CHANGE MATTERS

By Kass Green

Introduction

Change happens. All the time. Floods, wildfires, population growth, pest outbreaks, earthquakes, droughts and wars all inflict change upon our landscape. The ramifications of these changes become more significant over time as the world's population continues to grow, and the resiliency of our environments becomes increasingly taxed.

To plan for the future and to manage our resources wisely, we need to understand what has happened in the past - we need to monitor change. Comparing remotely sensed images over time has long been a riveting and effective method for monitoring change caused by population growth (Jensen, 1981), land use transformation (NOAA-CSC, 2011) forest harvesting (Tucker and Townshend, 2000; Goward *et al.*, 2008), pest outbreaks (USDA, 2011), drought (USDA-FAS, 2001) floods (Steinbruch *et al.*, 2002), and wildfires (USDA-FS, 2011), among others.

Recently three major transformations in policy and technology culminated to bring rapid remote sensing change detection functionality to a broad spectrum of internet users.

1. In 2008, the Department of the Interior announced its plan to make the U.S. government's Landsat satellite imagery free and accessible via the internet. Subsequently, the U.S. Geological Survey (USGS) and National Aeronautics and Space Administration (NASA) partnered to post the Global Land Survey (GLS) (http://landsat.usgs.gov/science_GLS2005.php) epochs of Landsat imagery, comprised of one image per each epoch worldwide from the 1970s, 1990s, 2000, and 2005. Images included in each GLS epoch are chosen for peak growing season and minimal cloud cover.
2. In 2010, Esri (www.esri.com) released ArcGIS Server 10 with the enhanced Image extension that has revolutionized how imagery is served, simplifying image management and increasing image access speed. Simultaneously Esri committed to serving the worldwide GLS Landsat data over the Web to all users for free.
3. In 2011, working with partners, Esri developed a Web tool, *ChangeMatters*[1], which allows users to navigate around the globe and quickly view the GLS Landsat imagery both multi-spectrally (in different Landsat band combinations) and multi-temporally (across epochs), and to conduct simple change detection analysis.

ChangeMatters provides increased access of Landsat imagery to both scientific and non-scientific users. This article introduces *ChangeMatters* by reviewing its background, functionality, and educational user interface.

Background

First launched in 1972, the imagery from the six successful Landsat missions provides continuity in Earth observations over the last four decades. All early Landsat missions captured imagery in the non visible infrared and the visible optical green and red portions of the electromagnetic spectrum. Current Landsats 5 and 7 additionally collect imagery in the thermal, and mid, and far infrared portions of the spectrum. Because human sight is limited to the optical portions of the spectrum, collection of data in the non-optical portions allows users "to see" phenomena that humans cannot perceive with their eyes. Figure 1 compares the different band combinations of Landsat imagery which highlight different types of land cover.

