MCEER Special Report Series

# Engineering and Organizational Issues Related to the World Trade Center Terrorist Attack

Volume 3

# Emergency Response in the Wake of the World Trade Center Attack: The Remote Sensing Perspective

By Charles K. Huyck and Beverley J. Adams

MCEER

MULTIDISCIPLINARY CENTER FOR EARTHQUAKE ENGINEERING RESEARCH

*A National Center of Excellence in Advanced Technology Applications*

## *The Multidisciplinary Center for Earthquake Engineering Research*

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*Comprising a consortium of researchers from numerous disciplines and institutions throughout the United States, the Center's mission is to reduce earthquake losses through research and the application of advanced technologies that improve engineering, pre-earthquake planning and post-earthquake recovery strategies. Toward this end, the Center coordinates a nationwide program of multidisciplinary team research, education and outreach activities.*

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June 2002

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# Foreword

The terrorist attack that took place on September 11, 2001 in New York City resulted in thousands of lives lost, the collapse of the twin towers of the World Trade Center as well as damage to adjacent buildings, and extensive disruption of transportation and other lifeline systems, economic activity, and other social activities within the city and the surrounding area. When the final accounting takes place, this attack will almost certainly constitute one of the most deadly and costly disaster events in U. S. history.

In a very real sense, the September 11 tragedy, the nature of the damage that occurred, the challenges that the city's emergency response faced, and the actions that were undertaken to meet those demands can be seen as a "proxy"-albeit a geographically concentrated one-for what a major earthquake can do in a complex, densely-populated modern urban environment. Like an earthquake, the terrorist attack occurred with virtually no warning. As would be expected in an earthquake, fires broke out and multiple structural collapses occurred. As has been observed in major urban earthquakes and in other disasters (e.g., Hurricane Andrew), structures housing facilities that perform critical emergency functions were destroyed, heavily damaged, or evacuated for life-safety reasons. Additionally, because the majority of the damage occurred to relatively new and well-engineered structures and because the emergency response system in New York City was considered very well prepared for all types of emergencies, particularly terrorist attacks, the attack and its aftermath provide a useful laboratory for exploring a variety of engineering and emergency management issues.

In this perspective, the Multidisciplinary Center for Earthquake Engineering Research initiated a research project (funded by the National Science Foundation) to collect perishable data in the aftermath of the attack for later study to gain a better understanding of how resilience is achieved in both physical, engineered systems and in organizational systems. The project is divided into two major components, focusing on the impact of the disaster on engineering and organizational systems:

(a) Damage to Buildings in the Vicinity of Ground Zero - The objective of this effort is to collect perishable information on the various types of damage suffered by buildings at Ground Zero, including, most importantly, those that suffered moderate damage from the impact of large debris but that did not collapse, and to investigate whether state-of-practice analytical methods used in earthquake engineering can be used to explain the observed structural behavior.

(b) Organizational and Community Resilience in the World Trade Center Disaster - The objective of this effort is to collect information on the response activities of the City's Emergency Operations Center and on other critical emergency response facilities. Of particular interest is to identify the plans that were in place at the time of the disaster, as well as how decision systems and remote sensing technologies were used and coordinated with engineering decisions. Efforts will also include identifying the technologies and tools that were most useful or failed (or did not meet expectations) during the emergency period, the types of adaptations that had to be made by these organizations, how well intra-organizational communication and coordination functioned, and whether any emerging technologies were used during the emergency period.

The MCEER special report series "Engineering and Organizational Issues Related to The World Trade Center Terrorist Attack" was initiated to present the findings from this work. The decision to publish a number of brief individual reports focusing on different topics was prompted by the desire to provide timely access to this information. As such, each report in the series focuses on a narrow aspect of the disaster as studied by MCEER researchers. A compendium of these short reports is planned at a later time. It is hoped that this work will provide a useful contribution that can lead to a better understanding of how to cost-effectively enhance the resilience of buildings against catastrophic events.

# Acknowledgments

This work was supported primarily by the Earthquake Engineering Research Centers Program of the National Science Foundation (NSF) under a Supplement to Award Number ECC-9701471 to the Multidisciplinary Center for Earthquake Engineering Research. The authors thank Dr. Priscilla Nelson and Dr. Joy Pauschke of NSF for their initiative and support of this project.

Additionally, the following individuals were kind enough to speak to the authors concerning their knowledge of the use of remote sensing after the attacks on the World Trade Center. This information was absolutely indispensable to the production of this report.

Kay Adams, URS Corporation
Dr. Sean Ahearn, Hunter College
Dennis Atkins, United States Geological Survey
Dr. Susan Cutter, The University of South Carolina
George Davis, Private Consultant
Jim Hall, Plangraphics
Russ Johnson, Environmental Systems Research Institute
David Kaplan, MITRE Corporation
Dave Kehrlein, State of California Governor's Office of Emergency Services
Ron Langhelm, The Federal Emergency Management Agency
Alan Leidner, City of New York, Department of Information, Technology and Telecommunications
Daniel O'Brien, New York State Emergency Management Office
Bruce Oswald, New York State Office for Technology
Charles Rigeway, The Federal Emergency Management Agency
John Schmidt, Keystone Aerial Surveys, Inc.
Chris Sheline, Environmental Systems Research Institute
David Shreve, State of California Governor's Office of Emergency Services
Debbie Simerlink, EarthData Aviation
Harvey Simons, The Environmental Protection Agency
Jean Tu, Plangraphics
Chief Nicholas Visconti, The New York Fire Department

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# 1.0 Introduction

A combination of factors culminated in a breakthrough for remote sensing technology in emergency management, following the events of September 11th. First, the World Trade Center attack is an event unparalleled in history. The devastation was beyond the imaginative capabilities of emergency management professionals - there was simply no appropriate script for such an event. The demand for information proved to be immense. Second, Manhattan is unique in the United States because of the density of high-rise buildings and the value of real estate. Because of this, and the logistical needs that follow, the City of New York had already undertaken intense mapping efforts, resulting in the production of highly accurate vector and raster databases. Third, even though this was a very large disaster, the scale of events in New York was highly localized, with primary impacts concentrated in a small geographic area. The need to coordinate the response for an event of this magnitude, in a dense yet relatively small area, made the combination of imagery and data maps particularly useful.

As an emerging technology in emergency response, a thorough evaluation of the value added by remote sensing data is warranted. However, the value of this data can be partially established by its use. Many top officials worked with the detailed images and maps of Ground Zero. Mayor Guliani visited the Emergency Mapping and Data Center (EMDC) on a daily basis to examine the images and map products. Chief Phiefer and Chief Werner from the New York Fire Department (FDNY) were also frequently at the EMDC, gathering imagery for planning purposes. Standing before the United States Congress Committee on Science, the role played by remote sensing technology during the initial response was formally acknowledged by Robert Shea, representing the Federal Emergency Management Agency (FEMA, 2002). President Bush and Donald Rumsfeld, Secretary of Defense are featured on the front cover of Geospatial Solutions (April 2002) examining high-resolution images of damage at the Pentagon. Across the world, newspapers published IKONOS images that illustrated the magnitude of devastation. It is clear that remote sensing played a vital role in communication during the months that followed September 11th.

Remote sensing data is most valuable for emergency responders when integrated into a Geographic Information System (GIS). The capabilities of GIS units to spatially analyze multivariate data is almost endless. The GIS analyst needs to know which combination of data, processed in what manner, would be most valuable to the response teams. Modeling, geospatial analysis, regression analysis, image processing, change detection, data mining, damage assessment and other advanced forms of analysis may be factored into the process, but to a limited extent.

As with any information systems product, communication, input, and feedback from end users is essential. The end user may not utilize GIS units to the fullest extent, as they are not aware of all potential capabilities. After a disaster, both the end user and GIS personnel are extremely busy, stressed, and sometimes emotionally volatile. This is not the best time to assess needs, or learn new material. The data sources and tools should be presented to emergency management personnel before the incident so that they know what will be most useful. The concepts, as well as the end products, need to be documented. For example, it is clear to many that the GIS and remote sensing response would have been more effective after September 11th had there been onsite mobile units. Also, it is clear the primary responders, the FDNY, were able to make tremendous use of maps and remote sensing data during this disaster. This may be due in part to the influence of the remote sensing unit within the department (Phoenix Photography and Imagery Group).

The purpose of this report is to document the use of remote sensing in response to the World Trade Center attack. Approaches that worked should not be forgotten, such as overlaying the building footprints onto images of rubble to locate elevator shafts, where bodies were later found. Problems that were encountered should not be dismissed, such as the need for absolute temperatures, rather than arbitrary digital numbers. There are technologies such as Light Detection and Ranging (LIDAR) imagery that some found useful, while others questioned their value. There were also ideas that analysts had no time to investigate during emergency response, because they were overwhelmed with map requests. Through interviewing, and in a sense "brain-storming" with key GIS personnel that were involved, this report will address how each remote sensing data set was used, and how it might have been used if there had been more time dedicated to processing the data. New ideas are also presented for using the data collected. The general lack of experience with remote sensing technology as a tool in emergency management and threat of further disasters, especially from terrorism, underscores the need to harness the knowledge of those who responded to the World Trade Center incident, and to the extent possible, create a script for future events.

Although this report does not present a general timeline of events as they unfolded, specific occurrences after the incident are valuable for establishing the ways in which remotely sensed data can be used after a disaster. Section 2 of this report therefore documents the sequence of key events, including the timing of data acquisition and release of map-based products that proved pivotal to the integration of remote sensing data in emergency operations.

While Global Positioning System (GPS) technology, certain surveying equipment, and hand-held electronic devices can be considered remote sensing devices, the current emphasis is on airborne and satellite data with a resolution greater than 20 meters. These data sets are generally delivered in, or converted to a raster environment, which forms a two- or three-dimensional surface over the entire area analyzed. Because of this spatial ubiquity and multi-temporal acquisition, these types of remote sensing data are very useful for assessing emergency response requirements, especially in conjunction with other data. Given the localized scale of events, it is unlikely that lower resolution data, from systems such as Landsat TM, ERS and MODIS, would have been useful. The catalog of primary remote sensing data used to support emergency operations is described fully in Section 3. Each sensor is accompanied with a brief description for laymen, a discussion of how the data was used, problems that were encountered using the data, and how such data might be used in future events. While the focus is shifted away from organizational, GIS, database, or other issues that impacted the use of advanced technologies, problems in these areas that directly impeded the use of, or were addressed using remote sensing data, are briefly discussed.

Although highly valued and of widespread use following September 11th, it is important to recognize that with better planning and preparedness, remote sensing and GIS could have played an even greater role. Based upon information gathered from interviews with key individuals involved in the emergency response, Section 4 considers lessons learned with respect to data acquisition, processing and logistical aspects of integrating remote sensing and GIS into emergency operations. Working with post-event imagery, new methods of data visualization are also presented, which may have proved useful for response and recovery teams. These findings establish the basis for a series of recommendations for future applications of remote sensing in disaster management, which are presented in Section 5. Interviews undertaken with key emergency management and GIS personnel constitute the main source of information for this document. Coupled with ImageCat's knowledge of remote sensing and emergency response, these accounts underpin the evaluation of the role played by advanced spatial technologies following September 11th.

# 2.0 Historical Overview

The following section provides a historical view of the role played by remote sensing data and GIS technology in the first critical weeks after September 11th. First, a summary of key events is provided, which was produced using information from published documents, written accounts (see, for example, Geoplace.com, 2001b), and interviews conducted by ImageCat with personnel involved in emergency operations. Details are then given of the remote sensing datasets acquired at the World Trade Center, including the data source or platform, type of imagery, and date of release to response and recovery workers. Table 2-1 provides a timeline of the acquisition of remote sensing data.

**Tuesday 11th September 2001**

- The World Trade Center is attacked.
- Commercial air traffic ban instituted.
- SPOT sensor acquires satellite coverage of Ground Zero, and images are posted on the Internet.
- Collapsed buildings include 7 World Trade Center, where the New York City map and municipal geographic database were housed.
- Hard-copy maps of World Trade Center are delivered by Alan Leidner (Department of Information Technology and Telecommunications (DOITT)) to the new emergency center at the New York (NY) City Police Academy.

