

Change in the Right Direction

Monitoring land-cover change by satellite

— by Garrett Love

Introduction

Problem

Can city utility services use remote satellite data, processed with geographic information systems (GIS), to help track urban development? In particular, *which areas of the city of Raleigh exhibit evidence of possible change in land cover during a period of high growth, and what kind of change is it?*

The City of Raleigh, North Carolina, is interested in meeting and maintaining federal standards of water quality in the local waterways. As in many other municipalities, programs to reduce water pollution are funded through a utilities fee levied on city landowners based on the area of impervious surfaces on properties within the city. The city Public Works Department is responsible for maintaining accurate records of these surfaces, both for fair collection of these fees and for appropriate planning of projects to manage storm water runoff. This is a considerable task for the 45th largest and eighth fastest growing city in the United States (City Data), but perhaps the use of high-resolution satellite imagery can make the process both faster and less expensive.

Location

Raleigh, North Carolina

Time to complete the lab

Three to three and one-half hours

Keywords: impervious surfaces; storm water; satellite imagery; change detection; change vector analysis; change magnitude; spectral space; components, distance formula; mask; raster calculator; Spatial Analyst; layer properties; reclassify; symbology

Prerequisites

This lab is intended for upper-class undergraduates who have a familiarity with the manipulation and presentation of raster data in ArcMap, including use of the Raster Calculator tool.

Data used in this lab

- IKONOS satellite imagery (www.geoeye.com)
- City of Raleigh Planimetric Shapefile—Impervious surface polygons
- Geographic coordinate system: GCS_WGS_1984
- Datum: D_WGS_1984
- Projection: Universal Transverse Mercator Zone 17N

Student activity

Consider the following scenario: You have recently started a job with the Storm Water Management Division in the Public Works Department of the City of Raleigh, North Carolina. The division oversees construction projects and city maintenance that guards against flooding and helps maintain the quality of water that flows into local streams, rivers, and the local drinking supply. These projects (and your salary!) are funded through the collection of a fee on impervious surfaces—i.e., buildings and paved surfaces such as parking lots, sidewalks, and driveways, which all contribute to excess surface runoff by preventing rainfall from soaking into the ground (infiltrating).

The city maintains a database of impervious surfaces and requires registration of new construction as part of the building permit process, but every few years it spends a great deal (\$330,000) verifying the accuracy of the database for the entire city. Part of this process uses high-resolution satellite imagery to help identify impervious surfaces. Your first task on the new job was to explore whether such imagery could be used instead to discover “priority” areas where land-cover change had occurred.

Not all detected change, however, is necessarily the creation of new impervious surfaces. Buildings can supplant parking lots, or get new roofing. Developed land is occasionally returned to vegetation. Temporary features such as shadows and clouds that appear in satellite imagery will often give positive results in change detection algorithms. Better accuracy in change detection will necessarily require more work in processing the available data. Your goal in this exercise, like its optional antecedent¹, is still to determine *which areas of the city of Raleigh exhibit evidence of possible change in land cover during a period of high growth*, but in this follow-up exploration, you will make some incremental advances in your processing procedure that should help elucidate *what kind of change it is*.

¹ A related exercise, *A Little Spare Change*, complements this exercise but is optional.

Your data for this project consists of two aligned sets of multiband high-resolution IKONOS satellite imagery (GeoEye foundation) for a portion of the city: one image set for the year 2002 and another set for the year 2006. It also includes a planimetric shapefile indicating the extent of surface features in the same area that were identified by the City of Raleigh Storm Water Management Division as “impervious” in 2002.

In this lab, you will

- use environment settings to apply a vector mask to raster data;
- collect statistics for multiple raster bands;
- calculate multiple-band components for a vector of reference change;
- create, analyze, and visualize a directional change magnitude raster;
- create a map of likely change areas; and
- investigate the effectiveness of using a directed change magnitude raster.

PREPARE YOUR WORKSPACE

You will be working with and generating a number of data files as part of this project, so it will be important to stay organized. If you do not already have a SpatiaLABS project folder, begin by creating one on your computer or storage device (e.g., My Documents\SpatiaLABS).

- 1 Create a SpatiaLABS folder under the My Documents folder.
- 2 Create a Data folder under the SpatiaLABS folder.

COLLECT AND PROCESS DATA

Download and extract data from the data.zip file.