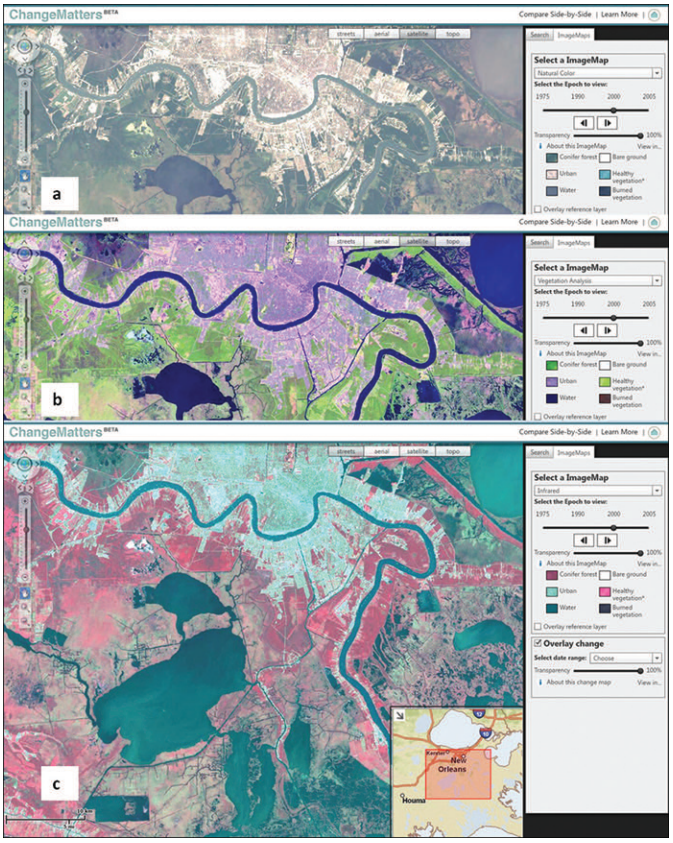

Figure 1. Landsat GLS 2000 imagery displayed in natural color, (a) vegetation analysis (b), and infrared (c) ImageMaps in Esri's ChangeMatters web browser.

Continuity of Observations

All Landsat missions have been configured to ensure continuity of Earth observation. Therefore, each new mission was designed so that scientific comparisons can be made of imagery collected from any mission. Table 1 shows how the spectral ranges of each band have remained relatively unchanged across all missions. *ChangeMatters* allows Internet users to view and compare Landsat imagery in different band combinations and from epoch to epoch.

Policy Changes

From 1972 to 1982 imagery collected by the Landsat missions was available to the public at low cost. However in 1979, President Carter signed Presidential Directive 54 which authorized

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[1] ChangeMatters was developed by Esri with partners Kass Green & Associates, Tukman Geospatial, and DTSagile.

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Table 1. Comparison of spectral resolutions of the Landsat missions

Spectral Resolution (in nanometers)								
Sensor	*Blue*	*Green*	*Red*	*Near Infrared*	*Near Infrared*	*Mid Infrared*	*Mid infrared*	*Thermal*
Landsats 1- 3	NA	0.50 - 0.60	0.60 - 0.70	0.70 - 0.80	0.80 - 1.10	NA	NA	NA
Landsats 4-5 MSS Sensor	NA	0.50 - 0.60	0.60 - 0.70	0.70 - 0.80	0.80 - 1.10	NA	NA	NA
Landsats 4-5 TM Sensor	0.45 - 0.52	0.52 - 0.60	0.63 - 0.69	0.76 - 0.90		1.55 - 1.75	2.08 - 2.35	10.40 - 12.50
Landsat 7 ETM+ Sensor	0.45 - 0.52	0.53 - 0.61	0.63 - 0.69	0.76 - 0.90		1.55 - 1.75	2.08 - 2.35	10.40 - 12.50

the "commercialization "of Landsat imagery by shifting the program from the federal government to a private company. The assumption was that sales of imagery would support the costs of future missions and ground operations. By the late 1980s the cost of a Landsat image had risen to over $6,000 for a terrain corrected and geo-referenced image, and sharing of the imagery was prohibited under a license agreement. As a result, operational and research uses of Landsat imagery were severely curtailed.

Fortunately, in 1992, Congress passed the Land Remote Sensing Policy Act which moved Landsat ground operations and image distribution to USGS, under the Department of the Interior. USGS removed all licensing restrictions, drastically lowered prices to a nominal fee ($600 per image) to cover the costs of reproduction. Subsequently, in 2008, the Secretary of the Interior announced the Department's intention to make Landsat imagery downloadable from the Web for free. As a result, the use of Landsat imagery for both science and operational applications grew exponentially (see Figure 2).

In February of this year, President Obama reaffirmed the United States' commitment to the continuity of Landsat Earth observations by requesting $48 million for the establishment of a Landsat program within the USGS which includes funding for current satellites (Landsats 5 and 7); the Landsat Data Continuity Mission (Landsat 8 -scheduled to launch in December 2012); and the development of Landsats 9 and 10.