**Wednesday 12th September 2001**

- NY State Office of Technology (OFT) coordinates with Alan Leidner and Sean Ahearn (Professor of Geography at Hunter College), to develop a list of remote sensing needs. This includes orthophotography, LIDAR and thermal data.
- OFT investigates the logistics of gathering data, including getting permission to fly.
- IKONOS sensor acquires satellite coverage of Ground Zero, and images are posted on the Internet and published in newspapers around the world.
- A backup copy of the New York City GIS database (comprising digital orthophotographs of the city, and vector attributes including streets, building footprints, transport networks, rivers and waterways) is set up

as a base map for GIS operations, by Al Leidner and Sean Ahearn, at the temporary Emergency Mapping Center at the NY Police Academy.

**Thursday 13th September 2001**

- The Federal Aviation Authority lifts the air traffic ban for approved aircraft.
- Digital photographs are obtained by the Fire Department Phoenix Photography and Imagery Group, by holding a digital camera out of the window of a police helicopter.
- Vertical aerial photographs are flown by Keystone Aerial Surveys for the NY State Emergency Management Office (SEMO).

**Friday 14th September 2001**

- The OFT awards the contract for remote sensing data to EarthData International.
- The EMDC is moved from the NY Police Academy to Pier 92 on the Hudson River. The center houses organizations with remote sensing and GIS expertise, from the DOITT, the Deep Infrastructure Group, the New York Parks Department, ESRI and Plangraphics.
- EarthData sets up a centralized data collection and processing facility in Albany.

**Saturday 15th September 2001**

- EarthData flies the first round of aerial photography, LIDAR and thermal imagery. The data is received on removable disk and processed in Albany.
- Three centers for GIS are up and running: (1) EMDC on Pier 92, dealing both with Ground Zero and the wider New York area; (2) FEMA Disaster Field Office on Pier 90; and (3) Urban Search and Rescue at the Jacob K. Javits Convention Center, focusing on Ground Zero alone.

**Sunday 16th September 2001**

- AVIRIS hyperspectral sensor is first deployed by the Jet Propulsion Laboratory (JPL) and the National Aeronautical and Space Administration (NASA) to acquire visible and thermal imagery of Ground Zero.

**Monday 17th September 2001**

- The State police and Metropolitan Transit Authority police deliver the remotely sensed EarthData images on CD-ROM to emergency response workers. The data circulation list includes: the FDNY; FEMA;

Environmental Protection Agency (EPA); US Army Corps of Engineers; and the State Office of Emergency Management (OEM). For data security and confidentiality, new users require approval from Al Leidner.

**September/October 2001**

- Remote sensing data became available on-line at the OFT and EROS data center. Initially this was limited to the processed imagery. Later, information was added concerning the flight history, data specifications and remotes sensing devices.
- 50 standard maps are produced at the EMDC and revised every one or two days. In total, more than 2,000 requests are made and 10,000 maps produced. In terms of accuracy, all maps satisfy the national mapping standards of +/- 2ft.
- FEMA sets up a separate data acquisition contract with EarthData Aviation, to map the debris disposal ground on Staten Island.

*Table 2.1. Timeline showing the acquisition of remote sensing data for Ground Zero.*

| Date | Source | Type of Data | Comments |
|---|---|---|---|
| 9/11/2001 | SPOT | Multispectral and panchromatic imagery | Data available on Internet |
| 9/12/2001 | IKONOS | Multispectral and panchromatic imagery | Data available on Internet |
| 9/13/2001 | Fire Department<br>Keystone | Digital photographs (oblique)<br>Digital photographs (vertical) | |
| 9/14/2001 | | | |
| 9/15/2001 | EarthData<br>IKONOS | Digital aerial photographs (vertical)<br>LIDAR imagery<br>Multispectral and panchromatic imagery | |
| 9/16/2001 | AVIRIS<br>EarthData | Hyperspectral imagery<br>Thermal imagery | |
| 9/17/2001 | EarthData | Digital aerial photographs (vertical)<br>LIDAR imagery<br>Thermal imagery | EarthData releases orthophotos and thermal imagery of Ground Zero |
| 9/18/2001 | AVIRIS<br>EarthData | Hyperspectral imagery<br>Thermal imagery | EarthData releases LIDAR imagery; AVIRIS thermal data released |
| 9/19/2001 | EarthData | Digital aerial photographs (vertical)<br>LIDAR imagery<br>Thermal imagery | |

*Continued on next page*

*Table 2.1. Timeline showing the acquisition of remote sensing data for Ground Zero (Continued).*

| Date | Source | Type of Data | Comments |
|---|---|---|---|
| 9/20/2001 | EarthData | LIDAR imagery<br>Thermal imagery | EarthData releases orthophotos and LIDAR imagery of Lower Manhattan |
| 9/21/2001 | EarthData | Digital aerial photographs (vertical)<br>LIDAR imagery<br>Thermal imagery | Poor photography and thermal data due to cloud cover<br>EarthData releases orthophotos and LIDAR imagery of Staten Island |
| 9/22/2001 | AVIRIS<br>EarthData | Hyperspectral imagery<br>Digital aerial photographs (vertical)<br>LIDAR imagery<br>Thermal imagery | |
| 9/23/2001 | EarthData<br>AVIRIS<br>NOAA | LIDAR imagery<br>Thermal imagery<br>Hyperspectral imagery<br>LIDAR imagery<br>Aerial photography (vertical) | |
| 9/24/2001 | | | Poor weather conditions |
| 9/25/2001 | EarthData | LIDAR imagery<br>Thermal imagery | |
| 9/26/2001 | EarthData<br>NOAA | Digital aerial photographs (vertical)<br>LIDAR imagery<br>Thermal imagery<br>LIDAR imagery<br>Aerial photography (vertical) | |
| 9/27/2001 | EarthData<br>Pictometry | LIDAR imagery<br>Thermal imagery<br>Digital aerial photographs (oblique) | |
| 9/28/2001 | EarthData | LIDAR imagery<br>Thermal imagery | |
| 9/29/2001 | EarthData | Digital aerial photographs (vertical)<br>LIDAR imagery<br>Thermal imagery | Poor data due to turbulence |
| 9/30/2001 | EarthData | Digital aerial photographs (vertical)<br>LIDAR imagery<br>Thermal imagery | |
| October 2001 | EarthData | Digital aerial photographs (vertical)<br>LIDAR imagery<br>FLIR imagery | EarthData continues acquiring data. FLIR system is used from 10/17/2002 to 10/22/2002. |

# 3.0 Evaluation of Remote Sensing Data

The historical overview in Section 2 outlines the remote sensing data collected for emergency operations following the World Trade Center attack. This section of the report provides details of the datasets that were acquired (see also Table 2-1), including: aerial photographs and multispectral imagery, thermal, LIDAR, and hyperspectral systems. In each case, the equipment specification is considered. Its usefulness in rescue, response and recovery is also discussed, based upon a series of conversations with key individuals involved in emergency operations (sources are noted in parenthesis, and their full name and affiliation is listed in the Acknowledgments section of this report), together with published reports and articles (see, for example, Geoplace.com, 2001a; New York State Senate, 2001). The evaluation goes on to consider problems that emerged, and potential data sources and uses that could prove critical in future emergency situations. Finally, methods of geospatial cross-referencing are described, which combine remote sensing and GIS analysis in supporting emergency operations.

## 3.1 Aerial Photography

Aerial photographs are images of the earth's surface, taken from an airplane or helicopter. There are two main types of air photographs discussed below – vertical, which look straight down, and oblique shots that are taken from one side. The amount of detail shown by the photography depends on the height of the aircraft, the type of digital or film-based camera, and whether the shot is taken in color or black and white.

As shown by the schedule in Table 2-1, several organizations were involved with the acquisition of aerial photographic coverage for the World Trade Center site. Initially, Keystone Aerial Surveys acquired black and white vertical images for the NY State Emergency Management Office (SEMO), and the photography group of the Fire Department of New York (FDNY) took digital photographs of Ground Zero from police helicopters, on an intermittent basis. However, once remote sensing data was formally requested to aid response and recovery, the organization EarthData collected high-resolution vertical digital photographs on a regular basis. Later on during the recovery operations, supplementary vertical scenes were obtained by the National Oceanic and Atmospheric Administration (NOAA), and oblique shots by Pictometry International.

### 3.1.1 Specification

Vertical aerial photography was initially flown by Keystone on 13th September, by a Cessna 320 aircraft carrying a Leica RC30 camera. EarthData then acquired coverage (EarthData, 2001) on 19 occasions between 15th September and 22nd October 2002, using a Navajo Chieftain aircraft equipped with a Kodak Megaplus Model 16.8i panchromatic digital camera. Flights were timed to coincide with midday, in order to minimize shadowing effects. The output is a 256 grayscale image. During all flights, precise changes in the position and orientation of the camera were recorded using an Applanix POS/DG Inertia Measurement Unit (IMU), and coordinates of a known control point measured using a GPS receiver. Since the flying height ranged from 3000-5000 ft, the imagery has a spatial resolution of 0.3-0.5ft. Image rectification and processing procedures (see EarthData, 2001) were completed on these raw scenes, and data released for general circulation 12 hours later.

Additional vertical scenes were acquired by NOAA on five occasions between 23rd September and 15th October 2002 (NOAA, 2001). The Cessna Citation jet was flown at 3,300 ft with a film-based Leica/LH systems RC30 camera. In this instance, the output is a detailed color photograph.

The potential value of high-resolution oblique photographs was demonstrated by the single dataset acquired by Pictometry International, on 27th September 2002. However, limited information is available concerning this mission. Specifications for the numerous digital photographs taken on a daily basis by the FDNY are unknown. The uses and usefulness of these images are described in the next subsection.

### 3.1.2 Uses and Usefulness

The value of remote sensing coverage for Ground Zero was immediately apparent from the digital photographs taken from the police helicopter. Although these were merely photographs taken out of a window, they helped fire chiefs assess damage, and accessibility (A. Leidner) and locate hazards such as hanging debris and unstable ground.

The high-resolution digital coverage collected by EarthData (see Figure 3-1) was the most widely used source of aerial data. In particular, orthophotographs proved to be extremely valuable. Orthophotographs are processed so that they have the same properties as a map (i.e., distances and orientations are correct), but look like a photograph. For non-specialists, they offered an aerial view that was easy to interpret. Initial optical coverage enabled rescue teams to orient themselves, and gave a clear indication of the magnitude of damage and extent of debris on the site (B. Oswald). Overlaid with Computer Aided design (CAD) models of the twin towers floor plan, they enabled workers to pin point specific locations of infrastructure, such as stairwells and elevator shafts (J. Tu). This composite of data was also used for logistical planning, when it was necessary

Note: Although much of the smoke arising from the debris pile has abated, part of the image remains obscured by the plume.

*Figure 3.1. High-resolution vertical aerial photograph acquired by EarthData, showing Ground Zero on the 15th September 2001.*

to identify a safe and stable position within the Ground Zero site, for cranes lifting and clearing debris. Identifying potentially dangerous areas on the debris pile around voids and depressions also helped, by reducing the risk of injury to recovery teams (A. Leidner). The photographs aided orientation for members of the emergency task force who were unfamiliar with the Lower Manhattan area. Presented alongside optical data of the World Trade Center prior to its collapse, the orthophotographs were widely distributed and used extensively for comparative purposes.

In view of these factors, it is hardly surprising that orthophotographs were the most requested product at the Javits GIS center (D. Shreve). In subsequent stages of the recovery, these optical images were used monitor the shrinking ‘red zone’ (zone of restricted access), catalogue evidence, coordinate building inspections and show damage states for buildings and utilities.

The orthophotographs were widely employed as a base map, on which data collected for ground zero was overlaid. For firefighters, thermal and optical data was a useful combination. The two-dimensional 75 ft square, numbered, transparent grid established by the FDNY for logistical purposes, was also superimposed on the images. This provided a common reference system for tracking objects found amongst the debris. It also enabled recovery workers to discuss activities and locations on the site. This was particularly important, since the GPS devices were not working due to interference. One can imagine a conversation between tired firefighters, trying to discuss the location associated with a clean up task. Thousands of conversations just like these were significantly shortened through using this data.

