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Preface

About This Users Guide

This Users Guide is designed to aid you in understanding the effective use of the DeltaCue software for image pair change detection tasks. It provides a general introduction to the topic of change detection in remote sensing and details the procedures implemented in the initial release of the DeltaCue software. The Users Guide steps you through the processes, including inputs, pre-processing, change detection, thresholding, results filtering and display. It also gives you tips on the proper implementation of the techniques and presents knowledgeable advice for attaining the best results using the software.

Example Data

Sample data sets are provided with the software. This data is separately installed from the data DVD. For the purposes of documentation, <ERDAS_Data_Home> represents the name of the directory where sample data is installed. The Tour Guides refer to specific data which are stored in <ERDAS_Data_Home>/examples.

Documentation

This manual is part of a suite of on-line documentation that you receive with ERDAS IMAGINE software. There are two basic types of documents, digital hardcopy documents which are delivered as PDF files suitable for printing or on-line viewing, and On-Line Help Documentation, delivered as HTML files.

The PDF documents are found in <IMAGINE_HOME>/help/hardcopy where <IMAGINE_HOME> represents the name of the directory in which ERDAS IMAGINE is installed. Many of these documents are available from the ERDAS Start menu. The on-line help system is accessed by clicking on the Help button in a dialog or by selecting an item from a Help menu.

Conventions Used in This Book

In ERDAS IMAGINE, the names of menus, menu options, buttons, and other components of the interface are shown in bold type. For example:

“In the Raster dialog, select the **Fit to Frame** option.”

Raster is the name of a specific dialog and **Fit to Frame** is an option within that dialog.

Terminology

When asked to use the mouse, you are directed to click, shift-click, middle-click, right-click, hold, drag, etc.

- click — designates clicking with the left mouse button
- shift-click — designates holding the Shift key down on your keyboard and simultaneously clicking with the left mouse button
- middle-click — designates clicking with the middle mouse button
• right-click — designates clicking with the right mouse button

• hold — designates holding down the left (or right, as noted) mouse button

• drag — designates dragging the mouse while holding down the left mouse button

Special Characters and Fonts

Certain characters and font styles have special meaning in ERDAS IMAGINE documentation.

When you see words enclosed in < >, substitute the proper information for these words. For example, when you see <IMAGINE_HOME> in this document, replace it with the name of the drive and directory where ERDAS IMAGINE is installed on your system.

Special Paragraphs

The following paragraphs are used throughout ERDAS IMAGINE documentation:

⚠️ These paragraphs contain strong warnings or important tips.

⚠️ These paragraphs direct you to the ERDAS IMAGINE software function that accomplishes the described task.

 книги These paragraphs lead you to other sections of this manual or other specified manuals for additional information.

💡 These paragraphs draw your attention to useful information.

NOTE: Notes give additional instruction.
Getting Started with DeltaCue

The DeltaCue software package is fully integrated with ERDAS IMAGINE software allowing you to make use of IMAGINE’s advanced viewing and processing functionality for all DeltaCue process inputs and outputs. A wizard-type interface steps you through the initial change detection process and a special DeltaCue change display viewer with features specifically designed for change detection analysis may be used to view the results. From the change display viewer, you can then execute iterations on the original process until you get the exact results that you want and then save those settings for future processing runs. The combination is a powerful operational tool for detecting change in image pairs acquired by spectral imaging sensors.

**ERDAS IMAGINE Icon Panel**

DeltaCue software is installed as a main process within the IMAGINE processing suite. Access its functionality by clicking the DeltaCue icon on the main IMAGINE icon panel or by selecting **Main > DeltaCue...** in the IMAGINE Main menu.

Once you have elected to start the DeltaCue process, the main DeltaCue dialog is displayed. Refer to “DeltaCue Wizard Interface” on page 53 for detailed instructions on how to use the DeltaCue wizard to get started processing.

**Help System**

There are several ways to obtain more information regarding dialogs, tools, or menus, as described below.
On-Line Help

There are two main ways you can access On-Line Help in ERDAS IMAGINE:

- select the Help option from a menu bar
- click the Help button on any dialog

Status Bar Help

The status bar at the bottom of the Viewer displays a quick explanation for buttons when the mouse cursor is placed over the button. It is a good idea to keep an eye on this status bar, since helpful information displays here, even for other dialogs.

Bubble Help

The User Interface and Session category of the Preference Editor enables you to turn on Bubble Help, so that the single-line Help displays directly below your cursor when your cursor rests on a button or frame part. This is helpful if the status bar is obscured by other windows.

Preference Settings

Before using DeltaCue software within IMAGINE, it is best to change certain IMAGINE preference settings to maximize ease of use.

It is recommended that you set the following preference settings under the User Interface & Session section as described below.

1. From the main menu, select Session | Preferences. The Preference Editor dialog opens.
2. Click in the category User Interface & Session to display the specific options for this category.
3. Locate the option Keep Job Status Box as shown here, and uncheck the checkbox.

The DeltaCue process runs a number of separate job tasks during processing. If this preference is not turned off, you will have to select OK to dismiss each job status dialog when the process has completed.
4. In the same preference category, you may also wish to check **Use Bubble Help**.

5. Under the Preference Category of **Image Files (General)** the **Compute Pyramid Layers** should be checked. If left unchecked the software will prompt you for the calculation of pyramid files when it displays the imagery.

6. Click the **User Save** button to save your changes.

---

**Process Inputs/Outputs**

The DeltaCue process is designed to work with uncalibrated imagery in IMAGINE .img, .ntf, .tif, and .jp2 formats. The image data need not be corrected for atmospheric effects since scene-to-scene normalization is part of the DeltaCue process. Images in other image formats need to be converted to .img format prior to use with the DeltaCue process.

The DeltaCue process produces a color-coded change detection output layer that is stored in a raster .img file. This image is overlaid on the original image in the DeltaCue change display viewer and may also be viewed using the regular ERDAS IMAGINE viewer. Other IMAGINE tools can then be used to produce output products. The displayed data can be saved to a wide range of standard output formats including JPEG and GeoTIFF. You can also use the ERDAS IMAGINE annotation capability to add annotation to your data and produce map compositions for final output.
The DeltaCue process produces a single final output change detection layer which represents the composite detection of all significant change between the two images specified. Individual intermediate change detection files and masks are retained in the project workspace directory. These files are also stored in IMAGINE .img format and can be viewed and used to produce output products. Refer to “DeltaCue Workspaces” on page 101 for more information about these outputs.

The output of the DeltaCue process is a pseudocolor raster image that overlays on the original images. Non-zero pixels within this overlay image represent change detections and are color-coded according to material change type. If you open the image in the regular IMAGINE viewer, under the Raster Options tab, select Pseudo Color as the Display As option. These images are automatically opened as pseudocolor images in the DeltaCue change display viewer.
**What is DeltaCue?**

DeltaCue is a software package specifically designed to help you identify changes of interest in remotely sensed imagery acquired on two dates. The software provides a series of algorithms, procedures and automated processing steps central to change detection in a user-friendly form that helps efficiently manage the image processing activities associated with this task.

The DeltaCue change detection process operates on co-registered image data and performs a differencing operation as its core change detection process. Whenever you difference two images, all kinds of change are present in the output. A key feature of DeltaCue software is its approach to finding changes of interest to you. It first tries to distinguish significant change from insignificant change and then helps you identify changes that are of specific interest to your application.

Significant change is any real change in the landcover materials present in the two dates of imagery. For example, a new road or building or a change in soil conditions are considered significant change, though they may not be of interest to you. Insignificant change is change due to sensor noise, atmospheric differences, or image misregistration. These apparent changes are not due to scene feature changes and are never of interest.

DeltaCue software allows you to eliminate insignificant change in a number of ways. The process provides a threshold mechanism that eliminates change based on change magnitude. Small-magnitude change due to sensor noise or random reflections may be eliminated by applying a minimum threshold for significant change. Also, a maximum threshold is available to eliminate very large apparent changes, such as those due to presence/absence of clouds or cloud shadows. A misregistration filter is provided to help eliminate apparent change due to pixel misregistration between the two dates of imagery.

Once you have thresholded the change output, the remaining changes evident in the output are considered significant change. In general, however, this output will represent a mixture of different types of change due to various effects. For example, a new road might be included alongside changes in agricultural fields. The DeltaCue software provides several mechanisms for distinguishing changes of interest from other changes.
One mechanism for identifying changes of interest is the change detection algorithm used. DeltaCue change detection algorithms first apply a transform to the image data before performing the differencing operation. These transforms are intended to better enhance those sorts of landcover materials you are interested in. For example, if you are interested in vegetation changes, the Tasseled Cap greenness transform is a good indicator for vegetation, and hence changes in vegetation are highlighted in the difference of the greenness between dates. The primary color algorithms are best suited for detecting man-made objects that appear red, green, or blue. Thus, the choice of change detection algorithm eliminates changes that are not of interest to you.

The second mechanism for identifying changes of interest using DeltaCue software involves change filters. Change filters eliminate uninteresting change based on spectral and spatial characteristics of the detected significant change areas. You can eliminate change based on the spectral characteristics of the landcover materials in time 1 or time 2 and you can restrict the output to specific transitions between materials based on spectral properties. For example, you can eliminate change involving vegetation in time 1. You can also eliminate changes that do not involve a change from one type material to another. If you are only interested in changes from vegetation to pavement, the software provides mechanisms for filtering out all other changes, leaving only the change of interest.

You can also filter change based on spatial properties. Following the change detection difference operation, regions of change are identified and these regions loosely correspond to objects within the scene. The spatial characteristics of these regions, such as area or elongation, can be used to distinguish a change of interest from other changes. DeltaCue software provides filtering on several geometric properties that are useful in different applications. The combination of spectral and spatial filtering allows you to weed out changes that are not of interest, leaving only changes that meet your interest criteria.

DeltaCue is designed to address the needs of both advanced users, such as Image Scientists, willing to experiment with the process, and production users, such as Image Analysts, who are primarily focused on deriving a product. Typically an Image Scientist will develop a change detection methodology for a given task and then provide those procedures to the production analysts to perform on numerous image pairs of similar characteristics. DeltaCue provides a series of algorithms, filters and automated processing steps that the advanced user can easily test and adjust to achieve optimized results for a given change detection scenario (image type, environment, change of interest, etc.). The procedures and parameter settings used can be saved in a parameter file for future use by a production analyst on other image pairs under a similar scenario.
These processing parameters can be subsequently implemented by a production user with very little input other than input file names, parameter file name and output file name. DeltaCue also incorporates customized ERDAS IMAGINE viewers with many features specific to the process of viewing and interpreting change detection results. The DeltaCue change display viewer presents the results of the change detection process in a viewer designed for detecting change in a broad area search mode. An additional Site Monitoring Mode Viewer provides tools for discrimination of subtle image characteristic changes in a specific area of interest. Finally, the software also provides image accounting procedures in order to help you manage the resulting ancillary image files of successive iterations and documents the various procedural steps implemented in a session file.

Change Detection Basics

Change detection within the context of digital image processing of remotely sensed imagery of the earth’s features can be approached from broad area search or site monitoring perspectives. In the first case you wish to efficiently and accurately identify changes of a particular type across a large area, potentially encompassing many image pairs to cover the area spatially. For example you might be interested in new roads across an entire country between two dates. In the site monitoring scenario you are investigating a spatially limited area, but perhaps has many images of that location over a period of time. In this case the detection of a new road does not require much more than visual inspection of the images; however the detection of more subtle changes, which could aid in the interpretation of less obvious changes, may require more advanced processing and visualization techniques. The former case lends itself well to the automation of procedures while the latter requires more human interpretation.

Change detection entails different procedures and techniques, some of which are standardized, while many depend upon the given application. For example, in order to compare one image to another, a pixel in one image must correspond to the same ground area in the accompanying image. Image-to-image registration is a standardized procedure that applies to any image pair. Conversely, filtering out detected change based on a particular size is dependent upon the size of the change phenomena in which you are interested. This will vary from user to user, session to session.
While many things may have changed in the imagery between the two dates, normally you are only interested in a limited number of specific types of change. Incidental changes confound the detection of these changes of interest. Illumination changes related to image acquisition at different times of the day or different times of the year may result in an unchanged object appearing to have changed in its brightness values. Obviously, deciduous trees will appear quite different in their leaf-on state than their leaf-off condition. River and tide levels may fluctuate from time 1 to time 2, snow and ice may cover a landscape, vehicle traffic will likely move and agricultural lands will cycle through fallow periods and different crop types. For some users these changes are of interest, while for others these image changes represent clutter to be filtered out of their analyses.

Filtering through the myriad of changes between two images is achieved through a combination of the selection of change detection algorithms appropriate for a given phenomenon and the implementation of post-processing steps designed to eliminate detected change not fitting criteria indicative of a change of interest.

**Preliminary Steps**

Pre-processing of an image pair consists of standardized procedures that help eliminate sources of spurious or invalid change. Image registration and radiometric normalization are two pre-processing steps that are common to nearly all change detection studies and therefore can be standardized and automated to a degree. An additional technique to speed processing and improve the appearance of the results includes cropping the images down to the common area in the image pair.

**Co-Registration**

In order to be certain that the pixel value at row $i$ column $j$ in the image at time 1 is being compared to the same ground area represented by the pixel value at the same row/column location in the image at time 2, the two images must be precisely registered one to the other. In imaging terminology the two images should be co-registered. This process guarantees that a given pixel in one image will correspond to the same pixel in the other image. This does not imply any correction for sensor acquisition distortions, terrain distortions, or other geometric transformations of the pixel grid. Therefore the pixels in the co-registered images may not be square and they could contain geometric distortions; however each pixel, no matter how distorted, corresponds in a one-to-one relationship with a pixel in the other image. Figure 1 shows the co-registration of one image (blue) to a reference image (green), maintaining the geometric distortions of the reference image. The image to be registered is sometimes referred to as the slave image and the image to which the slave must be registered is called the master (or reference) image.
In order to perform the transformation of the slave pixel grid to the master image a resampling of the slave image must occur, producing a new, co-registered image. This resampling process alters the values of the pixels, typically through an interpolation process, and could therefore have an impact on the results of any change detection process. For this reason it is best to register the images using the fewest resampling procedures possible.

A co-registered image pair is not necessarily *geo-referenced*, meaning that the image grids are aligned to a known, earth-based spatial framework or coordinate reference system, such as Universal Transverse Mercator (UTM) or latitude/longitude coordinates.

**Radiometric Normalization**

Scene illumination differences and radiometric distortions in the sensor can result in unchanged features having different brightness values in one image relative to another image. This will result in apparent change detected where none has actually occurred. This effect can be minimized by ensuring that the images are collected under similar illumination conditions (images of the same time of day and time of year) and through the avoidance of images impacted by either atmospheric haze or sensor anomalies.
To best eliminate or greatly minimize the effects of scene-to-scene radiometric difference, DeltaCue software performs a radiometric normalization of the two images. A radiometric correction to reflectance is also a possible solution, although this process typically requires additional information, as well as more processing time, and must be performed outside of DeltaCue. Additionally, studies have shown that in the context of change detection, the results achieved by simply normalizing one image to another are as good, and in some cases better, than attempts at radiometrically correcting both images to reflectance and then performing change detection (Collins and Woodcock, 1996; Chavez and MacKinnon, 1994; Jensen et al, 1995; Varjo, 1996; Olsson, 1995; Hall et al, 1991).

Change Detection Methods

Change Detection Algorithms

There are numerous algorithms and procedures for detecting change between two images. They can be broadly divided into two categories: transformational techniques that produce a change image for which a change/no change threshold must be established, and change classification techniques where image pixels deemed to represent change are directly detected in the source imagery and mapped. DeltaCue focuses on the former set of techniques.