Technology Changes

Even in the early years, when Landsat imagery was initially low cost and in the public domain, it was not readily accessible. Image files were huge relative to the communication and disk drive technologies of the 1970s when the internet did not exist, processing software was difficult to use, imagery was delivered on seven 9-track tapes (one for each band), and computers and disk space were profoundly expensive.

Fast forward to 2011, when a two terabyte hard drive costs $120 and a 375–400 megabyte Landsat image can be downloaded over the Web in 5–10 minutes. Acquiring Landsat

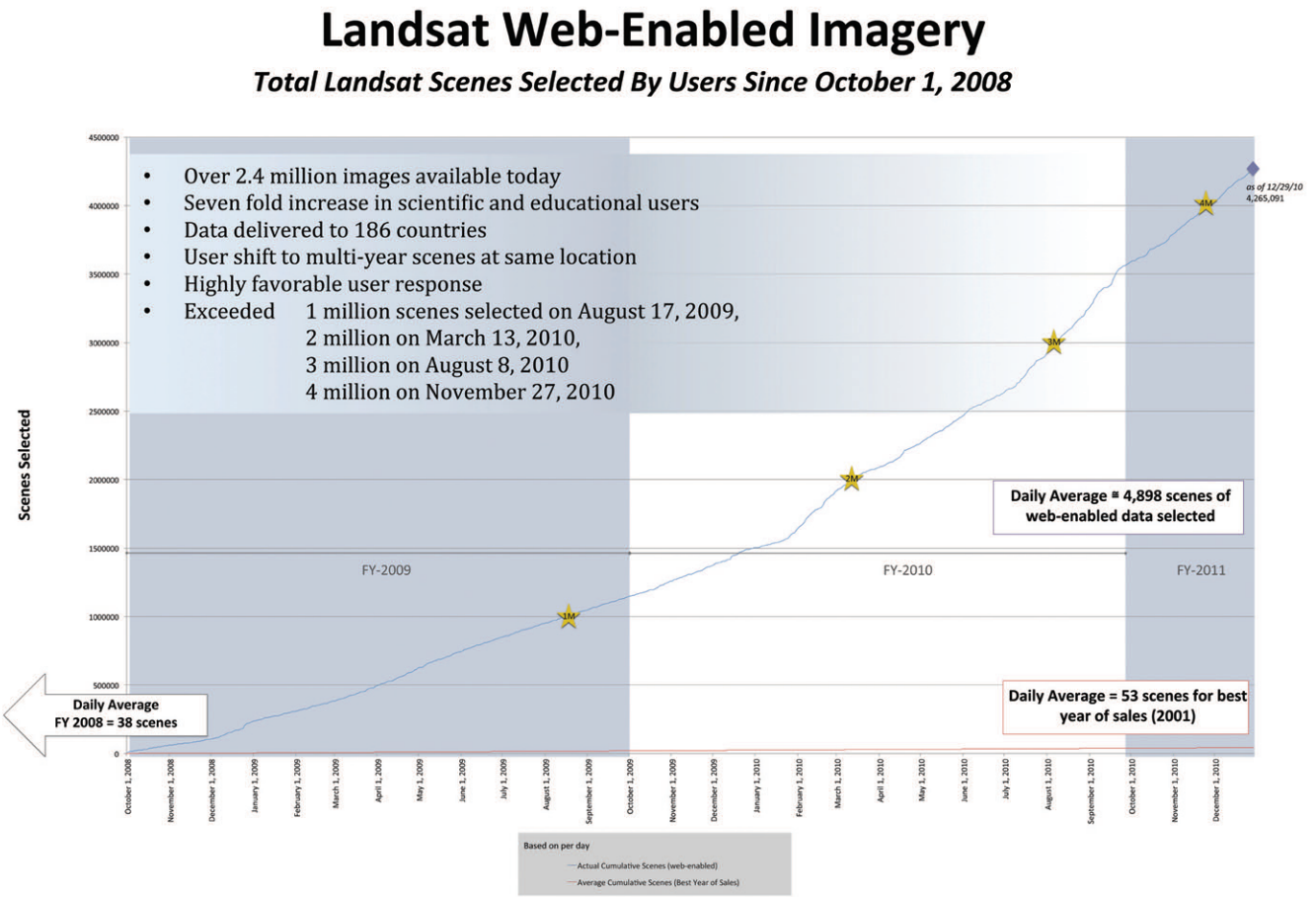

Figure 2. Growth in Landsat scenes selected since Landsat imagery downloads have been available over the Internet (Source: USGS).

imagery is not only now free, but also fast. But obtaining Landat TM data for a project by combing the USGS archives is still very much a manual process.

