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Remote Sensing in Response to September 11th

ABSTRACT

Remote sensing technology has been widely recognized for contributing to emergency response efforts following the World Trade Center attack on September 11th, 2001. The need to coordinate an event of this magnitude, in a dense yet relatively small area, made the combination of imagery and data maps very powerful. This paper evaluates the role played by airborne and satellite imagery at Ground Zero. It examines how these data were used by emergency managers within a GIS environment, including their integration with other GIS datasets. It goes on to present further ways in which the data could have been used. A summary is given of the lessons learned, together with steps that should be taken to maximize the effectiveness of remote sensing in the future events. Interviews with key emergency management and GIS personnel provide the basis of this paper. An expanded discussion is available in the MCEER/NSF report "Emergency Response in the Wake of World Trade Center Attacks: The Remote Sensing Perspective" (see Huyck and Adams, 2002).

INTRODUCTION

The World Trade Center attack was an event unparalleled in history. There was no plan for such an event, and the demand for information proved to be immense. Remote Sensing and geospatial information played a critical role in response efforts (Haitt, 2002; Huyck and Adams, 2002; Logan, 2002; Williamson and Baker, 2002). Before the attack, the City of New York had undertaken detailed mapping efforts, resulting in the production of highly accurate vector coverages. These GIS datasets, coupled with raster data collected by organizations including EarthData, NASA, NOAA and Space Imaging, provided an evolving depiction of the disaster response, which otherwise, would not have been possible.

Remote Sensing data are most valuable for emergency responders when integrated into a Geographic Information System (GIS). The capabilities of GIS units to spatially analyze multivariate data are almost endless. The GIS analyst needs to know which combination of data, processed in what manner, will be most valuable to response teams. As with any information system, communication, input, and feedback from end users are essential. The end user, in turn, may underutilize GIS units, as they are unaware of potential capabilities. After a disaster, both end users and GIS personnel are extremely busy, stressed, and sometimes emotionally volatile. Clearly, this is not the best time to assess needs, or learn new material. To be most useful, key concepts and products require thorough a priori documentation, while data sources and tools should be presented to emergency management personnel as a preparedness measure, before a disaster occurs.

This paper evaluates the use of: aerial photography; multispectral satellite imagery; Light Detection and Ranging (LIDAR) altimetry; thermal coverage; and hyperspectral data, within a GIS framework. It discusses the integration of remote sensing and other GIS datasets, going on to introduce several additional ways in which the data could have been combined. Finally, the lessons learned are presented, together with recommendations for integrating remote sensing into future emergency operations.

EVALUATION OF REMOTE SENSING DATA

The following section provides details of remote sensing imagery that was acquired following the World Trade Center attack. For a complete description of the data, please refer to the MCEER/NSF report "Emergency Response in the Wake of World Trade Center Attacks: The Remote Sensing Perspective" (see Huyck and Adams, 2002).

Information concerning the application and performance of each dataset was primarily obtained through a series of interviews, undertaken by ImageCat with key individuals involved in emergency operations, from organizations including: the Federal Emergency Management Agency (FEMA); the New York Fire Department (FDNY); the City of New York Department of Information, Technology and Telecommunications; the New York State Office for Technology; the State of California Governor's Office of Emergency Services, managing FEMA's Urban Search and Rescue GIS operation at Ground Zero; the Environmental Protection Agency (EPA); the United Sates Geological Survey (USGS); Environmental Systems Research Institute; MITRE Corporation; Plangraphics; the University of South Carolina; and Hunter College.

Aerial Photography

High-resolution digital images collected by EarthData were the most widely used source of aerial data (see Earthdata, 2003). Panchromatic, 6-inch scenes were collected 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.

These images were tremendously useful to response personnel. Initial optical coverage enabled rescue teams to orient themselves, and gave a clear indication of the magnitude of damage and extent of debris within the site. 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. This composite of data was also used for logistical planning, when it was necessary to identify safe and stable positions within Ground Zero 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. 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 before its collapse, the orthophotographs were widely distributed and used extensively for comparative purposes.

