Production of Imagery-Derived Maps to Aid the Japanese Earthquake / Tsunami Relief Effort

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ABSTRACT

On March 11, 2011, the magnitude 9 Tohoku earthquake and resulting tsunami struck off the coast of Japan. An estimated over 400,000 persons were displaced from their homes and the damage to the coastline and nearby urban areas was extensive. Additionally, the combined effects of the earthquake and tsunami caused damage to the Fukushima Dai'ichi Nuclear Power Station. As part of the International Charter "Space and Major Disasters", the US Geological Survey coordinated a volunteer effort to aid in the response to the disaster. The goal of the project was to produce maps derived from civilian (NASA Landsat and ASTER) and commercially available (DigitalGlobe and GeoEye), high resolution satellite imagery to be delivered to the Japanese authorities. RIT, as part of our Information Products Laboratory for Emergency Response (IPLER) program, was one of the organizations involved in this effort. This paper describes the timeline of the response, the challenges faced in this effort, the workflow developed, and the products that were distributed. Lessons learned from the response will also be described to aid the remote sensing community in preparing for responses to future natural disasters.

Keywords: emergency response, high resolution imagery

1. INTRODUCTION

On March 11, 2011, the magnitude 9 Tohoku earthquake and resulting tsunami struck off the coast of Japan. An estimated over 400,000 persons were displaced from their homes and the damage to the coastline and nearby urban areas was extensive. Additionally, the combined effects of the earthquake and tsunami caused damage to the Fukushima Dai'ichi Nuclear Power Station. As part of the International Charter "Space and Major Disasters", the US Geological Survey coordinated a volunteer effort to aid in the response to the disaster. Traditionally, when the Charter is activated, participant countries are required to provide imagery to support the relief efforts. However, for this event, the decision was made to organize a volunteer effort to produce map products presenting information to the government of Japan to aid the response. The goal of the effort was to produce high quality maps of damaged areas using commercial and government satellite imaging systems. The volunteer effort was made up of approximately 10 organizations including Harvard University, George Mason University, Penn State, the Jet Propulsion Laboratory, and the Digital Imaging and Remote Sensing (DIRS) Laboratory at the Rochester Institute of Technology.

The DIRS laboratory at RIT, through an NSF funded program called the Information Products Laboratory for Emergency Response (IPLER), had previous experience in the use of remote sensing for disaster management during the 2010 Haiti Earthquake.[1,2] Under funding provided by the World Bank and in collaboration with industry partners ImageCat, Inc. and Kucera International, a multispectral airborne imaging system developed and operated by RIT[3] was flown over damaged areas of Haiti for seven days shortly after the earthquake, eventually covering over 250 square miles of land. The imagery was then provided to the disaster response community via web-based dissemination. In that instance, the RIT role was to deploy an airborne system to the affected area, collect the imagery, and then provide that imagery to other entities for analysis. Here, the goal was to take images collected with commercial satellite systems and perform the analysis. The end result would be maps for use by relief workers on the ground in Japan.

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Table 1. Timeline of events in the Japanese response.

Date	Activity
March 11, 2011	Tohoku earthquake (magnitude 9) and resulting tsunami
March 14, 2011	First contact between RIT and USGS, decision to proceed
March 15, 2011	RIT assigned Hachinohe and Kesennuma regions internal teams organized, download of imagery initialized
March 16, 2011	First draft products delivered to USGS for QC and approval
March 17, 2011	First products uploaded to Hazards Data Distribution System
March 18, 2011 (10:00AM ET)	RIT assigned Fukushima nuclear power plant site
March 18, 2011	Products delivered for Hachinohe and Kesennuma
March 18, 2011 (6:00PM ET)	RIT delivers product covering nuclear power plant
March 21, 2011	No new sites assigned, product generation continues
March 22, 2011	Final delivery of map products

Table 1 shows the timeline of our support to the Japanese disaster relief effort. The earthquake struck on March 11, 2011 and the tsunami followed soon thereafter. On March 14th, the DIRS laboratory was in contact with the US Geological Survey regarding participation in a volunteer effort to generate information product maps to support the relief effort. This effort was in line with our previous work in disaster response funded through our Information Products Laboratory for Emergency Response (IPLER)[4] program. In this instance, the Japanese Government activated the International Charter, Space and Major Disasters, on the day of the earthquake, requesting aid from member organizations.[5] As described by the Charter web page, "The International Charter aims at providing a unified system of space data acquisition and delivery to those affected by natural or man-made disasters through Authorized Users. Each member agency has committed resources to support the provisions of the Charter and thus is helping to mitigate the effects of disasters on human life and property." In this instance the USGS, as the representative of the United States, organized an effort to produce not just imagery data, but derived information products in the form of high resolution maps. RIT was one member of the team that volunteered in this effort.