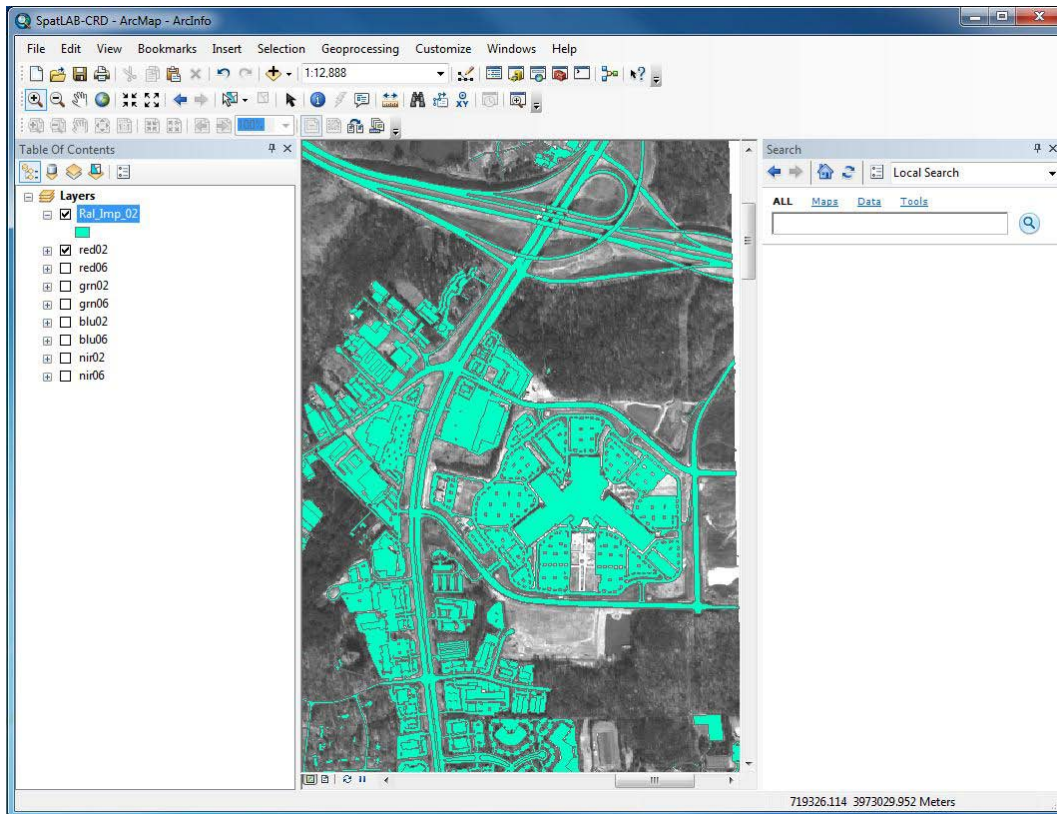
- 1 Download CRDdata.zip.
- 2 Extract CRDdata.zip to the workspace (e.g., My Documents\SpatiaLABS\Data).

View the data to confirm extraction before moving on to the analysis.

- 3 Start ArcCatalog.
- 4 Examine the Data folder. There should be eight raster datasets, containing values for each of four spectral bands for two years (red02, grn02, blu02, nir02, red06, grn06, blu06, nir06). There will also be one vector dataset, a shapefile titled Ral_Imp_02, which was generated from a database of planimetric features maintained by the City of Raleigh.

PREPARE DATA

- 1 Start ArcMap.
- 2 Add the eight data bands as layers to the ArcMap data frame.
- 3 If the datasets appear featureless, you may need to modify the symbology of each layer (in the *Layer Properties*) to *Stretched* using *Standard Deviation*.
- 4 Add the vector shapefile Ral_Imp_02 as a layer. Select a layer color and display the vector data overlaid on one of the 2002 raster data layers. The vector shapefile identifies surfaces that were identified by the City of Raleigh as impervious surfaces in 2002. Zoom to an area of the map that is of interest to you and toggle the vector layer display on and off to observe the corresponding raster features displayed underneath.

Question 1: What types of features are identified as “impervious” surfaces?

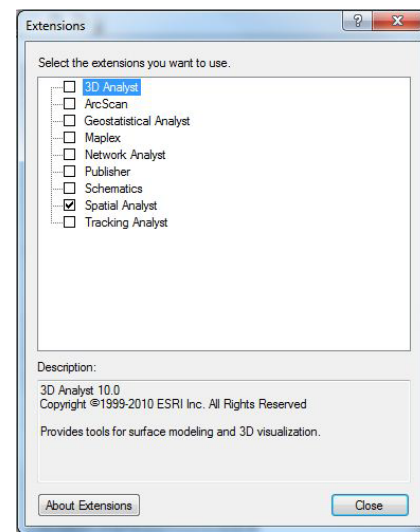
(GeoEye)

PROCESS DATA

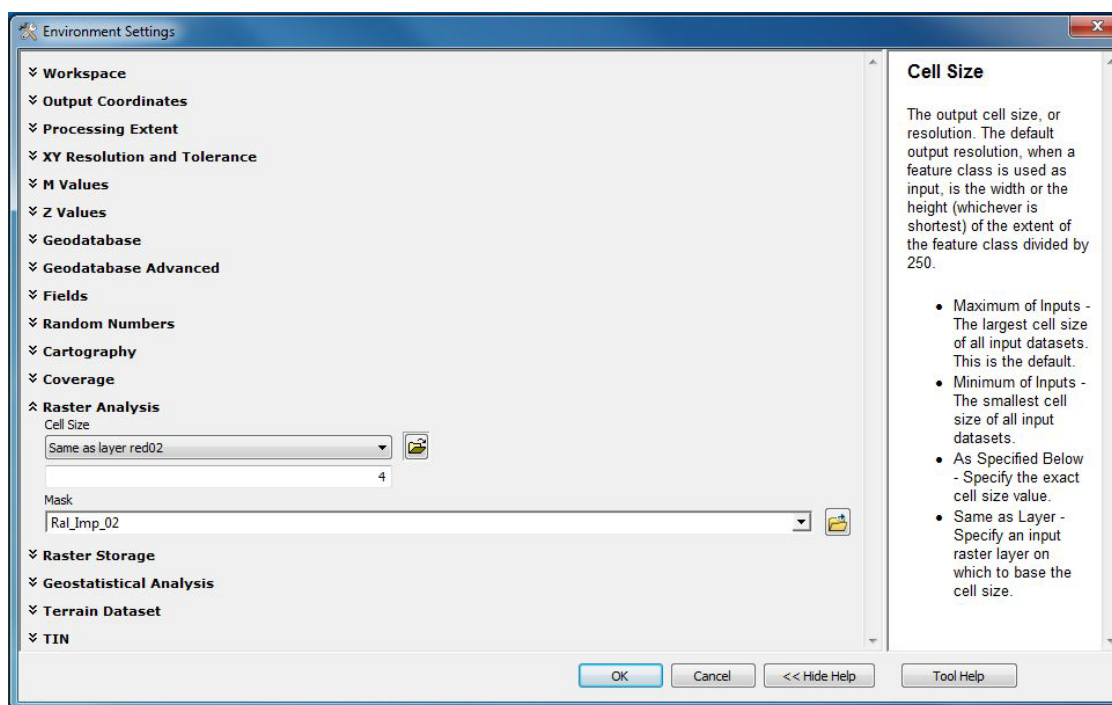
Although a simple analysis of change can be made by direct comparison of two rasters, you should be able to take advantage of the existing impervious-surface classification data, by considering how the statistics of impervious and nonimpervious compare. To do so, you will need to extract the impervious data from a full raster layer. One possible method follows.