Satellite Imagery

Following the World Trade Center attack Space Imaging and SPOT quickly made satellite imagery available on the Internet. These scenes were used in emergency efforts several days before the aerial photography. 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 (SpaceImaging, 2003).

The 1m spatial resolution of IKONOS coverage provides a detailed representation of the ground surface. Consequently, IKONOS data were widely employed as a base-map. Presented as a before/after sequence, these images were particularly useful for visualizing the site as it once stood, a task which proved difficult for the many out of town relief workers. SPOT 4 data played a limited role in response efforts at Ground Zero, due to a comparatively low resolution of 10m.

LIDAR Altimetry

LIDAR instruments record earth surface elevation 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 point samples collected along a designated path or swath. LIDAR data are typically interpolated onto a raster grid. Alternatively, a Triangulated Irregular Network (TIN) may be 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. Towards the end of the program, NOAA acquired additional scenes and the frequency of collection by EarthData was reduced to 3 or 4 day intervals.

The basic 3D models were employed by Fire Chiefs as a planning and visualization tool. They used the resulting maps to discuss events as they correlated with the debris pile. The models were also widely used by response teams and FEMA, for assessing the extent of damage, together with the shape, volume and depth of depressions. In terms of map-products, overlaying the 3D LIDAR model with a map of hazardous materials and fuel sources was particularly useful for ascertaining what was happening underneath the ground. The correlation between voids and the position of fuel and freon tanks also provided a focus for Fire Fighters, possibly preventing explosions that would have released toxic gases.

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 radiation in the thermal region of the electromagnetic spectrum, which falls just above the visible wavelengths that are studied using multispectral sensors. For the World Trade Center, data was collected using both airborne and satellite sensors.

Response crews called the usefulness of EarthData thermal imagery into question on several counts. First, heat and fire locations were not always correlated. Although Fire fighters used the thermal scenes for reference and cross-checking, teams mainly relied on onsite sensors. Offset between remote sensing imagery and observations could have resulted from the method of data acquisition – videotaping and screen capture, coupled with inaccurate image registration relative to the orthophotographs. However, it is likely that some observed changes were linked to actual heat migration caused by of the fire fighting efforts and the high conductivity of the material. Second, there was 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. Finally, the value of thermal data was questioned because initial EarthData coverage, captured using a Raytheon camera, 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.

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' 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.

Hyperspectral AVIRIS data was 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, 2001, USGS Open file Report 01-0429). If the processing time can be drastically reduced, in the event of future biological or chemical attacks, hyperspectral imagery may be key data soure.

GIS and REMOTE SENSING INTEGRATION

Once pre-processed and geo-referenced, remotely sensed images were imported into an ESRI environment, often using ArcView. These images were then combined with GIS data and maps produced. In addition to a number of standardized map-products that were generated on a daily basis, individuals requested customized maps at the Emergency Mapping and Data Center (EMDC). Initially, map 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 were subsequently posted on-line at the NY State Office for Technology and EROS data center. Initially, datasets were limited to processed imagery and GIS files. Later, a summary of the flight history, data specifications and remote sensing devices were added.

In many cases, the integration process significantly enhanced the information content of a given dataset. In simple terms, integration involves draping and overlaying series to produce composite scenes. The datasets in Table 1 were superimposed with base-maps, such as: orthophotographs from EarthData and the New York City GIS database; oblique images; and 3D LIDAR terrain models.

A wide range of useful composite images were 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 potential of this geospatial information as an aid to disaster response.

Integrated Datasets	Examples
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 or 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.

TABLE 1: Examples of datasets that were integrated with remote sensing base-maps, including orthophotographs, oblique images, and 3D LIDAR terrain models.

As shown by the sequence of models in Figure 1, a composite scene combining LIDAR, aerial photography and thermal data provides a comprehensive 3D representation of conditions at Ground Zero. Combining the terrain model and orthophotography aids general orientation within the site. The thermal data reveals where the hot spots lie in relation to nearby buildings and the 3D debris pile. The two frames presented here are part of a Virtual Reality Modeling Language (VRML) file, which can be uploaded onto the internet and visualized using 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. Advanced users can than manipulate the model to take the guess work out of assessing hot spot location. Rescue workers could also use it to communicate locations within the debris pile, identify visible objects, and judge themselves exactly where the dangerous hot spots lie. Furthermore, this file could be accessed from disparate desktop locations without difficulty.