Members of the team were assigned regions to monitor and on March 15, RIT was assigned the two cities of Hachinohe, Aomori prefecture, and Kesennuma, Miyagi prefecture. Kesennuma is approximately 145 km north of Sendai, Japan (the nearest major city to the epicenter) while Hachinohe is approximate 300 km north of Sendai. Both cities are directly on the coast and were subject to inundation by the resulting tsunami. Imagery were collected by the USGS from sources such as commercial vendors (DigitalGlobe and GeoEye) and government resources such as the NASA Landsat program. Members of the team were required to monitor the data distribution site for available imagery over their assigned areas, collect the imagery and pre-process it (*e.g.*, project into desired coordinate system, usually UTM), and then produce map products for distribution to relief workers in Japan. USGS had responsibility for final Quality Assurance and Quality Control before distribution of the maps. Final products were required to be of high resolution such that they could be printed onto size A0 paper.

In Section 2 we describe the methodology and workflow developed to ingest imagery and produce map products. In Section 3 we describe and present representative products delivered. Finally, in Section 4 we present a summary of the effort and some lessons learned.

2. METHODOLOGY DEVELOPED

The RIT team, composed of faculty, staff, and graduate students, was organized into groups assigned to tasks such as data acquisition and pre-processing, visual analysis and further processing, and final product creation and dissemination. The first task required monitoring the USGS data distribution system for new imagery collected over the assigned regions of interest. After download of the imagery to the RIT servers, the images were projected typically into the UTM coordinate system. When available, images from both before and after the disaster were collected to provide maps for use in visual change analysis. New images were being continuously collected and the data distribution site was monitored for approximately one week.

After collection of the imagery, regions of interest were identified and members of the team proceeded to perform visual analysis of the imagery, identifying specific features of interest (*e.g.*, destroyed bridges) and compiling before and after mosaics. When available, Color Infrared (CIR) imagery was used to aid in identification of still-flooded regions. High-resolution panchromatic imagery was used to provide more detailed maps showing much more specific elements of the destruction. As part of the visual inspection of high-resolution imagery, large area coverage maps were divided into specific regions of interest to provide maps with both synoptic and concentrated views of the specific regions (see, for example, Figure 1 below). Most of the image interpretation and analysis was performed with the ENVI software tool.

After the images were analyzed for specific information and / or collected into the appropriate regions of interest, they were processed into the final map products. A template was created to highlight both the imagery and the information specifically denoted. Additional comments regarding the image interpretation were also included on the map products. The final map product was scaled to fit on A0 paper and was generated at high resolution for printing. Map products were delivered to the USGS for final quality control and approval. After approval, the maps were uploaded to the Hazards Data Distribution System for download by the Japanese relief workers.

3. PRODUCTS DELIVERED

The process described above was used to generate initial maps for the Hachinohe and Kesennuma regions of Japan. In Hachinohe the damage was assessed to be severe, but largely contained to the near-shore area. A single map was created using a CIR image from the Worldview-2 satellite to cover the region. As stated above, the CIR image was used to better identify regions of inundation and flooded fields.

The Kesennuma region suffered more severe damage and several maps of this area were produced. Initially, a north-south composite CIR map was produced from Worldview-2 imagery covering the majority of the region. After acquisition of a high-resolution panchromatic image by the Worldview-1 sensor, a map was produced highlighting the northern inland region of the city. Finally, a high resolution panchromatic image collected with the GeoEye 1 sensor was acquired and was used to produce maps with the estimated extent of the debris field identified. In total, eight of these maps were produced to cover the entire region of Kesennuma. An example is shown in Figure 1.

