

Manual

Introduction to Image Analysis in ArcView 3 – Land Cover Changes in the Rwenzori Mountains 1973-2005.

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Introduction

This exercise manual and the data that comes with it was produced in 2006 by the project “Information Products for the Nile Basin Water Resources Management”, which is implemented by the Nile Riparian States with financial support from Italy and operational and technical assistance from the Food and Agricultural Organisation (FAO) of the United Nations. The exercise was done as part of the Rwenzori –Abruzzi centenary celebration, marking the 100 years since the first climbing of the Rwenzori by a scientific expedition headed by Luigi of Savoy the Duke of Abruzzi.

Requirements

This exercise requires a PC with Windows 98SE/2000/NT/XP, or later and ArcView 3.x. To do the full exercise the ArcView extension Image Analyst is needed, as an alternative the free extension Imagine Image Support is available with the NileBasin database (see below).

Objectives

This exercise will give an introduction to basic image processing using ArcView. The exercise will also introduce satellite images derived from different generation of high resolution sensors. The geographical area used in the exercise is the Rwenzori Mountains, straddling the border between the Democratic Republic (D.R.) of Congo and Uganda. The thematic focus of the exercise is to use time series of satellite images for studying changes in land cover. After completing the exercise students should be able to use satellite images for analyzing vegetation and its changes from satellite imagery.

Image Analysis in ArcView

This exercise requires that you have ArcView 3.x and the extension Image Analysis. If you have ArcView 3.x, but lack the Image Analysis extension you can still do most of the exercise by installing a free extension for viewing and visual enhancing the image data used in the exercise. The extension is supported in the NileBasin database - data\NileBasin\Spatial\Images\AV_ext\IMAGINE.AVX. To install an extension for ArcView you just copy it to the extension library that is set up automatically when you install ArcView – if your ArcView license is installed with default settings the extension folder (EXT32) is under ...ESRI\AV_GIS30\ARCVIEW\EXT32.

Part 1: Satellite images over the Rwenzori – image enhancement

The high resolution satellite images available for this exercise are given in table 1.

Sensor	Image date	Image name	Directory
MSS	19730204	uga-rwe_1m19730204.img	data\NileBasin\Spatial\Images\landsat mss\rwenzori\image\
MSS	19750312	uga-rwe_2m19750312.img	data\NileBasin\Spatial\Images\landsat mss\rwenzori\image\
TM	19870807	uga-rwe_5t19870807.img	data\NileBasin\Spatial\Images\landsat tm\rwenzori\image
TM	19950117	uga-rwe_5t19950117.img	data\NileBasin\Spatial\Images\landsat tm\rwenzori\image
ETM	20010131	uga-rwe_7t20010131.img	data\NileBasin\Spatial\Images\landsat tm\rwenzori\image
ETM	20011211	uga-rwe_7t20011211.img	data\NileBasin\Spatial\Images\landsat tm\rwenzori\image
ETM	20030131	uga-rwe_7t20030131.img	data\NileBasin\Spatial\Images\landsat tm\rwenzori\image
ASTER	20050221	uga-rwe_aster_9b20050221.img	data\NileBasin\Spatial\Images\aster\rwenzori\image

MSS = Multi Spectral Scanner (Landsat); TM = Thematic Mapper (Landsat); ETM = Enhanced TM (Landsat); ASTER = Advanced Spaceborne Emission and Reflection Radiometer (Terra).

The ASTER Image directory contains three image files, a 9 band image combining the three visible and near infrared (VNIR) bands with the 6 middle or Short Wave infrared (SWIR) bands in 30 m (uga-rwe_aster9b20050221.img), an image with visible and Near Infrared (VNIR) bands in the original resolution of 15 m, and a Thermal InfraRed (TIR) image with 5 bands in 90 m resolution. For this exercise the image data were precision corrected using GPS data, and resampled to have exactly the same size (28.5 m resolution). The VNIR and TIR data from ASTER were kept at their original resolution. The characteristics for the sensors used in this exercise are given in Table 2.