Now, however, Esri has developed the technology to deliver global, cloud minimized GLS Landsat imagery dynamically using just a web browser. With the release of ArcGIS 10 Server Image extension, Esri transformed the management of image databases and removed the requirement to cache imagery for serving over the Web. The ArcGIS Server Image extension provides the following benefits:

- Simplification of image management by allowing users to directly publish large image collections without preprocessing .
- Dynamic mosaicing of images in different projections, formats, locations, and pixel sizes.
- Fast, server-based processing, enabling on-the-fly creation of multiple image products from multiple or a single source. As a result, labor and disk space requirements for image manipulations are greatly reduced because no intermediate files are required.
- Effortless distribution of huge volumes and numbers of images to a large range of client applications.

Esri's global Landsat GLS image services highlight the power of the ArcGIS Server Image extension by instantaneously serving 34,000 (8 terabytes) of raw Landsat GLS scenes in over 20 variations (called ImageMaps) including different band combinations, derived products, and change images (listed in Table 2). Each type of ImageMap is dynamically served on-the-fly from the raw imagery. The ImageMaps cross 4 epochs of time spanning from the 1970s to 2005. The 2010 GLS Landsat imagery will be added to the Esri services when USGS and NASA complete the data set later this year. These robust Landsat GLS image services are available to anyone through ArcGIS Online at no cost. Users worldwide now have easy access to Landsat imagery for their Web and desktop applications. Unlike other Web sites, Esri's image services do not rely on caching, instead, delivering the imagery using on-the-fly processing which enables users to view different band combinations, different epochs of imagery, and to process multiple bands against one another to derive new products.

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Table 2. List of Landsat GLS ImageMaps served by Esri.

ImageMap Name	Landsat Bands Served	Accessed in ChangeMatters
Image services for the GLS epochs 1975, 1990, 2000, and 2005		
Agriculture	*R=5, G=4, B=1*	*yes*
AtmospherePenetration	*R=7, G=5, B=4*	*no*
HealthyVegetation	*R=4, G=5, B=1*	*yes*
Land/Water Boundary	*R=4, G=5, B=3*	*yes*
NaturalColor	*R=3, G=2, B=1*	*yes*
NaturalWithAtmosphereRemoval	*R=7, G=4, B=2*	*no*
ShortwaveInfrared	*R=7, G=4, B=3*	*no*
VegetationAnalysis	*R=5, G=4, B=3*	*yes*
Infrared	*R=4, G=3, B=2*	*yes*
NDVI	*R, G, B = (4-3)/(4+3)*	*yes*
NDVI_Colorized	*NDVI with a color ramp applied*	*no*
MSS_Multispectral_1975	*all bands*	*no*
TM_Multispectral_1990	*all bands except thermal*	*no*
TM_Multispectral_2000	*all bands except thermal*	*no*
TM_Multispectral_2005	*all bands except thermal*	*no*
Change Image Services		
NDVI Change Image 1975 to 1990	*R=NDVI 1975, G=NDVI 1990, B=NDVI 1975*	*yes*
NDVI Change Image 1975 to 2000	*R=NDVI 1975, G=NDVI 2000, B=NDVI 1975*	*yes*
NDVI Change Image 1975 to 2005	*R=NDVI 1975, G=NDVI 2005, B=NDVI 1975*	*yes*
NDVI Change Image 1990 to 2000	*R=NDVI 1990, G=NDVI 2000, B=NDVI 1990*	*yes*
NDVI Change Image 1990 to 2005	R=NDVI 1990, G=NDVI 2005, B=NDVI 1990	yes
NDVI Change Image 2000 to 2005	R=NDVI 2000, G=NDVI 2005, B=NDVI 2000	yes
NDVI Change Map 1975 to 1990	NDVI 1975 - 1990 (rescaled to 0-255)	yes
NDVI Change Map 1975 to 2000	NDVI 1975 - 2000 (rescaled to 0-255)	yes
NDVI Change Map 1975 to 2005	NDVI 1975 - 2005 (rescaled to 0-255)	yes
NDVI Change Map 1990 to 2000	NDVI 1990 - 2000 (rescaled to 0-255)	yes
NDVI Change Map 1990 to 2005	NDVI 1990 - 2005(rescaled to 0-255)	yes
NDVI Change Map 2000 to 2005	NDVI 2000 - 2005 (rescaled to 0-255)	yes