The most direct technique is to subtract one image pixel from the corresponding pixel in the other image. Theoretically, if no change has occurred, the difference between the two is a zero mean noise distribution. Assuming the subtraction of time 1 from time 2, pixels that have gotten brighter would have positive values and pixels that have gotten darker would have negative values. The distance of that value from zero indicates the degree of change which has occurred.

The resulting change image is a single band, gray scale image for each band to band comparison in the original image pair.

DeltaCue software uses a symmetric relative difference formula to measure change, as in:

$$\frac{T_2 - T_1}{|T_1|} + \frac{T_2 - T_1}{|T_2|}$$

Dividing the difference by the pixel's value at time 1 and time 2 allows the derivation of a change image that measures the percentage change in the pixel, regardless of which image is chosen to be the initial image. A pixel that had a value of 20 at time 1 and a value of 80 at time 2 would have an absolute difference of 60, and a percentage change value in the change image of 375%:

$$\frac{(80 - 20) / 20 + (80-20)/80} * 100 = 375\%$$

Another pixel with a value of 140 at time 1 and 200 at time 2 would also have an absolute difference of 60, but its percentage change would only be 72.86%:

$$\frac{(200 - 140) / 140 + (200-140)/200} * 100 = 72.86\%$$
In most cases it can be assumed that the percentage change of a pixel’s brightness value is more indicative of actual change in the image than simply the absolute difference.

A percentage difference change image can be created by simply differencing every band in one multispectral image from its corresponding band in the accompanying image, although this will result in as many change images to interpret as bands in the image. There are many different ways to condense the information contained in the bands of one image into one which can then be differenced with the other image’s condensed band image. For example, one can difference each pixel’s overall magnitude across all bands.

In addition to using techniques to compress the information contained in multiple bands, other processing techniques can be used to highlight certain spectral features and suppress others. If a phenomenon of interest is known to exhibit certain spectral behaviors in multi-temporal imagery, then procedures can be implemented to exploit that behavior. For example, recent forest clear-cuts are associated with a decrease in near-infrared bands (Landsat Thematic Mapper band 4) and an increase in shortwave-infrared bands (TM band 5). In order to highlight this particular spectral feature, a differencing of the ratio of bands 5:4 from time 1 to time 2 is an effective method of detecting this change.

Image transformation procedures based on scene phenomenology, such as the Tasseled Cap Transformation (Kauth and Thomas, 1976; Crist and Cicone, 1984; Crist, 1985; Collins and Woodcock, 1996), are another option. This procedure converts imagery from the original bands to a set of components that correspond to scene elements such as soil brightness, greenness, haze and others. The resulting phenomenological components can be differenced and a change image of soil brightness or greenness can be created. There are nearly as many ways to draw out change from imagery as there are ways to process the data; the key is to use a method which highlights the change of interest, if it is known.

**Change Threshold**

A deviation from zero in the change image may not be the result of actual change in scene elements but could be due to the natural spectral variability of objects in the images. Even when accounting for illumination differences and other exogenous, non-change related effects, rarely will an unchanged target have exactly the same value in the pixels that represent it in the two images. Therefore, it is necessary to establish the distance from zero at which an apparent image change is representative of a real physical change in landcover.
The setting of this change threshold can be done arbitrarily by selecting a percentage change value or you may decide upon a statistical value, such as a number of standard deviations away from the mean. In a change image the mean is typically centered at or near zero (assuming the majority of the scene is not change). The data are characteristically distributed as a Gaussian (or Gaussian-like) curve, the tails of which represent the negative and positive changes. **Figure 2** Shows the histogram of a change image with data mean centered at or near zero (no change) and distribution tailing off to increasing levels of positive and negative change.

**Figure 2: Histogram of a change image.**

---

**Figure 3** shows the Histogram of a change image illustrating change thresholds established through the use of image statistics, 2.5 standard deviations from the mean. Data falling beyond these thresholds are classed as change.
Establishing a change threshold is a matter of deciding which points along the tails are the points where the normal variability of the image ends and values corresponding to actual scene changes (either negative or positive) begins. The use of a number of standard deviations normally implies that the threshold for negative and positive changes are equal, only differing in their signs, for example, +/- 2.5 standard deviations (Figure 3). However, there is no reason to assume that the negative and positive change thresholds are at equal distances from the mean; that depends on the vagaries of each image pair and the change detection algorithm used.

Change thresholds can also be set based on the percentage change that was detected in the percentage difference image. If a threshold of 30% is established, then a pixel whose value in the image increased by 30% or more would be mapped as change:

\[
\frac{(200 - 170)}{170} + \frac{(200-170)}{200} \times 100 = 32.64\%,
\]

32.64% > 30%, therefore is mapped as change.

Real change exists above this threshold, or below if it is a negative threshold. Similarly an outer threshold could be set to mask out extreme changes, such as percentage changes over 300%.
Figure 4 shows the histogram of a change image with upper and lower bounding thresholds for both negative and positive change. Introducing upper and lower bounds to the change regions of the histogram potentially introduces additional resolving power on the visualization and also introduces an additional level of complexity. The outer bounds can be useful when changes that are not of interest are found in the extreme tails of the change image, such as with clouds or cloud shadows.

**Figure 4: Histogram of a change image with bounding thresholds.**

Filtering Unwanted Change

In the case where a user has no particular phenomena of interest in mind and wants to see any and all change between two dates of imagery, you may begin to analyze the change image immediately after the thresholding process. However in many instances, you will have some idea as to what kinds of changes are important and which are trivial. You need tools to winnow out detected changes that are not of interest. These are not false change detections, merely detections not pertinent to the current analysis.

Spatial Filtering

For instance, a user interested in new buildings of a given size will not care about change detections that are much smaller than a typical building of interest. In an image with 2-meter pixel resolution, single pixel change detections can most likely be considered spurious and removed.
In that same scenario, you may decide to disregard contiguous groupings, or “blobs” of detected change below the size of a building. However, if the change detection method or thresholding process results in only a partial detection of a building, then a filter that only looks for groupings as large as a building, would result in partial building detections being omitted. Therefore it is advisable to allow for detection sizes at least one half the size of the change phenomenon of interest.

It is also possible to filter change regions in terms of additional characteristics besides area. DeltaCue software provides the ability to filter on several types of geometric characteristics, including the length of the principal axes, geometric compactness, and elongation. The change region blob may be thought of as a mass in two-dimensional pixel space. The center of mass or centroid of the blob defines the mathematical center point for the region. The centroid is one of several geometric moments (analogous to moments of inertia in physics). The major principal axis is a line through the centroid along the bulk of the region’s mass. The minor principal axis is perpendicular to the major axis.

Figure 5: Change Region Blob

The length of these axes essentially defines the characteristic dimensions of the region, particularly for regularly shaped regions. These lengths can be used as shape discriminators. For example, to detect new buildings of a particular size, you could filter based on the length of the major axis using the length of the longer side of the building. A major benefit of using principal axes is that you do not need to know the orientation of the building in order to filter the change. For regular shapes like buildings, the major axis will correspond to the major dimension of the building.

Elongation is defined as the ratio of the major principal axis length to the minor axis length. For regularly shaped change regions, elongation is a measure of how extended the region is. A circular region or square would have an elongation of 1.0 whereas a long thin region like a new road would have an elongation value that is much higher.

Geometric compactness is another shape characteristic that can be used to filter change. This quantity is defined as the area of the change blob divided by the product of the major and minor axes:
where $A$ is the region area, $P_1$ is the major axis and $P_2$ is the minor axis of that region. As the change region grows longer in one dimension, the compactness tends to decrease. A perfectly square area would have a compactness of one. The table below shows compactness values for various rectangles and shows how compactness can be used to discriminate various shapes.

**Table 1: Comparison of Compactness Values for Various Rectangular Shapes**

<table>
<thead>
<tr>
<th>Ratio of Rectangle Length to Width</th>
<th>Compactness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (square)</td>
<td>0.785</td>
</tr>
<tr>
<td>2</td>
<td>0.698</td>
</tr>
<tr>
<td>3</td>
<td>0.589</td>
</tr>
<tr>
<td>4</td>
<td>0.502</td>
</tr>
<tr>
<td>5</td>
<td>0.436</td>
</tr>
<tr>
<td>10</td>
<td>0.260</td>
</tr>
<tr>
<td>15</td>
<td>0.184</td>
</tr>
<tr>
<td>20</td>
<td>0.142</td>
</tr>
</tbody>
</table>

Further information on setting the various parameters of the spatial filter is available in "Change Filtering" on page 30.

**Misregistration Filtering**

Another type of spatial filtering that can be applied to the thresholded change image is a procedure to adjust for known levels of misregistration between the two images. Images that have not been precisely co-registered will exhibit certain predictable behaviors in the resulting change image. Along roads and the edges of buildings there may be detections of change related to the slight mismatch of the pixels being compared. A misregistration of one pixel across an image pair will result, for example, in a pixel representing the edge of a road being compared to a pixel corresponding to the vegetated field on one side of the road. At the same time on the other side of this linear feature the pixel corresponding to the water body on the other side of the road may be compared to a road pixel in the other image.

**Figure 6** shows a schematic representation of properly and improperly registered image pairs: A represents a properly co-registered pair while B represents a mis-registered pair.
Figure 6: Properly and improperly registered image pairs.

Typically a set of pixels with one sign of change (negative or positive depending on the targets involved) will occur on one side of the linear feature and another set of pixels with the opposite type of change will be found on the other side of the same feature.

Figure 7 shows a schematic representation of the effect of misregistration on the change image: Red and blue colors indicate erroneous detected change. This problem can be minimized through careful registration, but frequently some level of local misregistration is unavoidable.

Figure 7: Representation of the effect of misregistration.

One way to compensate for this effect is to pass a filter over the change image that will investigate incidences of detected change and ascertain whether or not that change may be due to a misregistration effect. For every pixel highlighted as change, the algorithm can go back to the original images and see if, for that pixel, there exist in a search window of a given size (3x3, 5x5, etc.) two spatially mismatched pixels that, had the image been shifted over a slight amount, there would have been no change detected.
Figure 8 shows how misregistration has caused pixel A to be shifted to the location of pixel A’ in the time 2 image, and a change to be detected between the value of A and B’. A search in the 5 x 5 window around B’ reveals a pixel, A’, which matches pixel A in time 1. This misregistration is confirmed by checking B’ against B. If not only A matches A’ but also B’ matches B then the change from A to B’ is due to misregistration. The shift from B’ to B is with the same amount of shift from A to A’ but with opposite direction.

**Figure 8: Detection of Misregistration.**

Spectral Filtering

Aside from filtering detected change based on its spatial characteristics, change pixels can also be filtered on the basis of their spectral nature. Spectral characteristics can be associated with physical landcover types and hence, spectral filtering is a means of filtering out unwanted change based on landcover.

DeltaCue software uses a form of spectral segmentation which classifies change pixels in the Time 1 and Time 2 images using unsupervised classification. These classes represent the before and after landcover classes. The combination of the two classes represents transitions from Time 1 (before) landcover to Time 2 (after) landcover.
The DeltaCue change display viewer allows you to filter out unwanted change based on either the before class (material), the after class (material), or the transition from one class to a second. For example, if you are only interested in changes in which vegetation became bare soil, you can filter out all before classes that are not vegetation and all after classes that are not bare soil. The remaining transitions represent changes from vegetation to bare soil. You can get even more specific by filtering out specific transitions, for example, trees to bare soil. The remaining change pixels represent changes from spectrally similar before and after materials.

The spectral filtering process in DeltaCue does not assign information to the spectral classes; they are simply numbered classes. It is your interactive interpretation that allows you to remove or keep spectral change classes on the basis of their interpreted information class. The “DeltaCue Tutorial” on page 35 provides an example of how you could use the spectral segmentation tool to remove change classes not of interest on the basis of spectral classes.

**Material Filtering**

Spectral segmentation is an effective method for separating out change pixels into different data classes, but it does not tell you what those classes correspond to in terms of scene features. You must interpret this information. Without rigorous image calibration and atmospheric corrections combined with spectral signature libraries and ground truth data sets, it is very difficult to identify information classes such as landcover types or scene features.
DeltaCue makes use of the Tasseled Cap Transformation procedure to conservatively filter out change pixels on the basis of their material type in either the time 1 or time 2 image. This technique is intended to assist in further removing changes not of interest, such as phonological changes (leaf on/leaf off comparisons) or water-related changes.

**Analyzing Change**

After the filtering of a change image, you are left with an image where pixels that have been classed as change are coded, perhaps for the direction of the change (bright to dark-negative or dark to bright-positive), the intensity or magnitude of the change (as a percentage change or as classed range of change) or as change of a particular type (soil brightness change, greenness change, etc.). Areas of no change are classed as zeros. While this result could be directly exported into a GIS as a model input or for decision support, the majority of the time the results are overlain on the original imagery for you to evaluate. Ultimately, a human interpreter looks at the highlighted pixels in the original imagery and makes a decision as to the nature of the change, the importance of that change, the need for further investigation or a decision on a course of action.

This process of interpretation typically consists of overlaying the change on the original imagery and then switching between the first and second date of imagery. Using the graphical user interface of an image processing software package the analyst makes use of the existing tools to assist in their interpretation. In the case of ERDAS IMAGINE software this includes the ability to swipe or flicker between two dates of imagery, to change the band combinations of the imagery, to alter the opacity or color of a given change class and many other functionalities.

The highlighted pixels of the change image act as a “cueing tool” to guide the eye of the interpreter to specific regions of an image for analysis. The ultimate product of the exercise may be a series of point coordinates that you locate on the basis of his/her interpretation of the change results. Filtering out the changes not of interest, you would only flag those highlighted change areas that have been evaluated as truly of interest.

As an example, let us consider a user interested in the construction of new structures at industrial facilities on the outskirts of an urban area. Using the appropriate change detection algorithm and filtering procedures, the detected change could be filtered of change due to misregistration, small change areas associated with vehicles, and vegetation changes of similar size to the buildings of interest. You would be left with a series of change pixels that fit the spectral and spatial description of the target of interest. However among the new industrial structures there would be some new residential structures also identified. Having a similar spectral composition and spatial size these features would fit the same description as the new industrial structures. On the basis of his/her interpretation (based on the interpreted context of the structures) you could flag just those points that have been interpreted to be the change of interest and leave out the other valid, but not-of-interest, changes.
For some applications there may be a desire to use the imagery to not only answer the question of the existence of change and determine its location, but to also quantify that change. For watershed modeling purposes the existence and point location of a forest clear-cut or impervious surface may not be enough. There may be a desire to delineate polygons of forest loss for input into models or acreage estimates of impervious surface growth. In these cases you would do more than define a point where the change occurred but select out the changed block of pixels for inclusion into a GIS layer for model integration or statistics generation.

**DeltaCue Change Detection**

DeltaCue Change Detection software brings together a collection of image processing techniques and assembles them into an integrated procedure. While principally designed to address the needs of broad area search scenarios, DeltaCue also includes tools for site monitoring applications. Ideally a fully automated process for detecting change is desired; however the variety of possible data types, image environments, targets/changes of interest and image acquisition parameters leads to a complexity that renders automation nearly impossible. DeltaCue attempts to bridge the gap between the highly skilled Image Scientist (IS) who can develop a sophisticated change detection methodology for a specific application and the Image Analyst (IA) who is responsible for the processing of many images in short turn around time.

DeltaCue achieves this by linking together a series of procedures best suited for a range of potential change detection applications in general. The software allows the IS to easily test out settings and algorithms to achieve best results. Through a process of iteration and testing using customized viewer tools, you establish a useful set of procedures for their particular change detection task. These procedures are saved as a parameter settings file which can then be used to automatically select the appropriate algorithms and filter settings in subsequent processing by an IA. The interpretation and evaluation of results are done similarly by both ISs and IAs.