Create impervious surface rasters for each band

- 1 On the main menu, click *Customize » Extensions* and, if necessary, activate the *Spatial Analyst* extension with the check box list under *Customize » Extensions*.

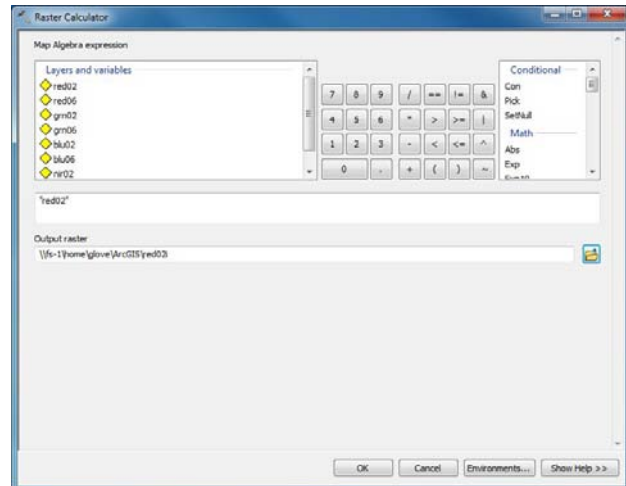


- 2 On the *Geoprocessing* menu, click *Environments* to open the *Environment Settings* dialog box. Locate *Raster Analysis* from the 17 settings categories and click to see the associated settings.
- 3 Use the selection menu to set *Cell Size* to *Same as layer red02* or any of the other existing raster layers. This should fill in the associated text field with a value of 4.
- 4 For the *Mask* field, select the *Ral_Imp_02* layer.
- 5 Click *OK*. Note that these environment settings will now apply to your subsequent raster calculations.



- 6 Open *ArcToolbox*  and find *Raster Calculator* under *Spatial Analyst Tools* » *Map Algebra* » *Raster Calculator*. Activate the raster calculator.

- 7 The rasters actually require no calculations, just the application of the environment mask. Select one of the four 2002 bands (e.g., “red02”) and create an output file name that indicates the ‘impervious’ association of the new band (e.g., “red02i”). Click *OK* to generate a new raster. When it is complete, zoom in to compare the new raster to the impervious surface vector layer. (You may need to turn off the other data layers to see clearly).



- 8 Repeat for the other three data files and organize your layers.

Question 2: *What do these new raster layers represent?*

Question 3: *Why is the term “nonimpervious” used instead of the simpler term “pervious”?*

- 9 Return to the *Environment Settings* dialog box, delete the *Ral_Imp_02* setting in the *Mask* field, and click *OK*. This step is important so that further raster calculations will not be masked with the impervious vector layer.
- 10 You may want to save your map document at this point, if you haven’t yet done so.

Generate the pixel counts for each classification

- 1 Select *Properties* for one of the full raster layers (e.g., red02).
- 2 Click the *Symbology* tab.
- 3 Select *Classified* from the *Show* menu on the left.
- 4 Click the *Classify* button. Read and record the *Count* of pixels for the layer.
- 5 Repeat for one of the impervious raster layers (e.g., red02i).
- 6 Record the pixel count for “all” pixels in the original dataset, as well as for the number of impervious (“imp”) and nonimpervious (“ni”) pixels:

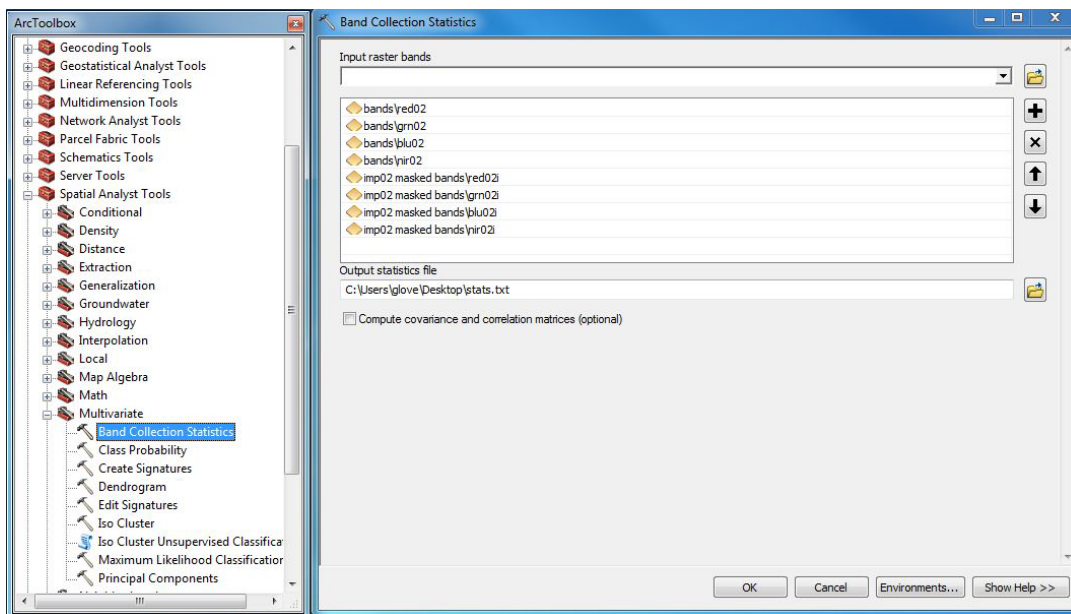
count_{all} =

count_{imp} =

count_{ni} =

Generate the statistics for each band

- 1 In *ArcToolbox*, locate *Spatial Analyst Tools* » *Multivariate* » *Band Collection Statistics* and activate the tool.
- 2 Select each of the four full raster bands for 2002 and each of the four impervious raster bands for 2002, making note of their order. They will appear in a list in the *Band Collection Statistics* dialog box as you select each of them, and you can move them within the list if you wish.
- 3 For the *Output statistics file* field, select a location and name for an output text file (e.g., \Desktop\stats.txt). Click *OK* to generate a statistics file.



- 4 Locate the stats.txt file on your computer and open it with a text file reader, word processor, or spreadsheet. You should note that the layers you entered will only be labeled by layer number according to how they were entered. Copy the MEAN and STD (standard deviation) of each raster layer to a spreadsheet.

Layer	MIN	MAX	MEAN	STD
1	1.0000	2047.0000	173.1698	93.3783
2	1.0000	2047.0000	219.9060	87.0940
3	40.0000	2047.0000	218.2122	56.0232
4	1.0000	2047.0000	255.8160	110.6232
5	1.0000	2047.0000	226.5550	125.8279
6	1.0000	2047.0000	276.0329	120.3737
7	40.0000	2047.0000	256.9549	78.2135
8	1.0000	2047.0000	250.0756	124.9723

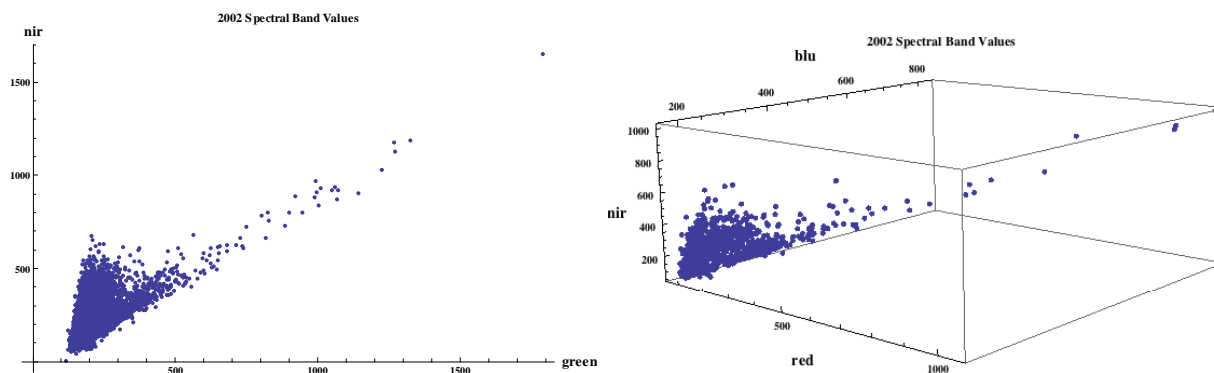
For each band, you now have the pixel count ($\text{count}_{\text{all}}$) and mean pixel value (mean_{all}) for the entire raster and similar statistics for the subset of pixels that were classified as impervious in 2002 ($\text{count}_{\text{imp}}$ and mean_{imp}). You also need statistics for the subset of pixels that were *not* classified as impervious in 2002 (the nonimpervious pixels).

- The mean of all the pixels could be calculated as a *weighted* mean of the impervious pixels and the nonimpervious pixels. Use the count and mean information you already have, along with the following weighted mean equation, to generate count and mean information for the nonimpervious pixels (count_{ni} and mean_{ni}).

$$\text{mean}_{\text{all}} = (\text{count}_{\text{ni}} * \text{mean}_{\text{ni}} + \text{count}_{\text{imp}} * \text{mean}_{\text{imp}}) / \text{count}_{\text{all}}$$

PERFORM DIRECTIONAL CHANGE VECTOR ANALYSIS

Each raster pixel in the datasets is represented by eight values: four measured in 2002 and four from 2006. Each of the four spectral values can be considered as a component of a four-dimensional vector representing the specific location at the specific time. You can imagine or draw these vectors as points in what is called *spectral space*, with axes that represent the spectral band components (see the examples below in two and three dimensions).