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ChangeMatters Functionality

The free Web application, *ChangeMatters* showcases Esri's image service technology by allowing Internet users to rapidly view Landsat GLS imagery anywhere in the world, both multi-spectrally and multi-temporally, and to map change over time. The application's functionality includes the ability for users to rapidly

- Search for Landsat GLS imagery anywhere in the world.
- View Landsat GLS imagery in up to 11 different band/product variations (see Figure 2 and Table 2) and compare the imagery to base maps.
- View two dates of imagery and a change image side by side with linked pan and zoom (Figure 3). The change image is a composite of NDVIs for the two dates with the *later* year in the green gun of the display and the *earlier* year in the red and blue guns. Unchanged areas appear in shades of grey because the earlier and later images have relatively the same NDVI values. Areas with *higher* NDVI in the later year than the *earlier* year will be green indicating an increase in vegetation vigor or a decrease in water level. Areas with lower NDVI in the *later* year than the *earlier* year will be magenta (red+blue = magenta) indicating a decrease in vegetation vigor or an increase in water level.
- Interactively map change between two dates of imagery. Change is mapped by subtracting the NDVI values of the later year from the earlier year and rescaling the resulting difference to a range from 0–255. A histogram of the resulting rescaled change values is created and the first approximation of change is set at ±1.5 standard deviations from the mean. Because change is a rare event, most of the change map values will be distributed around the middle of the rescaled histogram which represents no difference in NDVI values between the two dates, and, therefore, no apparent change in the landscape. The user can adjust where the histogram is sliced to adjust areas mapped as change as illustrated in Figure 4.

The application allows the user to directly analyze the changes against a range of ArcGIS base maps, including topographic, street and new high resolution imagery, and the Landsat GLS images used to display and map the changes.

Educational User Interface

Multi-temporal analysis of Landsat GLS data is effective for change detection because there is often a high correlation between spectral variation in the imagery and land cover variation on the ground. As with any remote sensing tool, *ChangeMatters* requires that the user understand the causes of variation in the imagery and how that variation is linked to variation on the ground. To help the user gain this knowledge, *the application* includes multiple tutorials on remote sensing, Landsat imagery, and change detection. The variation on the ground and in the atmosphere which cause variation in each of the diverse ImageMaps is thoroughly explained (e.g., why is vegetation red in the Infrared ImageMap and what do the different shades of red represent?), as are the concepts of change detection and the techniques used by *ChangeMatters* to map change.