	Band 1	Band 2	Band 3	Band 4	Band 5	Band 6	Band 7
MSS	0.55	0.65	0.75	0.95			
TM/ETM	0.485	0.56	0.66	0.83	1.65		2.215
Aster							
VNIR	0.56	0.66	0.82	0.82*			
SWIR	1.65	2.16	2.2	2.26	2.33	2.40	
TIR	8.3	8.65	9.1	10.6	11.3		

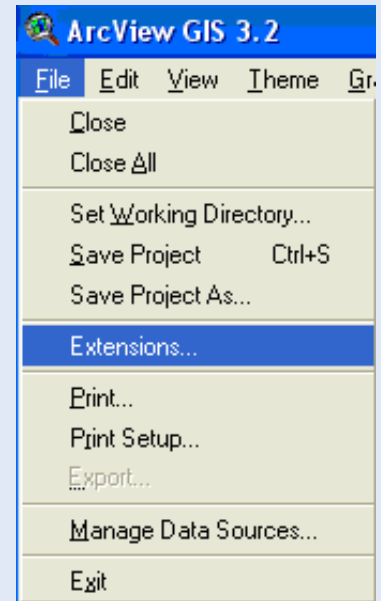
* backward looking for stereo imagery – not included in the NileBasin database.

Image Enhancement

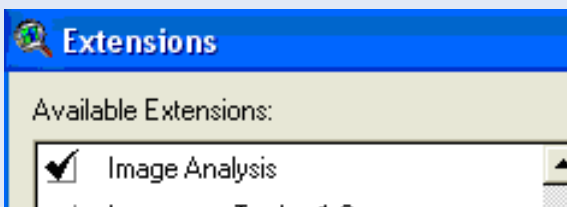
Image enhancement aims at improving the information content in images, in order to facilitate interpretation. Enhancement techniques much resemble the standard techniques used in more popular photo editing programs (e.g. Adobe Photoshop). Image enhancement techniques include stretching the display of individual bands (“colors”), filtering to remove noise or sharpen edges, band combinations to create false color images, and band rationing for highlighting e.g. vegetation. This part of the exercise can be done with either the Image Analysis extension, or the Image Image Support extension.

Install an extension for viewing images in ArcView

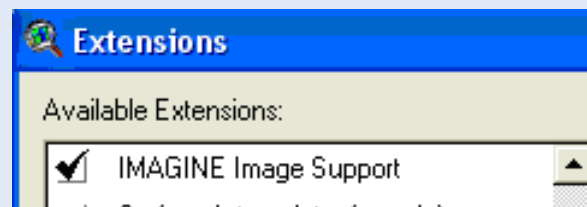
Start ArcView3.x and open a new view. If asked if you want to add new data, click No. As you are going to use satellite images in this exercise, you must start by adding the necessary extension. To load an extension, click the menu item: File – Extensions (if that option is not seen, it is because you need to have a view as the active document).



If you have the Image analyst extension installed, you load that extension by clicking its checkbox..




If you do not have image analyst extension installed, you need to download and install the extension for Imagine Image support (see above)..



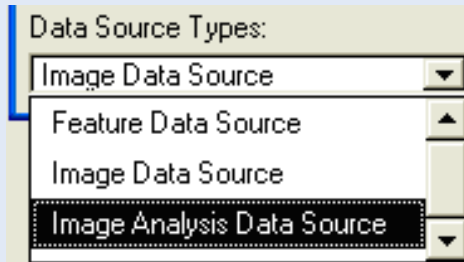
Click OK and return to the empty View Document.

Before continuing you need to create a directory for your project. It is easier to create the directory using e.g. Windows Explorer – I choose to create the directory data\NileBasin\Spatial\Images\my-work. Once you have created your working directory, you need to set this directory to be your working directory, which is done from the menu: File – Set Working Directory. Then also save your project as a project file in this directory, again use the menu: File – Save Project.

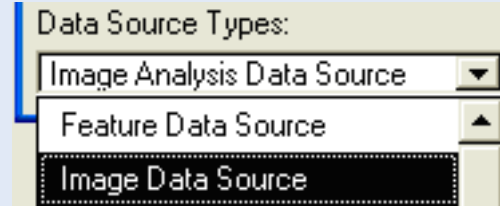
Image display and band stretching

With the extension installed click the Add Theme button, , and load the Aster scene with 9 bands (VNIR and SWIR combined – see tables 1 and 2).

If you loaded the image analyst extension, you select Filetype to be Image Analysis Data Source.