**Processing Strategy**

The change detection strategy used by DeltaCue in broad area change searches, is to allow as much change as possible to pass through the detection process and then to limit the amount of detected changes with subsequent runs of various filters. It is critical that all change is detected and initially passed to the filters. While it is desired to minimize the amount of time spent evaluating highlighted change that is not of interest, this should not be done by restricting detections to the point of missing valid changes of interest. Excessively conservative thresholds may prevent these changes from being passed through to the viewer and you will not be cued to that area of the image. Therefore, it is advisable to allow generously open thresholds that will pass more change than may initially be desired with the idea that subsequent filters will assist in winnowing out the change pixels not of interest.
If a user has no particular type of target in mind, but is interested generally in all things that have changed between the two dates, then an algorithm such as the magnitude difference would be appropriate. All changes, regardless of associated phenomena, are detected on the basis of the overall magnitude of the pixel’s brightness change. If on the other hand you know that they are only interested in changes related to soil disturbances and not vegetation-related changes, then a phenomenological-based approach, such as Tasseled Cap Differencing, would help to initially filter out some of the intense vegetation changes that would otherwise be passed by a magnitude difference approach. This should allow you to set a more open threshold on the soil brightness difference image, without fear of overwhelming the change image with extreme vegetation-related, changes that while valid, are not of interest.

Pre-Processing

DeltaCue has been designed to automate as much as possible the repetitive and time consuming steps of pre-processing. Tasks such as cropping an image pair to a common coverage area or performing image to image normalization are for the most part standardized procedures.

Co-Registration

The task of automated image to image co-registration has been a challenge for the remote sensing community for many years. As DeltaCue is an integrated add-on module to ERDAS IMAGINE, it integrates with the available tools in that software for this process. AutoSync is an automated image registration tool in ERDAS IMAGINE used to automatically generate control points and co-register the image pair. Refer to the AutoSync documentation for more information.

DeltaCue assumes that you bring to the process two acceptably co-registered images. The images do not need to cover exactly the same area, as the automated cropping procedure will ensure this, but they should be co-registered to within a half of a pixel as a rule of thumb. The exact level of accuracy will depend upon the data source and your needs. Also if certain areas within an image are of more interest than others, a lower overall accuracy level, as measured by the Root Mean Square (RMS) error of an image transformation, is not that bad if the areas of interest are well registered.
Radiometric Normalization

There are a number of approaches to image-to-image normalization. DeltaCue implements an automated procedure that forces the mean and standard deviation of the time 2 image to match the same statistics of the time 1 image. This is done through the calculation of two band-wise linear transformation coefficients from the mean and the standard deviation spectra of the two images. This linear transformation is then applied to the time 2 image to force its statistics to match those of the time 1 image on a band to band basis.

This procedure is based on the following assumptions: environmental effects such as illumination or homogeneous haze are the dominant source of differences between the two images and there exists a band-wise linear transformation between pixel values of the two images. Violations of these assumptions, such as clouds, can cause a less than optimal normalization which could impact the change detection results. In order to address this problem, DeltaCue allows you to specify the presence of clouds in either of the images. The normalization procedure will then implement routines to remove the effect of the clouds and cloud shadows on the overall statistics of the images.

NOTE: This will not remove change detections corresponding to the presence of clouds or cloud shadows. This procedure will simply minimize the effect of these clouds on the normalization routine. Non-linearities in sensor response and differential haze across an image will also affect the quality of the image normalization.

Should you have images that have already been normalized or even corrected to reflectance through an external procedure, there is the possibility of opting out of the normalization procedure and running the images as is. If there is doubt as to whether the images should be normalized, it is recommended that you run the normalization routine in DeltaCue.

Change Algorithms

DeltaCue incorporates a set of change detection algorithms which are described below. Future versions of the software could include new algorithms or alterations of the current set. The current algorithms are: Magnitude Differencing, Tasseled Cap Soil Brightness and Greenness Differencing, Primary Color Differencing, Single-Band Difference, and Band-Slope Difference. You can run just one or iteratively experiment with them all. All of the change algorithms use the following formula for computing relative difference:

\[ \frac{T_2 - T_1}{|T_1|} + \frac{T_2 - T_1}{|T_2|} \]

Magnitude Difference

As the name implies the Magnitude Difference algorithm calculates for each pixel its brightness magnitude across all bands in the image based on the following formula:
A pixel's magnitude value at time 1 is then subtracted from its value at time 2 and the relative difference is computed using the formula above.

This provides a measure of change across all the bands in an image. This detection approach works well for many types of phenomena that change a pixel's brightness value in all spectral bands. This would include presence/absence events when the background is dissimilar to the target, for instance when a bright vehicle moves off an asphalt parking lot. Likewise standing water changing to bright dry sand as river levels recede would be another phenomenon that lends itself well to detection by the magnitude differencing process.

**Tasseled Cap Differences**

The Tasseled Cap Transformation involves the application of linear transformation equations to the original data sets based on empirically derived transformation coefficients specific to the sensor. The new transformed image components correspond to scene phenomena such as soil brightness and greenness. These components are then differenced to provide a change image of the given component, that is, positive or negative changes in soil brightness or greenness.

DeltaCue specifies either a soil brightness or greenness difference image as a change detection algorithm; however it will compute the entire transformation the first time either of the two methods is used. Subsequently, should you choose to use the other Tasseled Cap method, DeltaCue will not compute the transformation again but use the pre-existing components, resulting in a much faster difference image calculation for the second method called.

The Tasseled Cap difference images produce change images which can be very different from the magnitude difference image. The greenness difference image will typically provide more detailed discrimination of subtle vegetation changes. Extreme changes, such as forest removal, building construction and fire scars will at times be detected in the Tasseled Cap procedures regardless of whether they are related to the phenomenon of the component in question. These same extreme change events will also be present on the magnitude and principal component change images as well.

Finally, the Tasseled Cap Transformation requires multispectral imagery, which means it cannot be used with panchromatic imagery. Not all multispectral sensors have had Tasseled Cap Coefficients calculated for them. In those cases, routines based on this transformation will not be available. The transformation can also be sensitive to the atmospheric conditions of the original imagery and sensor response anomalies and noise.
Primary Color Differences

DeltaCue software provides a change detection algorithm that highlights changes in scene objects that are predominated by one primary color. The algorithm first thresholds pixels in both the time 1 and time 2 images based on how red, blue or green an object appears and then those pixels that are considered to be of one particular color are differenced as in a normal image differencing process. The color of a pixel is defined using a spectral angle transform. Consider a three-dimensional color space in which the band numbers are ordered in wavelength ascending order. The pixel spectrum is represented by \( \vec{P} = (P_1, P_2, P_3) \)

The cosine of the spectral angle transform of the pixel vector with a reference vector \( \vec{R} = (R_1, R_2, R_3) \) is given by

\[
\cos \alpha = \frac{\sum_{i=1}^{N} R_i P_i}{\left( \sum_{i=1}^{N} R_i^2 \right)^{1/2} \left( \sum_{i=1}^{N} P_i^2 \right)^{1/2}}
\]

Reference spectra representing the red, green, and blue primary colors are given by

\[
RED = (0,0,1) \\
GREEN = (0,1,0) \\
BLUE = (1,0,0)
\]

Using the red, green, and blue color vectors as references gives the following red, green, and blue transforms:
The primary color change detection algorithm applies a given transform to each image and then differences the result using the regular DeltaCue difference spatial model. Since false change indications can be obtained from spectral angles far away from the primary color reference, the transformed cosine value is first thresholded before the difference is taken. This prevents changes in greenness, for example, from showing up as a change in redness even though the cosine of the spectral angle changed. If neither angle was close to red to begin with, then neither is included in the final result. Essentially, the color threshold separates things of one given color from other scene elements and then the change threshold will define changes within those pixels.

Detecting primary color changes in a high spatial resolution image, such as a multispectral QuickBird image, can be quite useful for tracking changes in the location of differently colored vehicles or in assessing changes to buildings and other painted structures. This is because an entire pixel covers a surface painted a given color. In the case of medium resolution imagery, such as Landsat TM or SPOT data, each individual pixel will most likely cover a variety of different colored materials. Unless an entire 30 meter by 30 meter area is covered by a given color, the chances are that it will not pass the initial color threshold and it will not be detected as being of that color.

\[
\cos(\alpha_{\text{RED}}) = \frac{P_3}{\left(\sum_i P_i^2\right)^{1/2}}
\]

\[
\cos(\alpha_{\text{GREEN}}) = \frac{P_2}{\left(\sum_i P_i^2\right)^{1/2}}
\]

\[
\cos(\alpha_{\text{BLUE}}) = \frac{P_1}{\left(\sum_i P_i^2\right)^{1/2}}
\]
The primary color difference algorithm assumes that the input imagery is from a multispectral scanner that has a blue band (\(~0.4 - 0.5 \, \mu m\)) as band 1, a green band (\(~0.5 - 0.6 \, \mu m\)) as band 2 and a red band (\(~0.6 - 0.7 \, \mu m\)) as band 3. This assumption is correct for IKONOS, QuickBird or Landsat TM imagery, however for SPOT-5 imagery the behavior of the software is different. In SPOT-5 imagery band 1 is green, band 2 is red and band 3 is a near-infrared band. Therefore, running the blue color algorithm will actually highlight changes in green objects. Similarly the red algorithm will result in changes in objects dominated by near-infrared reflectance. You should be aware of this feature of the software, as it could lead to confusing results in multispectral imagery where the bands are not in blue-green-red order. Also, by reordering the layers in an image (using the Layer Stack functionality in IMAGINE), an advanced user could apply the color change detection algorithm to non-primary color bands, such as near and mid-infrared bands. The primary color change detection algorithm is disabled when single band or panchromatic imagery are used as inputs.

**Single-Band Differences**

Single-band differences are sometimes useful if a particular change phenomenon occurs primarily in one band or if only single-band imagery is available. DeltaCue provides the capability to produce a change result based on a single band relative difference. While simple and intuitive, this single-band difference can result in a large amount of insignificant change being detected. This technique is most appropriate for use with panchromatic imagery or when used in conjunction with other filters.

**Band-Slope Differences**

The difference in band slope between adjacent bands can also be a useful indicator of change. DeltaCue provides a simple band-slope change detection algorithm. The slope between adjacent bands \(j\) and \(j+1\) are computed, as in

\[
T_1 = B_1[j + 1] - B_1[j] \\
T_2 = B_2[j + 1] - B_2[j]
\]

The relative difference of these quantities is then computed using the regular DeltaCue relative difference formula. The band-slope computed is always specified by the lower band \(j\), which ranges from 1 to N-1. N is the number of bands for each of the inputs used in the algorithm for change detection.
**Change Threshold**

The setting of a change threshold is a critical step in the change detection process. DeltaCue provides a flexible tool for setting this threshold. A user could simply use a specified percentage change value as a threshold, for example, any pixel whose brightness value has changed by more than 90% is considered change. Unfortunately, change images can be very different from one image pair to the next, from one application scenario to the next. Knowing what the percentage change value should be without first investigating the change image is not always possible.

While many image processing packages provide the flexibility to use different thresholds, DeltaCue uses a unique, interactive tool for change threshold setting that allows you to immediately see the effects of changing the threshold before creating the change image. Using the change image’s histogram as the interface, you can move the threshold using the mouse relative to the histogram. This will change the masked change image which is simultaneously displayed alongside the threshold tool. While this process does still require user interpretation, it provides a more readily understandable means by which to do so. For the Image Scientist this tool speeds up the process of developing an optimized procedure for their change detection task.

The DeltaCue process allows successive iterations to be tested, saved and evaluated. You may decide to re-run the same change detection algorithm using a different change threshold. Additionally, the change threshold tool also allows for more complex threshold setting than normal image processing procedures. You could set upper and lower limits to the range of interest should this suit their needs (see Figure 4). For advanced users this could help to detect subtle features within a change image by masking out extreme changes in the image which exist as outliers on the tails of the change image histogram. Additionally, you could decide to threshold out change in a given direction (for example, things that got darker) if they know that their phenomenon of interest is in the opposite direction (only pass positive changes, things that got brighter).

**Change Filtering**

The DeltaCue change detection strategy is to allow a large amount of change to pass the threshold process and then rely on filtering to limit the final detected change to those pixels that most closely match your change of interest. The DeltaCue software incorporates both spectral and spatial change filtering. If Tasseled Cap coefficients are available for the images, changes may be filtered based on before and after material types (vegetation, non-vegetation, and water/shadow). The software also classifies each change pixel into spectrally similar before and after states. These classes can be used to interactively eliminate change.

Geometric properties of the change regions identified can also be used to filter change. Once the change quantity is thresholded, change regions become evident in the output. A change region is a contiguous blob of connected pixels. As long as any part of the region is connected via one of its eight neighbors to any other region, it is considered part of the same region. For example, the pixels shown below are considered one shape since the two regions are connected through a common neighbor.
Also, the shape and size of the change regions can depend on the change thresholds used. Thus, the spatial filter should be used as a general filter with loose tolerances to filter out classes of change, not necessarily precise characteristics.

Also, it is important to keep in mind that discrete change features that abut one another are represented in the change image as one continuous blob. For instance a vehicle may be parked next to a bare field in time 1. In the time 2 image, the vehicle is gone and the field is now full of corn. Both the vehicle absence and the greening of the cornfield could be detected and pass a threshold as change. If you are interested in detecting vehicle movements, not agricultural change, he or she might set a filter to remove large blobs, while retaining smaller regions corresponding to the size of a vehicle. The region representing the vehicle in this case would be filtered out since it would be part of the large region corresponding to the field.

Continuing the above scenario, you could target the vehicle change of interest by first selecting the appropriate change detection algorithm, such as the Tasseled Cap Soil Difference algorithm which would help minimize the effect of the vegetation-related change. If a particular colored vehicle was of interest the primary color change algorithm would also be an option for use. Secondly, the material filter could be set to filter out change pixels that appear to be vegetation in the time 2 image; this would further reduce the contribution of the vegetation change to the final change image. Keeping the filter slightly larger than the object of interest will help avoid the effect of removing a specific sized vehicle being removed because it abuts a larger group of change pixels (such as the corn field). Finally, the spectral segmentation routine will allow you to perceive the difference of the vehicle from the nearby vegetation pixels and interactively turn off those classes that correspond to the vegetation. What should be left as cues in the change image are those change pixels that most closely resemble the changes of interest.
There is also a special kind of spatial filter available in DeltaCue that works on spatial misregistration in the image. As described in "Filtering Unwanted Change" on page 16, errors in image-to-image co-registration can result in spurious change detections. DeltaCue attempts to model and correct for these detected changes. You can select different search window sizes and the number of misregistered neighbor pixels to test for in their original images. This procedure is appropriate to use when there is known misregistration in the imagery.

**Change Results Viewing**

The final, filtered results of the change detection process are displayed in the DeltaCue change display viewer. This viewer is similar to the existing viewers of ERDAS IMAGINE, while incorporating new features specifically designed to aid the interpretation of change results. In particular, you can filter out unwanted change based on spectral classes of before materials, after materials, and transitions between classes. Chapter 5 provides a detailed description of the functionality of the change display viewer.

**Process Management**

The above series of steps and procedures for change detection normally results in numerous image files and notes of algorithm and filter settings. If a user should return to a change detection activity after some time, it can frequently be difficult to sort through the various images and ancillary files in order to ascertain exactly which procedures had been run and what settings were used in a given process. DeltaCue helps you organize and manage this information.

The principal process management tool that DeltaCue uses is the Project file (.dqw file). This XML file is used to store the history of a change detection session, including the input images, the preprocessing steps run and their resulting image files, the change detection algorithms used, thresholds established and their image files, and the filters implemented and their settings. The Project file documents each iteration performed and, through the change display viewer, allows you to call up the results from any of the iterations for comparisons. A user can also open up a previously run project and pick up processing where he or she left off.