The oblique photography captured several weeks after the attacks by Pictometry, provided a valuable indication of damage to buildings surrounding Ground Zero. Like the initial photographs taken from helicopters by the fire department, they showed the sides of buildings, the extent of debris on rooftops and the level of damage sustained by facades. These images may have enabled fire fighters to assess the hazards associated with hanging debris. GIS managers who examined this trial dataset identified it as a potentially useful tool for emergency situations.

### 3.1.3 Problems

Although aerial photography was widely used at Ground Zero, there are a number of problems, which if resolved, could improve its role in emergency operations. First, it is important to note that optical coverage is of limited use when the scene is obscured by smoke. This was a major limitation of the earliest vertical coverage acquired by Keystone on 13th September. If fires are burning during the early phases of a disaster, this is not the optimal source of data. Shadowing is also a problem associated with aerial coverage of dense urban environments with a concentration of high-rise buildings. Unless data is acquired at midday, when the sun is at nadir, shadows can impair visual interpretation, by obscuring areas of interest.

Second, digital images were collected by EarthData in black and white. However, color datasets are generally easier for non-specialists to interpret, since features are distinguished by color, in addition to shape and contrast. Ideally, color photographs, like those acquired later by NOAA, should have been available immediately after the event. The spatial resolution of these scenes is also an issue. The Phoenix Photography and Imagery Group of the NYFD identified a pixel size of ~3 inches as ideal for the identification of individual girders (New York State Office for Technology, 2002).

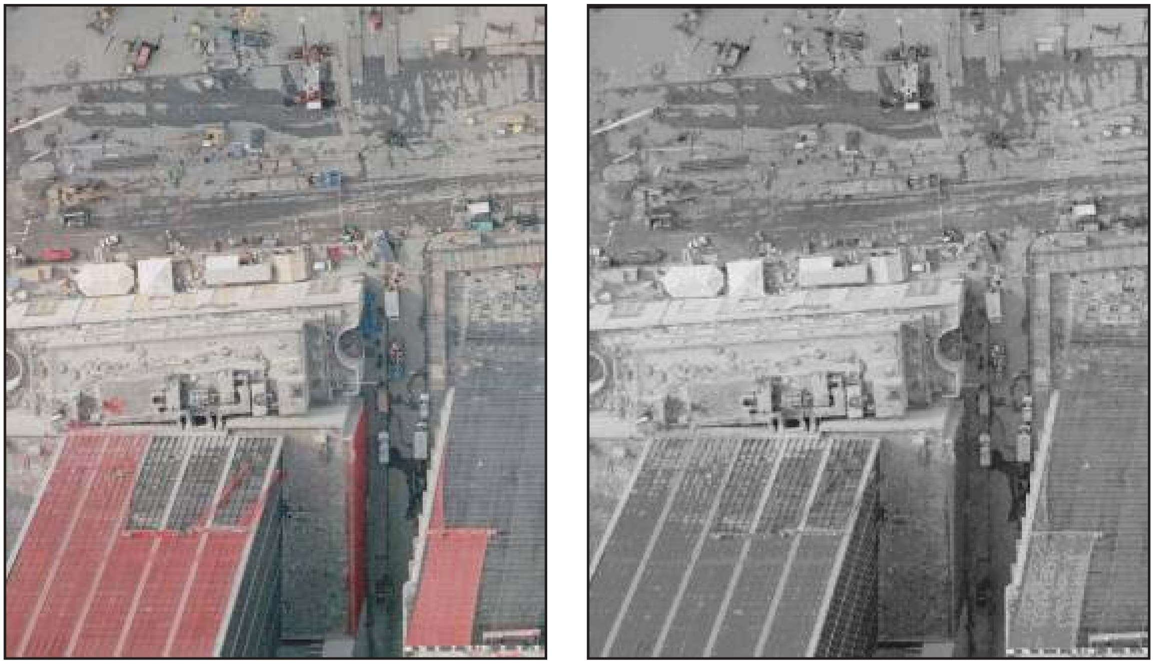
Third, the usefulness of orthophotographs to response teams was limited by the 12 hour lag between data acquisition and release, during which time conditions at Ground Zero had changed. Although this was the stipulated requirement on which EarthData acted, turnaround time was identified by the FDNY as a major obstacle to use (D. Schiavo, C. Chang, D. Shreve). Finally, oblique photographs are not suitable for GIS programs, thereby limiting their usefulness for developing map-based products.

### 3.1.4 Potential Uses

Learning from World Trade Center events, color rather than grayscale aerial photography would greatly assist response and recovery operations, enabling crews to distinguish features by their color. In Figure 3-2, on the left hand side, it is possible to visualize the progress of covering the surrounding buildings with protective material. It is difficult to discern this information from the same resolution imagery in the black and white version on the right. Several of the cranes and cars in the color image are difficult to see in the black and white image. Furthermore, it is not possible to discern in black and white that the windows are boarded up on the first floor. Perhaps most importantly, the color provides a tie between the image and the world around the person viewing the image on site, allowing them to quickly orient themselves.

Feedback from response crews further suggests that oblique coverage, such as that acquired by Pictometry, could prove useful if acquired immediately after the event. This perspective could also aid 3D visualization. Using architectural rendering software, oblique shots could be draped on high resolution DEMs as 'wallpaper,' providing a side view of building facades that is absent from the orthophotography.

Image processing techniques could generate additional information from high-resolution aerial photographs. Enhancing the visual representation could reduce shading effects. Procedures such as edge enhancement would be useful for mapping the locations of girders. Multi-temporal change detection could be used to monitor clean-up operations in an automated manner. Density splicing and classification techniques could also be used to categorize debris for planning purposes. Once images are brought into image processing software packages, they become much easier to interpret.



a) b)

Note: On the left hand side, it is possible to discern the progress of protecting buildings, the locations of cranes, and the locations of boarded up windows. It is much more difficult to discern this information in the black and white image on the right, created by ImageCat for illustrative purposes.

*Figure 3.2. High-resolution aerial photography acquired by NOAA, showing Ground Zero on the 23rd September 2001.*

## 3.2 Multispectral Satellite Imagery

Satellite imagery of Ground Zero was acquired by the SPOT and IKONOS earth orbiting systems, several days before the high-resolution aerial photographic coverage. Whereas the aerial photographs from EarthData (see Section 3.1) are simple black and white or color scenes, these satellite sensors collect digital multispectral imagery, which spans a wider range of the electromagnetic (light) spectrum. Data is acquired in a series of 'bands', which are sensitive to blue, green and red reflectance, and may also extend beyond visible wavelengths, into infrared regions of the spectrum.

### 3.2.1 Specification

At 11:55 am of September 11th 2002, only three hours after the terrorist attacks, SPOT 4 acquired a multispectral scene of Ground Zero. Operated by the French organization SPOT Image (SPOT, 2002), this system has been sending back images of the earth since its launch on 3/24/1998. The satellite has two sensors:

a multispectral device with a spatial resolution of 20 meters (m) and a finer resolution panchromatic device that can record objects of 10m. Four multispectral bands occupy blue (0.5-0.59 μm), green (0.61-0.68 μm), red (0.79-0.89 μm) and infrared (1.58-1.75 μm) wavelengths. The panchromatic band occupies a single range in the visible (0.61-0.68 μm) region of the spectrum.

The IKONOS system, operated by Space Imaging (Space Imaging, 2002), also includes multispectral and panchromatic devices. Multispectral bands include blue (0.45-0.52 μm), green (0.52-0.6 μm), red (0.63-0.69 μm) and near infrared (0.76-0.90 μm) bands. The panchromatic spans the visible part of the spectrum (0.45-0.9 μm). Compared with SPOT 4, this newer system, launched on 9/24/1999, displays the Earth's surface in much greater detail. Acquired on 12th September – one day after the terrorist attacks, IKONOS coverage of the World Trade Center has a resolution of 4 m, while the panchromatic band shows details of ~1 m.

### 3.2.2 Uses and Usefulness

Following the World Trade Center Attack, multispectral IKONOS and SPOT data were quickly made available on the Internet. Thus, it was employed in emergency efforts several days before the aerial photography. As shown in Figure 3-3, IKONOS imagery gave the general public a view of Ground Zero, with the extent of damage published on the front page of newspapers around the world. For non-specialists, the realistic color format is easy to understand and the 1 m spatial resolution provides a detailed representation of the ground surface below. For visualization purposes, IKONOS imagery was used as a base-map, and presented as a before/after sequence. These images were very useful for visualizing the area as it once stood, as it was difficult for the relief workers from out of town to discern on site.

Although useful as an overview of Ground Zero in the wider context of lower Manhattan, the SPOT 4 data in Figure 3-4 played a limited role in emergency operations, due to poor spatial resolution (S. Ahearn).

### 3.2.3 Problems

Many of the subsequent IKONOS images were acquired off-nadir. With off-nadir acquisition, the sensor is tilted away from directly below the satellite to acquire a specific region. Due to the offset sensor position relative to the study site, features of interest at Ground Zero were obscured by other tall buildings in lower Manhattan.

In addition, visibility was limited in the IKONOS images by smoke obscuring the ground surface immediately after the terrorist attacks. This is a limitation

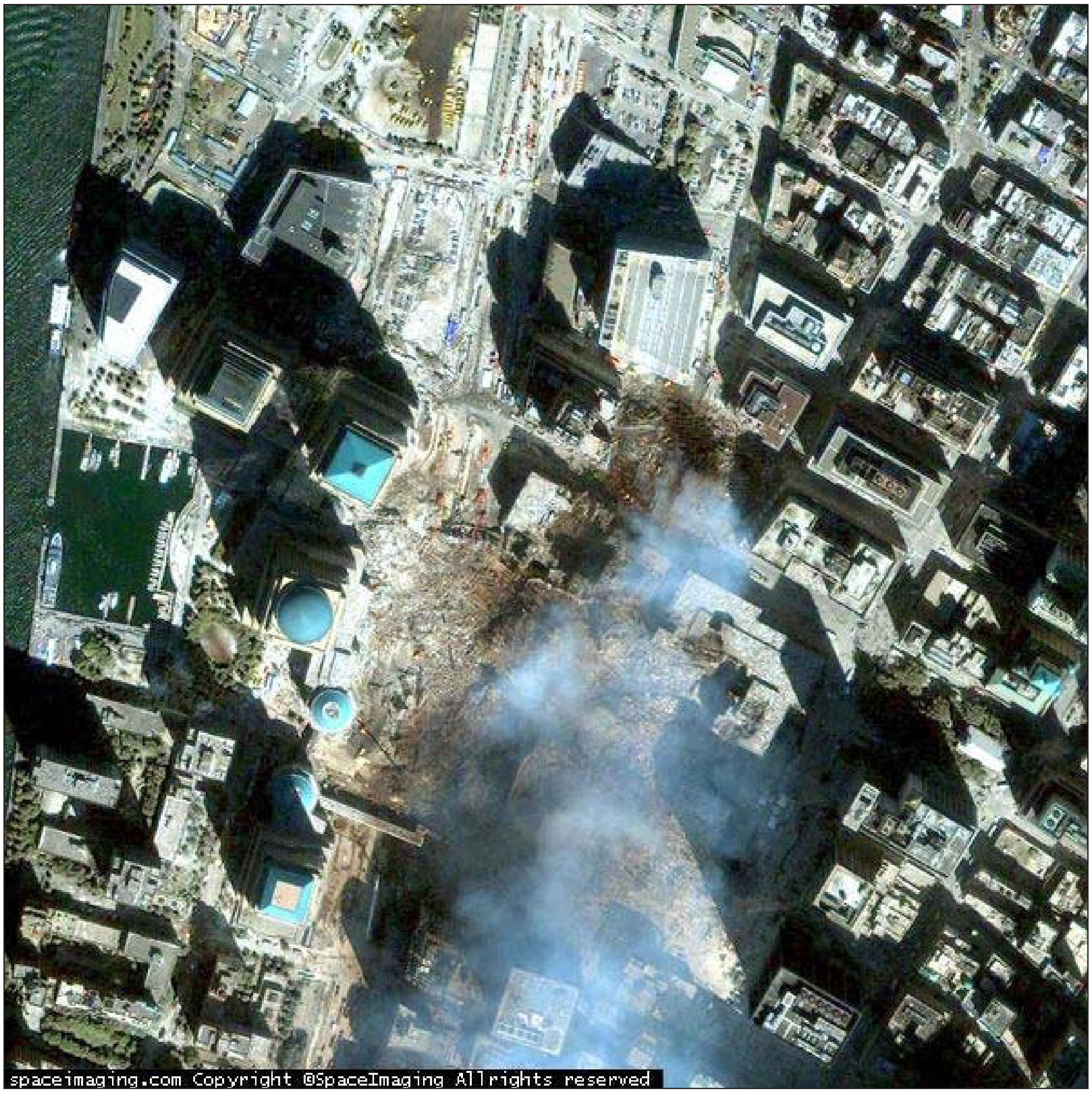


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*Figure 3.3. Multispectral IKONOS satellite coverage of Ground Zero, acquired on the 15th September 2001.*

of visible sensors, and points towards the value of sensors operating in other regions of the electromagnetic spectrum, such as Synthetic Aperture Radar (SAR). The revisit frequency is also an issue for earth orbiting satellites such as these. For 1 m data captured near nadir, this is 2.9 days. In the case of SPOT, its usefulness was severely limited by the coarse spatial resolution, where only objects larger than 10 m could be distinguished.

