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Land cover change methods

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Land cover change methods

The purpose of this document is to provide guidance on conducting land cover change projects using satellite imagery. A number of different approaches will be presented along with their strengths and weaknesses. If you are unfamiliar with land cover mapping concepts you might want to read the Land Cover Classification guide on this web site.

This guide is not meant to be a change detection tutorial, but we provide information on some of the methods of visual change detection, as well as the limitations of this approach. Explaining the details, however, about creating a land cover change map using automated classification methods is beyond the scope of this guide. If you plan to conduct a land cover change project, we strongly recommend that you seek advice from people with experience in this area. After reading this guide, we hope that you will have sufficient information to understand how land cover change mapping works and what approaches are available to answer your specific questions.

Throughout this guide, we refer to an early (older) date and late (more recent) date image. Limiting change detection to two images is done to keep the examples simple in this guide, but in actual projects more than two dates can be used.

Why is there such interest in land cover change?

Before starting a land cover change project, it is important to define some objectives concerning what you plan to gain from the analysis. Reviewing these goals will provide insight into what methods are necessary to achieve your specific objectives. This seemingly obvious step is often skipped when, in fact, it is a crucial stage of the project.

So, what are some reasons for conducting a land cover change analysis? Here is a list of common objectives:

- Identify areas of deforestation/reforestation
- Monitor growth of urban or rural populations
- Predict future change based on past change
- Provide data for climate or carbon budget models
- Monitor changes in species habitat
- Monitor changes in agriculture patterns

Another question that should be answered before designing a land cover change project deals with the type of output that can be generated from a land cover project. Three different output options will be described in the following section.

What are the options for output products?

Land cover change output can be grouped into three categories: classified maps, statistics, and image maps.

Classified maps

Classified maps (Figure 1) are the most typical form of land cover change output. These maps group the landscape into discrete change classes, such as: forest to non-forest, forest unchanged, non-forest to forest, and non-forest unchanged. Perhaps the main advantage of this method is that it provides mapped output that is a necessary format for automated spatial analysis, such as modeling and analysis of landscape metrics. Once an accurate baseline change map is generated, it can be updated periodically, often at a fraction of the time and money required to produce the baseline map. Statistics can be easily generated from these mapped products, so in some sense one effectively obtains all three output products when producing classified maps.

In spite of all these advantages, classified maps have some disadvantages. For example, the classification process can be costly and time-consuming, especially if robust error analysis is performed to assess the quality of the output.

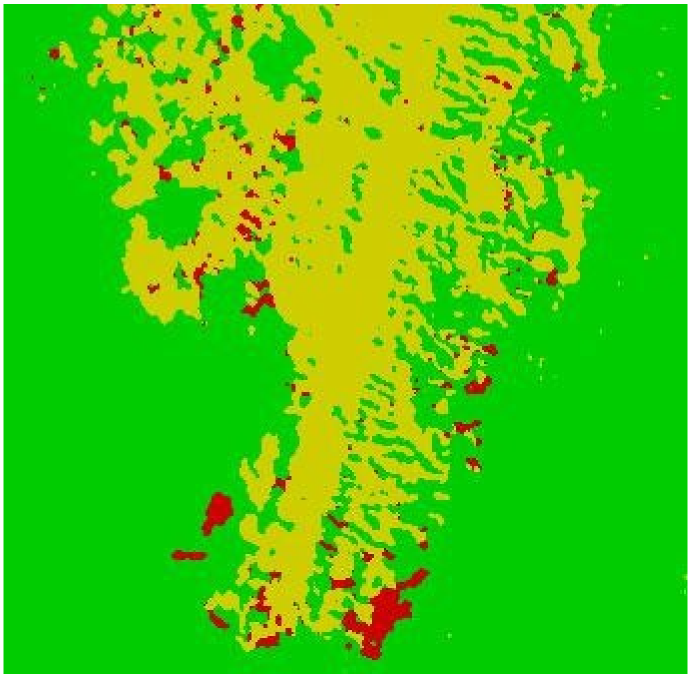

Figure 1: Legend: Green = forest for both dates, Yellow = non-forest for both dates, Red = deforestation

A classified map for a region in northeastern Madagascar using imagery acquired April 8, 1993 and April 19, 2000.

Statistics

During the early years of applied satellite remote sensing, the most common approach to change detection relied on statistics, simply because creating classified maps for large areas required too much computer power. To create change statistics (Table 1), a sampling strategy is developed whereby small portions of the image are accurately classified.

Table 1: Forest cover change statistics for two images acquired over an area in northeastern Madagascar (Landsat path/row 158/72). The early date image was acquired April 8, 1993, and the more recent image was acquired April 19, 2000.

Forest unchanged	6271 Hectares	67.4%
Non-forest unchanged	2823 Hectares	30.3%
Deforestation	212 Hectares	2.3%
Total area	9306 Hectares	100%

Then, using statistics, estimates for the various cover types are generated for the entire study area. This approach tends to produce more accurate statistics, for a given level of effort, as compared to those generated from a classified map, even though a classified map effectively samples the entire population of pixels. This conclusion is based on the assumption that the accuracy for the land cover change estimates for the small portions (sample sites) will be more accurate than the results from a classified image.

The major disadvantage to the statistics-only approach is that there is no mapped output. In this age of spatial analysis, this often rules out the use of the statistics-only approach.

Image maps

An often shunned approach to monitoring changes in land cover is a simple visual approach. With this approach, two images from different dates are viewed simultaneously. This can be achieved by overlaying bands from the different dates (Figure 2), displaying the images side-by-side, or rapidly switching between images acquired at different times using flicker or swipe options offered by many image processing software products (Figure 3). The primary advantage to this approach is that the results are nearly instantaneous. Another advantage is that you can obtain a better sense of the actual landscape because you are effectively looking at a picture of the landscape, rather than a map of discrete categories, as with a classified map.

The downside to this approach is that a quantitative product is not produced. That said, before this method is discounted, it is important to decide if a visual product can meet your needs.