Another aid for you is the settings file (.dqs file) which allows one user to save their process settings (change algorithms and filters) in a file so that another user can apply them to a different image pair under a similar change scenario. This is designed to allow a more advanced Image Scientist to develop an appropriate change methodology that could be easily implemented by an Image Analyst with less image processing knowledge.

The settings file allows for the capture of algorithm and filter settings that have been optimized for detecting a given change phenomenon while minimizing changes not of interest, such as detecting new roads in an image containing many other kinds of changes. While the settings can be saved and applied to the detection of the same phenomenon in another image pair, there are some image pair parameters that are unique to each image pair, and therefore each DeltaCue session.
An Image Analyst can specify a settings file when initiating a DeltaCue session through the Wizard interface to assist in initializing the parameters of the shape filter, the material filter and the selection of the appropriate change detection algorithm.

See “DeltaCue Wizard Interface” on page 53.

However, the settings file will not be able to tell the analyst whether the current image pair should be cropped, whether it has clouds in either the time 1 or time 2 images, or the settings for the misregistration filter, should it need to be run.

Ideally, the change threshold should be one number that is set for all image pairs, but in reality there are many cases where it is necessary to alter the threshold for a given pair.

In general the settings file will help the Analyst with the more complex filter settings for a given application. With a minimum of training you will be able to define the additional processing steps necessary for the particular image pair at hand and can then focus your attention on interpreting the change results and not on how to derive the results.

References


DeltaCue Tutorial

This chapter presents a tutorial based on a small pair of DigitalGlobe QuickBird images. These images have been co-registered (but not cropped) and may be used to experiment with DeltaCue software. The tutorial will step you through initial processing using the wizard interface and change analysis using the DeltaCue change display viewer. An example of iterating the processing parameters is also included so that you can see a normal processing sequence from start to finish. The tutorial quickly steps you through the three main features of DeltaCue software:

- Wizard Interface - described in detail in “DeltaCue Wizard Interface” on page 53
- Change Display Viewer - described in detail in “DeltaCue Change Display Viewer” on page 69
- Iteration Capability - described in detail in “DeltaCue Iterations” on page 81

The tutorial data set consists of two small QuickBird images of the area near Arâk, Iran, courtesy of DigitalGlobe. The goal of the tutorial is to identify changes due to construction and changes in agriculture. This process will illustrate typical usage of the DeltaCue software, from initial processing to change analysis to iteration to final product.

Data Set

The DeltaCue software installs two QuickBird images in the examples directory of your IMAGINE software installation. Table 2 lists the image names and sizes. The images have been co-registered and remapped to a common pixel grid, but they have not been cropped.

Table 2: Tutorial Image Data Files

<table>
<thead>
<tr>
<th>Image Name</th>
<th>Image Date</th>
<th>Image Size (pixels)</th>
<th>Pixel Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>DeltaCue.1.img</td>
<td>September 2002</td>
<td>1443 W x 1397 H x 4 bands</td>
<td>2.4 m</td>
</tr>
<tr>
<td>DeltaCue.2.img</td>
<td>July 2004</td>
<td>1443 W x 1397 H x 4 bands</td>
<td>2.4 m</td>
</tr>
</tbody>
</table>

Figure 10 shows the tutorial image pair in false color (4-2-1 band combination). Note that the images have a large overlap area, but they have not been cropped to their common extent. This cropping operation is performed using the DeltaCue software. Also note that the images do not have clouds within the common area. This fact is used when specifying the image normalization process.
Initial Processing

Prior to using DeltaCue software, you must co-register the two images from different dates. For this tutorial, that process has already been performed on the example image data pair. Image co-registration is outside the scope of DeltaCue software, but it is a critical preprocessing step. The pixel data in each must spatially correspond to each other in order for DeltaCue’s change difference process to perform properly. If you have data that has not been co-registered, you must manually co-register the data by either remapping both to a common pixel grid (as was the case with the example data) or remapping one image to the other. For this tutorial, it is assumed that you have already co-registered the image pair and you are ready to start using DeltaCue software to detect change between the two dates.

Begin the change detection process by selecting DeltaCue icon in the IMAGINE icon panel.

Imagery courtesy DigitalGlobe
The DeltaCue main menu dialog opens.

Normally, you always begin processing a new image pair using the Wizard Mode in DeltaCue software. This interface helps you create a project file and workspace directory for the image pair and automatically runs DeltaCue processing workflow to create the initial iteration. You then view that initial iteration using the DeltaCue change display viewer. From within that viewer, you can select different processing parameters for subsequent iterations on the process.
Click the **Wizard Mode...** button to open the following dialog.

Keep the default option to create a new project and specify a project file name (for example, tutorial). The software automatically appends the correct file extension (.dqw). If you do not select a directory, your default data directory is used. The DeltaCue software will create a workspace subdirectory with the same name as the project file (minus the extension) in the same directory as the project file.

Next select the **Time 1** input image (DeltaCue.1.img) and the **Time 2** input image (DeltaCue.2.img).

*NOTE: If you did not change your IMAGINE preferences for Default Data Directory and Default Output Directory to the directory where the tutorial data is located, click the file browse button to select the file image files.*

Select the sensor type to be **QuickBird MS** for both the Time 1 and Time 2 images.

Keep the default settings option of **Program Defaults**.

When all the options have been specified, click the **Next** button is enabled to move to the next wizard dialog.
The second wizard page allows you to specify whether to crop the image pair to a common area. This operation may or may not be part of the co-registration process. In this example, the two images are not cropped to a common area (see Figure 10), so you want to select the option to crop the images.

When the DeltaCue process runs, it will produce cropped images in the workspace directory. These images are called subset1.img and subset2.img.

See "DeltaCue Workspaces" on page 101 for more information.

Click the Next button to move to the next wizard page. You may cancel the wizard and the tutorial at any time. Note that no processing is performed until the Finish button has been selected on the final wizard page.
The tutorial images do not contain clouds, but should be normalized. The third wizard page allows you to specify whether the images should be normalized and whether either image has clouds. Generally, you should always normalize the images. DeltaCue normalizes the Time 2 image to the Time 1 image. Clouds can skew the normalization process so it is important to specify if either of the images has clouds visible.

NOTE: Indicating that an image has clouds will not remove the clouds from the change analysis, it will only adjust the normalization. In this case, leave the cloud selection checkboxes unchecked.

Select **Next** to go to the next wizard page.

The fourth wizard page allows you to select the change algorithm to be used. For this first iteration, we are looking for construction activity and the magnitude difference algorithm generally does a good job of identifying changes due to construction (new roads, new buildings, and so on). Select the **Magnitude Difference** algorithm and check the **Interactive Thresholds** box. Leave the **Systematic Change Threshold** at the program default value of 30%.

The interactive thresholds setting allows you to interactively change the set of four thresholds available when the process runs.
Select **Next** to go to the change filter selection wizard dialog, shown below.

The fifth wizard page is used for selecting change filters. Select **Spectral Segmentation** but do not select other filters for now. Generally, during your initial iteration, you want to see the most change available. If those results are not acceptable, you can apply a change filter in a subsequent iteration. Of course, if you know that you are only interested in a particular size change, then you can apply a spatial filter during this initial iteration.
Select **Next** to move to the final wizard dialog.

The final wizard dialog allows you to remove selected material categories of either the time 1 or time 2 input images from the change detection result. For this initial run, do not remove any materials from the output by leaving all check boxes unchecked.

Specify the output change image file name, as shown below. Enter a name like “tutorial-1.img” (for the first tutorial iteration). For this tutorial, we will not use a processing AOI so leave that option unchecked.

Click the **Finish** button to begin processing. The DeltaCue change detection workflow is run automatically at this point. A series of progress dialogs similar to the one shown below is displayed as each individual process within the workflow is executed.

You can force these progress dialogs dismiss automatically when the process has completed by changing your IMAGINE preferences.

See **Preference Settings on page 4.**
Since you elected to review and set the change detection thresholds on the fourth wizard page, once the change has been computed the software will display a viewer with the Time 1 image and the change displayed as an overlay.

If the image does not have pyramid layers, an attention box is displayed asking whether or not to compute pyramid layers.

A histogram of the change is also displayed (see Figure 11). This dialog allows you to interactively change the upper and lower thresholds and immediately see the amount of change remaining by looking at the change overlay in the viewer. The histogram tool is displayed on top of the viewer that contains the thresholded change image so you should move the histogram window to the side.

The histogram plot consists of two tabbed displays, one for the **Lower Thresholds** and one for the **Upper Thresholds**. Lower thresholds control the cyan overlay and upper thresholds control the yellow overlay. Triangle controls at the bottom of the plot allow you to adjust the threshold values. There are two upper and two lower thresholds. Only change values between the two sets of thresholds are retained. You can control the horizontal scale of the histogram plot using the **Range** pull down control.

The default outer threshold and range values prevent both upper or lower triangle controls from being displayed initially.

The change values in the histogram are relative difference values (fractions) that have been scaled by a factor of 1000. The total possible range for the change values is ±32767 which corresponds to the range of signed 16-bit image data. Thus, the initial 30% threshold corresponds to a change value of 300 (0.3 x 1000). The outermost threshold values are initially set to the extent of the change histogram.

As you adjust the lower (cyan) thresholds using the triangle controls at the bottom of the histogram, the amount of negative (cyan) change will vary in the viewer. If you select the tab for Upper Thresholds, you can adjust the upper thresholds and the amount of positive (yellow) change in the viewer.
Try varying the thresholds and note the impact on the amount of change left. You can also adjust the threshold values using the text boxes.

For more information on setting thresholds refer to "Setting Interactive Change Thresholds" on page 65.

For the purposes of this tutorial, reset the thresholds using the Reset button beneath the histogram display and then select Finish to accept those values and complete the process. This will reset the thresholds to their initial 30% values and continue with the DeltaCue workflow.

When you click Finish, the Viewer and the Histogram windows are closed.
Change Analysis

Once the DeltaCue workflow completes, the software automatically launches the change display viewer to help you analyze the detected change. An example is shown on the next page. Use the “zoom in by 2″ control and the roaming control to zoom in on the area shown. Note that both sides of the viewer act in unison. If the two sides should get out of sync with each other in terms of zoom level, you can use the control to resync the views. Detailed usage of the change display viewer is covered in DeltaCue Change Detection on page 23.

The change pixels are color-coded according to their before, after, or transition classes. To see the color coding better, select the button to remove the background image on the right side. The set of before classes are shown here.

To see an example of new construction, select the change magnifier and select a yellow pixel in the right hand display. Blue areas are areas where the overall magnitude of the pixel value is brighter in Time 2 than it was in Time 1 and the before class material was soil. Magnitude changes are frequently associated with significant changes in the landcover material, such as a new road or new building. The example above shows new road construction leading to a tunnel. By selecting other points within the image you can see other areas where change has occurred.
A second possible iteration at this point would be to call up the DeltaCue iteration menu and select a spatial filter to eliminate small clutter or the misregistration filter to eliminate unwanted change due to local misregistration between the two images.

For the purposes of this tutorial, however, at this point we will turn our attention to agriculture. The magnitude difference algorithm does not necessarily do a good job of detecting changes in agriculture because the overall spectral magnitude may be the same between the two dates. An example of this effect is shown below.

In this example, the field marked is displayed in Time 1 but not in Time 2 and the change has not been indicated. The magnitude difference is not especially sensitive to vegetation changes. A better algorithm to use would be the Tasseled Cap greenness difference which is better tuned to vegetation changes. As a second iteration, we will reprocess the image using the Tasseled Cap greenness difference to indicate changes in vegetation.

**Iteration**

Select the DeltaCue iteration control . The iteration dialog opens, as shown below.
This dialog consists of three tabs: one for change algorithms, one for change filters, and one for material filters. The tab for change algorithms is shown. Select **TC Green Difference** as the change algorithm.

Enter an output file name such as tutorial-2.img (for the second iteration image). Select **OK** to begin processing for the second iteration. The DeltaCue software will run only those portions of the process that it needs to produce an output. Since image cropping and normalization have already been run and the results are stored in the workspace file, those processes will not be repeated.

Once again the threshold program will display a viewer with the Time 1 image and the change overlay (which is different from the first iteration). It will also display the change histogram and interactive controls. Experiment with changing thresholds to see their effect on the amount of change left. For the purposes of this tutorial, select the **Reset** button below the change histogram plot and select **Finish** to complete processing.

Once processing has completed, the change display viewer is updated with the new iteration results. The change layer on the right hand side will now contain the change detection results for the new iteration.

**NOTE:** The previously undetected field change is now clearly detected.
The Tasseled Cap difference is a sensitive indicator of changes in vegetation. The change in the agricultural field that was missed by the magnitude difference is clearly detected by the Tasseled Cap greenness difference.

To see what else was detected, use the Zoom All button to zoom the display to the full extents of the image, as shown below.
Zoom into the area shown above. This area contains numerous agricultural fields in various states of bare soil and vegetative growth at Time 1 and Time 2. As shown below, the blue colored fields represent a change from dark disturbed soil in Time 1 to something else in Time 2. We will next use the spectral segmentation tools to filter out all but very specific types of change.
Assuming we are only interested in changes from dark disturbed soil to bright, lush vegetation, begin by eliminating the unwanted before classes.

Right-click in the left view and select **Arrange Layers** from the Quick View context menu. In the Arrange Layers dialog, right-click on **tutorial-2.img** and select **Attribute Editor** from the PseudoColor Options menu. Scroll down in the Raster Attribute Editor to row 25 and click in the **Row** column to select it. Hold the shift key and select the remaining 3-x classes (rows 25-36). Right-click in the Row column and select **Invert Selection** from the **Row Selection** menu. Left-click the **Opacity** column head to select all in this column then right-click and select **Formula** from the Column Options menu. Click in the Formula window of the Formula dialog, enter **0**, and click **Apply**.

Select the Off control to turn off a selected class using the mouse. Select the On control to turn a class back on. Classes selected for elimination will turn white to indicate that they will be removed when you select **Apply**. Selecting the Reset button restores all classes. Begin by turning off all before classes that are not colored blue (see following page).
Now select the "After" state and turn off unwanted after classes. You may fine-tune the result by turning off unwanted transition classes.

The resulting spectrally filtered change detection result is shown below. All instances of these change pixels throughout the image represent changes from dark disturbed soil to lush active vegetation.
A possible new iteration on this result would be to apply a spatial filter to eliminate fields based on their area or spatial extent. The size parameter selected would depend on your particular application. The misregistration filter might also be applied to eliminate superficial apparent change along the edges of fields.
DeltaCue Wizard Interface

Introduction

The DeltaCue wizard interface is the primary method of using DeltaCue software to produce an initial set of change detection results. Once you have produced initial results, you can view them with the DeltaCue change display viewer and run new processing iterations from within the change display viewer. The wizard interface steps you through a sequence of dialogs that capture all of the necessary inputs to run the DeltaCue process end-to-end. The software creates a project settings file and a workspace directory to hold intermediate files. When the wizard process completes, the DeltaCue change display viewer program is automatically launched so that you can view and analyze the change detection results.

See “DeltaCue Change Display Viewer” on page 69 for more information about the special DeltaCue change display viewer.

Once you have created a project file using the wizard interface, you can then run different process iterations to fine-tune the results.

See “DeltaCue Iterations” on page 81 for more information about iterating with the DeltaCue process.