Note: Hotspots associated with fires raging at Ground Zero appear in red.

*Figure 3.4. Infrared SPOT image, acquired three hours after the World Trade Center Attack on the 11th September 2001.*

### 3.2.4 Potential Uses

In future disasters, high-resolution data from sensors such as IKONOS and Quickbird (which was launched in October 2001) will provide a useful alternative to aerial photography, particularly when data acquisition by aircraft and helicopters is prevented due to air traffic bans. For widespread disasters, this data would be useful for the same operations as the aerial photography listed above. The extensive coverage provided by satellite data is useful for monitoring events where damage is sustained at a regional rather than localized scale, especially when change detection algorithms are used. Infrared data can be particularly useful for monitoring heat and detecting damage. For analytical purposes, multispectral imagery has the potential to yield additional information, compared with grayscale or color aerial photography. Classification is an image processing technique that assigns features to groups or 'classes' depending on their spectral characteristics in different bands of the electromagnetic spectrum. For example, classification of high-resolution imagery could distinguish between ground surface materials and debris.

## 3.3 LIDAR Altimetry

Light detection and ranging instruments collect information about the elevation of the earth's surface, by measuring the amount of time taken for beams of light to strike the ground and return to the sensor. Devices are generally mounted on an aircraft platform, and a high density of point samples recorded along a designated path or swath. LIDAR data is usually interpolated onto a raster grid or a Triangulated Irregular Network (TIN) is used to produce terrain models, which present topographic variations as a basic 3D map. During the early stages of emergency operations, EarthData acquired LIDAR coverage of Ground Zero on a daily basis (see Table 2-1). Toward the end of the program, NOAA acquired additional scenes and the frequency of collection by EarthData was reduced to a three to four day interval.

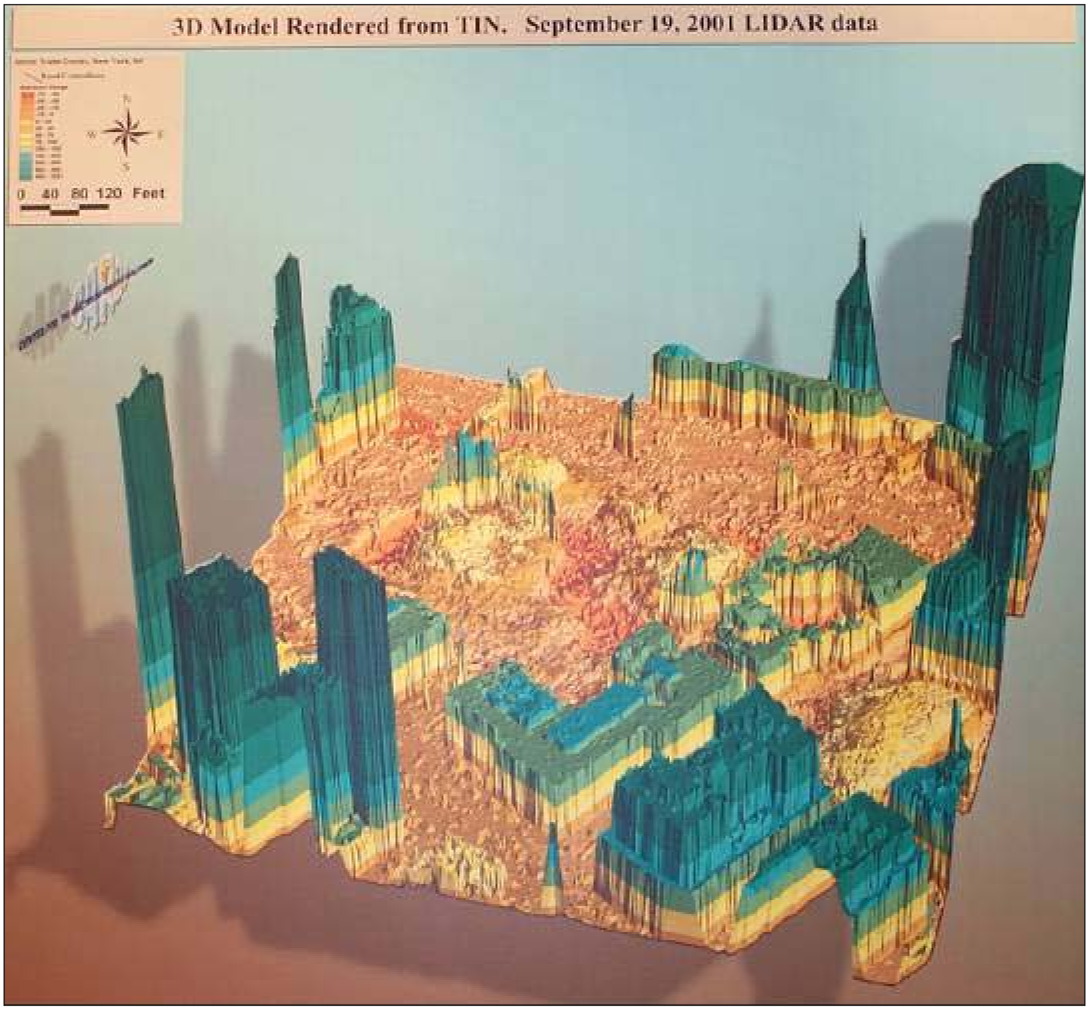
### 3.3.1 Specification

EarthData first acquired LIDAR coverage on 15th September, using an AeroScan multiple return sensor carried aboard a Navajo Chieftain aircraft (see EarthData, 2001; also Section 3.1). During all flights, precise changes in the position and orientation of the LIDAR unit were recorded using an Applanix POS/DG IMU, and coordinates of a known control point measured using a GPS receiver. Although the measurement frequency varies with the elevation and speed of the aircraft, spatial resolution was in the range 6-15 ft (EarthData, 2001). In this case, spatial resolution refers to the average distance between elevation readings, rather than the pixel size. Following image registration and processing, the first LIDAR surface models were available to response teams on 17th September. Difference images (created by subtracting two images from different dates) were perceived to have an accuracy of +/- 9 cm (S. Ahearn).

NOAA acquired five additional scenes between 23rd September and 15th October (NOAA, 2001), using an Optech LIDAR unit carried aboard a Cessna Citation jet. Flown at an altitude of 5,000-6,000 feet, the resolution of these models is coarser than the EarthData scenes.

### 3.3.2 Uses and Usefulness

The LIDAR imagery flown by EarthData (Figure 3-5) was particularly useful during the early stages of emergency operations when, on 17th September, it was used to visualize Ground Zero through the smoke (S. Ahearn). The basic 3D models were employed by fire chiefs as a planning and visualization tool. They would use the resulting maps to discuss events as they correlated with the debris (S. Ahearn). They were also widely used by response teams and the Federal Emergency Management Acency (FEMA), for assessing the extent of



Note: This is a photograph of the map from the exhibit "Charting Ground Zero Before and After" at the Woodard Gallery (see Woodward Gallery, 2002).

*Figure 3.5. Map of LIDAR 3D terrain model for Ground Zero, acquired by EarthData on the 19th September.*

damage, together with the shape, volume and depth of depressions in the debris pile. Later on during emergency operations, LIDAR difference images were used to track debris removal, and to explore subsidence in the debris pile (D. Kaplan, S. Ahearn), which if significant could have posed a considerable risk to emergency crews.

In terms of map-products, overlaying of the 3D LIDAR model with a map of hazardous materials and fuel sources was particularly useful for ascertaining what was happening underneath the ground. (A. Leidner). The correlation between voids and the position of fuel and freon tanks provided a focus for fire fighters (N. Visconti), possibly preventing explosions that would have released toxic gases.

### 3.3.3 Problems

The value of LIDAR data for visualizing ground surface features in the red zone and distinguishing between changes due to debris removal and subsidence could be improved by increasing the point sampling density. Its usefulness was also limited by the processing time between acquisition and delivery. Although imagery was delivered the following morning, the debris pile had often changed during this interim period. For similar reasons, response and recovery teams continued to rely on the real time monitoring of subsidence levels offered by an onsite laser altimeter (D. Kehrlein). Data processing issues may have affected the accuracy of LIDAR coverage. The highest elevations appeared to change, suggesting that interpolation algorithms were used to derive a trend rather than a precise elevation surface (C. Rigeway).

### 3.3.4 Potential Uses

When LIDAR collects elevation readings, often the intensity of the response is also captured. As with optical data or radar data, intensity changes with material. This data can be mapped, and the result resembles a black and white image, with metal objects standing out as the most reflective. The sensor used by EarthData was apparently unable to capture intensity, and many individuals working with the LIDAR coverage were unfamiliar with the concept of this dataset. During the early stages of events, when Ground Zero was obscured by smoke, intensity readings captured by the LIDAR sensor may have provided a useful indication of damage levels. However, in view of the general lack of familiarity with this dataset, remote sensing specialists would require training in the processing and interpretation.

Additional analysis could be undertaken and new composite images produced using LIDAR coverage. For example, a difference image could be created, by subtracting a temporal sequence of the 3D terrain models. This would provide a visual indication of the changing shape (see the illustrative example in Figure 3-10), and a numerical value of volumetric changes in the debris pile. The fusion of orthophotography and thermal imagery to this composite would clarify the relationship between depressions in the debris, hotspots and hazardous objects. Draping thermal difference maps with the LIDAR imagery (see, for example, Figure 3-9) could provide a more robust indication of successful fire fighting strategies and cool-down rates.

## 3.4 Thermal Imagery

In simple terms, thermal imagery records the temperature of a designated surface, in this instance the debris pile at Ground Zero. The ‘temperature’ is actually a calibrated measure of emitance in the thermal region of the electromagnetic spectrum, which falls just above the visible wavelengths that were studied using multispectral sensors (see Section 3.2). For the World Trade Center, data was collected using both airborne and satellite sensors. The SPOT 4 coverage was acquired soon after the terrorist attacks, with airborne imagery from EarthData Aviation and AVIRIS delayed until the 16th September, due to the ban on air traffic.

### 3.4.1 Specification

During the initial phase of response and recovery, flights by EarthData (EarthData 2001) provided thermal imagery every other day. Commencing on 16th September, data were acquired using a tripod mounted Raytheon Nightsight Palm IR 250 thermal camera, carried aboard a Navajo Chieftain aircraft. Flights were undertaken just after daybreak, to minimize the effects of solar heating on the scene. The resulting thermal data (see Figure 3-6) has a spatial resolution of 2ft and was captured on a video format. Individual scenes were obtained by "frame grabbing". This is a process of pausing the video, creating an image from the paused video that is transferable to image processing software, and registering the resulting still. Two stills were often required. It is important to note that output shows the relative (hot versus cold), rather than absolute (in terms of degrees Kelvin) magnitude of temperatures on the ground surface.