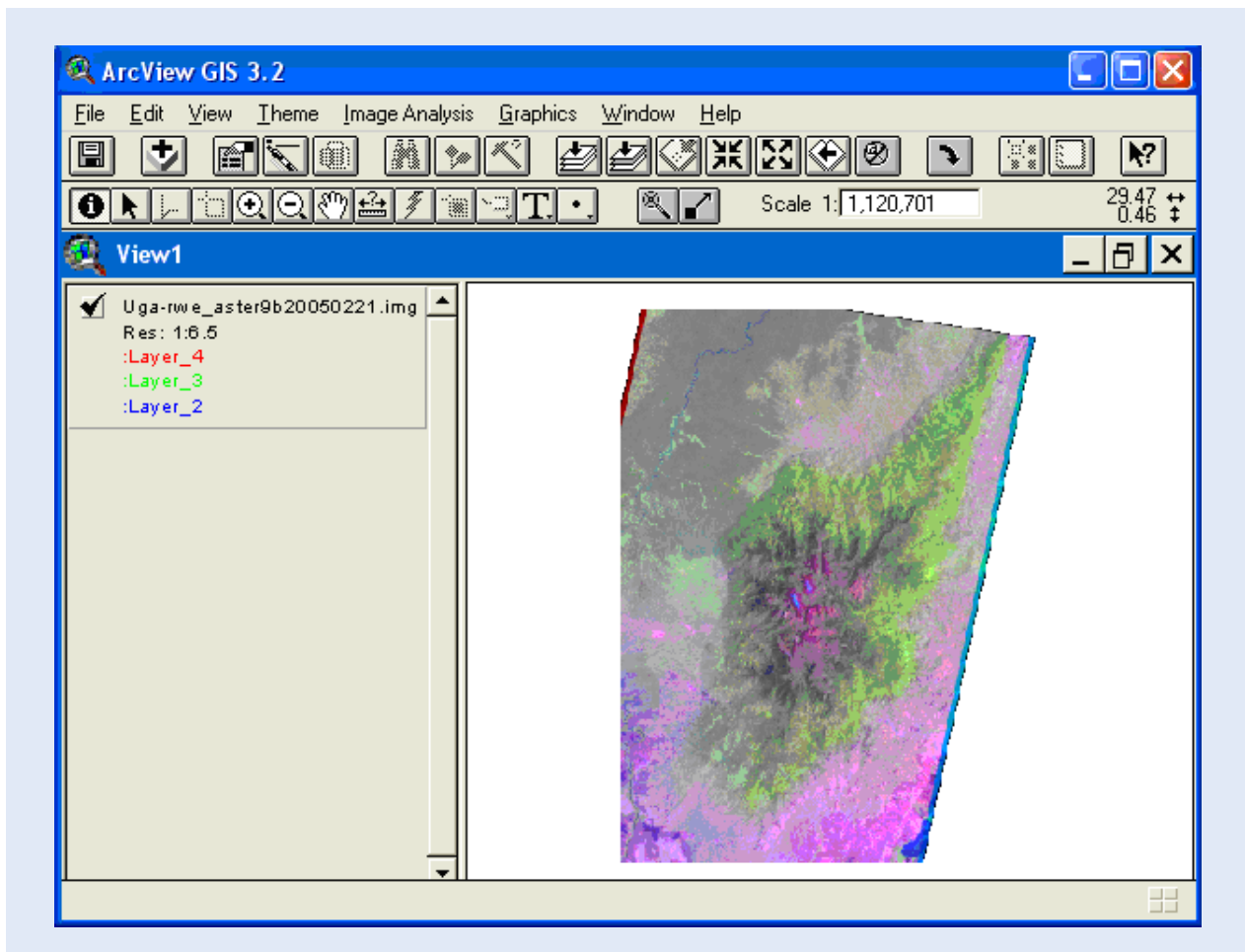


If you loaded the extension for Imagine Image support, you can load the image as an Image Data Source.