One way to visualize change is to combine bands from two images acquired on different dates in a single RGB composite (Figure 2). This can be done using Landsat imagery to select band 5 (mid-infrared, 1.55- 1.75 Âµm) from the more recent date for the red output channel and band 5 from the older date for the green and blue output channels. When the image is displayed, areas that have undergone change will be shown as different colors. For example, an area that was forest at the early date and cleared by the late date would appear red. Another band that is often used for this method is Landsat band 3 (red, 0.63-0.69 Âµm), although this tends to be noisier.

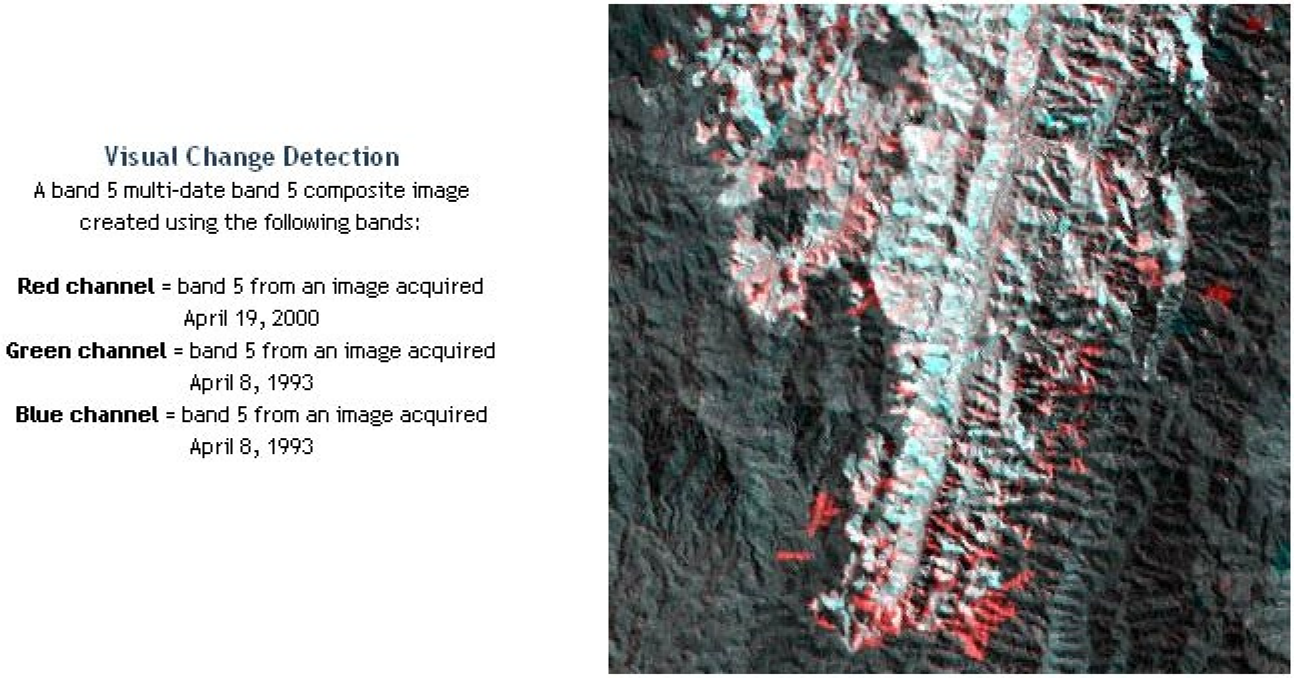

Figure 2: This combination creates an image where the dark red patches indicate areas that have been converted from forest to non-forest. Placing this image next to the original imagery (Figure 3) provides a quick overview of changes in land cover over time.

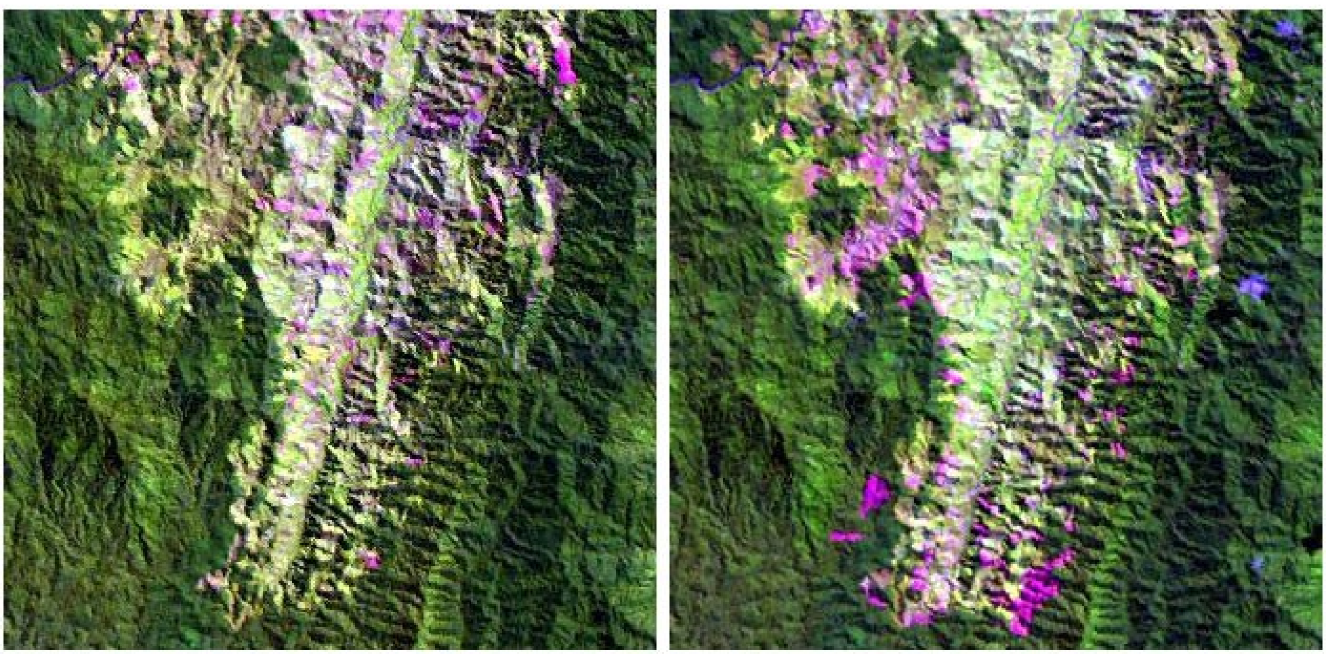

Figure 3: Two Landsat Thematic Mapper images acquired from an area in northeastern Madagascar (Landsat path/row 158/72). The left image was acquired April 8, 1993, and the one on the right was acquired April 19, 2000. Placing the images side-by-side, one can see some areas that have changed from forest (green color) to non-forest (pink color). Some software programs allow the user to flicker between two images to better visualize areas that have changed between the two different dates.