Initial Wizard Usage

The DeltaCue wizard interface is a typical wizard-style user interface that is designed to step you through a sequence of dialogs to capture information needed to run the DeltaCue process. Next and Back buttons control stepping through the various wizard interface dialogs. The program will not let you move to the next dialog until all the required inputs for the current dialog have been entered. The Finish button is used to actually launch the processing and the program will not let you select the Finish button until all required inputs have been entered. The Cancel button can be used at any time to cancel the process. Note that if you cancel the process all user inputs entered up to that point are lost.

Normally when you first use DeltaCue software to process an image pair for change, you will place the images in a working directory and co-register them using IMAGINE AutoSync or some other tool. The two input images must be co-registered before you begin the DeltaCue wizard process. The image pair does not have to be subset to a common area since DeltaCue will perform this operation if specified.

When you are ready to begin the DeltaCue process, select the Wizard Mode... button from the DeltaCue main menu.
Project Selection Dialog

The DeltaCue wizard interface project selection dialog is shown here.

This dialog is used to start the creation of a new workspace file (.dqw file) or select an existing project to which you want to add a new iteration. The default setting is to create a new project file. DeltaCue project files store the settings used for a processing run and allow you to view results and iterate on them. Project files are XML files that may be viewed (and carefully edited if needed) so that you have a history of the processing applied to achieve a certain result. This section describes the initial use of the wizard to create a new project. Refer to the next section if you want to use an existing project file with the wizard interface.

Leave the radio button selected on Create a New Project to create an initial project file for your image pair. The required inputs on the first dialog of the wizard are:

- Name of output project file
- Name of Time 1 image file
• Time 1 image sensor type
• Name of Time 2 image file
• Time 2 image sensor type

You must specify an output project file name. Use the file browse icon to control where the project file will be located. The DeltaCue process will create a workspace directory to hold intermediate process files in the same path as the selected project file and will have the same root name as the project file.

⚠️
You must have write permission to the project directory and the disk must have sufficient free space to hold the intermediate files produced, typically at least 1 GB.

Select two existing image files using the file browse icon. These images do not have to be located in the same directory as the project directory, but you must have write permission to the directory where the images are stored. The DeltaCue process will create image attributes auxiliary files (.atr files) in the directory where the images are located.

For each image, select the corresponding sensor type. If the sensor type for your imagery is not listed, select Other. The sensor type setting is used to determine whether Tasseled Cap coefficients are available for the image. Selecting Other as the sensor type will disable those features that rely upon the existence of a Tasseled Cap transform for the image. If your sensor is panchromatic (only one band of data per image), then all of the change algorithms are turned off with the exception of the single band difference algorithm as the other algorithms are designed for multispectral data.

DeltaCue software provides the ability to save program settings and use them for future processing. The optional Settings pull-down menu allows you to select a previously stored set of processing settings. These settings are applied in subsequent wizard dialogs as defaults. You may change them on those dialogs.

See "DeltaCue Iterations" on page 81 for more information on how to create a settings file.

Image Cropping Dialog

Once you have specified the required information on the first wizard dialog and select Next, the second wizard dialog opens, as shown here.
DeltaCue change detection processing requires that the co-registered image pair overlap exactly. All pixels in each image must be cropped to a common area and pixel size for both images. Images that mostly overlap must be cropped even if there is only one row or column of difference between the two images.

The process provides the ability to crop the two images down to a common area and pixel size. If the image pair has already been cropped as a result of the co-registration process, then you should select No, don’t crop the images which is the default. Otherwise select Yes, crop the images and the process will automatically crop the image pair to a common area subset and pixel size as a first step in the processing chain.

Normalization Dialog

The third initial wizard dialog, shown on the next page, controls the image normalization process within DeltaCue software. This process creates a normalized Time 2 image with statistics that match that of the first Time 1 image. It is important during this process that clouds not skew the results. Therefore you should indicate whether each image contains clouds or not. The default setting is that the images do not contain clouds and all pixels are used during image normalization. If an image contains clouds, an unsupervised classification process is used to identify the brightest classes and these are excluded from use in normalization. This unsupervised classification process adds time to the overall processing time, but is required if either image has substantial cloud cover.
Specifying that an image has clouds does not mask the clouds from the change detection process. It merely limits their influence during the normalization calculation.

If the images have previously been radiometrically corrected or normalized or you are confident that the two images are statistically similar (due to similar atmospheric and illumination conditions), you may skip the image normalization process in DeltaCue.

**Change Detection Dialog**

The Change Detection wizard dialog, shown here, is the main change detection selection dialog. This dialog controls which change detection method is used to produce the final change detection output.
You should begin by selecting the desired change algorithm (or keeping the selection specified in the settings file you selected initially).

Two forms of Tasseled Cap transforms are available for change detection. Tasseled Cap Greenness Difference measures changes primarily in vegetation while Tasseled Cap Soil Difference measures changes in soil and other non-vegetative materials. With either of these algorithms, you must specify a sensor on the first wizard dialog since these transforms are sensor specific. If the sensor for your imagery is not listed, you cannot use a Tasseled Cap change algorithm with your data. In that case, select either Magnitude Difference which detects change based on spectral magnitude differences or a single-band difference.

The Tasseled Cap change algorithms are disabled if the sensor type was specified as OTHER. Also, if processing panchromatic imagery, only the single band difference algorithm is available.

If you select one of the primary color difference algorithms (red, green, blue diff), you must also specify the color threshold as a percentage. This percentage applies to the spectral color cosine value before the difference operation is applied.

See “Change Algorithms” on page 25 for more information.
Thus, a threshold of 65% means that only those cosine values that exceed 0.65 are included in the difference. Otherwise, the value is set to zero. This insures that the difference only shows changes related to the primary color selected.

To loosen the criteria and let other colors possibly affect the result, lower the threshold. Increasing the threshold will restrict the resulting changes further so that only very pure primary colors will affect the change difference.

Once you have specified a change detection algorithm you must specify the threshold percentage. The DeltaCue process uses the histogram of the change detection output and thresholds that histogram using four thresholds as an initial way of eliminating unwanted change. An example of a change difference histogram is shown below.

For some applications a simple plus and minus percentage threshold, such as the one shown above may be sufficient to eliminate most of the unwanted change in the central peak of the histogram. All change greater than the positive percentage or less than the negative percentage is carried forward to other filters. In that case, specify a percentage amount and leave the box entitled Interactive Thresholds unchecked.
If you need finer control over the initial threshold, check the box entitled **Interactive Thresholds**. This will cause the DeltaCue threshold program to present an interactive display of the histogram showing the thresholds and an image display with a change area overlay. As you adjust the thresholds, the change overlay changes in response to show you the effect of each threshold. Four thresholds, two upper and two lower, are used. Only those change values that lie between the two upper and two lower thresholds are retained for further processing.

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**For more information on the interactive threshold program, refer to "Setting Interactive Change Thresholds" on page 65.**

**Change Filters Dialog**

The fifth wizard dialog allows you to select change filters. Change filters are also used to further eliminate unwanted change.

Three types of changes filters are controlled by this wizard dialog:

- spectral segmentation
- misregistration
- spatial filtering
Spectral Segmentation

Spectral segmentation is a process that is applied to the Time 1 and Time 2 images to classify the change pixels into spectrally similar classes. In the change display viewer, you can then interactively filter out change pixels based on their before or after spectral class. If you want a simpler output that merely indicates positive and negative changes, uncheck the **Spectral Segmentation** option and the process will skip classifying the Time 1 and Time 2 change pixels. This saves processing time, but the resulting change image only indicates whether the brightness change was positive or negative, and not the spectral class before and after.

Misregistration

The misregistration filter attempts to filter out unwanted change due to local misregistration of the image pair. Such pixel misregistrations can cause apparent change differences simply because the correct pair of pixels was not differenced.

The misregistration filter checks the local neighborhood surrounding each pixel identified as having changed. The size of the search window is specified in the wizard dialog, as shown on the next page. The filter will search within the search window to see if another pixel in that window would satisfy the criteria for no significant change. If a match is found, then that pixel is a candidate for being due to misregistration.

Since local misregistrations typically occur in a shift-like pattern, the process tries to validate the misregistration candidate by examining nearby neighbors to see if they follow the same pattern of no change. The number of nearby neighbors considered is controlled by the search window size. This parameter may be reduced to reduce run time if needed.

Spatial Filtering

The spatial filter identifies contiguous blobs of detected change by delineating the contour of the blob. A contiguous blob is a set of pixels that are connected by at least one neighbor in any of eight directions. Two change areas are connected if they share at least one neighbor in common.
Once the spatial filter process has detected the contour of a contiguous change area, it computes several geometric properties based on the contour.

The geometric properties considered are:

- area
- major axis length
- minor axis length
- compactness
- elongation

The definition of each geometric property is provided in Table 3. These geometric properties can be used to filter out unwanted change using a range of values.

### Table 3: Geometric Properties Used for Spatial Filtering

<table>
<thead>
<tr>
<th>Property</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area</td>
<td>Total area of the shape</td>
</tr>
<tr>
<td>Major Axis Length, $P_1$</td>
<td>Length of line segment intersecting shape along major axis of rotation (symmetry)</td>
</tr>
<tr>
<td>Minor Axis Length, $P_2$</td>
<td>Length of line segment intersecting shape along minor axis of rotation (symmetry)</td>
</tr>
<tr>
<td>Compactness</td>
<td>$C = \frac{A}{P_1P_2}$, $A =$ Area, $P_1 =$ Major Axis Length, $P_2 =$ Minor Axis Length</td>
</tr>
<tr>
<td>Elongation</td>
<td>$E = \frac{P_1}{P_2}$, $P_1 =$ Major Axis Length, $P_2 =$ Minor Axis Length</td>
</tr>
</tbody>
</table>

**Area, Major Axis, and Minor Axis** length have units associated with them. Select the **Units** from a dropdown menu.

For example, if the units are meters, the area is in square meters and the lengths are in meters.

**Compactness** and **Elongation** are dimensionless quantities.

To filter a geometric property, check the checkbox associated with that property and specify the minimum and maximum values to keep.

*NOTE: Minimum and maximum range is inclusive, therefore both the minimum value and maximum values are included and their corresponding shapes retained.*
Thus, if you specify a minimum and maximum area of 10 pixels, only shapes with exactly 10 pixels are retained. If the maximum area is set to 11 pixels, then shapes with both 10 and 11 pixels are retained. However, if the minimum area is set to 10.1 pixels, then only shapes with 11 pixels are retained.

Material Filter Dialog

Once you have specified the change algorithm, threshold parameter, and change filters, you may move on to the final dialog in the wizard interface, shown below.

Material Filtering is only available for sensors that have Tasseled Cap coefficients derived for them. If you selected one of the sensor types to be OTHER on the first wizard dialog, then the Material Filtering section is grayed out since Tasseled Cap coefficients are not available for that sensor pair.

Material Filtering allows you to exclude selected categories of materials from the change detection result.

For example, by clicking the checkbox for Vegetation in Time 1, you are electing to exclude any change that includes vegetation in Time 1 category. Changes that involve vegetation in Time 2 are not excluded unless you check the Time 2 Vegetation checkbox.

Material Filtering is intentionally conservative. The process generally does not exclude change pixels that include mixtures of material categories since those may be of interest. The material filter only applies to those pixels that clearly fit the category. Other change pixels will have to be filtered out by other means.
Once you select a Material Filter category by checking the checkbox next to the category in either Time 1 or Time 2, the parameters associated with that material filter become enabled. The default values generally apply since they are conservative.

Refer to "DeltaCue Material Filtering“ on page 105 for a description of the Material Filtering process.

**Session Output**

In the Material Filtering dialog, the Session Output section is the final output file selection and a mechanism for selecting an AOI to use during processing.

Specify the name of the output image file that will contain the filtered change detection results. This image is a color coded raster image in which the pixels indicate the type of change. The DeltaCue change display viewer is used to view this change image. The name is stored as part of the DeltaCue workspace file for easy retrieval in the change display viewer.

See "DeltaCue Workspaces“ on page 101.

If you would like to process only a portion of the input image pair, you may create an IMAGINE Area of Interest (AOI) and save that AOI to a file.

In this dialog, check the checkbox labeled Use AOI File. This enables the AOI file selection box. You may then select the AOI file that you previously saved. The AOI must be in a saved file and not just a temporary AOI created in a viewer. If you have a viewer with an AOI that you would like to use, first save that AOI to a file and then select it.

Once you have specified all required inputs, including the output image file name, the Record and Finish buttons at the bottom of the wizard dialog become active.

The Record button allows you to record the inputs in the previous wizard dialogs to the DeltaCue workspace file. These inputs would then be used to create an output iteration when you eventually run the process.
Recording an iteration allows you to click the wizard **Back** button to go back to previous dialogs and specify a different set of processing parameters. That set of parameters would then constitute a new iteration. When you finally select the **Finish** button, all recorded iterations are run during a single set of processing sequences. If you select the **Finish** button without selecting **Record**, then the process is run with only one iteration based on the parameters that you selected.

See “*DeltaCue Iterations*” on page 81 for more information on iterations.

When you click the **Finish** button, a project file (.dqw file) is created and a separate application, called dQrunprocess, takes over. This program reads the project file just created and controls execution of the DeltaCue change detection process based on the settings stored in the project file. A number of separate processes are spawned to create intermediate outputs. Each separate process will create its own progress dialog. When all of the processes in the processing chain have completed you will see the dQrunprocess progress dialog indicate completion.

If you modified your IMAGINE preferences to close all progress dialogs, then all progress dialogs will close automatically. Otherwise, you must close them by selecting the **OK** button on each progress dialog that was started. It is also a good idea to check the session log for any unusual occurrences or error messages.

As a final step, the dQrunprocess program automatically spawns the DeltaCue change display viewer program to allow you to see the new change detection results and possibly iterate on them.

Refer to “*DeltaCue Change Display Viewer*” on page 69 for information on how to use the change display viewer.

**Setting Interactive Change Thresholds**

The DeltaCue process is designed to be largely automatic. There is one optional step. If you selected the checkbox for **Interactive Thresholds** on the Change detection wizard dialog, the interactive version of the DeltaCue change threshold program is run.
This process applies the initial threshold percentage specified and allows you to interactively set four thresholds, two upper and two lower.

The process first displays the Time 1 image in a viewer with a color-coded thresholded change image overlay. In the viewer, the change area overlay is the top layer with the Time 1 image beneath it. Positive change is colored red and negative change is colored blue. A separate window is displayed with the change detection histogram plotted. An example is shown below.

The histogram window contains two tabbed plotting windows, one for the lower thresholds and one for the upper thresholds.

When the **Lower Thresholds** tab is selected, you may change the lower thresholds by moving the triangular symbols at the bottom of the histogram plot.

When the **Upper Thresholds** tab is selected, you control the upper thresholds by moving the triangle symbols at the top.

Another method to change the threshold values is to change the number box for each threshold.

When you change a threshold value, the change overlay in the viewer automatically updates to show the area included within the upper and lower thresholds. Increasing the extent between the threshold pairs increases the amount of image area covered by change. This change area is passed on to subsequent filters or to the final change output.

*NOTE: Right-mouse click on the threshold number boxes to set the threshold increment value when you press the up and down arrows.*
Note that the initial histogram **Range** displayed is +/- 1000. The histogram is scaled by a factor of 10 so this nominally represents +/- 100% change. However since some change detection algorithms can exhibit higher amounts of relative change, a **Range** dropdown menu is provided to change the scale of the histogram. If a threshold control value falls outside the displayed range, it will not be available for adjustment. Adjust the inner thresholds at finer range and use larger ranges for the outer thresholds as needed.

**Wizard Usage with Existing Project Files**

Normally, you would iterate through different processing settings using the DeltaCue iteration capability.

See “DeltaCue Iterations” on page 81.

However, you can rerun the DeltaCue wizard and select an existing project file to create a new iteration or set of iterations, as shown in the dialog below.