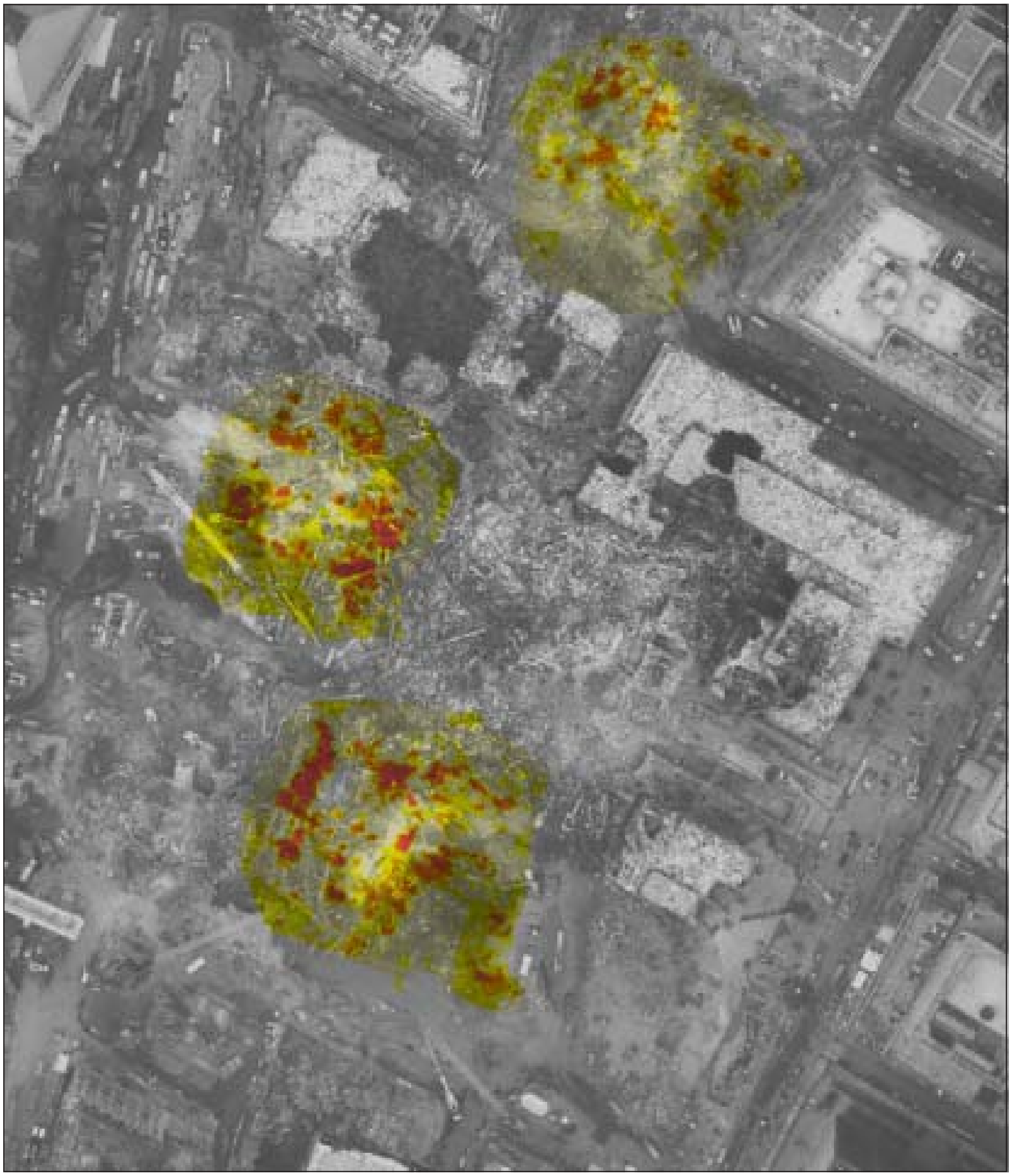
From October 17th to October 22nd, EarthData thermal imagery was also obtained using a FLIR ThermaCAM SC2000 radiometric camera. This logs individual frames on a PCMCIA card, rather than recording continuously on videotape. The resulting data is in 8-bit (256 level) format. Since neither of these thermal data sources were GPS referenced, both required registration relative to a baseline orthophotograph.

The first round of thermal data acquisition by JPL/NASA (Clark et al., 2001) coincided with that of EarthData. In this instance, thermal imagery was obtained as part of the hyperspectral Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) coverage, which is described fully in Section 3.5. The output (see, for example, Figure 3-7) is absolute temperature values in degrees Kelvin.

The SPOT 4 satellite coverage obtained on 12th September by SPOT Image (SPOT, 2002) precedes both the EarthData and AVIRIS datasets. Recording emitance between wavelengths of 1.58-1.75 μm, this data has a spatial resolution of 15 m. Further details of the platform and sensor are provided in Section 3.2.1.

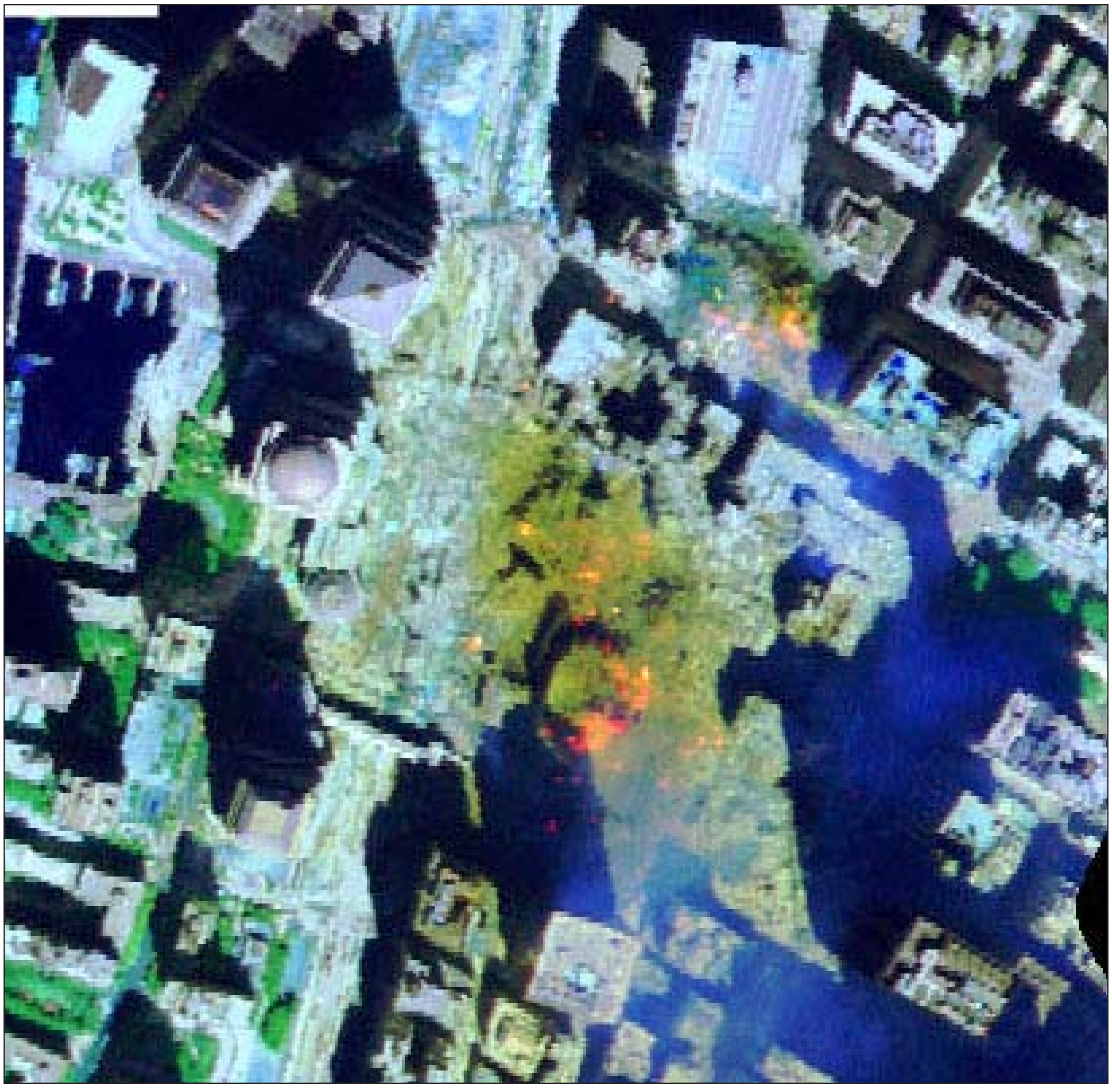
### 3.4.2 Uses and Usefulness

The most frequently used thermal infrared data was flown by EarthData (see Figure 3-6). As with all of the data collected by this company, imagery was



Note: Thermal data are overlaid on an orthophotograph obtained on October 8th. Variations in temperature are evident across the site. However, these values were acquired (and are therefore displayed) using an 8-bit radiometric scale, rather than an absolute calibration such as degrees Fahrenheit

*Figure 3.6. Thermal image of Ground Zero acquired by EarthData on the 7th October 2001, using a Raytheon airborne sensor.*



Note: This data was not integrated into GIS products produced in New York

*Figure 3.7. AVIRIS thermal image showing hotspots at Ground Zero on the 16th September 2001 (Clark et al., 2001).*

widely distributed and well publicized. In contrast, AVIRIS imagery was not circulated among the GIS units. Consequently, a key source of absolute temperate values was excluded from the mapping process. SPOT 4 data proved to be of limited value due to the coarse spatial resolution.

With fires raging at Ground Zero, the thermal data was used in a number of ways. Overlaid with orthophotographs, it was used for planning fire-fighting strategies, which needed to consider the location of hot spots in the pile. It was also used to evaluate firefighting strategies (B. Oswald). For example, where various chemicals were being used to tackle hotspots, chiefs assessed the success of fire-fighting techniques by visually noting the difference between a time series of the images (B. Oswald). However, there is no indication that this subtraction was performed digitally, or numerically.

Integrating thermal and attribute data also assisted operations. Superimposing the thermal data on GIS locations of transformers, and underground infrastructure highlighted potential hazards to the response teams (D. Kaplan). For fire fighters, building plans and maps showing hazardous materials and fuel sources provided a focal point for wetting down the areas around fuel and freon tanks (A. Leidner). From visual examination, firefighters also noted a correlation between hot spots and depressions in the terrain model (N. Visconti). They also attempted to track occurrences of 'flash-over,' when hot areas jump or migrate from one location to the other (D. Kehrlein).

### 3.4.3 Problems

Considerable debate surrounds the use of this data in emergency response. There is no question that the data were used extensively. However, a number of significant problems were identified. Timeliness was a key concern, since the distribution of heat was changing constantly. The EarthData processing routine had a turnaround time of 4-6 hours.

Response crews called the usefulness of EarthData thermal imagery into question, since heat and fire locations were not always correlated. Fire fighters used the thermal scenes for reference and crosschecking, but mainly relied on onsite sensors (D. Kehrlein). Offset between remote sensing imagery and observations appear to result from the method of data acquisition – videotaping and screen capture, coupled with inaccurate image registration relative to the orthophotographs. It is not clear that this actually was a problem, but it is clear that it could not be ruled out. Some observed changes were most likely linked to actual heat migration because of the fire fighting efforts and the high conductivity of the material. However, there was also speculation that the movement of hot spots was due to misregistration. When lives are at stake, the accurate positioning of hotspots is of pivotal importance. The value of thermal data was also questioned, because the EarthData imagery failed to display absolute temperatures. Ideally, fire fighters require a scale of values in degrees Fahrenheit, rather than a relative scale of 8-bit values.

Although correctly scaled, the AVIRIS data were not delivered in a GIS format to people at ground zero. Indeed, many of the top-level GIS responders were unaware that AVIRIS was collected. The SPOT imagery was widely distributed, but it was not delivered in a georeferenced format and therefore was not easily read into a GIS program. Although this was the infrared data delivered, there are no examples of maps that overlaid infrastructure onto this data, perhaps due to the resolution.