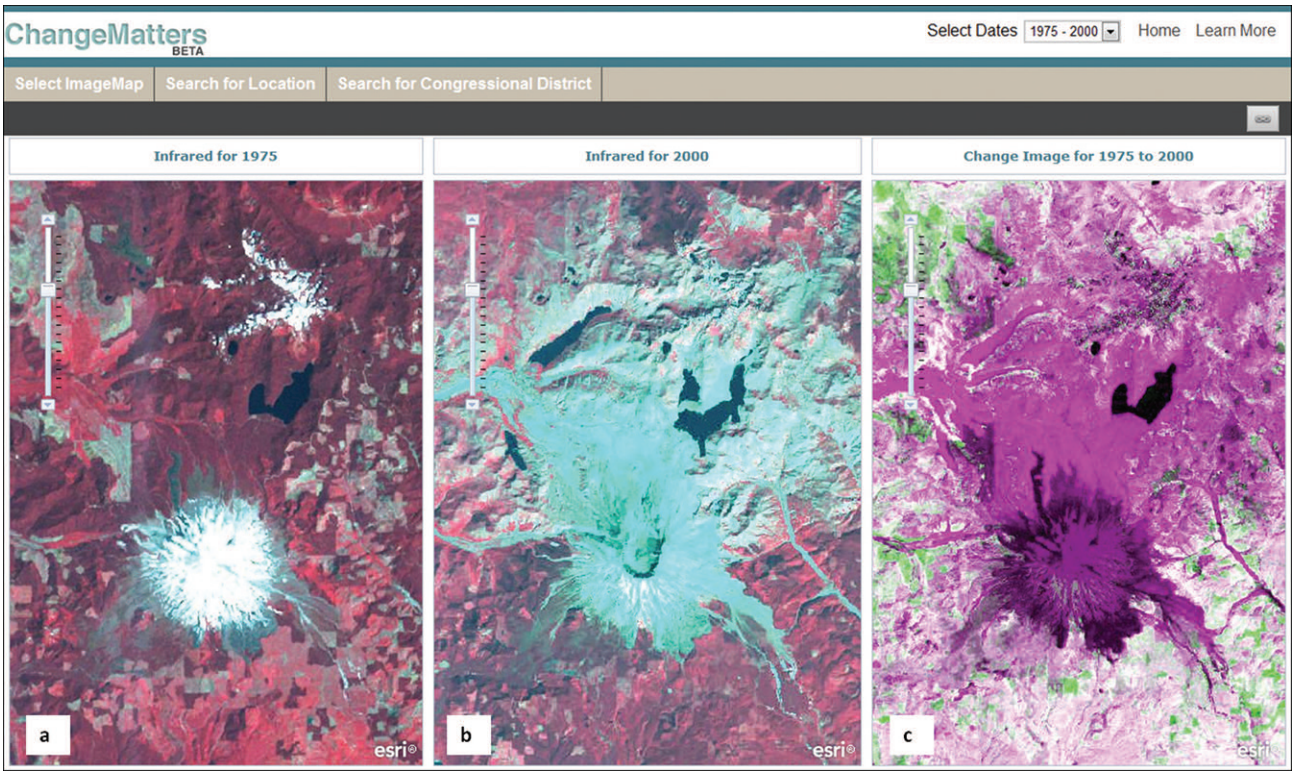

Figure 3. Side by side comparison in ChangeMatters of Landsat imagery of the Mt. St. Helens volcano (Washington State, USA) from the 1975 (a) and 2000 (b) GLS epochs served in an infrared band combination showing the impact of the volcano's violent eruption in 1980. The Change Image (c) is a multi-temporal image with the NDVI of the imagery from 2000 in the green gun and the imagery from 1975 in the blue and red guns. Magenta (red + blue = magenta) areas represent a higher NDVI in 1975 than 2000 and indicate a decrease in vegetation or an increase in water level. Green areas represent a higher NDVI in 2000 than in 1975 and indicate an increase in vegetation or a decrease in water level.

The application also includes tours of locations which have undergone change over the last 30 years. Each tour teaches the user about Landsat imagery and how to use *ChangeMatters* to analyze and map change. Example changes in the tours include deforestation in Haiti, urbanization in the Las Vegas basin, wildfires in the Grand Canyon, land use change in Paraguay, pest defoliation in the Rocky Mountains, lake level drop in Lake Mead, wetlands loss in the Mississippi River delta, and strip mining in Kentucky.