In that case, the settings from the last iteration of the project are used as the default. Since this is an existing project, the dialogs asking about common area subsetting and image normalization do not apply and these dialogs will not appear. Those steps have already been performed on the image pair in the project file. Likewise, DeltaCue settings do not appear at the bottom of dialogs since these have already been applied and possibly modified. The settings in use are those of the last iteration for that project file.

1. Enter the name of the existing project or click the file browse icon to locate the project.
2. In the Change detection dialog, modify the settings shown which reflect the settings used during the last iteration.

3. In the Change Filters dialog, modify the settings shown which reflect the settings used during the last iteration.

4. In the Material Filtering dialog, specify a new change detection output image name.
   
   This is normally a new file but you may overwrite an existing output file. The interface will prompt you before it overwrites an existing file.

5. Click **Finish**.

   The project file is updated with a new iteration and the dQrunprocess program is spawned to conduct the new processing steps. If existing intermediate project files exist, these will not be overwritten. The process will assume that you want to reuse these files and only create unique new files. This saves processing time when you only want to adjust a change filter or its parameters.

   Once the new change detection output file is create, the DeltaCue change display viewer program is launched so that you can view the new results. This process is similar to DeltaCue iterations, but the iterations mechanism is more flexible and allows you to save DeltaCue settings files for future use by yourself and others.

See "DeltaCue Iterations” on page 81.
DeltaCue Change Display Viewer

The DeltaCue change display viewer is a specialized IMAGINE viewer application specifically designed for change detection analysis. The viewer displays the original image pair as well as the change detection output. Tools appropriate for change detection interpretation and analysis are made readily available. The viewer accepts DeltaCue project files as input and provides an interface to the DeltaCue iteration capability. Using this capability you can perform different iterations on the processing to determine which settings are best suited for your particular application. You can save those settings in a DeltaCue settings file (.dqs file) for later use with other image pairs.

Viewer Features

By default, the DeltaCue change display viewer displays two views side by side. The left side view displays the original image pair as a layered stack with the Time 1 image on the top (visible) and the Time 2 image on the bottom. The right-side view displays the Time 2 image on the bottom and the color-coded change detection image on the top. An example is shown on the next page. Note that the change pixels are color-coded according to spectral classes while the non-change pixels have an opacity of 0, allowing the underlying time 2 image to be seen. You can view the change classes from time 1 (before classes) or time 2 (after classes) or the transitions from time 1 to time 2. You can interactively select these classes for removal from the change overlay.
You can zoom and pan around the image area using familiar IMAGINE viewer controls. These are described in more detail in subsequent sections. The two windows within the main viewer are linked with each other so that they change simultaneously, with one notable exception – the zoom tool buttons (🔍 and 🔩). When using the zoom buttons, only one window zooms in or out. The other window shows the geographic area covered in the zoomed-in window. A control button is provided to re-synch the views following a zoom operation using the zoomin or zoomout buttons. This is described in more detail below.

Layer swipe and flicker are two of most useful tools in IMAGINE for visualizing change between two images. The DeltaCue change display viewer provides convenient access to both tools applied to the two original images loaded in the left side of the viewer. An example of layer swipe used to visualize change is shown below. In this example, the detected change is shown in yellow and red on the right and layer swipe is used to peel back the top Time 1 image layer on the left to reveal the state at Time 2. The change between the two times is evident in the process. The flicker control, available as a button on the display controls, may also be used to switch back and forth between Time 1 and 2 images on the left to see the overall change between dates.
A special change magnifier has been added to the DeltaCue change display viewer to help locate and analyze change. An example is shown below.

When the magnifier button is turned on, two additional smaller display windows appear within the top portion of the left and right viewers. As you use the mouse to select locations within the lower main image, those locations appear in magnified form in the additional magnifier windows. The Time 1 image is displayed on the left magnifier window and the Time 2 image is displayed on the right. The difference between the two dates at that location is readily evident. You can control the appearance of the magnifier windows through a change magnifier properties dialog, shown here.

The classic IMAGINE viewer measurement and cursor tools are also available and function in both the left and right side of the change display viewer.
The DeltaCue change display viewer menus provide functionality for manipulating files, calling up utility functions, changing the viewer properties, invoking special tools, and online help, as shown here.

The **File** menu allows you to open and save files, print views, clear or close the viewer, and create new layers. You may only create new AOI, annotation, or shapefile layers using the **File | New** menu. These layers are overlaid on the existing raster layers in each view.

- **File** | **New** allows you to create new AOI, annotation, or shapefile layers.
- **File** | **Open** allows you to open a change detection project, and AOI, annotation, and shapefiles layers. The selected files are opened and overlaid in both the left and right side views and they may be manipulated separately.
- **File** | **Save** allows you to save left and right AOI, annotation, and shapefile layers to new files. You may create new layers, edit them with their associated tool sets, and then save them to files for later use.
- **File** | **Clear** button clears all layers in both the left and right views. This effectively resets the viewer. You may clear separate AOI, annotation, and shapefile layers using the Arrange Layers control described below.
- **File** | **Close** button terminates the viewer program.

The **Utility** menu provides access to two utility functions: the Inquire Cursor and the Measure tool. These utilities have separate standard IMAGINE interfaces and they apply to both the left and right views.
The **Tools** menu allows you to call up tool sets for the three types of overlays available with the viewer: AOIs, annotation layers, and shapefile layers.

These tools sets are standard IMAGINE tool sets for each layer type and are shown here. The vector tools apply to shapefile layers, which are the only vector layers used in the DeltaCue change display viewer. Refer to IMAGINE documentation for the usage of each tool.
Viewer Controls

The DeltaCue change display viewer controls are a set of icon buttons related to functions that are frequently used in change detection analysis. Many of these controls are standard IMAGINE viewer controls while some are new to this viewer.

The first row of viewer controls consists of the following:

- **File Open** – this control brings up the dialog for opening a change detection set, as shown on the right. You may specify either a DeltaCue project file (.dqw file) or specify the individual inputs. Unlike the regular IMAGINE viewer, this control is only used to open raster layers. Use the File | Open menu to open overlay layers such as AOIs, annotation layers, and shapefile layers.

- **Clear Viewer** – this control clears the viewer and removes all raster and overlay layers from both sides of the display.

- **Reset Zoom** – this control resets the zoom level in each view to a default level centered about the center of the images. Both sides of the viewer display are reset simultaneously to the same default zoom level and extent.

- **Zoom In By 2** – this control zooms both sides of the display in by a factor of two about the current center of each image. Both sides zoom in simultaneously and retain their relative views.

- **Zoom Out By 2** – this control zooms both sides of the display out by a factor of two about the current center of each image. Both side zoom in simultaneously and retain their relative views.

- **Zoom All** – this control zooms both sides of the display out to the full extent of each image.
**Synchronize Zoom** – this control re-synchronizes the zoom levels and extents of each side of the display. Occasionally one side may become more zoomed than another side and a box is displayed to show the extent of the side that has the higher zoom level. This control can be used to re-sync the two sides to the same zoom level. The side with the higher zoom level is used as the basis for synchronizing the zoom level.

**Cursor Tool** – this control invokes the IMAGINE cursor tool. This tool may be applied to either side by simply moving the cross-hair in that side. The information in the cursor window applies to the selected side. An example of the cursor tool is shown below. Note that cross-hairs are displayed in both views and are linked.

**Selection Tool** – this is the default selection tool. For raster layers it does nothing, but for overlay layers it can be used to select objects. This tool is used to turn off the other tools such as the zoom and pan tools.

**Zoom In Tool** – this control is used to zoom in the display. You may zoom in by a factor of two by clicking in a window or you can select the zoom extent by dragging the zoom tool cursor within a view window. Occasionally the other side of the display will not zoom to the extent selected. Use the tool to re-sync the displays.

**Zoom Out Tool** – this control is used to zoom out the display. You may zoom out by a factor of two by clicking in a window or you can select the zoom extent by dragging the zoom tool cursor within a view window. Occasionally the other side of the display will not zoom to the extent selected. Use the tool to re-sync the displays.
Pan Tool – this control is used to pan one side of the display. The other side automatically follows the panning action to keep the two sides of the display in synch.

Contrast/Brightness Adjustment Tool – this control is used to adjust the brightness and contrast of the time 1 and time 2 images. The control on the left brings up the simple contrast/brightness adjustment tool in IMAGINE. This tool may be used to adjust the contrast and brightness of the top image in the left-hand display. Use the Flicker tool to switch the order of the layers in the left hand display.

Contrast/Brightness Update Tool – this control applies your contrast and brightness changes, made in the left hand display using the Contrast and Brightness control, to all views, including the change magnifier views. Use this control once you have adjusted the contrast and brightness for the layers in the left-hand display.

DeltaCue Iterations – this control invokes the DeltaCue iteration dialog.

See “DeltaCue Iterations” on page 81.

DeltaCue Iteration Selection – this control allows you to change the currently displayed iteration without reloading the entire project. When you change the iteration selection, the change detection layer displayed on the right side changes to correspond to the selected iteration.

Shapefile Output - this control converts the current change area to a shapefile (.shp) and writes it to disk. You are first prompted for an output file name. The shapefile is automatically displayed in both views.
The second row of viewer controls is as follows:

**Zoom Tool** – this control allows you to adjust the zoom level in both sides of the display in small increments. The thumbwheel control can be used to adjust the zoom level up and down interactively. The negative zoom control zooms the display out by a small increment and the positive zoom control zooms the display in by a small increment. You can also reset the zoom level with the reset control on the far right side.

**Layer Swipe Tool** – this control brings up the layer swipe control panel shown below. The swipe tool allows you to pull back the top Time 2 layer on the left hand side to reveal the Time 1 image beneath. By swiping back and forth you can see differences between the two images. The boundary of the top layer is controlled by the swipe position slider bar in the swipe control panel. As you move this slider back and forth, the amount of Time 2 image visible on top changes. You can also change the direction of the swipe action and toggle an automatic swipe mode in which the left display continually swipes back and forth at a specified speed. When the swipe tool is cancelled, the display returns to normal.

**Flicker Tool** – this control toggles the order of the Time 1 and Time 2 layers in the left hand display to simulate a flicker control. When the Flicker Tool is in the depressed state, the Time 2 image is visible. Otherwise, the Time 1 image is visible. By repeatedly toggling this layer on and off you can see differences in the Time 1 and Time 2 images and correlate them with the change detection results shown in the right side display.
**Measure Tool** – this control invokes a pair of standard IMAGINE measurement tool sets as shown on the next page. The tool set for viewer #1 applies to the left side display and the tool set for viewer #2 applies to the right side display.

The measurement tool set allows you to measure coordinate positions, line lengths, areas, and perimeters in a number of different ways. You can save your measurements to a text file which can also be viewed by the measurement tool. Refer to the IMAGINE user documentation for more information on the features of this tool.

**North Symbol** – this control toggles a north arrow on and off in both the left and right side displays. You can reposition the north arrow by selecting it with the mouse and dragging it to a new position. The north arrow is automatically repositioned to the same location in both the left and right views.

**Scale Symbol** – this control toggles a scale symbol on and off in both the left and right side displays. The scale symbol provides a horizontal and vertical distance bar that can be moved around and compared with features in the image. You can reposition the scale symbol by selecting it with the mouse and dragging it to a new position. The symbol is automatically repositioned to the same location in both the left and right views.
**Change Magnifier** – this control toggles a special pair of change detection magnifier windows on and off. The magnifier window in the left side contains a magnified view of image data from Time 1 and the window in the right side contains the corresponding view of image data from Time 2. By comparing the two magnified images you can readily see changes that have occurred at that location. You cannot reposition the change magnifier windows, but you can change their size and magnification properties with the magnifier properties tool described below.

**Set Center** - this control is used to set the center of the magnified view. Click this control then click in the normal view at the location on which you would like the magnified view to be centered.

**Magnifier Properties** – this control brings up the change magnifier properties dialog shown below. This dialog can be used to change the height of the magnifier windows and the magnification level applied. Magnification levels can range from a factor of 1 to 8. Window height is expressed in terms of screen pixels. You can also change the color of the cross-hair symbol for better visibility.

**Change Background** – this control toggles the visibility of the background layer on the right side view so that you can more readily identify change areas. The icon changes to remind you that it is in effect.
Spectral Filtering – these controls allow you to interactively filter detected change based on the spectral characteristics of the before and after landcover materials or the transition between materials. Select the overlay to be displayed using the radio buttons for Before, After, and Transition. The display will change to show color-coded spectral classes associated with Before, After, or Transition classes. Select the Off control to interactively turn off a selected class using the mouse. The selected class will change color to white to indicate that it has been selected. Select the On control to interactively turn a selected class back on. The type of classes displayed and selected will depend on the radio button selected. The white classes selected for elimination are removed when you select Apply.

Once you are satisfied with your selections, select Apply to eliminate the selected classes from the display. Note that those classes are not eliminated from the image, simply from the display. Select Reset to restore all classes.

Spectral Bands – these controls allow you to change the band combinations that are associated with the red, green, and blue channels of the computer display. The Time 1 and Time 2 images in each side of the display automatically change when you change the band combination in effect.

Right-click in a viewer to display a Quick View context menu of additional functions.
DeltaCue Iterations

DeltaCue software provides the capability to easily try different processing settings to find the ones that provide the best results for your imagery and your application. Once you have created an initial project file using the DeltaCue wizard (see “DeltaCue Wizard Interface” on page 53) and you have viewed your initial results in the DeltaCue change display viewer (see “DeltaCue Change Display Viewer” on page 69), you can iterate on those results by changing various settings and noting the differences in the change display viewer. If you believe that a particular collection of settings have broader applicability, you can save those settings in a DeltaCue settings file (.dqs file) and even distribute that file to other users. The next time you run the DeltaCue wizard those settings are available for use.

Iteration Dialog

The DeltaCue Iteration dialog, shown below, is opened from within the DeltaCue change display viewer by selecting the Iterate button.

There are three tabs on this dialog; Change Algorithm, Change Filters, and Material Filters.
You must first load a project file into the change display viewer in order to open the Iteration dialog. The process reads the existing iterations within the project file and makes them available to you through the base iteration dropdown menu.

The first step in creating a new iteration is to select a base iteration from the pull down menu at the top in the section that is common to all tabs. The last iteration in the project file is displayed by default. As you select different base iterations, the settings displayed change to reflect the settings in effect during that iteration. This way you can review what settings were used for a particular iteration and then use a given set as the starting point for a new iteration.

The next step is to modify the processing settings. Note that the image subset and normalization settings are not shown since they are common to all iterations.
To create a new iteration, select the tab that contains the process setting you wish to change. The new iteration can contain several changes from the previous one. The parameters in each tab are discussed in subsequent sections.

Once you have specified a set of processing parameters and have entered a new output image name, the **OK** and **Record Iteration** buttons become active. You may use the **Record Iteration** button to add several new iterations to the project file. Each new iteration must have a unique output image name. When the **OK** button is selected, the recorded iterations are run in sequence. The last iteration is brought up in the viewer once all iteration processing is complete. If you simply select **OK** without recording any iterations, a single iteration is run using the currently selected processing parameters.

Note that each iteration may be processed over its own AOI. To specify an AOI, check the box labeled **"Use AOI File"** to activate the AOI file selection box. Then select an existing AOI that has been saved to a file. You must use an AOI that has been saved to a file, rather than a temporary AOI in a viewer. If you have an AOI in a viewer, first save it to a file.