### 3.4.4 Potential Uses

In the extensive gallery of maps produced at Hunter College, there is no analysis of the hot spots. It was assumed from looking at the images that the deepest holes were the hottest (N. Visconti). Through data integration, plotting the thermal infrared response by the depth is a simple task, which will establish whether or not this is the case. Correctly registered Raytheon, FLIR or AVIRIS thermal data could be draped onto the LIDAR coverage to assess the relationship between the depth and the hotspots and through multi-temporal analysis investigate other issues such as cool-down rates.

The AVIRIS thermal scenes could be brought into a GIS system, and integrated with optical, LIDAR and CAD data. A composite map showing hotspots, depressions in the pile, the locations of fuel and freon tanks, hazardous materials, and other features of specific concern, could provide a holistic view of the hazards faced by rescue teams and a focus for firefighting efforts.

## 3.5 Hyperspectral Data

In response to requests by the EPA through the US Geological Survey (USGS), the AVIRIS hyperspectral instrument was deployed by JPL/NASA soon after the terrorist attacks. The term 'hyperspectral' (as opposed to multispectral, as described in Section 3.2) reflects the large number of bands over which data is acquired. In the case of AVIRIS, radiance measurements span visible and infrared regions of the electromagnetic spectrum. The spectral characteristics of each pixel are recorded across this entire range of wavelengths.

### 3.5.1 Specification

Commencing on the 16th September, AVIRIS coverage of Ground Zero was acquired on five occasions (see Clark et al., 2001). The hyperspectral sensor was deployed aboard a De Havilland Twin Otter aircraft at altitudes of 6500-12500 ft, resulting in a spatial resolution of 2-4 m. The spectral resolution is also high, with 224 bands spanning a range of 0.37-2.5 μm. Despite the wide choice of bands, for the World Trade Center, studies focused on the thermal infrared region of the spectrum (see Section 3.4) and the reflectance characteristics of atmospheric particulate matter, with an emphasis on asbestos. After acquisition, data were calibrated and georeferenced at JPL. Imaging Spectroscopy Groups at the USGS applied atmospheric and ground calibrations to generate surface reflectance and absolute temperatures.

### 3.5.2 Uses and Usefulness

Hyperspectral AVIRIS data were used by scientists at the USGS to analyze contents of the smoke plume emanating from Ground Zero. It was also used to track particulate asbestos, which posed a considerable risk to response and recovery crews. Results from these studies were published several weeks after the terrorist attacks (Clark et al., 2001).

### 3.5.3 Problems

Although the first AVIRIS hyperspectral dataset was rapidly processed and released on 18th September, this information, which included useful maps of hotspots, was not generally available. The value of results showing atmospheric pollutants was limited by considerable time delays. These compositional results were not released until the 27th September, by which time the risk posed to response crews by airborne contaminants had abated. Many confided that it was very difficult to obtain any environmental information.

### 3.5.4 Potential Uses

During the early stages of emergency operations, many fire fighters experienced respiratory problems (D. Kehrlein). Clearly, AVIRIS data has the potential to provide key information about dangerous airborne contaminants. However, the turnaround time between data acquisition and release requires significant improvement.

Multi-temporal sequences of thermal data could be used to monitor changing hotspots and generate cool down rates, by mapping shifts in location and quantifying their diminishing extent. With proper training algorithms in place, this sensor could be absolutely critical in future events. This may prove particularly useful for tracking airborne contaminates which are far more deadly than asbestos.

## 3.6 SAR Imagery

RADARSAT1 is a commercial satellite (Canadian Space Agency, 2002) that acquires high-resolution imagery using synthetic aperture radar (SAR) sensors. Rather than passive devices, such as the multispectral and hyperspectral sensors described previously, these are active sensors, which emit and receive low frequency signals in the microwave region of the electromagnetic spectrum. SAR sensors collect information about the material of the ground surface based upon texture. It is particularly sensitive to manmade features, which are often metallic or contain right angles (referred to as corner reflectors). This data has been used extensively in the military. Interpreting this data takes practice, but there are many advantages to this data source, including the ability to see through smoke or at night. Where multiple images are captured, they can be used to generate terrain models. SAR can also be collected by aircraft, which produces higher resolution imagery.

*(Image courtesy of the Canadian Space Agency)*

Note: Backscatter from the Manhattan urban fabric highlights corner reflectors such as buildings, together with highly reflective metal surfaces.

*Figure 3.8. RADARSAT1 SAR imagery of Ground Zero, acquired on the 13th September 2001 using the sensor operating in 'Standard' mode.*

### 3.6.1 Specification

RADARSAT coverage of the World Trade Center was acquired on 13th September. The sensor operates in the radio wave regions of the spectrum at 5.6 cm, emitting and receiving a beam from a 15 m x 1.5 m antenna. The sensor may be set to 'fine' imagining mode, which results in a spatial resolution of 8 m. However, in this instance, the 'standard' mode produced imagery (see Figure 3-8) with a resolution of 30 m.

### 3.6.2 Uses and Usefulness

Although timely, little information was yielded by RADARSAT data, due to the limited spatial scale of Standard mode imagery compared with the localized scale of damage. Although the Manhattan area is clearly depicted (Figure 3-8), and a change in intensity is apparent, few features can be distinguished at Ground Zero.

### 3.6.3 Problems

In general terms, SAR technology is less widely used in remote sensing and GIS communities than optical data. Consequently, there were few users with the necessary expertise to incorporate this data into response and recovery efforts. Its usefulness was also fundamentally limited by the poor spatial resolution and the complexity of the built environment around Ground Zero.

### 3.6.4 Potential Uses

The change in intensity between before and after scenes acquired by RADARSAT suggests that SAR data may offer important insights into damage sustained. Active sensors, which operate at these longer wavelengths, are particularly versatile since they can be deployed at night, see through heavy smoke or clouds and operate during adverse weather conditions.

High-resolution imagery acquired by airborne sensors, or RADARSAT1 in 'fine' mode, would be particularly useful in regional emergency situations. It is also valuable for imaging manmade objects, since it is sensitive to 'corner reflectors', or 90-degree edges associated with buildings, and a much higher return is associated with metallic objects. However, SAR data is arguably more difficult to interpret than optical imagery. For SAR to play a more significant role in emergency operations, trained remote sensing experts would be required to analyze and evaluate results.

## 3.7 Geospatial Cross-Referencing and GIS

GIS technology provided the platform for integrating a diverse range of spatial datasets that were acquired during emergency operations at the World Trade Center site. The following section describes advanced methods of geospatial cross-referencing using remote sensing imagery, vector and raster datasets. The New York City GIS database was a particularly useful resource, providing both high-resolution orthophotographs of the World Trade Center prior to the terrorist attacks, and key attribute data. For illustrative purposes, examples of the resulting composite scenes for Ground Zero are described. Issues raised by end users are also discussed, together with ways of improving procedures for future events.

### 3.7.1 Methods

Once pre-processed and geo-referenced, remotely sensed images were imported into an Environmental Systems Research Institute (ESRI) environment, often using ArcView. These images would then be combined with GIS data and maps would be produced. In addition to a number of standardized map products that were produced on a daily basis, individuals requested customized maps at the Emergency Mapping and Data Center (EMDC). Initially, requests were addressed on an ad hoc basis. However, a system was later put in place, whereby requests were logged at a formal 'Map Request Desk.' The remote sensing data was subsequently posted on-line at the NY Office of Technology (OFT) and Earth Resources Observation System (EROS) data centers. Initially, this was limited to processed imagery and GIS files. Later, a summary of the flight history, data specifications and remote sensing devices was added.

### 3.7.2 Uses and Usefulness

In many cases, the process of integration significantly enhanced the information content of the datasets described in Sections 3.1 - 3.4. In simple terms, integration involves draping and overlaying series to produce composite scenes. A number of datasets were superimposed with base-maps, such as orthophotographs from EarthData and the New York City GIS database, oblique images, 3D LIDAR terrain models. These included (J. Hall, J. Tu):

- Response and recovery: thermal images showing hot spots, maps of underground fuel and freon tanks, maps showing command posts, facilities and food stations

- Rescue support: CAD floor plans showing the location of elevator shafts and pillars

- Deep infrastructure: Maps of subsurface structures and hot spots
- Inventory: location of items/evidence removed from the debris pile
- General orientation: street maps, maps of buildings and addresses, location of restricted zones
- Transport status: maps showing the closure status of roads, subways, bridges and tunnels, and routing information
- Utility outage: maps showing electricity, telephone, gas, steam and water outages
- Services: maps showing hospitals, mortuaries, vacant land
- Building status: maps of damage status and government office closures.

At the map request desk, a standardized catalogue of maps proved particularly useful, since it enabled non-specialists to select the most appropriate product. The widespread use of these standard maps (2,000 requests were made and 10,000 maps produced during September and October), visits to the EMDC by Chief Pfeiffer of the FDNY, and use of maps by Mayor Giuliani, highlights the success of this effort.

### 3.7.3 Problems

Lack of familiarity with geospatial data was one of the greatest challenges faced by GIS and remote sensing experts. Since most firefighters and response personnel were non-specialists, it was important to present the information in a format that was easy to understand and interpret. There was a steep learning curve, and requests were made for on-site educators.

The turnaround time between data acquisition and map production was on the order of 12 hours. Although this improved to 4-6 hours for FLIR imagery, to maximize the usefulness of remote sensing thermal data for firefighting efforts, a much shorter lag (on the order of three hours) is preferred. Until rapid registration, correction and automated image processing techniques become available, achieving this level of timeliness would incur costs in terms of accuracy. However, given the comments concerning misregistration of thermal data and steps taken by the EMDC to ensure that all map products adhered to strict standards, reduced accuracy may not be acceptable.

From a technical perspective, the use of GIS programs for image processing was problematic. ER Mapper, ERDAS Imagine and ENVI were not widely used.

It is difficult to extract values from the scenes, since data was manipulated as 'images' rather than converted to 'grids.' Poor performance of interpolation algorithms within MapInfo and ArcView also resulted in a distorted view of the LIDAR coverage, yielding different values for the maximum height of buildings and depth of depressions in the debris pile.

### 3.7.4 Potential Uses and Improvements

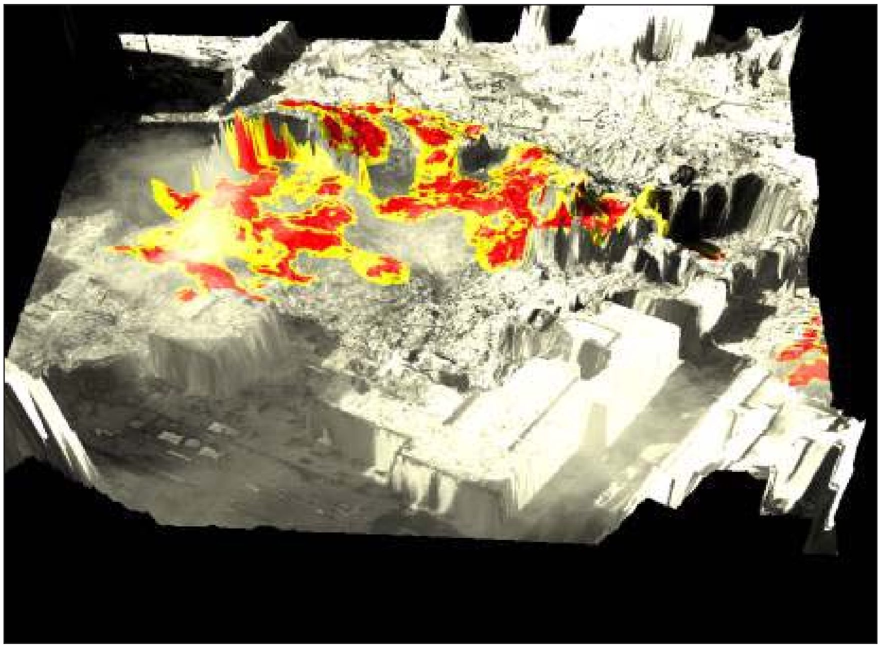
From a logistical viewpoint, a number of improvements can be made that impact the usefulness of remote sensing data. Since timeliness is a key concern in any emergency situation, data acquisition should be streamlined. First, key sources of remote sensing data should be identified. In preparation for future disasters, the necessary contracts and clearances for acquiring airborne imagery need to be established. Pre-processing issues delaying data release should also be addressed. An automated method of correcting and registering images to a predetermined coordinate system would significantly improve the turnaround time (B. Logan).