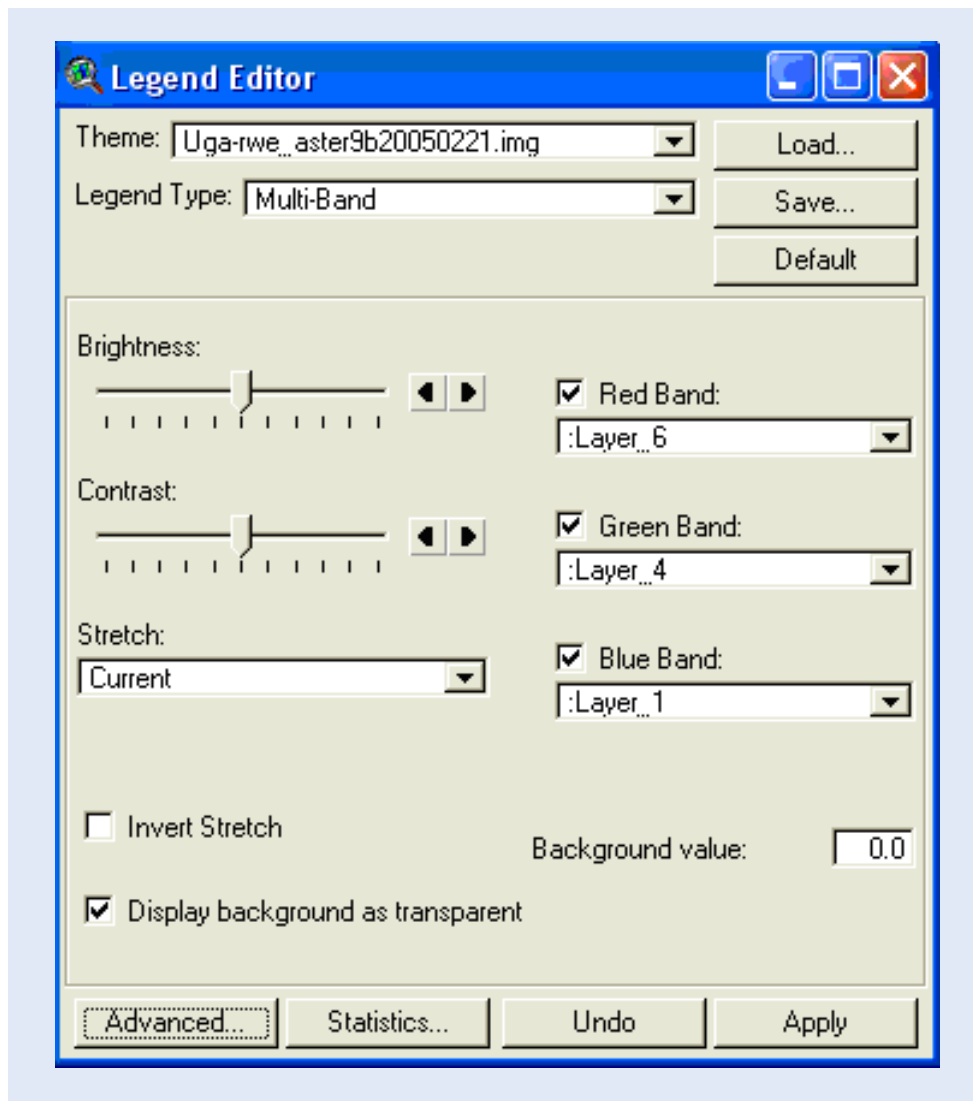


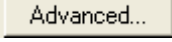
The color setting and the legend entry will look a bit different dependent on which Data Source Type you add the image as.