**Change Algorithms**

The processing settings are identical to those available in the DeltaCue wizard. You can select the change algorithm from the available algorithms which are:

- Tasseled Cap (TC) Transform Greenness difference
- Tasseled Cap (TC) Transform Soil difference
- Overall Magnitude difference
- Primary Color Difference (red, green, blue diff)
- Single-Band Difference
- Band-Slope Difference

Each difference is a relative difference of the form

$$D = \frac{(T_2 - T_1)}{|T_1|} + \frac{(T_2 - T_1)}{|T_2|}$$

where $T_1$ and $T_2$ are the change quantities at Time 1 and 2 respectively. For example, if the Tasseled Cap Greenness difference is selected, the change quantity is the greenness band of the Tasseled Cap transform output.

The Tasseled Cap difference algorithms are only available for sensors that have established Tasseled Cap transform coefficients. When you first created the project, you specified the sensor type (see "DeltaCue Wizard Interface" on page 53). If you selected OTHER as the sensor type, the Tasseled Cap algorithms are not enabled.

In conjunction with the change algorithm you also specify a change threshold percentage and whether you want to interactively review and alter the change thresholds. The threshold percentage is a +/- threshold that is applied to the change detection output to eliminate the center portion of the change histogram. This value is a difference ratio expressed as a percentage. If you do not interactively review the thresholds, the process will eliminate any change with values between the positive and negative threshold values.

If you elect to review the change detection thresholds, when the processing for this iteration is run, the process will display a viewer with the thresholded change as an overlay and also display a plot of the change histogram. You can adjust a set of four thresholds, two upper and two lower, using interactive controls. Only change between the two upper and two lower thresholds is retained.

For more information about setting thresholds interactively, see "Setting Interactive Change Thresholds" on page 65.
If you selected Interactive Thresholds in the previous iteration and you want to reuse that set of four thresholds, select the option to use a previous iteration’s thresholds.

In that case the process will use the threshold values from the iteration selected in the pull-down tool.

**Change Filters**

Three types of changes filters are available – spectral segmentation, misregistration, and spatial filtering. Spectral segmentation groups change pixels according to spectrally similar before and after classes so that you can subsequently filter on those classes. The misregistration filter attempts to filter out unwanted change that is merely due to errors in image pair co-registration. The spatial filter eliminates change based on contiguous size and shape.

**Spectral Segmentation**

Spectral segmentation is a process that is applied to the Time 1 and Time 2 images to classify the change pixels into spectrally similar classes. In the change display viewer, you can then interactively filter out change pixels based on their before or after spectral class. If you want a simpler output that merely indicates positive and negative changes, uncheck the Spectral Segmentation option and the process will skip classifying the Time 1 and Time 2 change pixels. This saves processing time, but the resulting change image only indicates whether the brightness change was positive or negative, and not the spectral class before and after.

**Misregistration Filter**

Even though two images have been co-registered some minor misregistration may remain, typically on local scales. Such pixel misregistrations can cause apparent change differences simply because the algorithm was applied to pixels that were not spatially coincident. The misregistration filter checks the local neighborhood surrounding each potential change pixel. A local search window is used to constrain the search for misregistered pixels. The size of the search window is specified in the Iteration dialog, as shown below. The filter will search within this window to see if another pixel in that window would satisfy the definition of no significant change. If a match is found, then that pixel is a candidate for being a misregistered pixel.
Since local misregistrations typically resemble a shift in pixels, the process tries to validate the misregistration candidate by examining nearby neighbors to see if they follow the same pattern of no change. The number of nearby neighbors considered is controlled by the search window size. This parameter may be reduced to reduce run time if needed.

Spatial Filter

The spatial filter identifies contiguous blobs of detected change by detecting the contour of the blob. Internal holes are considered part of the total change area. A contiguous blob is a set of pixels that are connected by at least one neighbor in any of eight directions. Two change areas are connected if they share at least one neighbor in common.

The spatial filter eliminates contiguous blobs of detected change based on their spatial size, either in terms of area or extent, as defined below. The spatial filter identifies change blobs based on the binary change mask provided as input. Typically this mask is produced by the initial thresholding program. Spatial filtering can be performed in terms of area or extent. Area is the total area of the contiguous blob, expressed in terms of square meters. If you select area as the spatial filter type, you must specify a minimum and maximum blob area.

Once the spatial filter process has detected the contour of a contiguous change area, it computes several geometric properties based on the contour. The geometric properties considered are area, perimeter, major and minor axis length, compactness, and elongation.

See “Spatial Filtering” on page 61.

Area and major/minor axis length have units associated with them. You can select the units from a dropdown menu. For example, if the units are meters, the area is in square meters and the lengths are in meters. Compactness and elongation are dimensionless quantities.
To filter on a given shape property, check the check box associated with that property and specify the minimum and maximum values to keep. Note that the range is inclusive. That means that both the minimum value and maximum values are included and their corresponding shapes retained. Thus, if you specify a minimum and maximum area of 10 pixels, only shapes with exactly 10 pixels are retained. If the maximum area is set to 11 pixels, then shapes with both 10 and 11 pixels are retained. However, if the minimum area is set to 10.1 pixels, then only shapes with 11 pixels are retained.

Once you have adjusted the change algorithm and change filter settings for the new iteration, you must enter a change detection output file name before the iteration can be run. The dialog **Ok** button becomes enabled once you specify a file name. Use the file browser button to specify the directory path for the output file name.

When you select the **Ok** button in the Iteration dialog, the process updates the existing project file (.dqw file) to include the new iteration settings and it launches the dQrunprocess program to execute the new iteration. If the settings for the change algorithm have not changed, then the intermediate files related to change detection are not recreated, but the existing files are used. This saves time by not having to re-run processes for existing quantities that will not change in the new iteration. The process only creates new quantities when the related settings are different from the base iteration or when settings upstream in the processing chain have changed. The process tries to minimize the amount of re-processing that must be performed.

**Material Filters**

The third tab on the Iteration dialog is used to specify Material Filtering. Material Filtering is only available for sensors that have Tasseled Cap coefficients derived for them. If you selected one of the sensor types to be OTHER in the "Project Selection Dialog" on page 54, then the Material Filtering section is grayed out since Tasseled Cap coefficients are not available for that sensor pair.

Material filtering allows you to exclude selected categories of materials from the change detection result. For example, by selecting the check box for Vegetation in Time 1, you are electing to exclude any change that includes vegetation in Time 1. Changes that involve vegetation in Time 2 are not excluded unless you explicitly check that box.
The material categorization process is intentionally conservative. The process generally does not exclude change pixels that include mixtures of material categories since those may be of interest. The material filter only applies to those pixels that clearly fit the category. Other change pixels will have to be filtered out by other means.

Once you select a Material Filter category by checking the check box next to the category in either Time 1 or Time 2, the parameters associated with that material filter become enabled. The default values generally apply since they are conservative.

Refer to "DeltaCue Material Filtering" on page 105 for a description of the Material Filtering process.

Saving Settings

You can save the current iteration settings at any time using the Iteration dialog Save button. In that case, the following Save Settings dialog is displayed.

You must enter a descriptive name for the settings being saved and a short description of what the settings are or what they apply to. The Settings Name will appear in the DeltaCue wizard parameter settings the next time you run the wizard.

Note that the settings saved are those currently visible in the Iteration dialog, not the base iteration settings. You can change the settings and save them without actually running the iteration.

When you save settings, the current settings are stored in a DeltaCue settings file (.dqs file) which is a special form of project file. Your setting file is stored in your temporary directory since you automatically have write permission to that directory. The DeltaCue wizard knows to look in that directory for settings files.
Settings files are automatically named dq<settings name>.dqs where <settings name> was the name string that you entered when saving the settings file. If you want to delete previously saved settings from the DeltaCue wizard settings dropdown menu, delete the corresponding settings file from your temporary directory. Simply locate the .dqs file with the corresponding name, delete it, and re-run the wizard.

Some settings files are distributed with the software, such as the program defaults. These settings files are installed with the software and are located in the directory <IMAGINE_HOME>/etc/DeltaCue. If you wish to distribute your settings files to other users, they should place them in this directory. Certain administrative privileges may be required to access this directory. Check with your Systems Administrator.

**Iteration Strategy**

DeltaCue iterations can be used to try different filters and filter settings, different change thresholds, and different algorithms. The number of iterations can quickly grow and a strategy is useful for constructing iterations and managing them. Also, in order to minimize run time for each iteration, it is best to make changes in parameter settings as far down the processing chain as possible so that the process will not re-run intermediate processes unnecessarily.

The DeltaCue processing chain consists of:

- Compute change quantities
- Difference change quantities
- Threshold change output (creates mask image)
- Apply Misregistration filter to change output (creates mask image)
- Apply Material filter to change output (creates mask image)
- Apply Spatial filter to change output (creates mask image)
- Apply mask images to create final change detection output
- Perform Spectral Segmentation of remaining change pixels

The basic iteration strategy recommended here is as follows:

- make settings changes that affect processes at the start of the chain first and then work your way down the chain
• save the use of filters for later iterations so that you begin with the maximum amount of change available and then reduce that amount

For example, your first iteration should specify a change algorithm, such as Tasseled Cap Greenness difference, with no change filters applied. This choice of algorithm affects the change quantities and their difference. Depending on your choice of threshold percentage, you should see a relatively large amount of change. You might next iterate using different change thresholds to reduce the amount of unwanted change, such as that due to clouds and cloud shadows. Once you have a reasonable set of change thresholds, you might start applying change filters to further reduce the final amount of change presented to you. If those results are not sufficient, then you could try a different change algorithm and work your way back down the chain. Making changes later in the chain saves processing time since early changes do not propagate down through the chain.

💡 You always want to begin iterating with a change detection algorithm that is appropriate for your application. For example, if you are interested in changes to vegetation, you would want to consider using the Tasseled Cap Greenness difference. If you are interested in soil changes, use the Tasseled Cap Soil difference or the magnitude difference algorithm. Carefully inspect this initial iteration to see that the algorithm is capturing the sort of change you are interested in. If not, try a different algorithm. You want your initial results to contain lots of appropriate change and if there is some unwanted change, you will try to filter it out in subsequent iterations. A strict change threshold that removes most all unwanted change may also remove some more subtle varieties of the change in which you are interested. With use you will begin to get a feel for how conservative or liberal you should be when setting a change threshold for a given change phenomenon of interest.
DeltaCue Site Monitoring Mode

The Site Monitoring mode within DeltaCue software is intended for those applications where you wish to identify changes at a specific site rather than search for change over broad areas. In this mode, you identify an Area of Interest using the IMAGINE AOI tools and the software subsets the image pair down to this area and displays change in a custom site-monitoring change display viewer. The viewer provides several change detection visualization tools and enhancements to help you quickly interpret changes at the site.

A Site Monitoring process assists you in automatically subsetting the Time 1 and Time 2 images down to the area of interest and then computes a difference image over the subset. It also layerstacks the two images into a multitemporal image with the Time 1 image in layers 1 through N and the Time 2 image in layers N+1 to 2N. If the Tasseled Cap coefficients are available for the images, the difference image can be based on the brightness, greenness, and wetness bands of the Tasseled Cap transform. This allows you to visualize change in a more physically meaningful way.

Two visualization modes are available with DeltaCue Site Monitoring software – Material View and Multitemporal View. Material View is only available for images with Tasseled Cap coefficients and presents change in terms of the brightness, greenness, and wetness difference following a Tasseled Cap transform of each image. Multitemporal View simply computes the difference on the original bands. You select the Time 1/Time 2 band difference and corresponding layerstack to see changes in that band.

Site Monitoring Process

The DeltaCue Site Monitoring process is a sequence of processing steps based on inputs that you provide. Click **Site Monitoring** from the DeltaCue main menu to open the Site Monitoring dialog, shown on the next page.
The Site Monitoring process stores intermediate results in a project workspace directory and captures the inputs in a project file (.dqm file).

**Create a New Project**

Begin by creating a new project. If you have an existing project, you can elect to open that project instead and the Site Monitoring viewer is opened without re-running the process.

To create a new Site Monitoring project:

1. Click **Create a New Project** radio button.

2. Enter a project file name in **Project File Name** field. If needed, click the file browse icon to change directories.

   The process will automatically create a workspace directory in the same directory as your project file and with the same base name.

   For example, if you specify a project file called C:\test\site.dqm, the process will create a workspace directory called site in C:\test. The intermediate difference and layerstack images are placed in this workspace directory. When you reopen a project, you need only specify the project file. The software automatically finds the files in the workspace.

3. Enter the Time 1 and Time 2 image names in the respective fields.

   These images must be co-registered to each other using a process such as IMAGINE AutoSync, but they need not be cropped to a common area.

4. Select the sensor type for each image by clicking in the **Sensor Time 1** and **Sensor Time 2** dropdown menus.

   If your sensor does not appear, select **Other** as the sensor type. If you select **Other, Material View** is disabled since it depends on sensors that have established Tasseled Cap coefficients.
5. Enter the **AOI File Name**.

If you do not have an existing AOI that encompasses your site of interest, open an IMAGINE viewer and create an AOI around the site. Then save that AOI to a file. You must save your AOI to a file since the Site Monitoring software does not use temporary AOIs in the viewer by design. If you want to run the site monitoring process over an entire image, simply draw an AOI that encompasses the entire image.

6. Click **OK**. A project file (.dqm file) is created and a number of separate processes are spawned to create intermediate outputs. Each separate process will create its own progress dialog. When all of the processes in the processing chain have completed, the dQrunsitemonitor progress dialog indicates completion.

**Use an Existing Project**

If you elect to use an existing project, the Site Monitoring dialog changes to the one shown here.

![Site Monitoring Dialog](image)

Click the file browse icon to open an existing project file and select **OK**. The Site Monitoring Viewer is launched with the selected project as input.

**Site Monitoring Viewer**

The DeltaCue Site Monitoring Viewer is similar to the regular DeltaCue change display viewer. They share a number of features and controls in common so that once you become familiar with one, the other viewer will also be familiar.

The Site Monitoring Viewer is configured in one of two modes depending on your selection of Material View or Multitemporal View. The main difference between the two modes is the type of change image loaded and the viewer control at the top.
Material View

The Material View is available for sensors that have Tasseled Cap coefficients. In this view, the change difference is based on the first three Tasseled Cap transform layers which are Brightness, Greenness, and Wetness. In addition to differencing these layers, the Site Monitoring viewer also provides a view of a multitemporal layerstack of these layers.

An example of the Material View mode is shown here:

The left side of the viewer contains the pair of AOI-subsetted images with Time 1 on top and Time 2 on the bottom. The right side contains the layerstack image on the top and the difference image on the bottom. As in the change display viewer the two windows are linked so that panning in one window will cause the other window to pan similarly. The two windows’ zoom levels can be synched using the zoom synching tool and the change magnifier behaves as in the change display viewer.

If you wish to view the lower image in the right-hand window, click the Change Background icon to turn off the upper layer in the window so that the underlying layer is visible.

The Time 1/Time 2 layerstack of the Tasseled Cap transform image, which is the top-most image in the right-hand viewer, provides a simultaneous view of two dates of one of the tasseled cap components. Select which quantity to view using the radio buttons above the right-hand window. Select only one quantity at a time for display.
You can also select **Regular** or **Invert** to reverse the order of the Time 1 and Time 2 images in the layerstack display.

The various quantities’ associated color channels or color guns are roughly related to the components (red to soil, green to greenness and blue to wetness).

For example, Brightness in Time 2 (Regular mode) is displayed in the red channel and Brightness in Time 1 is displayed in the blue and green channels. Increases in Brightness will appear as reddish pixels while decreases will appear cyan. Greenness in Time 2 is in the green color channel, while Time 1 is in red and blue, therefore increases will appear as greenish pixels, decreases in magenta.

Similarly, Wetness in Time 2 is in the blue channel and increases in its value will appear as bluish pixels, decreases as yellow pixels. This leads to an intuitive interpretation scheme of “if something is bright red, green or blue, that indicates an increase in the associated physical variable (soil, vegetation or water) between the two dates. The tables below summarize the color schemes for the layerstack image.