How to select a classification method

There are literally dozens of ways that land cover change maps can be created, and it is beyond the scope of this guide to provide sufficient details to implement each one of these. The purpose of this section is to provide an overview of the more common options and describe the advantages and limitations of each.

Comparing two classified images (post-classification)

This is likely the most common and intuitive change detection method. Surprisingly, however, it rarely produces the best results. In this method, a land cover map is produced for each of the two dates and then these two land cover maps are compared, using simple image math, to determine the land cover change map (Figure 4).

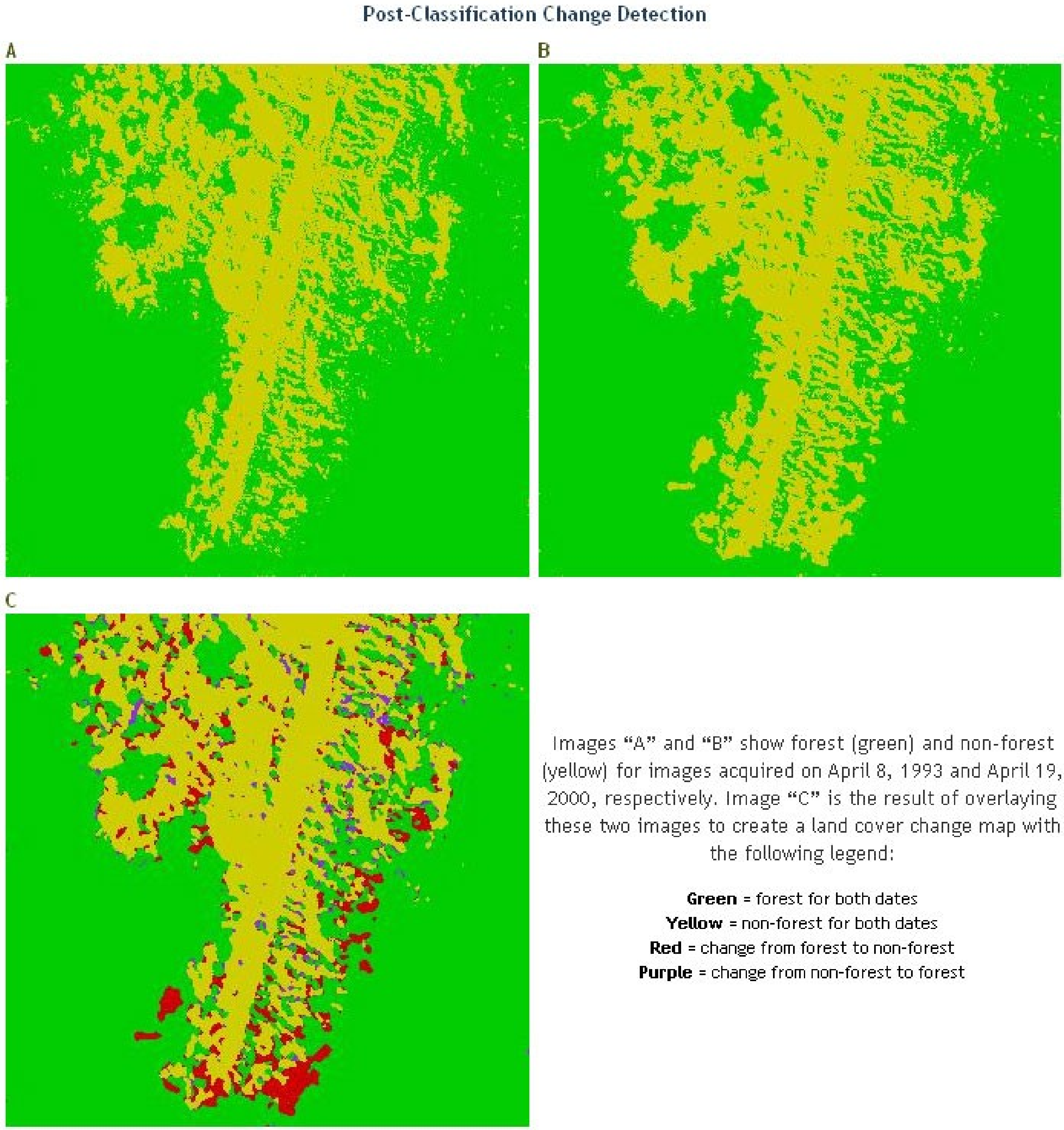

Figure 4

Logically this approach makes a lot of sense, and it has the advantage of directly providing land cover maps for the individual dates. This application also indicates the change in land cover between the two dates. The problem is that the errors, which are cumulative, from each of the individual land cover maps are incorporated into the final change product. The error of the final map is therefore significantly worse then the individual land cover maps.

One way to illustrate this problem is to classify the same image twice and then overlay the resulting products as if they represented imagery acquired on different dates. When these images are superimposed, we perceive changes in the land cover, even though identical images were used to represent the early and late time periods.

One instance where this method may be appropriate is when the images from the two dates have significant variation not related to changes in vegetation cover. When this is the case, some of the other change methods would tend to lump together the non-land cover changes with those related to changes in land cover. For example, if we are studying land cover change in an area with deciduous vegetation, and one of the images was acquired with leaves on and the other with leaves off, the other change methods might have a difficult time differentiating between such vegetation changes and land cover changes.