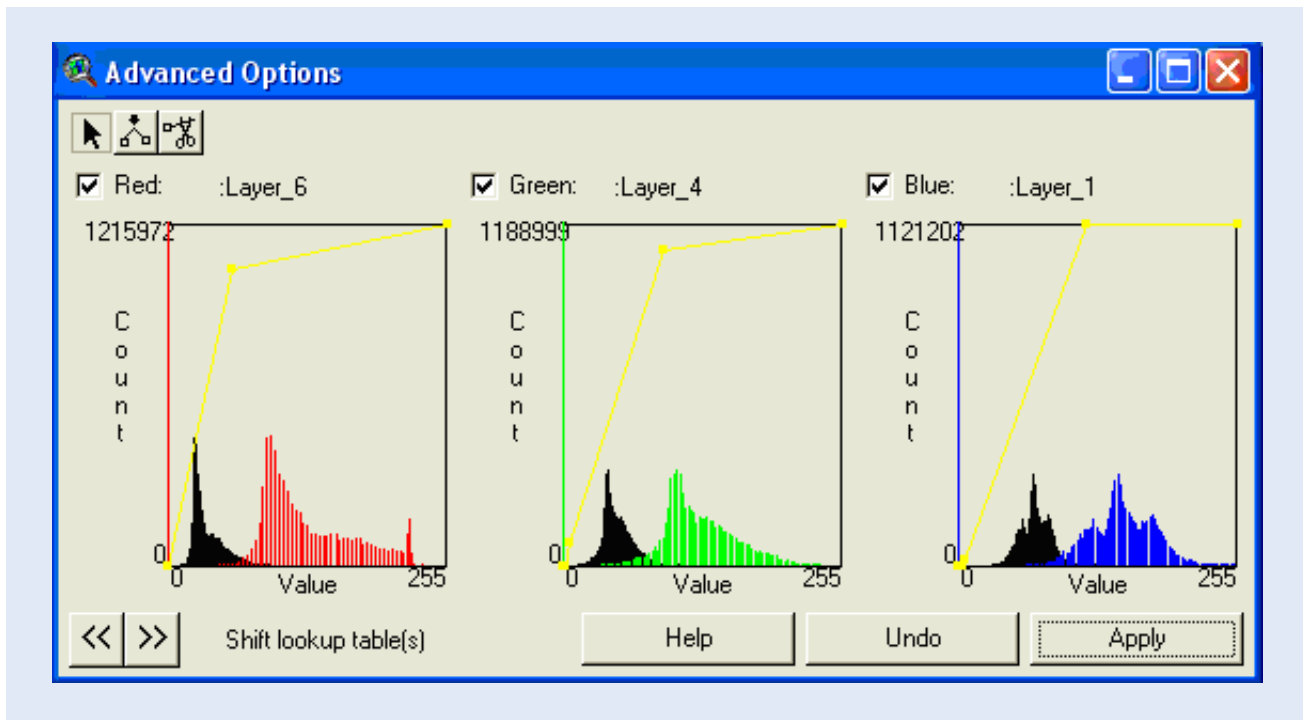
If you added the data as Image Analysis Data Source the default coloring is that the first band is used for blue, the second for green and the third for red. Images with more than 3 bands (the ASTER image has 9 bands) the coloring is instead based on bands 4-3-2. To change the change the color setting by double clicking the image in the Legend window, or use the menu entry: Theme – Edit Legend.



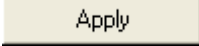


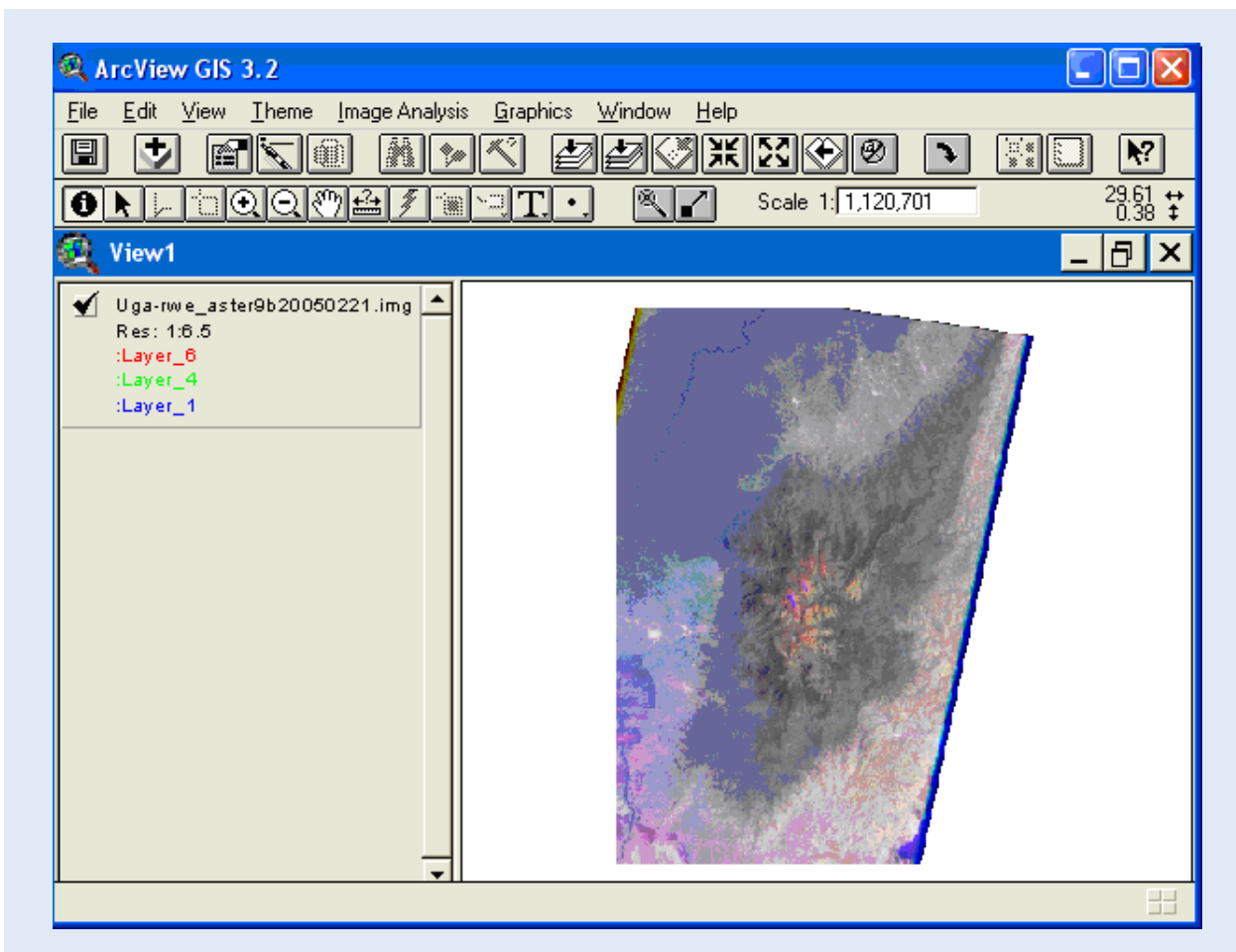
In the example I have changes the R-G-B coloring to bands 6-4-1.