Spatial data will be used more effectively if emergency management personnel are familiar with the tools and their capabilities. For map requests, a comprehensive catalogue of useful images and composite scenes is invaluable. However improved data visualization, such as virtual representations using VRML or other 3D modeling software, would allow emergency personnel to interactively explore the data for rapid planning and decision making purposes. Mobile map production units would aid the distribution of data, while on-site technical consultants are needed to assist non-specialists with interpretation. This would provide a feedback mechanism between mapping operations and end users, which would quickly identify issues that could limit usefulness, such as data visualization or turn around time.

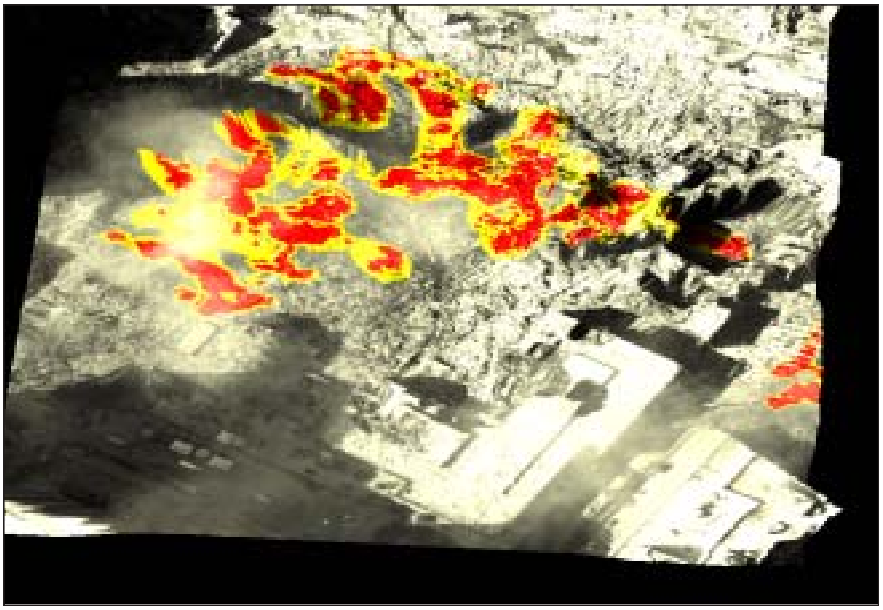
Clearly, a wide range of very useful composite images was produced at the EMDC, FEMA and Urban Search and Rescue GIS and mapping centers. However, additional composite scenes may have further assisted response and recovery teams. The following examples generated by ImageCat reinforce the power of this geospatial information as an aid to disaster response.

#### (a) LIDAR 3D model overlaid with orthophotography and thermal data

As shown by the sequence of models in Figure 3-9, this composite scene provides a three dimensional representation of conditions at Ground Zero. Combining the terrain model and orthophotography aids general orientation within the site. The thermal data, although relative values, provides an indication of where the hot spots lie in relation to buildings and debris piles, as represented in three



(a) Oblique view



(b) Near vertical view

Note: The yellow and red zones represent hot spots. Smoke is still present in the images, affecting visibility. The data represented here were all collected on September 17th by EarthData.

*Figure 3.9. Visualization of Ground Zero, with orthophotography and thermal data draped over a LIDAR 3D terrain model.*

dimensions. The data represented here were all collected on September 17th by EarthData. Although there are two frames represented here, this is part of a Virtual Reality Modeling Language (VRML) file, which can be uploaded onto the internet and visualized with Internet Explorer. The end user then has the ability to rotate and position the data so that they can see the hot spots from any location. The advanced user can then manipulate the model to take the guess work out of assessing the location of the hot spots. Rescue workers could refer to the location of debris piles, visible objects in the debris, and one's own perspective view to pinpoint exactly what should be hot, and this file could be accessed from many locations without difficulty.

This model could be improved further with a higher LIDAR point sampling density and color imagery. Absolute thermal readings would make the model much more meaningful, first for assessing the level of hazard, and later establishing the degree of success in extinguishing the fire. Although CAD models showing floor plans and the location of fuel and freon tanks were unavailable for the present evaluation, the addition of building footprints, streets, and labels would enhance the information content. Additionally, smoke is still present in the imagery.

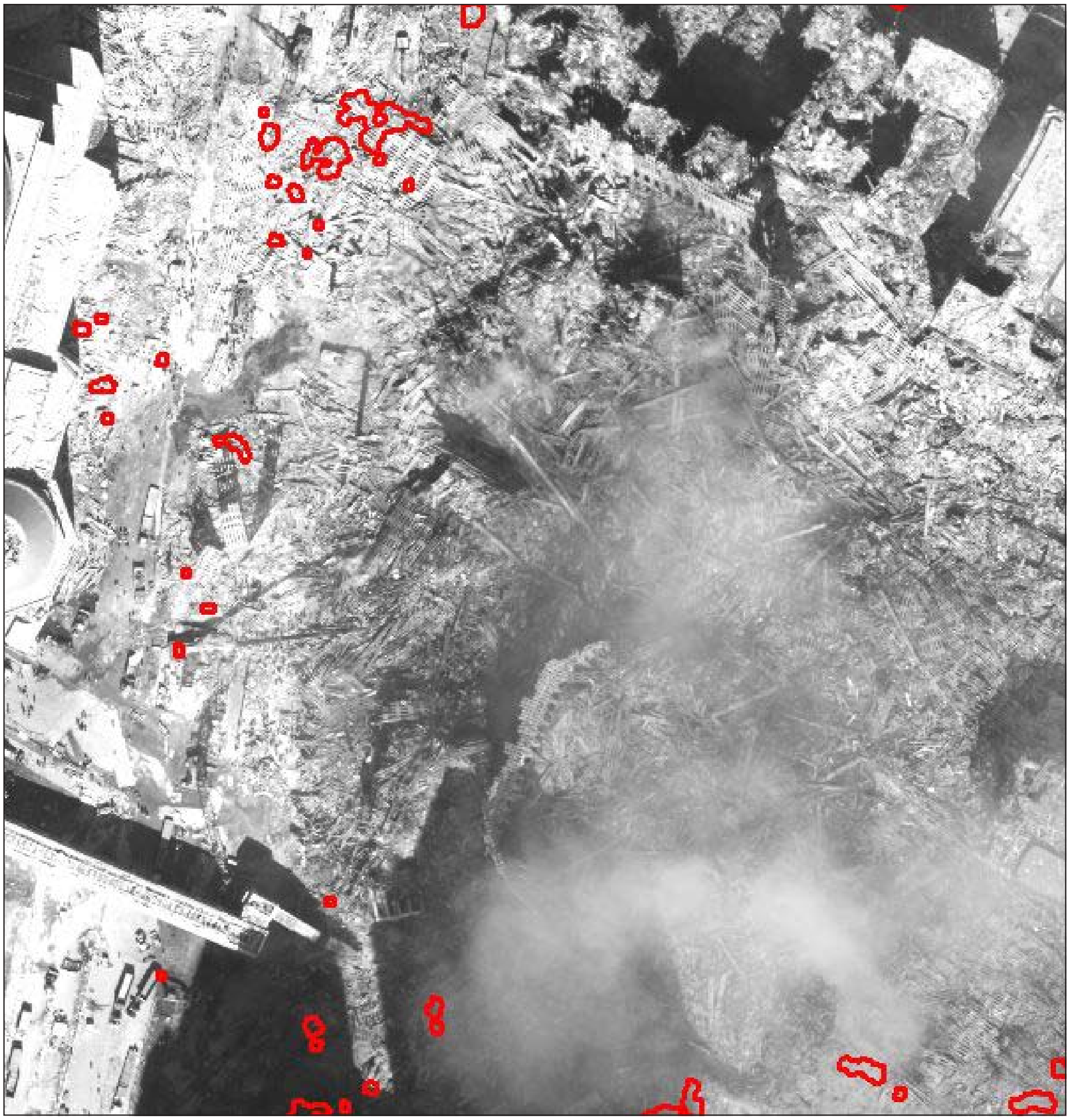
### (b) Temporal pairing of 3D LIDAR terrain models, showing elevation changes within the debris pile.

Remotely monitoring changes in topographic characteristics of the debris pile could provide an early warning of emerging hazards due to subsidence. In Figure 3-10, the zones highlighted in red correspond with a decrease of 5-10 ft between the LIDAR elevation datasets from September 17th and September 19th. The largest of these areas covers 1,500 sq ft.

To perform these calculations, elevations falling within a 5-foot grid mesh were averaged. Cells without values were populated by taking the value of the nearest populated cell. After subtracting the grids, the data were grouped, based upon the range of the difference. Areas with less than five contiguous cells were eliminated. This minimized the effect of arbitrary differences between the temporal pairing of LIDAR grids, which arise from creating a surface from point data. The results were converted to a vector file. The method of image analysis differs from a similar manipulation of the 3D terrain models undertaken by Sean Ahearn at Hunter College, inasmuch that it focuses on regional differences between the scenes that might be consistent with subsidence. The aim here is to distinguish persistent regional differences, whereas a subtraction of interpolated data would capture all differences.

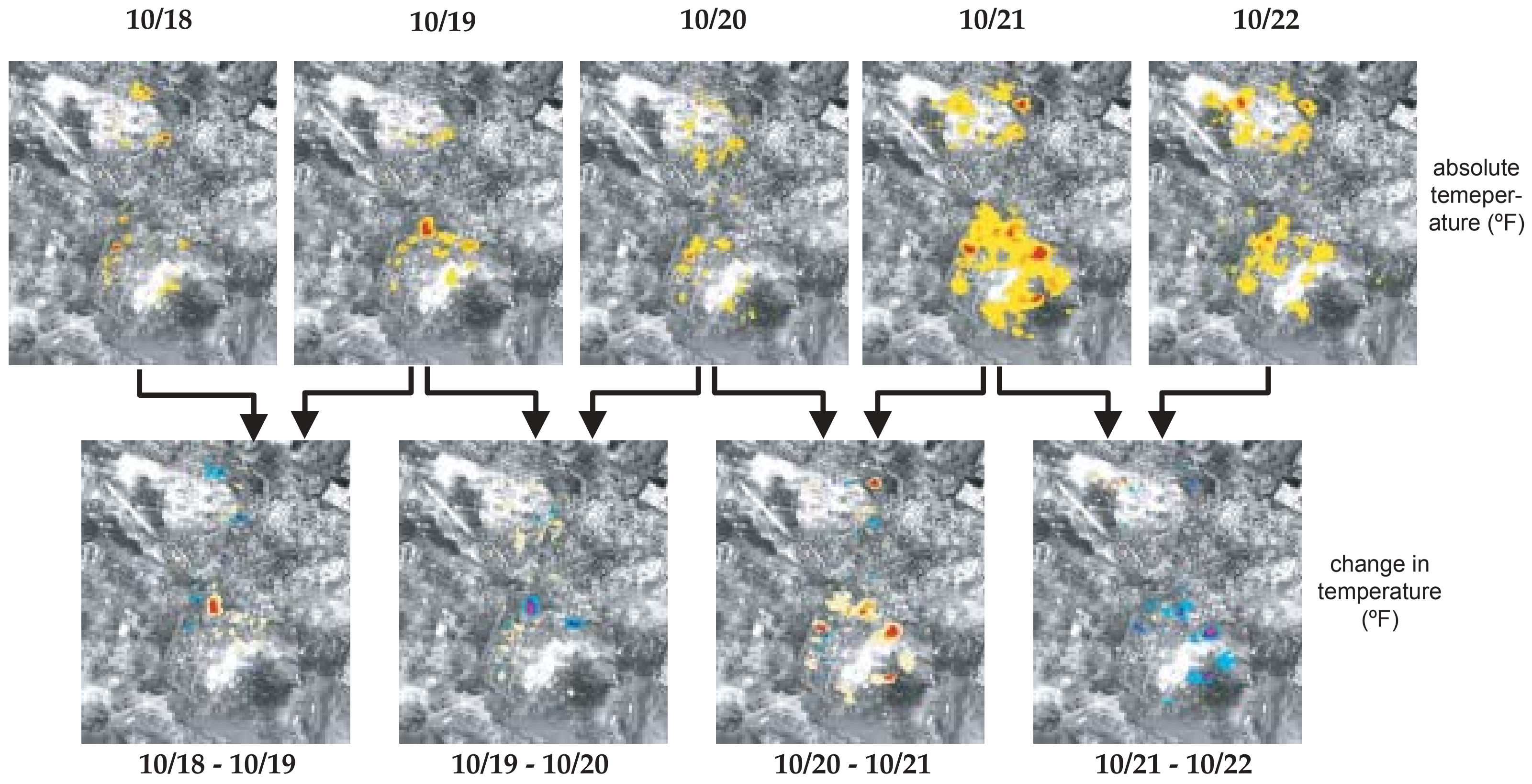
### (c) Temperature data and thermal subtraction showing cool down rates at Ground Zero

Firefighting teams identified the lack of absolute temperature data as a significant limitation of the thermal datasets initially available to response teams. The sequence of temperature readings, shown in the top row of Figure 3-11 were acquired by EarthData between 18th-22nd October, using the FLIR thermal



Note: The red zones show a decrease of 5-10ft between these dates. To enhance visualization, results are overlaid on an orthophotograph acquired on September 17.