A variation of this method is to compare maps created at different times, using different methods to determine the changes in land cover over time. With this approach, when there is little or no control over the methods used to create the maps, the results can be very misleading.

Although comparing two classified images can produce acceptable results, there are often other approaches that will produce a higher-quality product for a given level of effort and resources.

Multi-date composite classification

With this approach the images from the two dates are combined into one multi-temporal image. This multi-temporal image is then classified using the automated classification method of choice, such as supervised or unsupervised. Some of these methods are described in the Land Cover Classification guide. For example it is common to combine Landsat TM bands 1-5 from the two dates to create a 10-band image containing all of the bands from the two dates (Figure 5). The 10-band image is then used as input into the classification algorithm. This approach has the advantage of directly outputting the change classes, which effectively reduces the classification error when compared to the post-classification method described above. Although this method does not directly output land cover maps for the individual date, this information can be derived from the change classes.

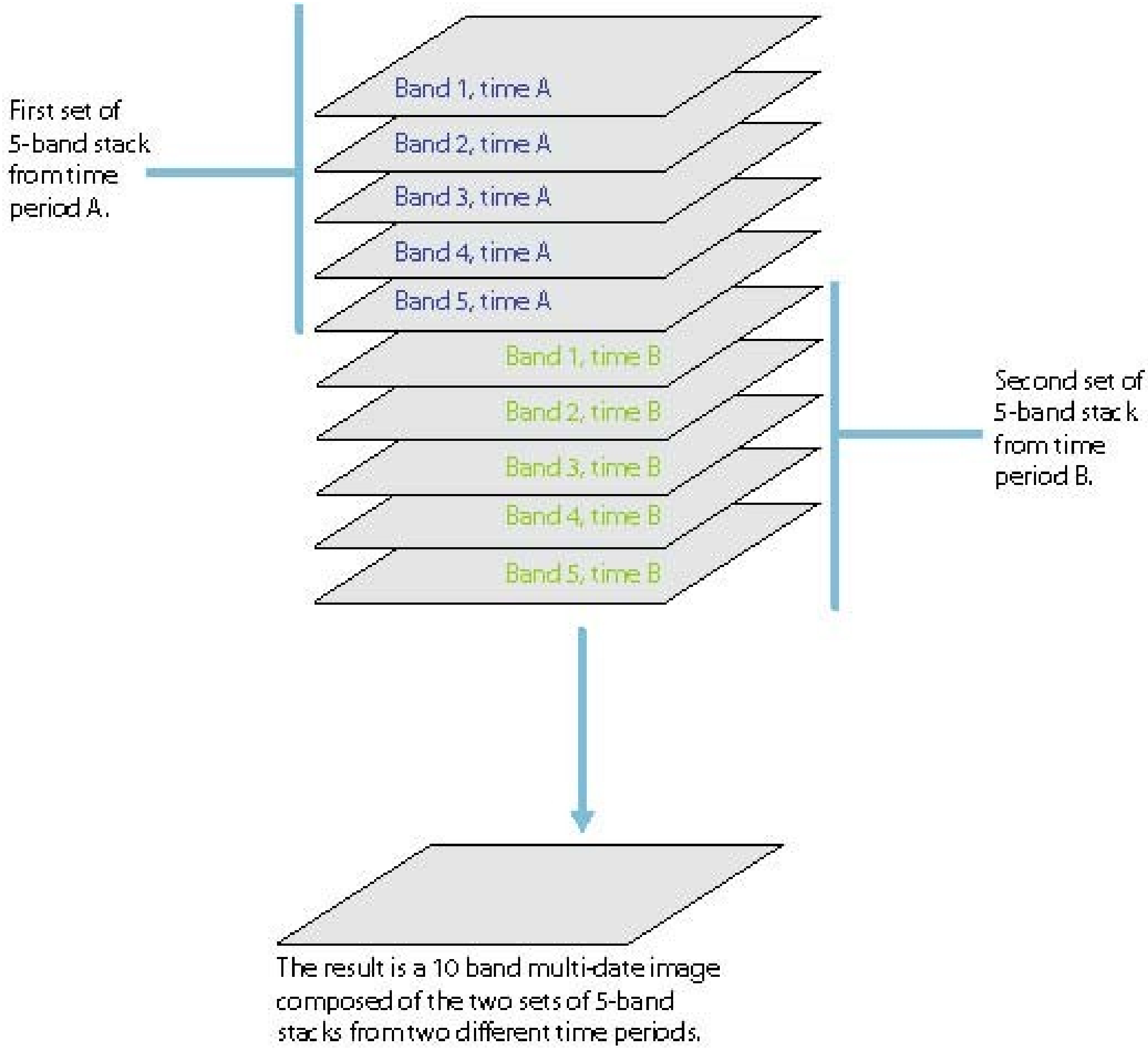

Figure 5: Images from multiple dates can be combined to create a single, multi-date image. The multi-date image can then be processed using the automated methods similar to those used to create land cover maps, except the result here is a land cover change map.

The limitations to this method are similar to those associated with automated classification in general. Depending on the quality of the two images, there may be sufficient variation across one or both images that is not related to changes in land cover. This variation would make it difficult to consistently identify change with reasonable accuracy. Some of these issues are addressed in the section on "Issues to consider when conducting a land cover change analysis."

Image math (difference, ratio)

When using an image math approach, the analyst works with either individual bands or, more commonly, single-band image products, such as vegetation indices or individual image bands. The single- band images from the two dates are then compared by subtracting or differencing them, and then the resulting image is analyzed to determine the range of values that represent a change in land cover from one date to the next (Figure 6). For example, people often create Normalized Difference Vegetation Index (NDVI) images for each date, and then they subtract the NDVI images from each other to determine which pixels in the image represent actual changes in land cover. The advantage to this approach is that it is very easy and fast. The primary disadvantage is that the output highlights areas that have changed, but it does not provide information on what the land cover changed from or to. It is also sensitive to changes not related to land cover, such as changes due to seasonality and changes in atmospheric conditions (clouds and haze).