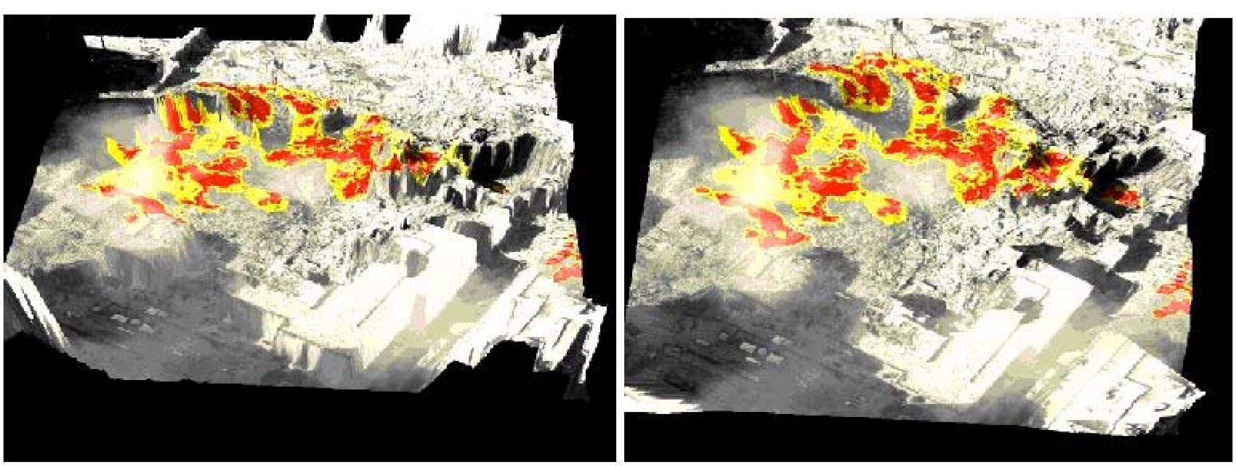

FIGURE 1: VRML visualization of Ground Zero from several perspectives, with orthophotography and thermal data draped over a LIDAR 3D terrain model. Datasets were acquired by EarthData on September 17th.

The integrated model would be improved by increasing LIDAR point sampling density and using color imagery. In addition, absolute thermal readings would make the model far more meaningful, first for assessing the level of hazard, and later establishing the degree of success in extinguishing fires. 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.

Remotely monitoring changes in topographic characteristics of the debris pile could provide an early warning of emerging hazards due to subsidence. In Figure 2, 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.

