Results of Land Cover Change Detection Analysis In and Around Cordillera Azul National Park, Peru

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Five dates of Landsat TM data were used to determine the locations of forest disturbance. The accompanying map sheets plot the results of the disturbance mapping on a shaded relief image depicting the terrain of the region. Additional data layers have been added including transportation, hydrography, and boundaries. Sheet 2-5 are dedicated to showing a single year worth of disturbances while sheet 1 displays the aggregated results of all years. Cover photograph by David Halsing.

The data collected during this project are presented as a series of six maps available at http://pubs.usgs.gov/sim/2005/2879/. The six maps are as follows:

Sheet 1: Aggregated Disturbances – Cordillera Azul National Park, Peru
Sheet 2: 1996 Disturbances – Cordillera Azul National Park, Peru
Sheet 3: 1999 Disturbances – Cordillera Azul National Park, Peru
Sheet 4: 2000 Disturbances – Cordillera Azul National Park, Peru
Sheet 5: 2001 Disturbances – Cordillera Azul National Park, Peru
Sheet 6: 2002 Disturbances – Cordillera Azul National Park, Peru

ABSTRACT

The first product of the Optimizing Design and Management of Protected Areas for Conservation Project is a land cover change detection analysis based on Landsat thematic mapper (TM) and enhanced thematic mapper plus (ETM+) imagery collected at intervals between 1989 and 2002. The goal of this analysis was to quantify and analyze patterns of forest clearing, land conversion, and other disturbances in and around the Cordillera Azul National Park in Peru. After removing clouds and cloud shadows from the imagery using a series of automatic and manual processes, a Tasseled Cap Transformation was used to detect pixels of high reflectance, which were classified as bare ground and areas of likely forest clearing. Results showed a slow but steady increase in cleared ground prior to 1999 and a rapid and increasing conversion rate after that time. The highest concentrations of clearings have spread upward from the western border of the study area on the Huallaga River. To date, most disturbances have taken place in the buffer zone around the park, not within it, but the data show dense clearings occurring closer to the park border each year.

INTRODUCTION

This digital dataset is one of the results of the project Optimizing Design and Management of Protected Areas for Conservation. The data analysis we have completed creates input for other research stages of the project currently being conducted in the Cordillera Azul National Park, Peru. This dataset is being released so that others may use it in ecological or land-cover change research in the Cordillera Azul region and so that the data processing methodology is available for adaptation and application in other tropical protected areas. This report has three main sections. The first section provides background information on the history and status of the park and a description of its geography. This section also contains a brief description of the overall research project, of which this dataset is one result. The second section describes the methods used to obtain, process, and analyze the satellite imagery to produce the land-cover change datasets. The third section contains the results of the land-cover change analysis and provides a brief discussion of the trends and patterns seen in the data.

The authors acknowledge a few individuals for their assistance on this project: Jared Hardner of Hardner & Gullison Associates for his guidance in the design phase of the project, Lily Rodriguez for her help collecting and supplying data, and Liane Guild of NASA Ames Research Center for sharing her tropical remote sensing expertise.

BACKGROUND OF PARK AND PROJECT

CREATION OF CORDILLERA AZUL NATIONAL PARK

In May 2001, the government of Peru designated a 13,530 km^2 area of forest as Cordillera Azul National Park (abbreviated PNCAZ, from the Spanish words: Parque Nacional Cordillera Azul), which is the second largest park in the nation. Although bordered by many small to mid-size communities, the park is only minimally impacted by human activity. PNCAZ lies at the ecological boundary between the foothills of the Andes and the flat Amazon Plain.

The park was created primarily through the efforts of the Peruvian Association for the Conservation of Nature, in conjunction with scientific and technical assistance from The Field Museum. A new organization–el Centro de Conservación, Investigación y Manejo de Areas Naturales (CIMA)–was created and is now responsible for park management. Currently, these organizations are developing the master management plan for the park, setting up its organizational structure, and collaborating with the local communities to ensure effective and equitable protection of PNCAZ.

PARK GEOGRAPHY

PNCAZ lies between the Ucayali River and Huallaga River Valleys in northern Perú (fig. 1). Elevations in the park range from 200 meters (m) to more than 2,000 m above sea level. The eastern edge of the Cordillera Azul Range rises abruptly from the Amazon Plain to more than 1,600 m in elevation. This escarpment forms most of the eastern border of PNCAZ. A higher but less extensive part of the range forms the southwestern border of PNCAZ. Large rivers in gradually sloping valleys drain the western and northern sides of the park.