This method is often used to create a mask (Figure 6D) highlighting areas that have undergone some sort of land cover change. Other methods then use this mask to limit the analysis to those areas that are suspected of undergoing some sort of land cover change.

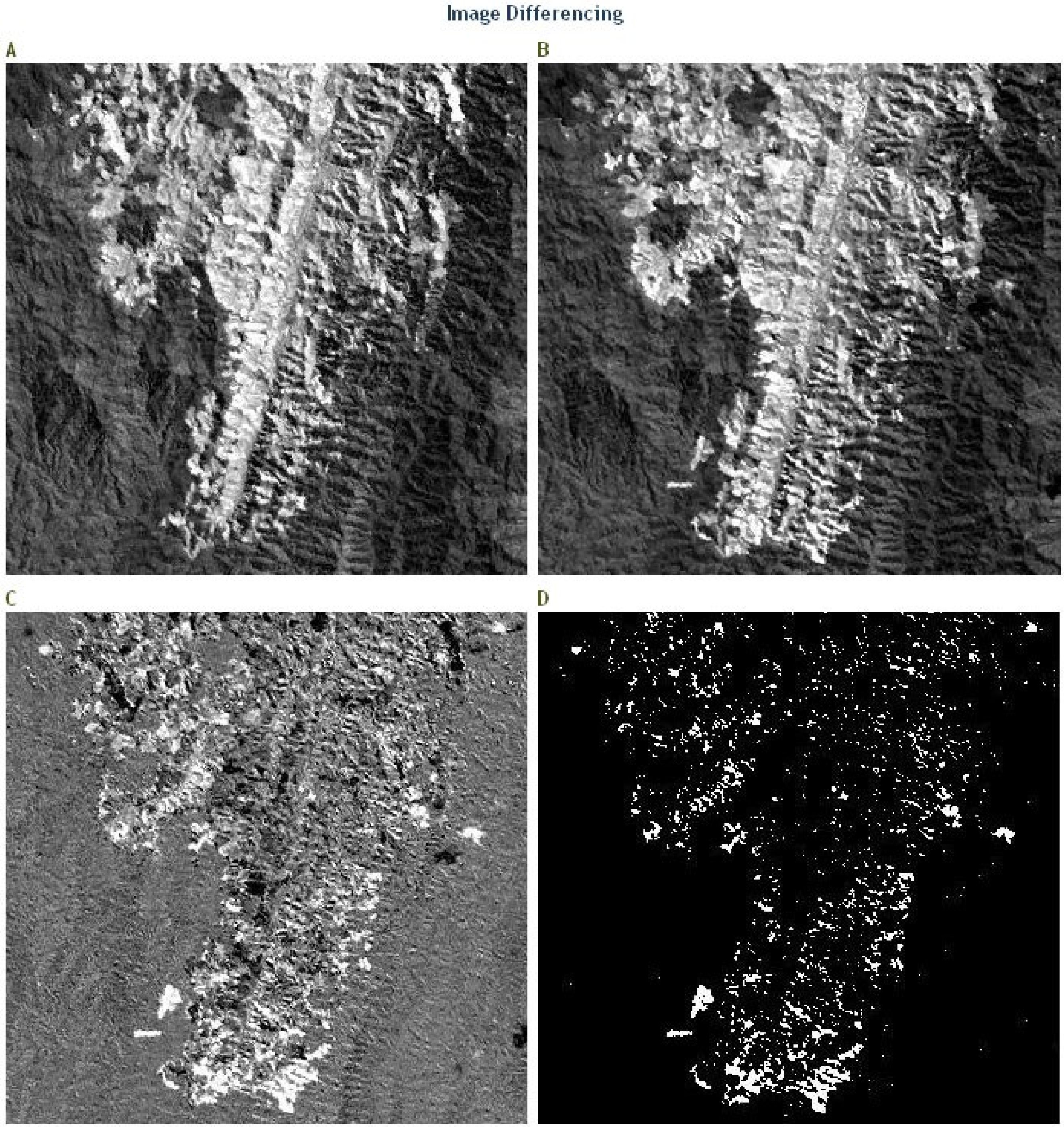

Figure 6: Images "A" and "B" are from Landsat Thematic Mapper band 5 data acquired April 8, 1993 and April 19, 2000, respectively. In these images, forest is dark and non-forest is lighter shades of gray. Image "C" is a difference image that shows the result of subtracting image "A" (1993) from image "B" (2000). The white patches show high values and correspond to areas that were dark in 1993 and bright in 2000. This is what we would expect when land cover changes from forest to cleared land, but other features such as clouds and shadows introduce significant noise in this image. Image "D" is a mask of all values greater than an analyst-selected threshold value (a value of 30 was used in this case) in the difference image (image "C"). These values are colored white and represent areas of possible land cover change.

Spectral change vectors

In spectral change vector analysis, changes in vegetation cover are noted by a change in brightness value (intensity) from one date to the next, and the direction of that change (change in color), as is illustrated in Figure 7 . For example, if an area was forested in the early image and was soil in the more recent image, there would be a change in intensity because soil tends to be bright in most spectral bands and forest tends to be darker. There would also be a notable directional component because the "color" of a forest is quite different from the "color" of bare soil.