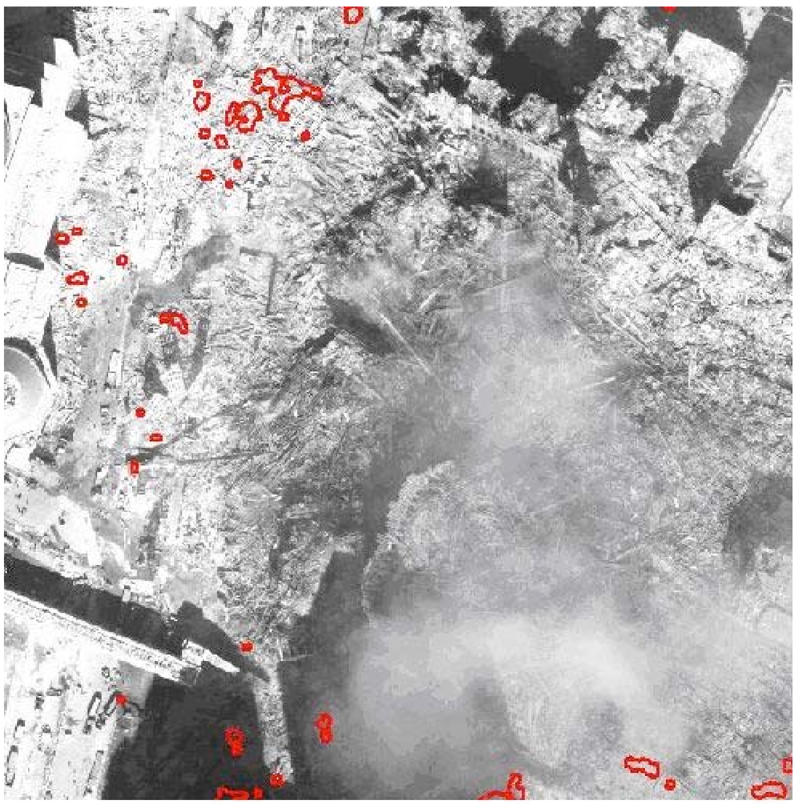

Figure 2 Changes in elevation on the debris pile at Ground Zero, recorded using 3D LIDAR terrain models for September 17th and September 19th. The red zones show a decrease of 5-10ft between these dates. To enhance visualization, results are overlaid on an orthophotograph acquired on September 17th.

To perform these calculations, in each scene, elevations falling within a 5 ft grid mesh were initially averaged. Cells without values were populated by taking the value of the nearest populated cell. After subtracting the pair of grids, data were grouped according to the range of difference values. Areas with less than 5 contiguous cells were eliminated. This procedure 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 Hunter College, inasmuch that it focuses solely on differences between the scenes that might be consistent with subsidence. The aim here is to distinguish persistent regional differences, whereas a straightforward subtraction of interpolated data would capture *all* differences.

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 on the top row of Figure 3, were acquired by EarthData between 18th-22nd October, using the FLIR thermal imagining device. They are overlaid here 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. The red areas correspond with temperatures exceeding 125^{o}F and the yellow class equates with temperatures from 75^{o}F to 125^{o}F . Values < 75^{o}F are omitted.