The dramatic topography and relative isolation from human activities contribute to PNCAZ's rich biodiversity. In addition to identifying at least 28 new plant and animal species, the rapid biological inventory team from The Field Museum in Chicago recorded 1,600 plant species and estimated that there could be as many as 6,000 plant species in the region. They also found 500 bird species; 82 amphibian and reptilian species; and 71 mammal species, 13 of which are endangered. A new species of palm tree (*Euterpe spp.*) was found that has multiple hearts, which may allow for cultivation and repeated harvest of hearts of palm without killing the tree (Alverson and others, 2001).

SOCIOECONOMIC CONTEXT

The Cordillera Azul region has seen substantial population growth recently. In the 1993 Peru national census, the districts in and around PNCAZ and its buffer zone had a combined total of 184,089 people. By 2002, the total human population for the districts was estimated at 248,753 (El Instituto Nacional de Estadística e Informática, 2001). Much of this population growth has been concentrated in the Huallaga River Valley west of PNCAZ and is a major contributing factor in land cover change in that region, as will be discussed herein.

In a region with little history of tourism and industry, most of the population is involved in subsistence farming and agriculture with the major crops being coca, coffee, corn, cocoa, and other foodstuffs (Gavin, 2002). There are also several groups of indigenous people who live in and around PNCAZ and its buffer zone (fig. 1). Park managers are actively coordinating with these groups to prevent damage to the park while allowing them to pursue their traditional use of land and resources (L.O. Rodriguez, written commun., 2002).

PROJECT HISTORY

In 2001, the U.S. Geological Survey (USGS) began a multiyear, multiparty collaborative research project to develop analytical tools, including models, to facilitate the design and management of protected areas for conservation. Our partners in this project are The

Field Museum, the Centro de Conservación, Investigación y Manejo de Areas Naturales (CIMA), and Hardner & Gullison Associates LLC. Collaboration with these groups provides benefits to all of the parties. The conservation efforts of our partners provide us with complex and interesting case-study dynamics, rich datasets, and a built-in audience/customer to field-test our products. In turn, the spatial analysis, database management, GIS creation, and risk assessment we conduct give them tools and insights they otherwise would not have.

For PNCAZ, the goal is to build tools, including models, to assist with park-management activities. These research products include a risk-assessment model to measure and predict land-cover change, a cost-effectiveness analysis of satellite imagery acquisition, and an Internet map server (IMS) website to make spatial data, satellite imagery, and research results freely available to the public. The map server is available on the World Wide Web at http://mapsonline.wr.usgs.gov/peru in either English or Spanish language. This Scientific Investigations Map and its dataset are the result of the landcover change detection part of the project.

We have measured the amounts and locations of land clearings in PNCAZ and its buffer zone occurring since 1989. These delineations are then inserted into a risk-assessment model that analyzes and predicts threats to the park and simulates the effects of management efforts to address and (or) mitigate those threats. This risk-assessment model starts with observations of past land clearings and other land-cover conversions as detected with Landsat satellite imagery. Physical and socioeconomic geospatial data are used within a Geographic Information System (GIS) to estimate the relative impacts of numerous variables such as slope, elevation, human population, location of human settlements, and roads. The strength of these variables in motivating or allowing land-use change is then used to predict the direction such change will take in the future.

METHODS OF DATA ANALYSIS

DIGITAL MAPPING PROCESS AND METHODS

The goal of this project phase was to produce a digital database of anthropogenic disturbances using remotely sensed data. Anthropogenic disturbances include forest clearing for timber production, crop production, and settlement. The digital database was created by using a combination of manual and automated image-processing techniques along with ancillary data supplied by local park officials. A full description of the methods can be found in Sleeter, 2002, but an overview is presented here for convenience.

LANDSAT DATA

Landsat Thematic Mapper (TM) data was chosen as the imagery source for this project because of its spectral and spatial characteristics. Cost was also an important factor because it was important to use data sources that were within the budget of park management organizations. Preliminary searches revealed limited data availability primarily due to high amounts of cloud cover over the study area. Database searches did provide us with five initial dates of imagery: 1989, 1996, 1999, 2000, and 2001. The 2002 epoch was added to the database after initial analysis began. We chose to use

Landsat Enhanced Thematic Mapper Plus (ETM+) data when it was available. However, there were no available cloud-free ETM+ images in 2000 so Landsat TM data were used instead.