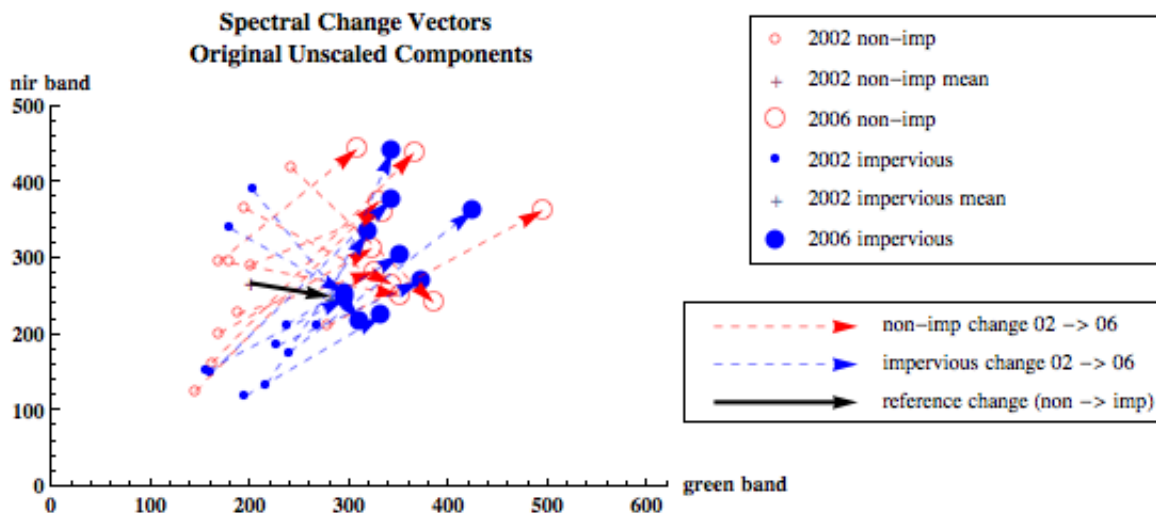
A *change vector* can be generated for each pixel by subtracting the 2002 vector from the 2006 vector, which is simply the subtraction of each component. A simple measure of change would then be the *magnitude* of each change vector.

It is possible in some cases to characterize a desired or expected direction of change in the spectral space, and thereby define a *vector of reference change*. Some examples in the literature use the angle between each change vector and the reference vectors to help analyze change. Another possibility is to recognize that the scalar product (dot product) of each change vector with the reference vector gives the relative magnitude of that vector *in the direction of the reference change*.

This analysis uses the observation that data pixels from surfaces categorized as nonimpervious and those categorized as impervious tend to cluster in different areas of the spectral space and

calculates the mean center (in four dimensions) of each dataset as an approximate spectral “location” for each of the two types. The vector of reference change is established from these two points, and although change in a particular pixel can occur due to a number of different factors, the assumption is that significant change parallel to this vector (“away” from one categorization and “toward” the other) is more likely to represent an actual change in classification than change in the other (orthogonal) directions.

In the graphic below, for example, the 2002 nonimpervious pixels (small red circles) are centered to the left (~ 80 units lower on the green band) and slightly above (15–20 units on the nir band) the center of the 2002 impervious pixels (small blue dots). Each pixel experiences some change (represented by a dotted vector) when images from 2002 (small icons) and 2006 (large icons) are compared, but whereas most pixels experience a general brightening (increase in both bands), the vectors for a few align with the reference vector, and those are chosen as the most probable locations of actual physical change that should be identified with a new categorization.



PREPARE THE ANALYSIS

Determine the *components of reference change*. The expected direction of change will be from nonimpervious to impervious, and although there are generally multiple spectral signatures associated with each of these classifications, the assumption for this analysis is that each classification can be represented by its mean value.

- 1 For each of the four data bands (red, green, blue, nir), use your spreadsheet or calculator to subtract the 2002 nonimpervious mean from the 2002 impervious mean. Let these be components of a reference change vector R.

$$R = \{ \text{mean}[\text{red02i}] - \text{mean}[\text{red02n}], \\ \text{mean}[\text{grn02i}] - \text{mean}[\text{grn02n}], \\ \text{mean}[\text{blu02i}] - \text{mean}[\text{blu02n}], \\ \text{mean}[\text{nir02i}] - \text{mean}[\text{nir02n}] \}$$

- 2 Calculate the vector length of R (square each component, sum, take the square root).
- 3 Normalize R to a unit length vector r by dividing each element by the total vector length. Record these four values: r_{red}, r_{grn}, r_{blu}, and r_{nir}.

Question 4: *What is the vector length of r? (Verify.)*

For each pixel in the raster, the “change in the right direction” can be found from the four-dimensional scalar product of the reference vector and the change vector:

$$r_{\text{red}} * (\text{red06} - \text{red02}) + r_{\text{grn}} * (\text{grn06} - \text{grn02}) + r_{\text{blu}} * (\text{blu06} - \text{blu02}) + r_{\text{nir}} * (\text{nir06} - \text{nir02})$$

where (red06 - red02) is the difference between the red components of the 2006 and 2002 rasters.

Calculate the directional change vector magnitude (DCVM) raster

- 1 Start the *Raster Calculator* tool.
- 2 Generate the raster by substituting values for reference change into the equation above and entering that equation, with appropriate rasters, into the *Raster Calculator* equation field.
- 3 You may once again want to save your map document at this point.

VISUALIZE

- 1 Display the DCVM raster. Modify the symbology so that the top 1% of the areas with the highest positive and highest negative values are highlighted.
- 2 Modify the color and transparency of the DCVM raster so that it can be displayed as an overlay of the original data. Select an imagery band and display the change raster with images for 2002 and 2006. Export these two maps as image files for your instructor.

ANALYZE

Identify areas on the change raster that appear to have significant change. Zoom in and compare these areas to one band of the 2002 and 2006 imagery.



2002 red band (GeoEye) with Directional Change Vector Magnitude extreme 1% values.



2006 red band (GeoEye) with Directional Change Vector Magnitude extreme 1% values.

Question 5: Can you identify regions that have experienced change between 2002 and 2006? Create “close-up” images of two different areas that demonstrate change and submit them, appropriately labeled, to your instructor. Describe the change you see—what was there in 2002, and how was it different in 2006?

Question 6: What do the “highest” and “lowest” values of the DCVM raster represent?