### Quantity | Regular | RGB
--- | --- | ---
Brightness | Red = increase in Time 2  
Cyan = decrease in Time 2 | T2, T1, T1
Greenness | Green = increase in Time 2  
Magenta = decrease in Time 2 | T1, T2, T1
Wetness | Blue = increase in Time 2  
Yellow = decrease in Time 2 | T1, T1, T2

### Quantity | Invert | RGB
--- | --- | ---
Brightness | Red = decrease in Time 2  
Cyan = increase in Time 2 | T1, T2, T2
Greenness | Green = decrease in Time 2  
Magenta = increase in Time 2 | T2, T1, T2
Wetness | Blue = decrease in Time 2  
Yellow = increase in Time 2 | T2, T2, T1
The layerstack image can provide you with a quick and intuitive depiction of change in a physical phenomenon across an area of interest.

For instance when viewing the greenness image, shades of green give an indication of how much vegetation has grown between the two dates, while Invert will display in green the loss or dieback of features related to vegetation. For some users the inverted display scheme may be more familiar. A mnemonic device sometimes used for image interpreters with the inverted layerstack image is “blue is new, red has fled” – meaning things that are displayed as red are from the Time 1 image and blue pixels indicate a greater response in the Time 2 image.

Under the layerstack image is the difference image of each of the three Tasseled Cap components. These are the images that would normally be thresholded for significant change using the interactive threshold tool or percent change option.

See “Change Threshold” on page 30 and “Change Detection Dialog” on page 57.

In the site monitoring mode these images are not thresholded but are displayed in a manner to highlight gradations of change in either the positive or negative direction (pixels that got brighter or darker between the two dates respectively) for each of the Tasseled Cap components.

The difference image contains three layers which are mapped to the red, green, and blue guns on the display. As in the layerstack layer, Tasseled Cap brightness is mapped to the red channel, the difference in greenness is mapped to the green channel, and the difference in wetness is mapped to the blue channel. All three colors can be displayed simultaneously. You can control which quantities are shown using checkboxes in the control panel.

In addition to which quantity is shown in the difference layer, you can also control whether positive or negative changes from Time 1 to Time 2 are displayed. The Positive and Negative radio buttons control the red, green, and blue lookup tables so that only positive or only negative changes are displayed in the lower difference image.
For example, if you want to see increases in vegetation (greenness) from Time 1 to Time 2, select the **Greenness** channel and Positive changes. The right-hand display will change to show only positive greenness changes (in green). Likewise, if you want to see decreases in vegetation over time, select the Negative option. The display will change such that bright green pixels represent large decreases in greenness over time. The direction (positive/negative) indicates the type of change and the intensity on the screen indicates the degree of change.

You can also control the standard deviation stretch. Click in the field under **SD** to change the standard deviation stretch for the difference layer. Select a value between 1 and 6 standard deviations.

![](image)

The intensity values are clipped at the selected standard deviation value so that any values greater appear at the same intensity. Small values are used to enhance subtle differences and larger values are used to see big changes between the two dates.

The Blend Tool is used to interactively blend the top layerstack image into the bottom difference layer. An example is shown here.

![Blend Tool Example](image)
As you move the slider bar back and forth, the right-side display blends from the top layerstack layer to the bottom difference layer. This can be useful for identifying changes of interest or for associating features in the difference image with features in the layerstack image.

It is best to return the blend slider bar to 100% before closing the Blend Tool. This restores the top layer to its original state.

Refer to On-Line Help for more information on the Blend Tool.

The Background Toggle tool can also be used to flicker between the two layers on the right side of the viewer.

**Multitemporal View**

The Multitemporal View is used when you want to examine change apparent in particular bands or when the Tasseled Cap coefficients are not available with your sensor data. In Multitemporal View, the right side of the display contains the layerstack of a selected band on top and the difference image of that band on the bottom layer. As this view displays only one band at a time, the lower difference image is a grayscale.

The upper layerstack image is a Time 1/Time 2 layerstack of the selected band. The red channel is always used to display the selected band at Time 2, so increases always appear reddish and decreases always appear cyan in color, unless the **Invert** radio button is selected, whereupon the color scheme will reverse. An example of the Multitemporal view Site Monitoring Viewer with the top layerstack image turned off is shown below.
The difference image is displayed as a grayscale image where brighter pixels indicate greater increases in that band from Time 1 to Time 2.

If you wish to view the lower image in the right-hand window, the Change Background tool can be used in the Site Monitoring viewer to turn off the upper layer in the window so that the underlying layer is visible.

The viewer controls for this mode allow you to specify the band of interest and to control the layer stack and difference image display options.

The Band menu is used to specify which band is used for both the upper layer stack and the lower difference image.

<table>
<thead>
<tr>
<th>Band</th>
<th>Layer Stack</th>
<th>Difference Image</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Regular</td>
<td>Pos</td>
</tr>
<tr>
<td></td>
<td>Invert</td>
<td>Neg</td>
</tr>
</tbody>
</table>

Under the Layer Stack text are the radio buttons to control the display of the layerstack image. Regular is time 2 in red and time 1 in blue/green. Invert is time 1 in red and time 2 in blue/green.

Under the Difference Image text are the radio buttons to control whether to display positive (Pos) or negative (Neg) changes.
The **SD Stretch** menu allows you to select a standard deviation stretch for the difference layer. Values between 1 and 6 standard deviations are available. The intensity values are clipped at the selected standard deviation value so that any values greater appear at the same intensity. Small values are used to enhance subtle differences and larger values are used to see big changes between the two dates.

The Blend Tool is used to interactively blend the top layerstack image into the bottom difference layer.

```
As you move the slider bar back and forth, the right-side display blends from the top difference layer to the bottom layerstack layer. This can be useful for identifying changes of interest or for associating features in the difference image with features in the layerstack image.

**Tip**

*It is best to return the blend slider bar to 100% before closing the Blend Tool. This restores the top layer to its original state.*

Refer to On-Line Help for more information on the Blend Tool.
DeltaCue Workspaces

When you use the DeltaCue wizard to process an image pair, the software automatically creates a project file and corresponding workspace directory. The workspace directory name is derived from the base project name and is located in the same file path as the project file. So if your project file name is test.dqw, a workspace directory called test is created in the directory where the project file is located.

⚠️ The site monitoring mode works under the same premise, creating a workspace folder of the same name as the .dqm file where all the necessary files for the site monitoring mode are stored. If you create a .dqm file with the same name as an existing .dqw file, DeltaCue will place all the site monitoring files in the same folder where the broad area search mode-related files are stored. Both the .dqw and .dqm files will still be readable by the change display viewer and Site Monitoring Viewer, respectively.

⚠️ The workspace directory will contain a number of intermediate processing output files. As you iterate with DeltaCue software, the process attempts to reuse existing outputs files whenever possible to save processing time. The software looks to the workspace directory to see if certain output files already exist before recreating them. If a process is interrupted or exits abnormally, it is possible that it may leave a corrupted version of an intermediate output file in the workspace directory. In that case you should manually delete any files that appear to be causing problems.

The DeltaCue processes use a naming convention for intermediate files in any workspace directory, so it is easy to determine which files have been produced and their purpose. The following table describes the naming conventions for the files associated with the Broad Area Search mode, that is, files referenced by the .dqw file.
<table>
<thead>
<tr>
<th>File Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>subset1.img</td>
<td>Common area subset images for Time 1 and Time 2.</td>
</tr>
<tr>
<td>subset2.img</td>
<td></td>
</tr>
<tr>
<td>norm2.img</td>
<td>Normalized Time 2 image.</td>
</tr>
<tr>
<td>class1.img</td>
<td>Isodata classifications of Time 1 and 2 which will exist if during normalization you indicated that there were clouds present.</td>
</tr>
<tr>
<td>class2.img</td>
<td></td>
</tr>
<tr>
<td>ma1.img</td>
<td>Magnitude image for Time 1 and Time 2.</td>
</tr>
<tr>
<td>ma2.img</td>
<td></td>
</tr>
<tr>
<td>tc1.img</td>
<td>Tasseled Cap transform images for Time 1 and Time 2.</td>
</tr>
<tr>
<td>tc2.img</td>
<td>Each image contains a layer for greenness and one for soil.</td>
</tr>
<tr>
<td>sb1-n.img</td>
<td>Single band image for Time 1 and 2 for iteration $n$.</td>
</tr>
<tr>
<td>sb2-n.img</td>
<td></td>
</tr>
<tr>
<td>bs1-n.img</td>
<td>Band slope image for Time 1 and 2 for iteration $n$.</td>
</tr>
<tr>
<td>bs2-n.img</td>
<td></td>
</tr>
<tr>
<td>re1-n.img</td>
<td>Red color image for Time 1 and 2 for iteration $n$.</td>
</tr>
<tr>
<td>re2-n.img</td>
<td></td>
</tr>
<tr>
<td>gr1-n.img</td>
<td>Green color image for Time 1 and 2 for iteration $n$.</td>
</tr>
<tr>
<td>gr2-n.img</td>
<td></td>
</tr>
<tr>
<td>bl1-n.img</td>
<td>Blue color image for Time 1 and 2 for iteration $n$.</td>
</tr>
<tr>
<td>bl2-n.img</td>
<td></td>
</tr>
<tr>
<td>mag-n.img</td>
<td>Magnitude difference image for iteration $n$.</td>
</tr>
<tr>
<td></td>
<td>Note that a given image may be used for several iterations.</td>
</tr>
<tr>
<td>tcg-n.img</td>
<td>Tasseled cap greenness difference image for iteration $n$.</td>
</tr>
<tr>
<td></td>
<td>Note that a given image may be used for several iterations.</td>
</tr>
<tr>
<td>tcs-n.img</td>
<td>Tasseled cap soil difference image for iteration $n$.</td>
</tr>
<tr>
<td></td>
<td>Note that a given image may be used for several iterations.</td>
</tr>
<tr>
<td>sbd-n.img</td>
<td>Single band difference image for iteration $n$.</td>
</tr>
</tbody>
</table>
The DeltaCue project file (.dqw file) is an XML-based text file that is used to record the initial project settings and those used during all iterations. The project file contains XML tags for the various files and processing parameters used by the process.

A list of the XML tags used in the project file is shown below.

<table>
<thead>
<tr>
<th>Tag</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>bsd-n.img</td>
<td>Band slope difference image for iteration n.</td>
</tr>
<tr>
<td>red-n.img</td>
<td>Red color difference image for iteration n.</td>
</tr>
<tr>
<td>grn-n.img</td>
<td>Green color difference image for iteration n.</td>
</tr>
<tr>
<td>blu-n.img</td>
<td>Blue color difference image for iteration n.</td>
</tr>
<tr>
<td>XXXthresholds-n.txt</td>
<td>Text file of change thresholds for iteration n and change algorithm XXX where XXX = tcg, tcs, mag, etc.</td>
</tr>
<tr>
<td>XXXmask-n.img</td>
<td>Initial change threshold mask for iteration n and change algorithm XXX where XXX = tcg, tcs, mag, etc.</td>
</tr>
<tr>
<td>XXXmisregmask-n.img</td>
<td>Misregistration filter mask for iteration n and change algorithm XXX where XXX = tcg, tcs, mag, etc.</td>
</tr>
<tr>
<td>XXXmaterialmask-n.img</td>
<td>Material filter mask for iteration n and change algorithm XXX where XXX = tcg, tcs, mag, etc.</td>
</tr>
<tr>
<td>XXXspatialmask-n.img</td>
<td>Spatial filter mask for iteration n and change algorithm XXX where XXX = tcg, tcs, mag, etc.</td>
</tr>
<tr>
<td>XXXspatialmask-n.txt</td>
<td>Text file of spatial filter parameters for all blobs in change mask.</td>
</tr>
<tr>
<td>Time1ClassImage.img</td>
<td>Spectral segmentation of Time 1 and Time 2 change pixels.</td>
</tr>
<tr>
<td>Time2ClassImage.img</td>
<td>Spectral segmentation of Time 1 and Time 2 change pixels.</td>
</tr>
</tbody>
</table>
<WORKSPACE>
  <NAME></NAME>
  <WORKSPACEPATH></WORKSPACEPATH>
  <COMMON>
    <TIME1_INPUT></TIME1_INPUT>
    <TIME2_INPUT></TIME2_INPUT>
    <SUBSET_IMAGES SUBSET="Y/N">
      <TIME1_SUBSET></TIME1_SUBSET>
      <TIME2_SUBSET></TIME2_SUBSET>
    </SUBSET_IMAGES>
    <NORM_IMAGES NORMALIZE="Y/N">
      <TIME1_CLOUDS>Y/N</TIME1_CLOUDS>
      <TIME2_CLOUDS>Y/N</TIME2_CLOUDS>
    </NORM_IMAGES>
  </COMMON>
  <ITERATIONS>
    <ITERATION NUMBER="1">
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      <CHANGE_DETECTION CHANGE_TYPE="XXX">
        <CHANGE_FILE></CHANGE_FILE>
        <TIME1_TRANSFORM></TIME1_TRANSFORM>
        <TIME2_TRANSFORM></TIME2_TRANSFORM>
        <THRESHOLDS THRESH_APPLY="Y/N">
          <PERCENTAGE></PERCENTAGE>
          <THRESHOLD_FILE></THRESHOLD_FILE>
          <THRESHOLD_MASK></THRESHOLD_MASK>
        </THRESHOLDS>
      </CHANGE_DETECTION>
      <MISREGISTRATION MISREG_APPLY="Y/N">
        <MISREG_MASK></MISREG_MASK>
        <MISREG_WINDOWSIZE></MISREG_WINDOWSIZE>
      </MISREGISTRATION>
      <SPATIAL_FILTER SPATIAL_APPLY="Y/N">
        <SPATIAL_MASK></SPATIAL_MASK>
        <SPATIAL_MINAREA></SPATIAL_MINAREA>
        <SPATIAL_MAXAREA></SPATIAL_MAXAREA>
      </SPATIAL_FILTER>
    </ITERATION>
  </ITERATIONS>
</WORKSPACE>
DeltaCue Material Filtering

The material filtering process in DeltaCue software is based on the Tasseled Cap transformation which transforms a source image from its wavelength-based band spectrum to a space with more physical meaning. The Tasseled Cap transformation is derived via the Gram-Schmidt orthogonalization method that produces a linear transformation which aligns the first basis vector with the mean soil brightness followed by orthogonal basis vectors along the greenness direction and the wetness direction and so on. The projection of the pixel spectra onto the plane defined by the first basis vector (soil brightness) and the second basis vector (greenness) are naturally clustered into obvious groups and can be separated according to angles measured from the negative direction of the greenness axis.

Material Filter Parameters

In the case of a Tasseled Cap transformation derived using the Gram-Schmidt orthogonalization method, the theoretical angle of a non-vegetation material (including pure soil) is 90 degrees since it should align with the first basis vector.

Pixels representing vegetation have an angle higher than non-vegetation while water and shadow and bright (but flat in source spectrum) materials have angles lower than that of non-vegetation. There is a fuzzy zone between the vegetation and non-vegetation and another fuzzy zone between the non-vegetation and water (and shadow and bright but flat spectrum material).

For Quickbird II and IKONOS sensors, the vegetation/non-vegetation boundary is about 100 degrees and the non-vegetation/water-shadows boundary is 80 degrees.

For Landsat sensors, those two angles are 86 and 82 respectively.

The angle of 86 is less than 90 is because the non-vegetation axis is not aligned with the first principal component when the Tasseled Cap Transformation coefficients were derived. The bright but flat materials like clouds are within the same angle zone as that of water/shadow and another parameter – the soil brightness can be used to separate those two. That value is in the unit of DN and is 500 for Quickbird II and IKONOS.
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