The location of the park and buffer zone required four adjacent Landsat scenes for this project. They are identified using the Landsat World Reference System 2 (WRS-2) as Path 07 and 08, Row 65 and 66.

All TM (from here on all Landsat data discussed in this paper will be referred to as TM) data were ordered from the U.S. Geological Survey's EROS Data Center, Sioux Falls, South Dakota. The data were initially processed using the National Landsat Archive Production System (NLAPS) and produced six individual 8-bit GEOTIFF images for each scene collected. These individual bands were then “stacked” to create a single multispectral image for each scene. Radiometric and geometric corrections were performed automatically and the data were referenced to the Universal Transverse Mercator (UTM) projection using the World Geodetic Survey of 1984 (WGS84) spheroid, zone 18-South. For more information on Landsat data processing see the Landsat 7 Science Data Users Handbook (Irish, 1999).

Visual inspection of the data revealed horizontal discrepancies between successive image dates. To compensate, a vector hydrography dataset supplied by PNCAZ was used to co-register all successive image dates using a standard affine transformation technique. TM data were then spatially subset to the defined study area.

CLOUD AND SHADOW REMOVAL

Removal of clouds and their corresponding ground shadows was accomplished in a two-step process. First, an unsupervised classification was performed on each scene’s "blue" band (TM Band 1; 0.3-0.4 microns). This method effectively isolated all clouds from a particular TM scene. The resulting dataset was then used to mask, or remove, the clouds from the multispectral image stacks. Cloud shadow removal was accomplished through on-screen digitizing. Again, the resulting dataset was used to remove areas of "cloud shadow" from the multispectral images. Figure 2 is a flow chart of this process.

DISTURBANCE MAPPING

A Tasseled Cap transformation (Crist and others, 1985; Crist and Kauth, 1986) was used to detect and map areas of disturbance. To perform this transformation, the raw 8-bit digital number (DN) values contained in the TM images were first converted to at-sensor reflectance. This first involved a conversion from DN values to radiance. To facilitate this conversion of all TM data sets, a model was created using the ERDAS IMAGINE Model Builder application. To further streamline the Tasseled Cap conversion, the coefficients used to create the resulting Tasseled Cap image were incorporated into the model as well.

The three primary tasseled cap bands (brightness, greenness, and wetness) were used in an unsupervised classification algorithm to identify and map disturbance areas. The best fit was to cluster the tasseled cap images into 100 classes. The clustered image was then visually compared to the TM images to identify erroneously classified pixels. This included features such as landslides, riverbanks, muddy rivers, and mountaintops with extremely sparse vegetation cover. Edits were made to the cluster image and a final dataset of disturbance areas was created for each TM scene.

For each temporal interval, disturbance-image mosaics and area statistics were generated. Areas of no disturbance were classified as "ZERO" while areas of disturbance were assigned to "CLASS 1"'. Areas outside of the study area as well as clouds and cloud shadows were assigned "NO DATA."

No accuracy assessment has been performed on this data set owing to the lack of available ground control. Should higher resolution imagery become available, an accuracy assessment should be conducted to ensure the validity of this data.

RESULTS

The results of the area statistical analysis are presented in tables 1 and 2. Table 1 presents data for the entire study area, comprised of PNCAZ and its buffer zone, while table 2 contains a subset of results from only the northwestern quadrant of the study area, shown in figure 2. This part of the buffer zone has shown the most dramatic human population growth in recent years and has thus experienced greater land conversion rates. For each epoch of imagery, the total number of observed cells, the number of cleared cells, and the number of forest cells are presented. From these figures, the percent-cleared estimates are derived. Note the steady increase in percent cleared ground and in the rate of increase of clearings beginning in 1999.

The variation in number of observed cells in each year as a result of cloud cover along with possible inaccuracies in the thematic images prevents complete confidence in the exact results. For example, an area that was consistently cloudy might have experienced substantial clearings that do not appear in our data. As a result, the actual change on the ground is likely to be different from these results, but they are still useful for modeling, statistical analysis, and informing park management.