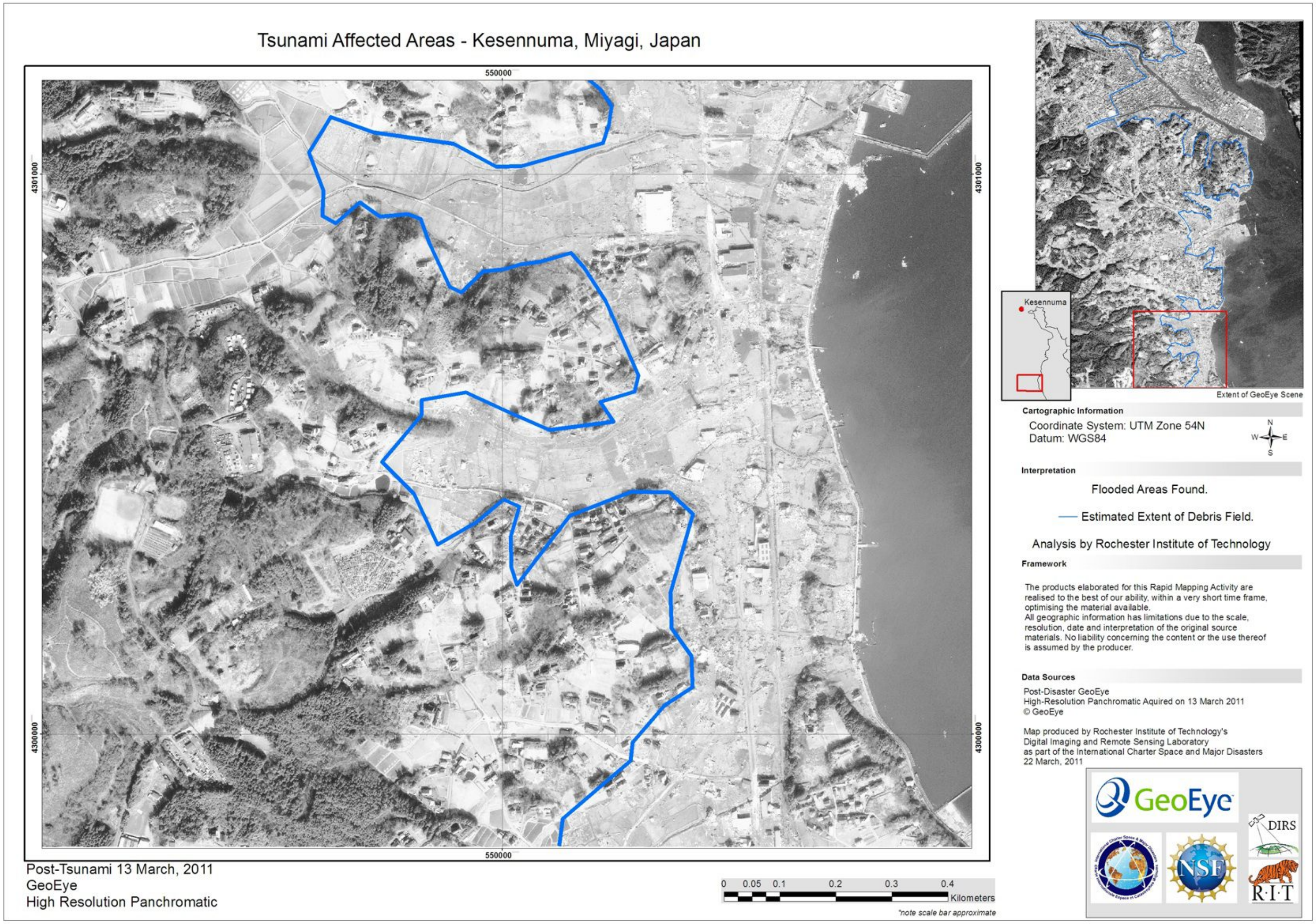

Figure 1. Example map product produced for the city of Kesennuma highlighting the extent of the debris field (blue line). The image is from the GeoEye 1 satellite.

Table 2. Total maps delivered by RIT under the response effort.

Region	Number
Hachinohe	1
Kesennuma	10
Fukushima	4
Total	15

After completion of initial maps of Hachinohe and Kesennuma, RIT was assigned the task of collecting imagery and producing information products covering the Fukushima Dai'ichi Nuclear Power Plant and the surrounding area. Fortunately, Worldview-2 collected high-resolution, nearly nadir-looking imagery on March 12, 2011 and March 17, 2011. The original image was after the earthquake and tsunami, but before the power plant began to suffer explosions, likely due to the disabling of their reactor cooling systems. RIT was tasked with producing high resolution imagery products to aid in the damage assessment at the plant as well as producing maps of the surrounding region to assess the extent of the inundation and damage. Additional imagery from Worldview-1 (collected pre-disaster on March 26, 2009 and post-disaster on March 14, 2011) and GeoEye 1 (collected on March 19, 2011) were also acquired. For the region surrounding the power plant, a visual inspection of the high-resolution imagery was performed and the estimated debris identified. An example product is shown in Figure 2.