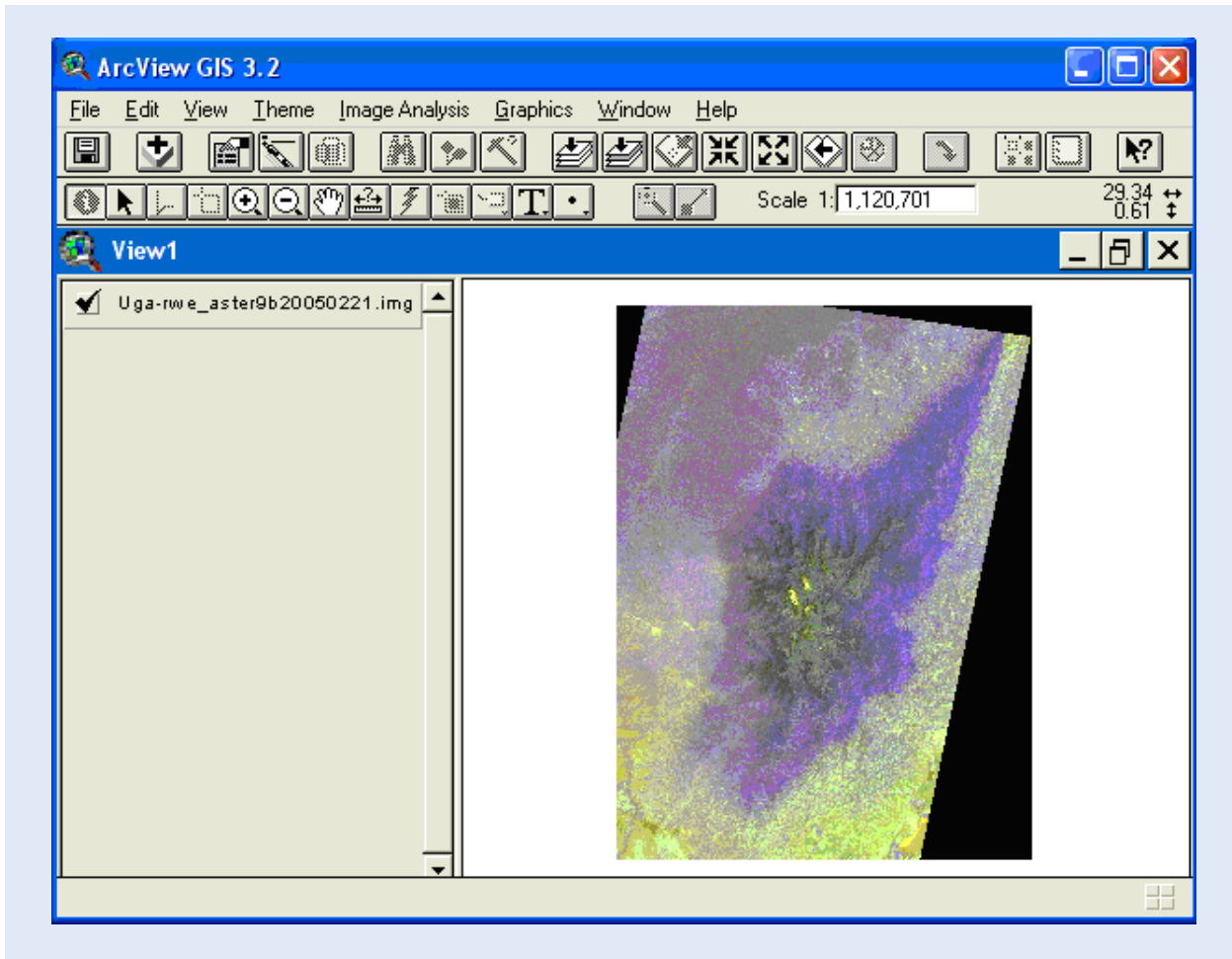
I then used the Advanced button  to stretch the bands individually. Stretching means that you shift the input histograms of a band to a new output histogram. In the example below all input bands are stretched from lower (black pillars) to higher (colored pillars) values, and the width of the Digital Numbers (DN) of the histogram is increased. The color balance of your output image depends on the histogram of the colored pillars. In ArcView there are several default stretch types available, and you can also stretch the overall Brightness and Contrast of an image from the Legend Editor.