One particularly evident trend is the spread of clearings in the northwest and southwest quadrants, near the Huallaga River on the western edge of the study area. Because this large river is a transportation corridor and its valley provides relatively flat land with good soil for crops and settlements, it is not surprising that most population growth and land conversion would begin near the river and spread outward from there. This is the pattern seen in the data, with disturbances, clearings, and settlements appearing farther upstream along the tributary rivers in each epoch. Clearings also radiate outward through the lowlands from these smaller rivers.

Ideally, a study of this kind would have obtained anniversary date imagery; that is, images obtained on or near the same date each year. This reduces issues of different phenology and soil moisture seen on the images and allows more accurate assessment of change. However because of the near-constant cloud cover over the Cordillera Azul region and the Landsat satellite's fixed fly-by schedule, anniversary imagery was often impossible. Instead, the images were first chosen on the basis of their cloud cover and then as close to an anniversary date as possible.

To date, most land conversion has taken place outside the park and in the buffer zone surrounding it. However, both the extent and the density of pixels classified as disturbed have increased in recent years and are approaching the park border, particularly throughout the river valleys northwest of the park. While cloud cover and other physical and technical limitations prevent complete confidence in specific results, the larger patterns and rates of change are clearly seen and should provide useful input to park managers.

Table 1. Land clearing rates over time in the entire study area.

Year	Number of observed cells	Number of cleared cells	Number of forested cells	Percent cleared
1989	30,850,534	456,773	30,393,761	1.48%
1996	31,612,523	474,848	31,137,675	1.50%
1999	31,984,391	487,863	31,496,528	1.53%
2000	28,761,747	589,369	28,172,378	2.05%
2001	31,593,901	800,036	30,793,865	2.53%
2002	27,325,199	797,712	26,527,487	2.92%

Table 2. Land clearing rates in the northwest quadrant of the study area.

Year	Number of observed cells	Number of cleared cells	Number of forested cells	Percent cleared cells
1989	6,318,393	147,422	6,170,971	2.33%
1996	9,515,933	389,125	9,126,808	4.09%
1999	9,398,705	316,113	9,082,592	3.36%
2000	6,668,484	282,180	6,386,304	4.23%
2001	8,116,633	542,794	7,573,839	6.69%
2002	8,776,328	703,503	8,072,825	8.02%

