-in. GSD. Ground truth was obtained in the form of digital pictures. Broadleaf trees and evergreens identified in ground-truth photos were located in the imagery on the median of the roadway (left), but cannot be distinguished visually. In addition, spectral tests run on broad-leaf and narrow-leaf trees indicated no significant differences. Leaf on/leaf off is clearly distinguishable in the upper lefthand corner of the images near the building where the entire rooftop is clearly visible (shown by an arrow in Figure 10a) in early February, but it is partly obscured by the canopy in late March. The distinctive fronds of three palm trees are clearly visible on the roadway median (right) in the lower righthand corner of the 8-in. GSD scene (shown by arrows in Figure 10b) but not in the 1-ft GSD scene. Other palms were also recognizable within the area at 8-in. GSD when present, even when growing among different species.



Figure 10. Site 5: Trees at (a) 1-ft GSD, 11 Feb 2001 (leaf off visible) and (b) 8-in. GSD, 28 Mar 2001 (palms visible).

6 CONCLUSIONS

Detectable-objects matrix

Table 1 shows a detection matrix for objects as a function of GSD. Individual roof rafters are always distinguishable with 8-in. GSD and often with 1-ft GSD. Wood covering vs. tarpaper and/or shingles can always be determined with 1-ft and 8-in. GSD, and often with 2-ft GSD. Saturation of all three bands and the resulting absence of contrast tend to obscure rafter detail.

Information in cloud shadows is not completely recoverable, but if there are few of them, sufficient solar illumination, and enough sensor quantization levels, then some information is available from the shadowed regions. Palms can be distinguished from other species with 8-in. GSD. The best display for visual interpretation of objects with these data sets was bands 1, 2, and 3 in red, green, and blue with a 2σ (standard-deviation) stretch to enhance image detail. We used the ERDAS image processing program (ERDAS 1999).

Objects/GSD	3-ft	2-ft	1-ft	8-in.
Roof rafters	Not visible	Barely visible	Often visible	Visible
Shingles/tarpaper (other) vs. plywood	Can sometimes separate	Can often separate	Can determine wood vs. other cover	Can determine wood vs. other cover
Rafters in 3-band saturation	Causes rafter detail loss	Causes rafter detail loss	Causes rafter detail loss	Causes rafter detail loss
Broad-leaf vs. narrow-leaf	Cannot separate	Can determine leaf on/off	Can determine leaf on/off	Palms are always visible
All in cloud shadow	Degrades image	Some info recoverable	Some info recoverable	Some info recoverable
Roofs as a function of sun to zenith angle	Best detail, near zero angle, overhead sun	Best detail, medium angle, shadow casting	Best detail, medium angle, shadow casting	Best detail, medium angle, shadow casting
All in 1,2,3 RGB, 2σ stretch	Enhances imagery	Enhances imagery	Enhances imagery	Enhances imagery

Study conclusions

The conclusions from this study are that:

1. It was demonstrated that a 53-frame data set can be acquired successfully in one day and post-processed, including orthorectification and creation of geoTIFF files, within 4 hr of the plane's landing.
2. It is possible to distinguish individual roof rafters at 8-in. GSD and plywood-covered roofs from roofs covered with shingles and/or tarpaper at 2-ft GSD or finer. Shingles and tarpaper are not visually distinct from each other in these data sets.
3. For high-resolution images (2-ft or finer), a medium angle (sun with respect to zenith) increases the roof detail.
4. 8-in. GSD is not sufficient to visually distinguish broad-leaf from narrow-leaf trees, but it does permit visual identification of palms.

Future recommendations

The following recommendations are made with reference to future acquisitions of emergency management imagery and processing:

1. Adjust all electronic camera sensors to avoid saturation of bright objects in any band because that results in permanent image contrast loss. This will increase the ability to detect roof rafters on damaged roofs.
2. Fly lower-resolution (3-ft) data with nearly overhead sun illumination and the higher-resolution (2-ft or finer) data at a medium angle between sun and zenith, since roof shadows increase the interpretable roof detail by increasing contrast.
3. Develop an algorithm to count damaged roofs automatically based upon scatter plots of band 1 vs. band 2 that have shown a linear cluster for intact roofs and have shown a nondirectional bright-end cluster for damaged roofs.

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14. ABSTRACT Large-scale natural or technological disasters often require some level of government response to mitigate their effects. U.S. Army Corps of Engineers response actions may occur under Public Law 84-99 authorizing the Chief of Engineers to activate the Corps for emergency flood control and coastal shore protection or under P.L. 93-288 as work for the Federal Emergency Management Agency (FEMA). Regardless of the type of disaster, rapid image acquisition and analysis is an important initial source of information that can detail conditions over a wide area. The time interval (a few hours to a few days) during which imagery provides added value is exceptionally limited, because once ground observations are reliably available, the imagery only provides duplicate information. Therefore, a test was developed to evaluate how quickly proxy hurricane damage imagery could be acquired with an airborne sensor and orthorectified into digital products that could be posted on an FTP site for the Corps of Engineers. Emerge, a company with sensors in the US, was tasked to acquire imagery with multiple ground sampling distances (GSDs) to determine the optimal pixel size for determining both cover on roofing and visibility of underlying rafters at new house construction sites and broad-leaf/narrow-leaf tree types in Lakeland, Florida. Emerge was also tasked to keep their response time interval within 12 hours from start of image acquisition to a finished geographic information system (GIS)-compatible product. The results were as follows: (1) Individual roof rafters were always distinguishable with 8-in. GSD and often with 1-ft GSD. (2) Wood covering vs. tarpaper and/or shingles was always visible with 1-ft and 8-in. GSD, and often with 2-ft GSD. (3) Neither spatial nor spectral analysis methods yielded tree type information, with the exception of palm trees. (4) Emerge demonstrated its capability to mount an emergency response collection from image acquisition to production of orthorectified frames within the 12-hr time frame.					
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