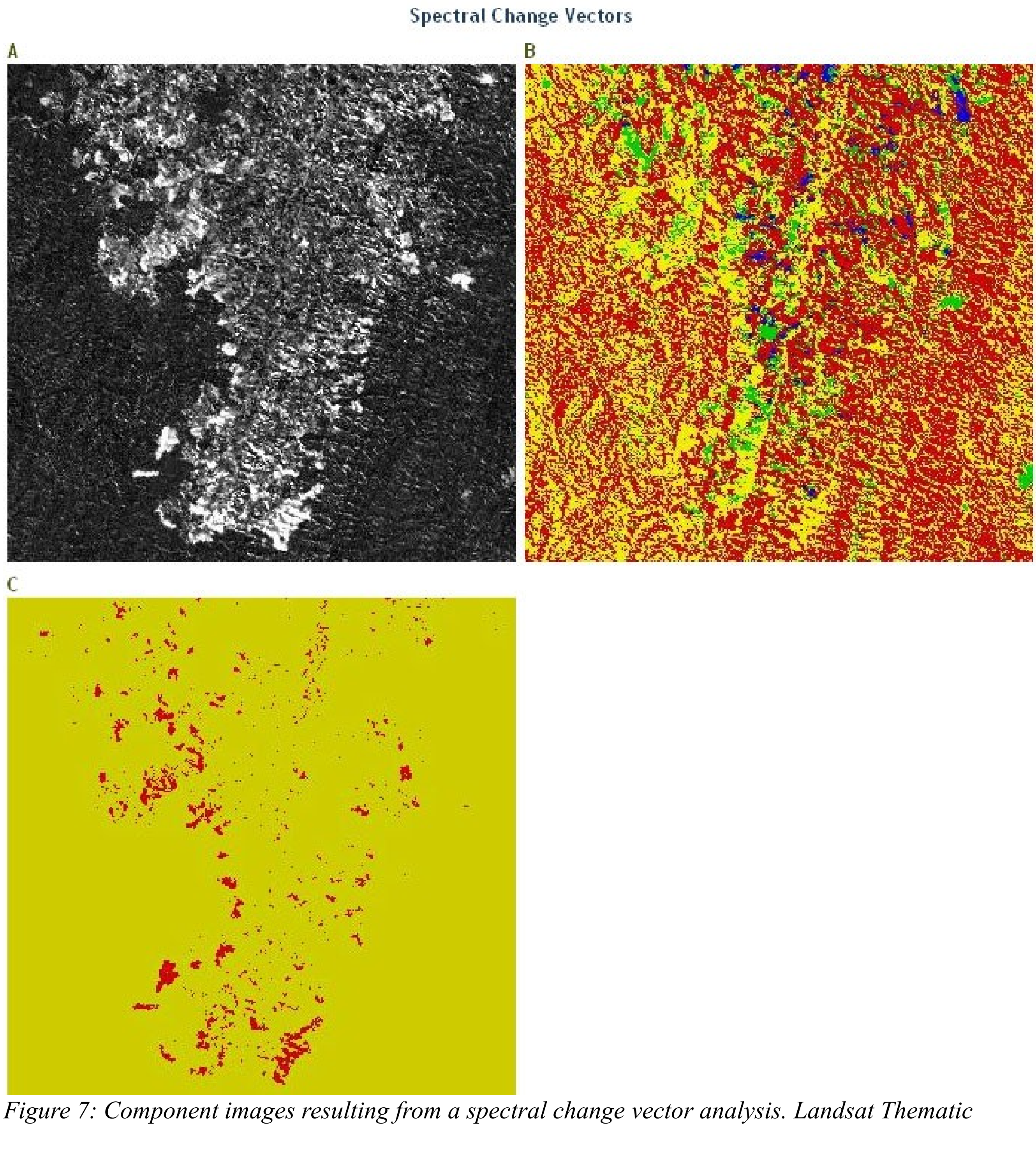

Figure 7: Component images resulting from a spectral change vector analysis. Landsat Thematic

Mapper bands 3, 4, and 5 from two images were used in this example. The two images were acquired over northeastern Madagascar on April 8, 1993 and April 19, 2000 (see Figure 3). Image "A" is the magnitude image showing the intensity of change between the two images acquired on different dates. Image "B" is the direction image, which contains numbers ranging from 1 through 8. Each number corresponds to a different sequence of changes in pixel values for band pairs, indicating which bands increased and decreased in pixel value in 2000 when compared to the 1993 image. In the following legend, each symbol (+ or -) corresponds to bands 3, 4, and 5, respectively. For example, a value of "-, +, -" means that the pixel value decreased for band 3, increased for band 4, and decreased for band 5. Here is the legend for the direction image ("B"):

Red = -, -, -

Blue = -, -, + Yellow = -, +, - Green = -, +, +

White = +, -, -

Purple = +, -, +

Aquamarine = +, +, -

Spectral change vector analysis provides two output images: the intensity of the change vector and the direction of the change vector. The intensity value is similar to what is calculated using image math. The difference is that spectral change vector analysis typically uses multispectral imagery, whereas image math is usually limited to single band comparisons. This approach shares some of the drawbacks with image math,but they are less severe. Using the direction information in combination with the intensity information, it is possible to classify land cover change into different classes.

On-screen digitizing / editing

On-screen digitizing, or heads-up digitizing as it is sometimes called, is a manual method for creating land cover change maps, relying on visual interpretation (Figure 8). For this method, an analyst draws polygons representing the land cover change classes on a computer screen, using the methods described in the "Image maps" section above or on a hardcopy printout. This is the most subjective of the above-mentioned approaches, and in some ways that is its greatest strength and weakness. It is a strength because the human brain is still better at classifying the vast array of landscape features than a computer algorithm. The downside is that this approach is more susceptible to operator fatigue and bias than automated methods, and it tends to be slower in complex or large areas.

Visual interpretation of change is well suited for creating land cover change maps through the process of editing an existing land cover map. In this scenario, a land cover map is created for one time period (either the early date or the late date), using your method of choice. This product should be validated to assure that the quality is acceptable. Next, this land cover map is edited, using image editing procedures available with most image processing software. The land cover map is compared with both the image used to create the land cover map and the complimentary image. If the land cover map represents the late date, then the complimentary image would be the early date satellite image. By comparing these three products, one can visually note areas that have changed from one cover type to another and appropriately update the land cover map to represent this other time period. During the process of interpreting change, the analyst will occasionally find errors in the original land cover map, and these errors can be corrected. This is another benefit to determining change via an editing process.