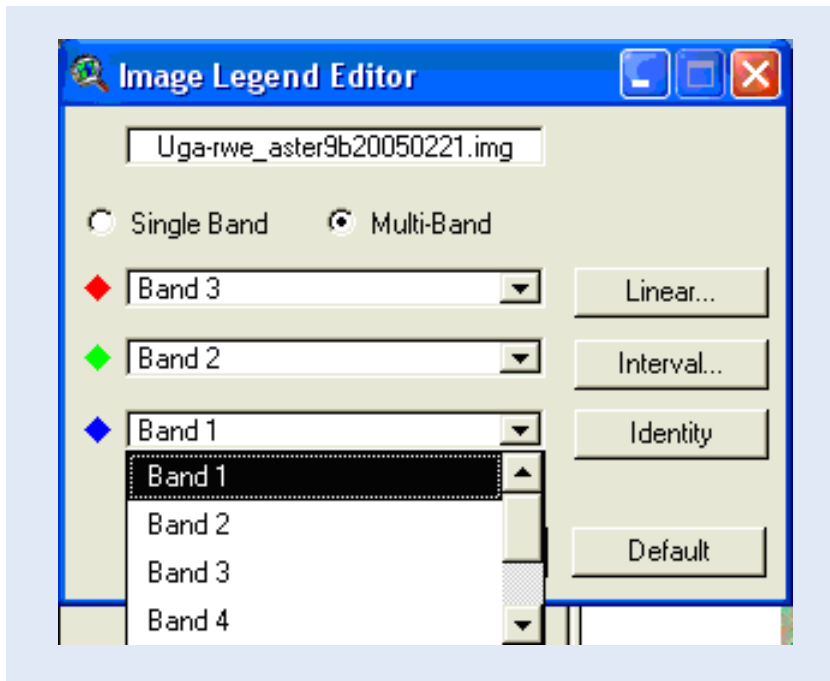
In the Advanced Options dialogue window you can create any stretch you want by using the buttons for Add Point , and Delete Point . Remember to press Apply , to force the changes to take place. My final effort in creating a naturally looking image you can see below.