High-resoultion imagery products were also generated for the Dai'ichi Nuclear Power Plant itself. A "before & after" pair product was created using the Worldview-2 panchromatic imagery collected on March 12 and March 17, 2011. Fortunately, cloud cover over the site in the March 12th image was just south of the area over the nuclear reactors. The images were collected from slightly different observation angles but provided a clear picture of the destruction caused by the explosions at the plant up to that point. Note that the "after" image was collected on March 17th and this product was uploaded to the dissemination website on the afternoon of March 18th, providing a timely piece of information for use in the relief effort. The first image product over the nuclear power plant is shown in Figure 3. A GeoEye 1 panchromatic image was acquired over the facility on March 19th. Using this image and the Worldview-2 image from March 17th, a second map product was produced to highlight the damage at the plant and the evolution of the situation over the intervening two days.

As shown in Table 2, 15 map products in total were created by RIT to aid the relief effort. Due to the extensive damage to the Kesennuma area, much effort was put into generating high-resolution maps of that area to provide both a synoptic view as well as more information on focused areas. Due to the dynamic events at the Dai'ichi Nuclear Power Plant, four map products were produced covering both the surrounding area and the power plant itself.

Other example products can be found at `http://www.cis.rit.edu/~dwmpci/Japan_Relief_2011/`.[6]