Question 7: Are there any “false positives” in your detection method—i.e., are there areas that were identified by the method that perhaps don’t represent actual change? Describe what you see.

Question 8: What features other than impervious surface change could be identified with this process? Describe how they would be identified.

References

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Submit your work

Submit to your instructor answers to questions 1 through 8 and your summary assessment of land-cover changes occurring in the city of Raleigh, North Carolina, between 2002 and 2006.

Credits

Sources of supplied data

CRDdata\blu02, IKONOS satellite imagery, © GeoEye—Satellite Imagery courtesy of The GeoEye Foundation.

CRDdata\grn02, IKONOS satellite imagery, © GeoEye—Satellite Imagery courtesy of The GeoEye Foundation.

CRDdata\nir02, IKONOS satellite imagery, © GeoEye—Satellite Imagery courtesy of The GeoEye Foundation.

CRDdata\red02, IKONOS satellite imagery, © GeoEye—Satellite Imagery courtesy of The GeoEye Foundation.

CRDdata\blu06, IKONOS satellite imagery, © GeoEye—Satellite Imagery courtesy of The GeoEye Foundation.

CRDdata\grn06, IKONOS satellite imagery, © GeoEye—Satellite Imagery courtesy of The GeoEye Foundation.

CRDdata\nir06, IKONOS satellite imagery, © GeoEye—Satellite Imagery courtesy of The GeoEye Foundation.

CRDdata\red06, IKONOS satellite imagery, © GeoEye—Satellite Imagery courtesy of The GeoEye Foundation.

CRDdata\Ral_Imp_02.shp, courtesy of City of Raleigh Public Works Department.

Instructor resources

This module is written as an extension of multispectral change analysis, which was introduced in a related, optional exercise, *A Little Spare Change*. This follow-up exercise is designed to introduce tools and concepts that may be used in more advanced analyses and to prompt thought about how to approach such problems. It is intended for upper-class undergraduates who have a familiarity with the manipulation and presentation of raster data in ArcMap, including use of the Raster Calculator tool.

Analysis and visualization tools

The lab is written with the presumption that the user will be using ArcGIS 10 with the Spatial Analyst extension.

Lesson notes and comments

PREPARE DATA

The band values in the original .tif imagery range from 0 to 65,535 and because of relative sparseness on the high end will appear nearly monochromatic. The example image uses a *Stretched* visualization of the *Standard Deviations*.

Question 1: *What types of features are identified as “impervious” surfaces?*

Answer: Buildings, roads, parking lots, patios, bridges, sidewalks, water tanks. Industrious students will reference the Description field in the Ral_Imp_02 attribute table.

PROCESS DATA

There are multiple ways to extract raster data using a vector mask. One alternative to the module method is to use the *Spatial Analyst Tools* » *Extraction* » *Extract by Mask* tool. This method was chosen to introduce the *Environment Settings*—you may want to emphasize the importance of returning to the *Environment Settings* (step 9) to ‘turn off’ the mask when it is no longer desired.

Question 2: *What do these new raster layers represent?*

Answer: The new layers all spatially represent areas that were classified as impervious surfaces in 2002. They are each subsets of satellite data bands that were gathered in either 2002 or 2006.

Question 3: *Why is the term “nonimpervious” used instead of the simpler term “pervious”?*

Answer: The “double negative” classification is actually appropriate here for the following reason: Pixels that are not confirmed as impervious are *not necessarily* pervious—they may not yet be classified. The nonimpervious classification captures both verifiably pervious surfaces as well as any surfaces that have insufficient data for classification according to the City of Raleigh records.

Generate the pixel counts for each classification

These are the expected pixel count values:

$$\text{count}_{\text{all}} = 4,851,945 \quad \text{count}_{\text{imp}} = 1,541,012 \quad \text{count}_{\text{ni}} = \text{count}_{\text{all}} - \text{count}_{\text{imp}} = 3,310,933$$

Generate the statistics for each band

Students will need to do some simple algebra, as follows, to determine the nonimpervious mean values, which can be easily done for each band in a spreadsheet. Expected values are in the table below.

$$\text{mean}_{\text{ni}} = (\text{count}_{\text{all}} * \text{mean}_{\text{all}} - \text{count}_{\text{imp}} * \text{mean}_{\text{imp}}) / \text{count}_{\text{ni}}$$

	Imp	All	Non-imp
COUNT	1,541,012	4,851,945	3,310,933
red	226.55	173.17	148.33
grn	276.03	219.91	193.79
blu	256.95	218.21	200.18
nir	250.06	255.82	258.50