*Figure 3.10. Changes in elevation on the debris pile at Ground Zero recorded using 3D LIDAR terrain models for the 17th September and the 19th September 2001.*



Note: Absolute readings are in degrees Fahrenheit, with red areas exceeding 125º F and yellow areas between 75º F and 125º F. Difference values reflect the change in temperature between sequential days, demonstrating the success of firefighting strategies and providing a focus for response teams the following day. Yellow, red and orange classes relate to new or expanded hot sports, where the temperature has increased by at least 25º F. Blue and purple areas are associated with cooling of at least 25º F.

*Figure 3.11. Temperature data, acquired by EarthData using the FLIR thermal device during October 2001.*

imagining device. These are overlaid with the aerial orthophotography from October 7th. Notably, the thermal data are calibrated to record temperature in degrees Fahrenheit, thereby addressing the limitations of relative magnitudes acquired using the Raytheon sensor (see Section 3.4.2). The red areas correspond with temperatures exceeding 125° F and the yellow class equates with temperatures from 75 - 125° F. Values less than 75° F are omitted.

The difference images on the second row of Figure 3-11 were calculated by subtracting temperature values for sequential days. They show day-to-day changes in thermal emitance at Ground Zero. Yellow, orange and red classes relate to new or expanded hot spots, representing areas where the ground, which can be far from the locations of the fires, is at least 25° F hotter than the previous day. Blue and purple areas are associated with appreciable cooling, where a decrease of at least 25° F has occurred. Although this method of analyzing and presenting the results may have proved useful for assessing the success of different firefighting strategies in terms of the reduction in heat intensity and extent of hot spots it apparently was not attempted by the EMDC or the GIS teams in New York. 'Flashover' was identified as a possible cause for the movement and resurgence of hotspots. Using difference maps to chart daily changes in the hotspots would help track this effect. If overlaid with other datasets, including LIDAR terrain data and CAD plans showing fuel tanks, this information could help to explain hotspot migration and predict future patterns of change.

# 4.0 Lessons Learned

The following section summarizes key lessons learned concerning the role of remote sensing and GIS in emergency response.

## 4.1 Remote Sensing Data

- Data is critical to managing emergencies. If an investment is made in remote sensing, as with the imagery collected by EarthData, the data will be used and referenced continually.

- The pre-existing New York City database of orthophotography and GIS data provided for a common base map and georeferencing system. These data were essential, underpinning the entire mapping operation.

- The resolution of remote sensing is a key concern in response efforts. In terms of temporal resolution, a short processing time is critical. The turnaround on the EarthData optical imagery was 12 hours. For a standard remote sensing project, this schedule is impressive. However, it is generally acknowledged that real time data is optimal, with a maximum lag of three hours.

- In terms of spectral resolution, firemen expressed a strong preference for color photographs. Orthophotos should therefore be taken in color. Ideally, supplementary images would extend beyond this visible region of the spectrum to infrared wavelengths.

- Optimal spatial resolution is largely dependant upon the scale of the disaster. For the site specific analysis at the World Trade Center, there was a strong preference for very high resolution data. Airborne imagery should be 1 foot or greater, and LIDAR samples should average every foot. Optical satellite resolution should be 1 meter or greater. SAR was not used, due to the poor resolution of the data available. High resolution SAR of 1 meter or greater also has the potential to aid disaster response and homeland security.

- Almost all processing occurred in an ESRI environment. Wider use should be made of programs such as ER Mapper, ERDAS and ENVI, which are specifically designed for the processing and analysis of remote sensing data.

## 4.2 Geospatial Cross-Referencing

- It is much more powerful to examine data sets in combination, rather than alone.

- Remote sensing data are often used as background pictures, and the information content within the digital numbers are overlooked. The many uses and analytical potential of this data need to be promoted.

- Responders at the site found 3D dimensional representations very useful. LIDAR data should have been used more frequently, both for assessing changes in debris volume and in conjunction with other datasets.

- Keep it simple. Although maps may convey a complex idea, the presentation must be straightforward and simple to understand. End users in an emergency should be able to interpret a map in ~30 seconds (S. Ahearn). Analysts should be trained in basic cartographic principles and the most effective visual presentation of quantitative information. As with all forms of communication, presentation is equally, if not more important, than content.

## 4.3 GIS Operations

- Given the many agencies with GIS personnel that were present, communicating between and managing mapping operations proved difficult. GIS personnel were generally unaware of activities at the other mapping centers. Arguably, operations would have run more smoothly, with less duplication of effort, had the GIS units been centrally located under a common command structure. As with all disasters, local, state, and federal agencies need to work together for the common good.

- GIS analysts who are primary responders need to know how to transfer from program to program and fuse vector and raster data to produce meaningful statistical results. Training should be provided before hand.

- Analysts should be tasked according to expertise. Remote sensing experts should concentrate on image processing, manipulation and analytical duties, while GIS analysts focus on geospatial cross-referencing and map production. There was a need for more technical consultants to guide data use and make analytical recommendations.

## 4.4 Feedback

- Remote sensing imagery and map products were given to the Fire Chiefs for distribution. Frequently, analysts did not hear whether the data was useful, or how improvements could be made. In the case of thermal data, some GIS analysts were not informed about the need for absolute temperatures until a lessons learned debriefing.

- Communication is also important to ensure that GIS teams have access to all spatial datasets. Although AVIRIS temperature readings were released to the FDNY, this key information was not received by any of the mapping centers.

- There were devices onsite measuring real time building movement and temperatures (D Kehrlein). Had this data been made available to the EMDC, it could have been overlaid with a basemap and used to aid planning and decision making.

- Mobile GIS units would encourage better communication. An on-site GIS unit, set up to assist with the Rockaway Beach the airplane crash, proved very useful (A. Leidner).

## 4.5 Education

- Emergency managers need to be versed in GIS and remote sensing capabilities. It is difficult to assimilate new ideas and analytical techniques during a disaster. Training does not need to be technical, and should be software independent.

- Emergency managers should be made aware of different types of imagery, its uses and usefulness, image processing techniques, geospatial cross-referencing and outputs from statistical analysis. Knowing the capabilities of these datasets, personnel will be able to make informed map requests in future disaster situations.

- Equally, GIS personnel need to understand capabilities and limitations of the data, so that they can give advice to emergency teams. This apriori knowledge should improve data quality, since analysts would be familiar with problems such as misregistration.

# 5.0 Recommendations

Now that the usefulness of remote sensing data is acknowledged, a summary should be prepared for emergency managers, which clearly explains the entire suite of remote sensing devices and their capabilities/applications. Along with this remote sensing 'menu,' there needs to be a 'remote sensing emergency response directory,' which includes information such as: access to sensors; names, expertise and contact details for analytical teams; and details of existing databases. Ideally, these planning provisions would be coordinated by a federal body, such as FEMA (A. Leidner).

To enable rapid response, acquisition and delivery needs to be streamlined. Unmanned vehicles would be ideal for collecting data more frequently, without concerns about clearance. Sensor specific problems, such as the misregistration issue associated with thermal data, need to be resolved and standard procedures established for tasks such as temperature calibration.

Image processing algorithms designed specifically for damage detection and locating hazardous materials, or other search and rescue tasks, need to be developed in preparation for future emergency events. It is difficult to perform research in a disaster response environment.

Future geospatial cross referencing efforts should transcend the boundaries of vector attribute data, into image processing software and 3D rendering tools. Research targeting the seamless transfer of data between database, GIS, CAD, and image processing programs would significantly improve the efficiency of mapping operations.

Remote sensing data and map-based products will prove to be even more effective in future emergency situations if personnel are trained in the use of remote sensing data. On-site GIS units are recommended for future events, with experts available to advise and assist response teams with data requests and image interpretation.

# 6.0 References

Canadian Space Agency, (2002), "Radarsat1 Specifications," *http://www.space.gc.ca/csa_sectors/earth_environment/radarsat/radarsat_info/description/specifications.asp.*

Clark, Roger N., Robert O. Green, Gregg A. Swayze, Todd M. Hoefen, K. Eric Livo, Betina Pavi, Chuck Sarcher, Joe Boardman, and J. Sam Vance, (2001), "Images of the World Trade Center Site Show Thermal Hot Spots on September 16 and 23, 2001," Open File Report OF-01-405, U.S. Geological Survey.

EarthData, (2001), "World Trade Center Site – Manhattan, New York 15 September 22-October 2001," (Project Deliverable to the New York State Office of Technology).

Federal Emergency Management Agency, (2002), "Statement of Mr. Robert F. Shea Acting Administrator Federal Insurance and Mitigation Administration Federal Emergency Management Agency Before The Committee on Science House of Representatives United States Congress," *http://www.fema.gov/library/rfs030602.htm.*

Geoplace.com, (2001a), "Key Activities, Products and Lesson Learned from New York City's Emergency Mapping and Data Center," Online Interview with Jim Hall, *http://www.geoplace.com/gr/groundzero/lessons.asp.*

Geoplace.com, (2001b), "Bruce Oswald, Assistant Director, New York State Office for Technology," Online Interview with Bruce Oswald, *http://www.geoplace.com/gr/groundzero/lessons.asp.*

Geospatial Solutions, (2001), April, pg. 1.

New York State Office for Technology, (2002), "WTC Emergency Response Aerial Meeting Debriefing," (Notes from internal meeting at the New York City Emergency Operations Center), November 20, 2001.

New York State Senate, (2001), "Subcommittee Hearing on Technology in Times of Crisis, December 5, 2001," New York State Congressional Testimony by Will Pelgrin, *http://www.senate.gov/~commerce/hearings/120501Pelgrin.pdf.*

NOAA, (2001), "NOAA Conducts More Flights Over World Trade Center Site," NOAA News V. 796, *http://www.noaanews.noaa.gov/stories/s798.htm.*

Space Imaging, (2002), "IKONOS Statistics," *http://www.spaceimaging.com/aboutus/satellites/IKONOS/ikonos.html.*

SPOT, (2002), "SPOT System Technical Data," *http://www.spot.com/HOME/SYSTEM/INTROSAT/seltec/welcome.htm.*

Woodward Gallery, (2002), "Charting Ground Zero: Before and After," Broome Street, New York City, February 1 –28, 2002 (gallery exhibit).

## ▲ *Acknowledgements*

This report was prepared by the Multidisciplinary Center for Earthquake Engineering Research through a grant from the Earthquake Engineering Research Centers Program of the National Science Foundation (supplement to award number EEC-9701471), funding from New York State, and other sponsors.

The material herein is based upon work supported in whole or in part by the National Science Foundation, New York State and other sponsors. Opinions, findings, conclusions or recommendations expressed in this publication do not necessarily reflect the views of these sponsors or the Research Foundation of the State University of New York.

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