Summary

Esri's transformational image service technology leverages the United States multibillion investment in Landsat imagery over the last 4 decades and makes it easily accessible to users all over the world through ArcGIS Online. It also fulfills a dream of many remote sensing scientists – that is to create a venue where the public can understand the value of remotely sensing imagery and the power of imagery to help us monitor and manage our increasingly scarce resources.

For more information on the Esri technology described in the article, please visit www.esri.com/landsat

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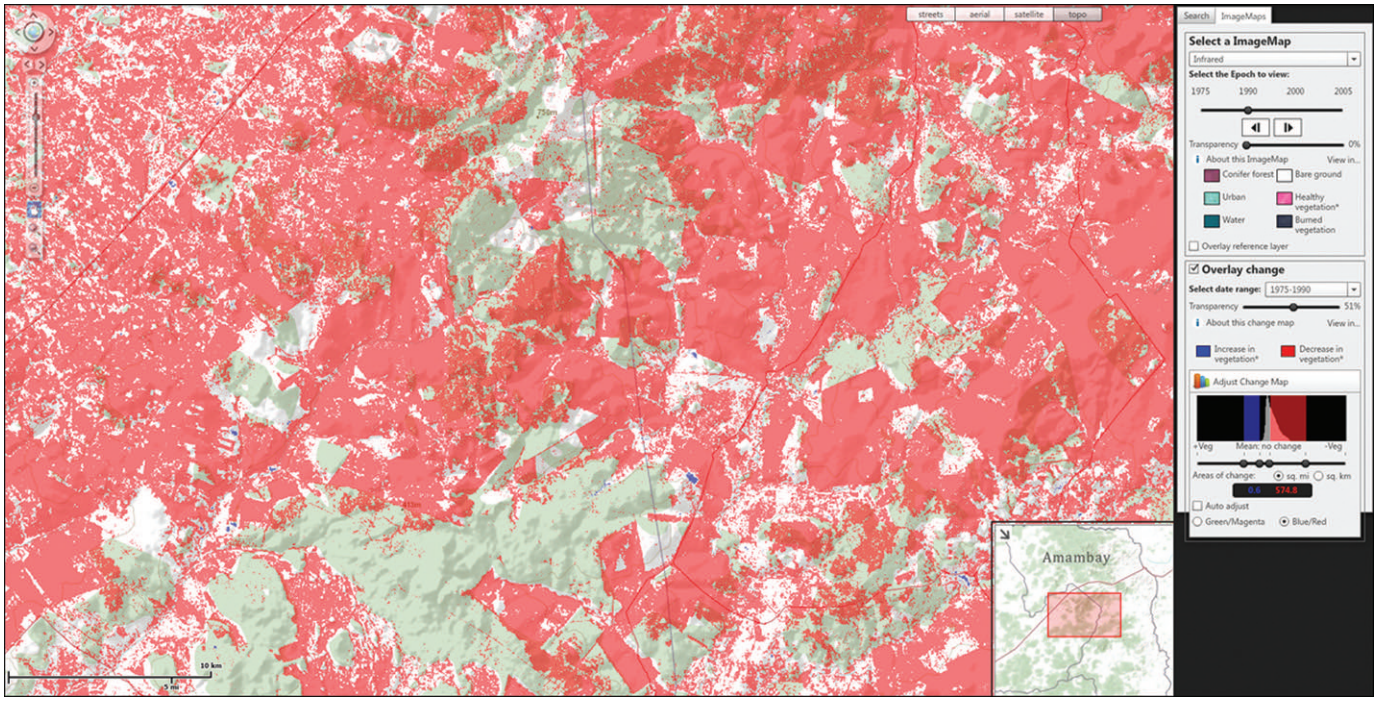

Figure 4. Change Map showing the conversion of forests to agriculture (in red) from 1975 to 1990 in the Amambay region of Paraguay. The Change Map is semitransparent and displayed over a topographic map. The Change Map histogram can be seen in the lower right corner of the Figure. Users can move the sliders underneath the histogram to adjust the amount of area mapped as changed.