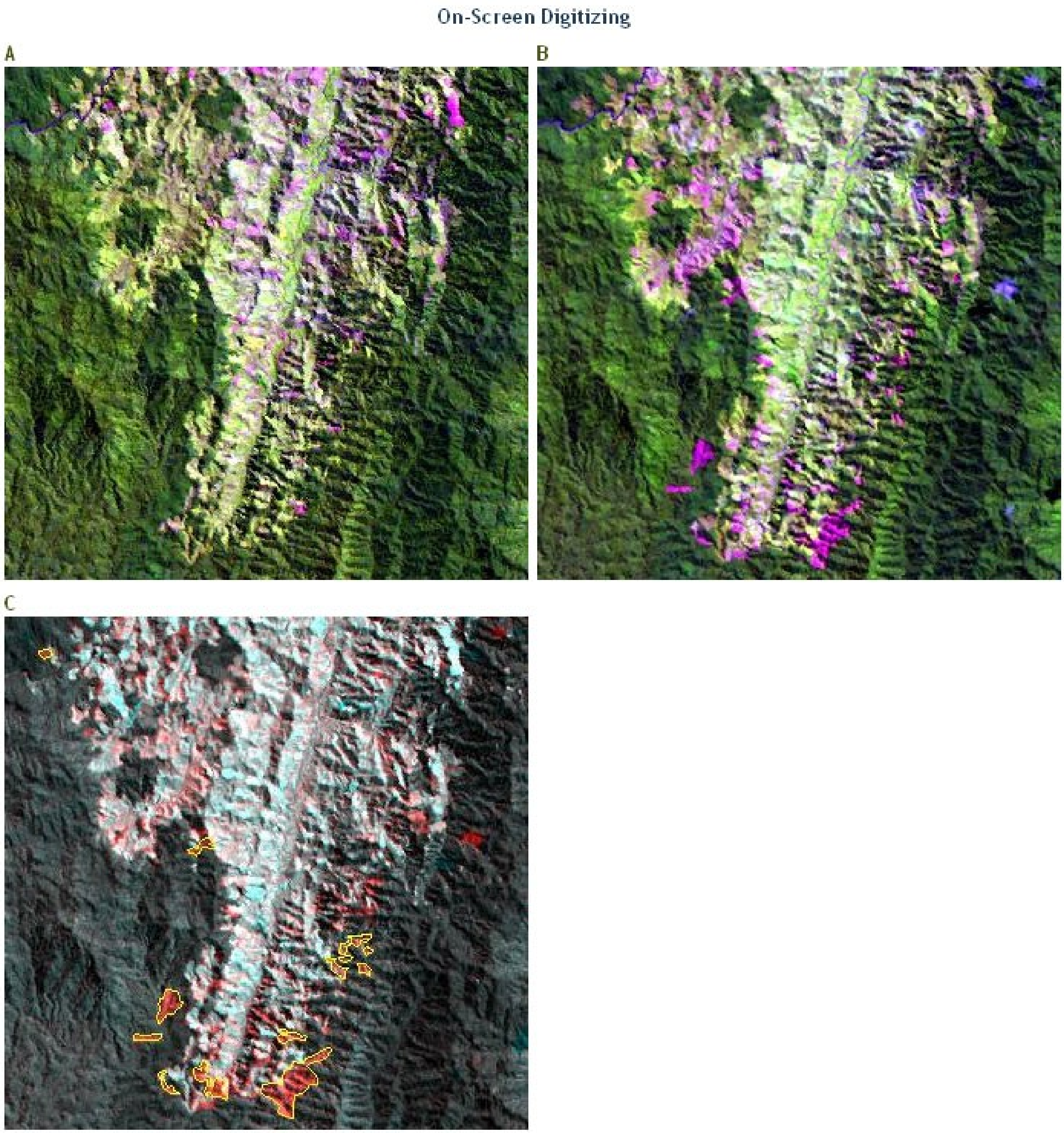

Figure 8: Images "A" and "B" are two Landsat Thematic Mapper images acquired from an area in northeastern Madagascar (Landsat path/row 158/72). Image "A" was acquired April 8, 1993 and image "B" was acquired April 19, 2000. Image "C" is a multi-date band 5 composite (Figure 2) with some lines drawn around areas of deforestation. During this process the color images ("A" and 'B") can be used with the multi-date band 5 composite image to locate areas of change, and then these

areas can be outlined and labeled.

Hybrid approach

The hybrid approach is a combination of the manual and automated classification methods. This approach involves doing the initial classification using one of the automated methods mentioned above, and then editing the results using visual interpretation. A variation of this is to use automated classification for those areas where automated classification performs well. Then the areas where there is a good deal of error associated with the automated methods can be reserved for on-screen methods, as described above. In effect, with the hybrid method, you are complimenting the strengths of automated methods (fast, systematic classification) with the strengths of visual methods (ability to interpret visual cues using one's brain).

How to deal with different data sources

One of the practical realities of change detection is that you are often forced to use different types of imagery for the different time periods of interest. For example, if you want to calculate changes in land cover starting with a period before 1972, you will almost certainly be limited to using aerial or satellite-based photography as part of the sequence of layers used to determine changes. The reason is that digital imaging land remote sensing satellites did not exist before 1972. Another common example of using different types of data is comparing Landsat MSS imagery with Landsat TM imagery. The primary differences between these two instruments are that Landsat MSS has a lower spatial resolution and a more limited band set than TM.

So, how does one deal with change detection when using different data types? One solution, and probably the most common when aerial photos are compared to satellite imagery, is to use the visual on-screen digitizing methods described above. This approach is greatly facilitated if the two image types are in a digital format (the aerial photos can be scanned) and are georeferenced so that they can be displayed in a coordinated manner on a computer screen.

If both datasets are multispectral in nature, then one can resample one of the data sets so that the pixel sizes for the two data sets are equal. When this is done the lower-resolution data set is usually resampled to equal the resolution of the other data set. This, of course, does not effectively increase the resolution of the coarser resolution image. It does, however, provide a data set that can be processed using the automated methods described above without compromising the detail of the higher-resolution image. Some GIS and remote sensing software packages allow you to combine imagery with different resolutions, and in that case resampling would not be necessary.

Fortunately, since mixing data types is a common problem with change detection, a search through the literature will provide a broad selection of methods used by other analysts.

Why worry about data normalization?