PERFORM DIRECTIONAL CHANGE VECTOR ANALYSIS

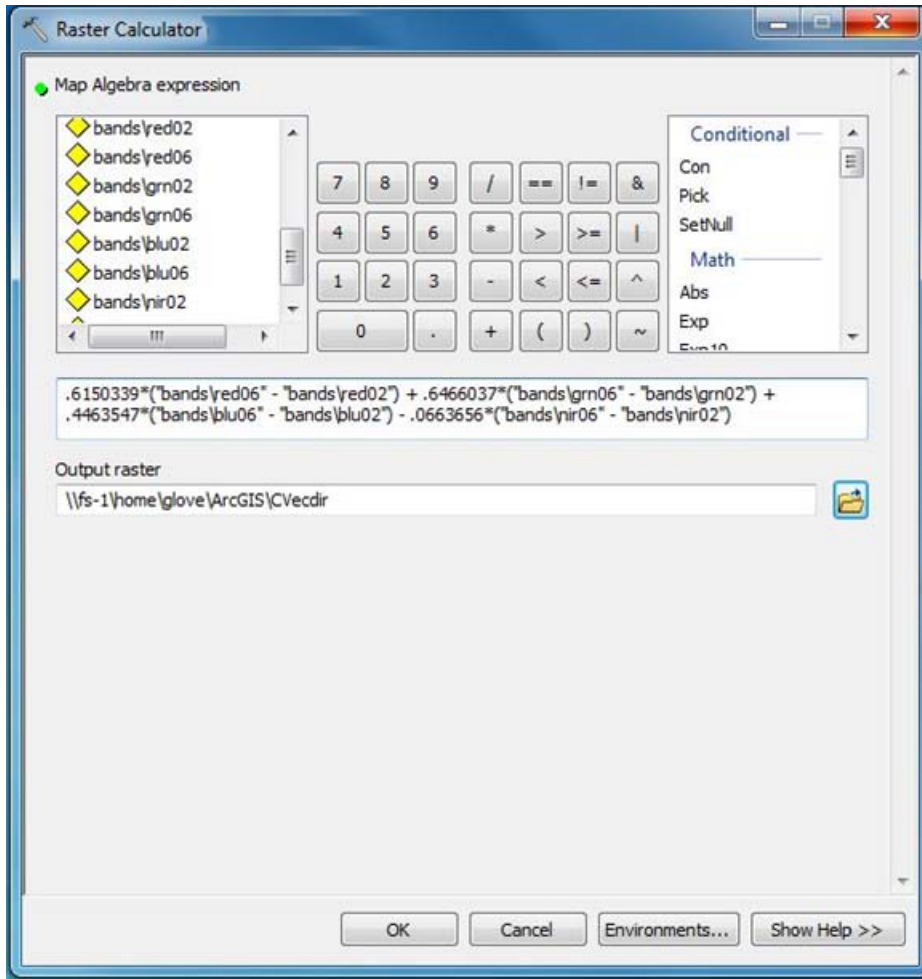
PREPARE THE ANALYSIS

Question 4: *What is the vector length of r? (Verify.)*

Answer: r should be a unit vector and should necessarily have a vector length of 1. Expected values for R and r are in the table below.

	R	r
COUNT		
red	78.2247252058559	0.615033940195399
grn	82.2400070916567	0.646603685345931
blu	56.7708103123802	0.446354717931243
nir	-8.44088454825265	-0.0663655956449133
LEN	127.187655986926	1

Note that it is not actually necessary to use a unit directional vector. The same operation is being applied to every pixel, so using R instead of normalized r would simply result in the final DCVM raster being scaled by the relative lengths of the vectors (127.19 in this example).

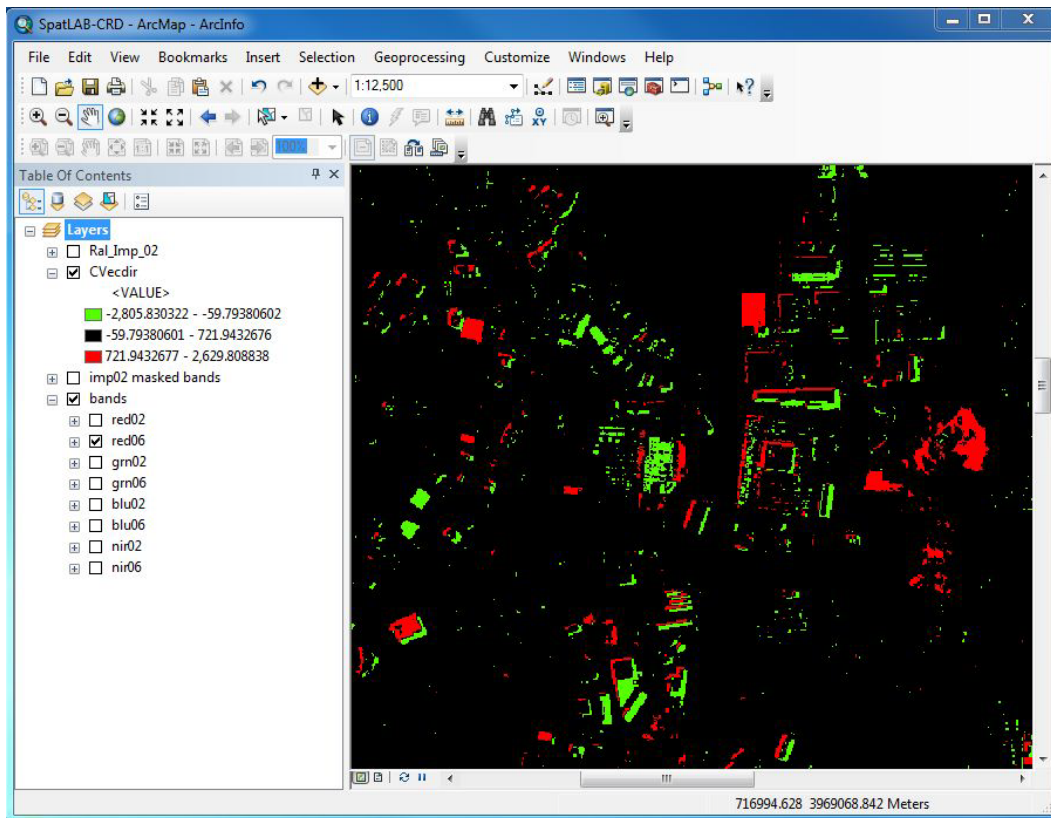


A screen capture of the full DCVM equation in the raster calculator.

VISUALIZE

Even with the multiple calculations, there are a limited number of combinations of the semidiscrete spectral band values, and the resulting directional change vector magnitudes are not unique. One consequence is limited accuracy for any threshold value that would delimit a particular quantile. Threshold values and associated counts listed below were used to generate the following example rasters.