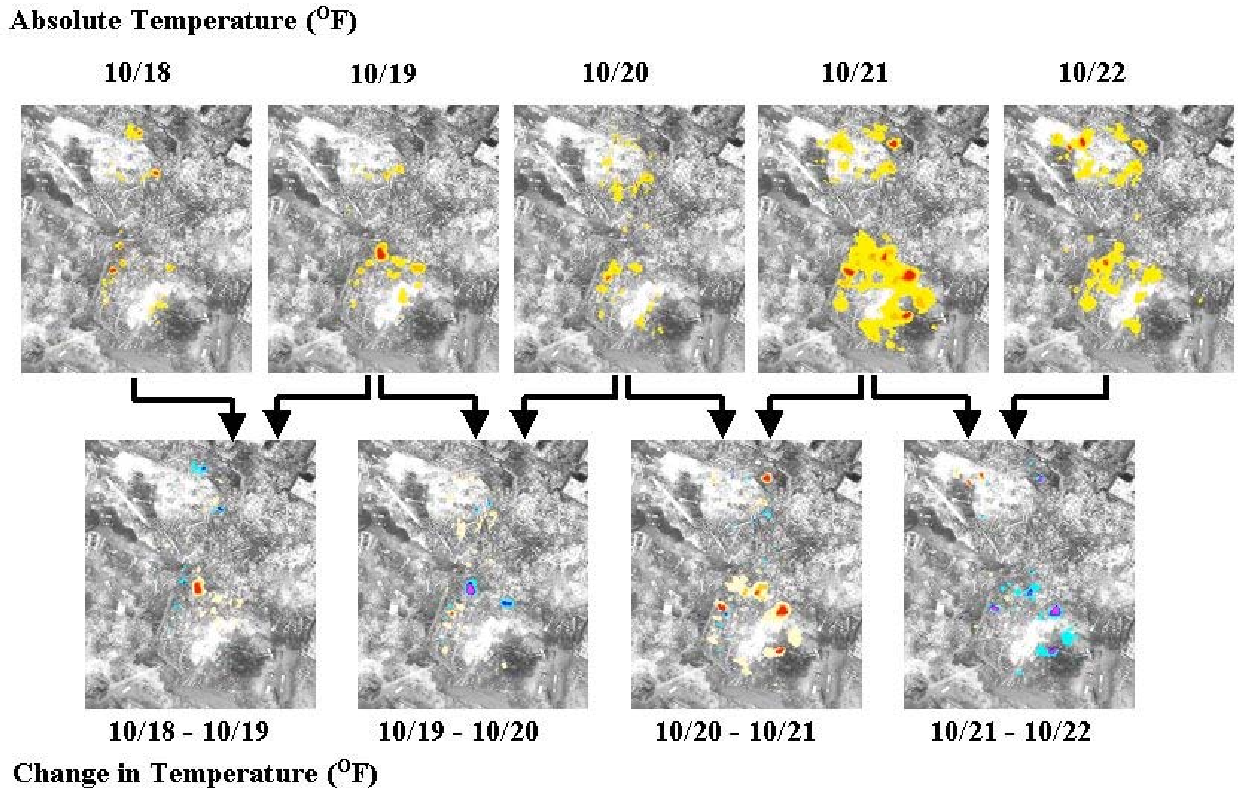

Figure 3 Temperature data, acquired by EarthData using the FLIR thermal device during October 2001. Absolute readings are in degrees Fahrenheit, with red areas >125^{o}F and yellow areas and above 75 ^{o}F. Difference values reflect the change in temperature between sequential days, demonstrating the success of firefighting strategies and providing a focus for response teams the following day.

The difference images on the second row of Figure 3, 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^{o}F hotter than the previous day. Blue and purple areas are associated with appreciable cooling, where a decrease of at least 25^{o}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, apparently, it was not attempted by the EMDC or 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.

LESSONS LEARNED

The following section summarizes key lessons learned concerning the role of remote sensing and GIS in emergency response. An expanded discussion is available in the MCEER/NSF report "Emergency Response in the Wake of World Trade Center Attacks: The Remote Sensing Perspective" (see Huyck and Adams, 2002).

- Data is critical to managing emergencies. Where an investment is made in remote sensing, as with the imagery collected by EarthData, the data will be used and referenced continually. Likewise, the pre-existing New York City database of orthophotography and GIS data provided for a standard base map and georeferencing system. This data was essential, underpinning the entire mapping operation.
- Remote sensing data is often used as a background picture, with the information content of its digital number (DV) values remaining overlooked. The many uses and analytical potential of this data need to be promoted. Almost all processing occurred in a vector environment. Wider use should be made of programs specifically designed for the processing and analysis of raster remote sensing data.
- It is much more powerful to examine datasets in combination, rather than alone. While GIS overlay of coverages is standard, the fusion of remote sensing imagery was largely overlooked
- 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. 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.
- During response efforts, there was a need for more technical consultants to guide data use and make analytical recommendations. GIS analysts who are primary responders need to know how to transfer from program to program and fuse vector and raster formats 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.

- 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. Equally, GIS personnel need to understand capabilities and limitations of the data, so that they can give advice to emergency teams.

ACKNOWLEDGEMENTS

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 are thanked for sharing their insights with the authors, concerning the use of remote sensing following the World Trade Center attack: Kay Adams (URS Corporation); Dr. Sean Ahearn (Hunter College); Dennis Atkins (United States Geological Survey); Dr. Susan Cutter (University of South Carolina); George Davis (Private Consultant); Jim Hall and Jean Tu (Plangraphics); Russ Johnson and Chris Sheline (Environmental Systems Research Institute); David Kaplan (MITRE Corporation); Ron Langhelm and Charles Rigeway (Federal Emergency Management Agency); Alan Leidner (City of New York, Department of Information, Technology and Telecommunications); Bruce Oswald (New York State Office for Technology); David Shreve (State of California Governor's Office of Emergency Services); Debbie Simerlink (EarthData Aviation); Harvey Simons (Environmental Protection Agency); and Chief Nicholas Visconti (Fire Department of New York)

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