There is a lot of discussion in remote sensing circles debating the practical value of normalizing images before conducting the change detection classification. Data normalization is primarily aimed at making the two input images similar with respect to radiometric qualities, so that the same land cover type on the two images have the same brightness value (digital number). In other words, it is an attempt to simulate the same illumination and atmospheric conditions that occurred when the two images were acquired. The idea is that if the images are normalized, then it is much easier to detect changes in land cover.

Even though this logic is quite sound, in practice it can be difficult to accomplish. There are two primary reasons for this. The first is that it is difficult to accurately create two normalized images. This is largely because the variations caused by illumination and atmospheric effects are rarely homogeneous across an image, and simple and reliable methods to normalize imagery are still being perfected. The second issue is that there is often a change in the state of the land cover between the two dates due to senescence, green-up, disease, or different growing conditions, such as growing degree days, water availability, and so on. The assumption, therefore, that similar land cover types will look the same on both images is often invalid.

One can argue that any improvement gained from data normalization will improve classification accuracy. From the author's experience, however, normalizing images does not always reduce the time spent on conducting the change detection, nor does it increase the accuracy of the output. Simple and effective data normalization algorithms are improving, but these capabilities are generally restricted to expensive software programs. When these algorithms become more accessible, it will be worth the effort to learn to use them, but in the meantime you do not need to worry about normalizing imagery.

How do you validate classification results?

Validating the results of a land cover change map can be difficult because one needs to determine what the land cover was for the time periods that are being compared. Typically when you assess the accuracy of a land cover map, you take note of the existing land cover. How does one, however, verify the land cover for a period in the past? The best answer is to use whatever information is available. In some cases, you might be able to find aerial photos that can provide sufficient detail for the time period of interest. A possibility, although rarely practical, is to use interviews from people familiar with the landscape. Another alternative that is advisable if one is putting in place a long-term project is to set up permanent plots or use some other method for systematically sampling the same area. The areas or plots can then be checked every time a new layer is added to the land cover change series of maps. In this way you effectively keep a running tally of the changing situation on the ground for specific areas.

Issues to consider when planning a land cover change project

Many of the same issues that one addresses in a land cover mapping project must be considered when mapping land cover change. For example, the change classes have to be thoughtfully selected so that they meet the objectives of the project and can be accurately delineated using the methods selected. The same goes for the selection of image dates that will be used for determining land cover change. The images have to provide sufficient spatial and spectral information to allow the detection of significant changes in the landscape. As for the selection of methods, it is important that the people doing the classification have sufficient experience in those methods so the work can be performed reliably.

There are a number of variables that must be considered when creating a change detection map. In a perfect world, all of these variables would be relatively equal in both the early and late date images. In practice, however, many or even all of these are beyond your control, and you, have to do the best you can with the available imagery.

Here is a list of some variables worthy of consideration when selecting imagery for a land cover change project.

Sensor characteristics (resolution, radiometric characteristics)

Ideally one would like to use imagery from the same sensor to keep the sensor characteristics as consistent as possible. The more similar the resolution and radiometric characteristics of the sensors, the closer you are to having similar features on the ground appear similar in the images from the two dates.

It should be noted that even using imagery from the same sensor is no guarantee that the sensor characteristics will be equal. Sensors degrade over time, thereby changing the radiometric qualities of the sensor and, in some cases, causing a partial loss of data. The degradation of a sensor can often be compensated for by applying published radiometric correction factors or simply by ordering radiometrically corrected imagery.

Solar illumination

Images acquired under similar solar illumination angles help assure that shadowed ground areas, as well as brightly illuminated areas, will be similar in appearance for both early and late dates. To accomplish this, it is necessary for the imagery to be acquired during the same time of the year and the same time of the day. Some of these effects can be reduced by using a DEM to normalize the effect of different illumination angles, but this approach is not perfect.

Atmospheric conditions

Ensuring similar atmospheric conditions between two dates of imagery is much harder to control than many of the other variables because it tends to change on an hourly or daily basis and is not always homogeneous across an image. Acquiring imagery at approximately the same time of the year can increase the chances of meeting this goal, but it is certainly no guarantee. As with the solar illumination variable, atmospheric effects can be reduced using atmospheric correction algorithms, but this too is an imperfect solution. See the section above on data normalization for more insight into this problem.

Soil moisture

Differences in soil moisture between images acquired on different dates can directly affect the interpretation of features when soil makes up a significant portion of the signal. This is especially noticeable when image bands that are sensitive to water, such as Landsat TM band 5, are used in the analysis.

Soil moisture can indirectly affect plant stress, thereby altering the appearance of similar vegetation so that it may appear as if the vegetation composition has changed.

Acquisition date and frequency

The acquisition date of imagery is important for a number of reasons. In addition to those stated above, it is best to select a time of the year when the features you are most interested in can be accurately differentiated from other features. This way it will be easier to detect changes in that cover type. For example, if you wanted to monitor changes in deciduous land cover, you would want to avoid using imagery acquired during green-up or senescence. In these cases, the vegetation you are interested in is changing rapidly, and it is nearly impossible to acquire an image from another time period with vegetation in the same state of green-up or senescence.

Another issue related to the acquisition date is the frequency of acquisition. If you are interested in monitoring changes over a relatively short period of time, you need to make sure that sufficient imagery is available for that time period. The acquisition schedules for some sensors are predictable. Even if you know when a satellite will acquire an image, however, it is impossible to predict if that image will be of sufficient quality. An array of environmental contaminants, such as clouds or haze, can interfere with efforts to perceive change in land cover. If the frequency for monitoring is on the order of several years between monitoring times, then this is less of a concern.

Typically an effort is made to acquire images at the same time of the year.

Water levels (tide / river level / lake level)

When working in areas with water, it is important to be aware of changes due to differences in water levels. If this change is permanent, it is certainly important to record it accordingly. If these changes are periodic, however, such as with tides and floods, then knowledge of these events and their timing should be considered when selecting and interpreting imagery. For example, when monitoring coral reefs, the tides can greatly influence the amount of water covering the reef or even whether or not the reef is exposed. Viewing different images acquired at different tide levels can present a very different picture of reef extent and condition.