	DCVM Value	Count	Fraction
Bot 1%	-59.79	51,140	1.05%
Top 1%	721.94	50,172	1.03%



Directional change vector magnitude extreme 1% values, central zoom.

This example area is located about one-third of the way down from the top of the data extent, off-center slightly to the left.

ANALYZE

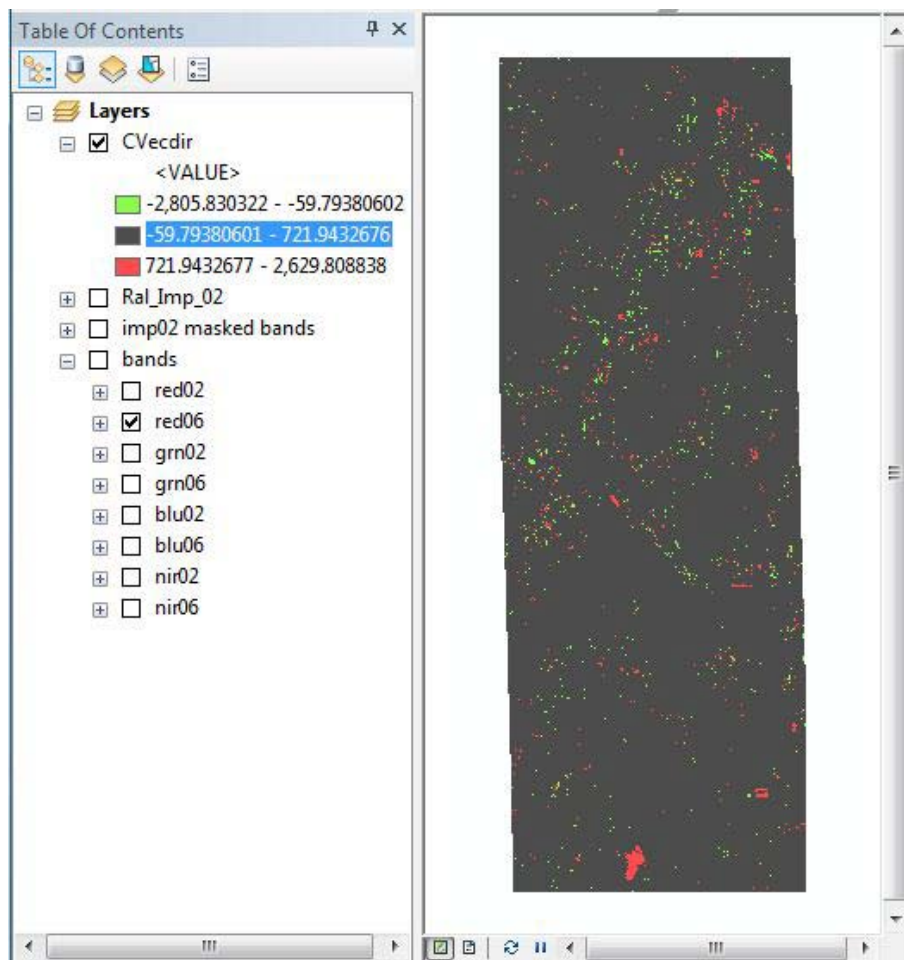
Question 5: *Can you identify regions that have experienced change between 2002 and 2006?*

Answer: The mall parking lot in the upper-right corner is the most obvious example. There are cleared development areas in the lower right and in the middle and new buildings scattered throughout the area.

Question 6: *What do the “highest” and “lowest” values of the DCVM raster represent?*

Answer: Unlike normal change vector magnitudes (CVMs), the directional CVMs can have negative values. These negative values represent a spectral change signature in the opposite direction of the reference vector. Because the reference vector in this analysis was chosen to represent change from nonimpervious to impervious, negative values of the DCVM necessarily connote the possibility of change in the other direction (from impervious to nonimpervious).

A next step in this analysis might be to use the impervious classification mask to identify “originally impervious” (in 2002) surfaces and highlight negative DCVM values for these pixels while highlighting positive DCVM values for “originally nonimpervious” surfaces.



Directional change vector magnitude extreme 1% values, full dataset.

Question 7: Are there any “false positives” in your detection method—i.e., are there areas that were identified by the method that perhaps don’t represent actual change? Describe what you see.

Answer: Clouds are the biggest source of false positives, the most notable being at the bottom center of the masked area. There are also a few examples of changed roof color, which will register as change, but students should note that this would not likely represent a change in imperviousness.

Question 8: What features *other than* impervious surface change could be identified with this process? Describe how they would be identified.

Answer: The most obvious answer to this question is “clouds”—students should note that clouds are both temporary and have high values in all bands, making them definite candidates for change vector detection. In this analysis, clouds only existed in the 2006 dataset and registered in the direction of “non-impervious to impervious” (essentially, darker to lighter). The presence of

clouds in the earlier dataset would register in the other direction, so this method should be able to detect and discriminate between differences in cloud cover between two different times. This might also prompt a discussion of other cloud detection methods, including fractal measurements of shape and so on.

A second possible answer is “shadows,” as darkened areas associated with either buildings or clouds register as detected change, although not as strongly as clouds and in the opposite direction.

Students should notice a pattern of paired positive-negative stripes respectively associated with the northwest and southeast sides of some features, most of which appear to be buildings. Depending on how they interpret the actual imagery, they may propose using the method to detect (and perhaps remedy) a minor misalignment in the dataset or recognize that the misalignment may correspond to a vertical component in the imagery and propose a method for identifying taller structures.