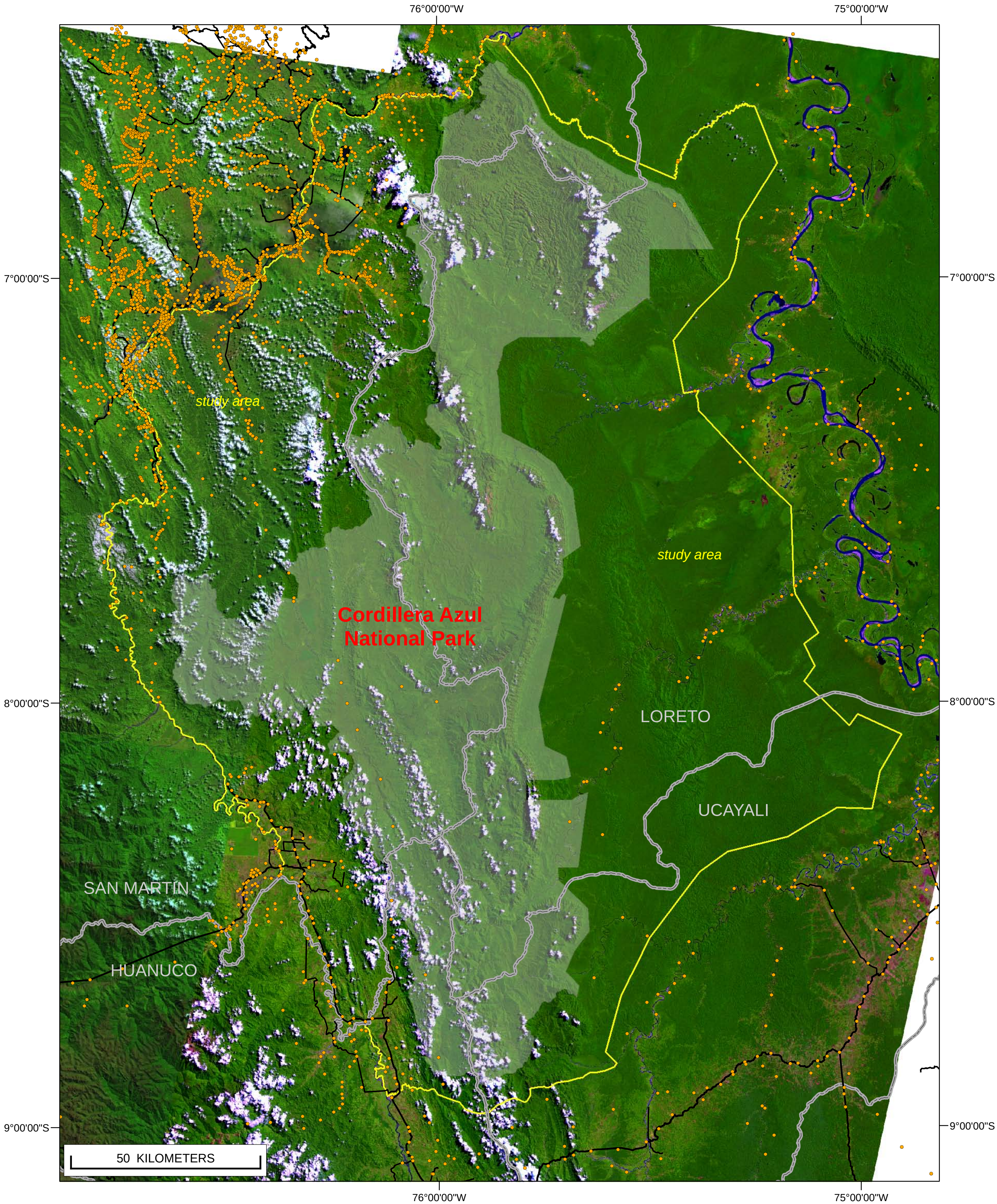

Figure 1. Cordillera Azul National Park and vicinity. Study area boundary shown by yellow line, roads shown in black, and department boundaries are in gray. Settlement locations are represented as orange circles. The background image is a mosaic of 1999 Landsat Enhanced Thematic Mapper imagery.

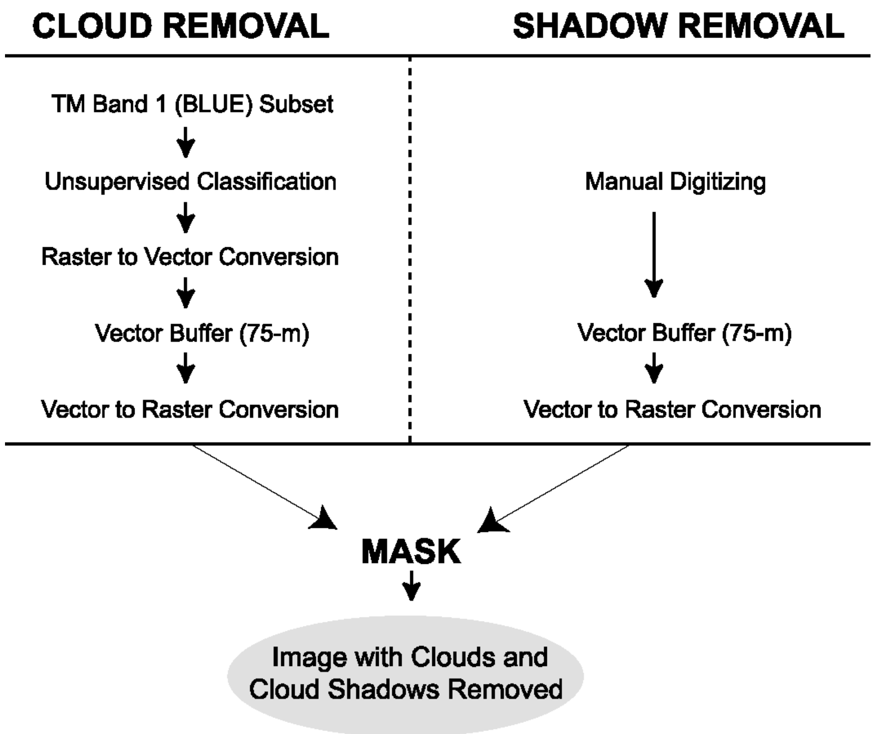

Figure 2. Cloud and cloud-shadow removal process diagram.

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