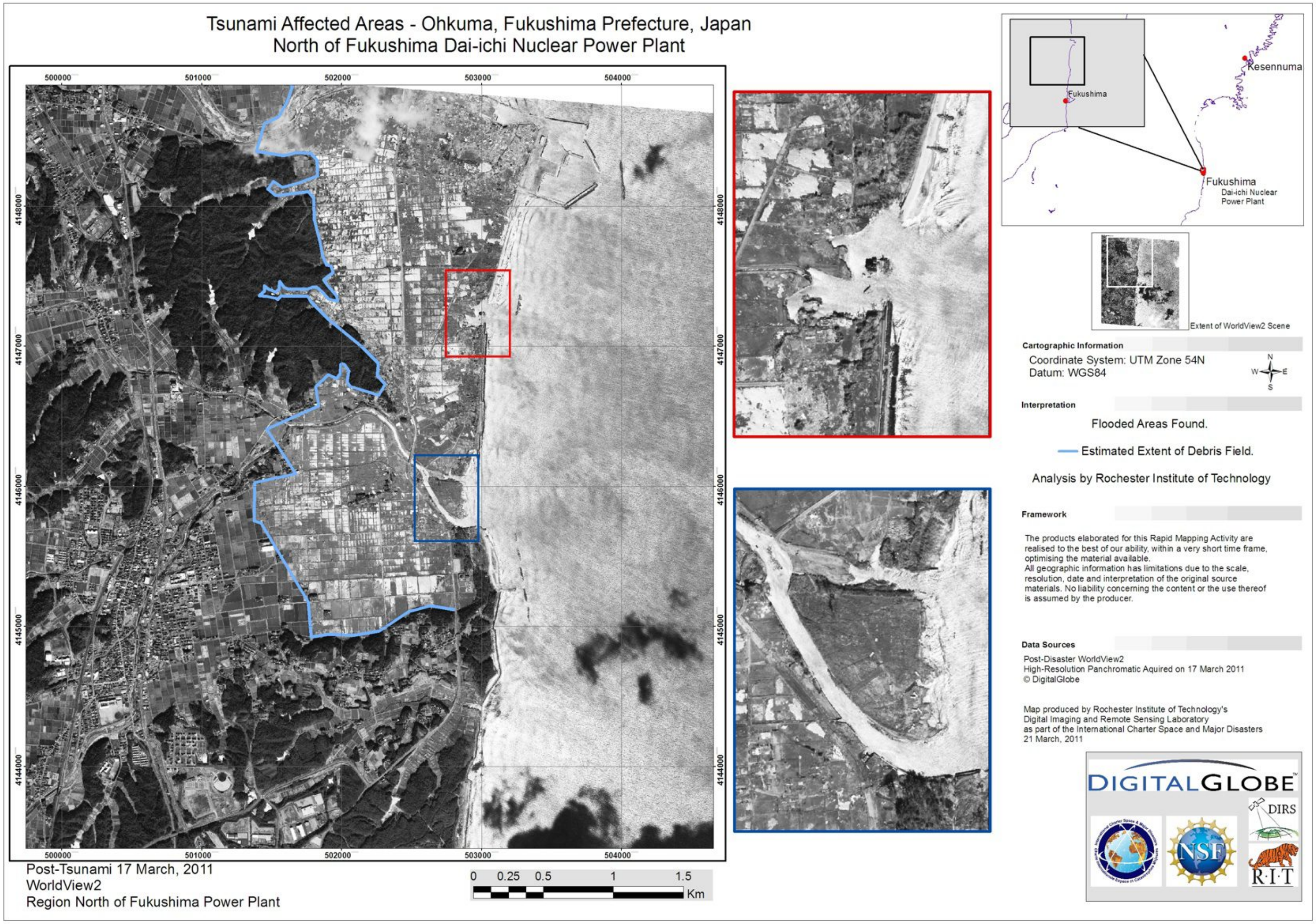

Figure 2. Example map product produced for the area North of the Dai'ichi Nuclear Power Plant. The debris field extent is highlighted in blue. The image is from the Worldview-2 satellite.

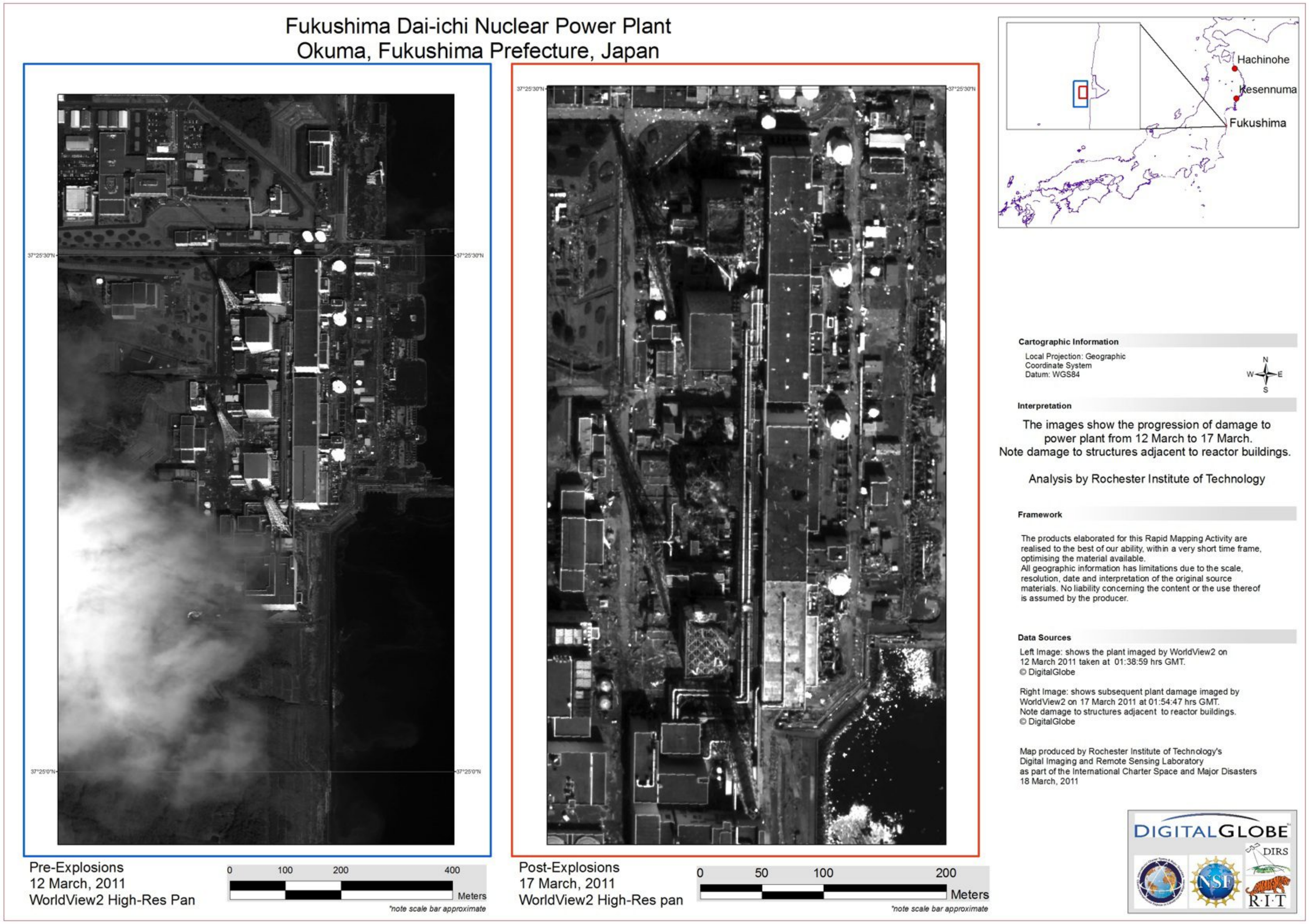

Figure 3. Example map product produced for the Dai'ichi Nuclear Power Plant. Left image is after the tsunami but before the explosions; right image is after explosions. The images are from the Worldview-2 satellite.

4. SUMMARY AND LESSONS LEARNED

This exercise and contribution to the Japanese Tohoku Earthquake and Tsunami Disaster was challenging in several aspects, but led to a greater understanding of how commercially available, high resolution, multispectral and panchromatic imagery can be used to aid relief workers in the event of a natural disaster. After over a week of intensive effort, RIT produced 15 detailed map products covering three areas of Japan: Hachinohe, Aomori prefecture, Kesennuma, Miyagi prefecture, and the Fukushima Dai'ichi Nuclear Power Plant. In a "Lessons Learned" session after the response, RIT gained important knowledge pertaining to a successful effort in the event we are asked to respond to another such crisis in the future.

Coordination and Requirements: A single point of contact between each volunteer organization and the coordinating organization is best. Past experience has shown that response to emergencies of this nature generates a very large amount of information traffic and it is important to have a single person who can "filter" out the information for the local volunteer team. Requirements must be clearly defined up front and adhered to if possible. Over the course of the response, requirements can change with feedback from users in the field, so the team must be flexible. However, it is important to recognize that the end users may not be experts in remote sensing technology so care must be taken to make sure requirements are achievable and expectations are met.

Data Acquisition, Access, and Pre-Processing: As the images were collected, it became apparent that an initial quality control step was required. This was simply looking for clouds, assessing the resolution due to look angle, assessing image coverage, etc. In this case, the addition of new imagery to the available collection was presented using an RSS server. However, we recommend in the future using GeoRSS to aid in the search for new imagery. According to the GeoRSS web page, "GeoRSS was designed as a lightweight, community driven way to extend existing feeds with geographic information."[7] This would allow a more efficient approach to allow volunteers to search for and discover new imagery over their assigned areas. Additionally, requirements as to the specific data projections changed over the course of this effort and so volunteers need to have appropriate tools in hand to re-project images as they are acquired.

Data Processing: A knowledgeable group of volunteers, with experience in image processing and analysis tools, as well as GIS tools, are essential to a timely response. It is difficult to train individuals during the response so a solid team is required ahead of time. We found it best to perform some "group interpretations" to "calibrate" all the volunteers as to what they would be seeing and how it should be reported. A good collaboration space helps to enable these types of interactions, as well as speeds the entire workflow. Processing methods, both good and bad, should be documented along the way as best possible to aid in future response efforts.

Infrastructure: It is important to not only have the right people and skill sets available, but also the appropriate hardware and software. Given the proliferation of space-based imaging systems, a very large amount of imagery is collected over a natural disaster such as this and the volume of imagery that can be rapidly acquired can be overwhelming. Having ample storage and data transmission infrastructure is essential. Additionally, having the right software tools in place to perform all the image and geospatial analyses is essential. Up to date versions of the software ensure that final products will be useful to the larger community and volunteers have the latest tools at their disposal.

The Digital Imaging and Remote Sensing Laboratory continues to support the disaster response community in several areas. As part of our IPLER program, we are continuing to research novel methods of information extraction from remotely sensed imagery to support first responders and policy makers with timely, relevant, and reliable information. We also continue to support ongoing disasters such as the series of earthquakes near Christchurch, NZ between September 2010 and June 2011.

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