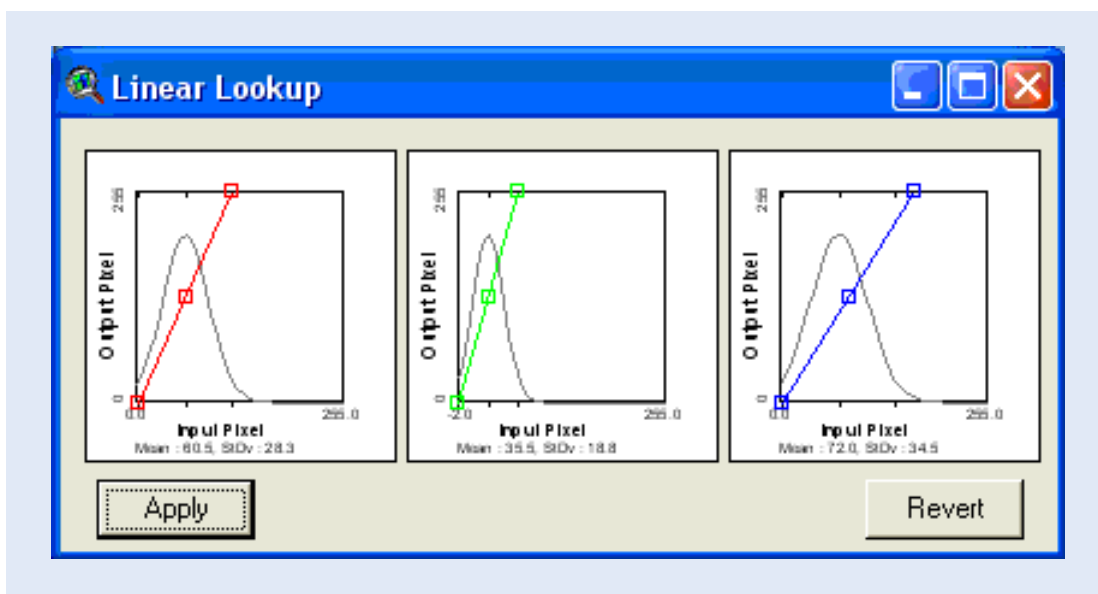
Even if you do not have the Image Analyst extension you can manipulate the display of an image to a high degree. Below is the Aster image loaded as an Image Data Source – the default setting is that the first band is used for red, the second for green and the third for blue (opposite the default for Image Analysis Data Source). You can change the color setting by double clicking the image in the Legend window, or use the menu entry: Theme – Edit Legend.



In the Image Legend Editor you can change the band composition for creating the color image (or change to a Single Band display). To get a better coloring of your, image change red to be band 3, and blue to be band 1, keep band 2 for green color.




The image should now have a basic red color instead of being blueish. To further manipulate the coloring you can use the Linear or Interval buttons in the Image Legend Editor to stretch the individual bands in the compositions. The options are not as advanced as for Image Analysis Data Sources, but are enough for most purposes.

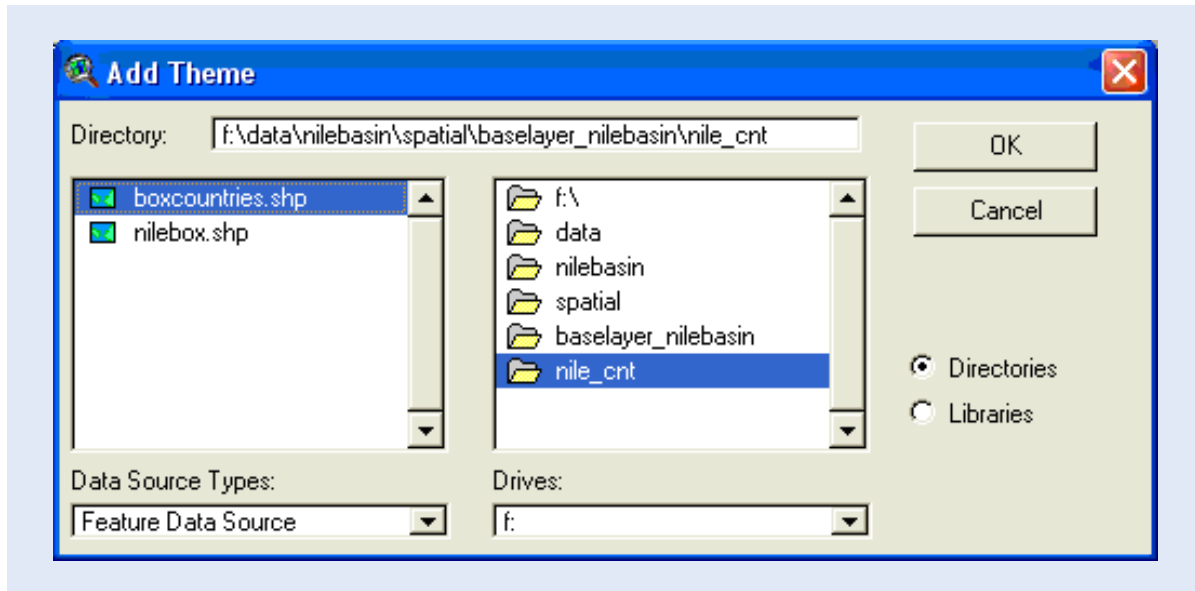



Load naturally looking image

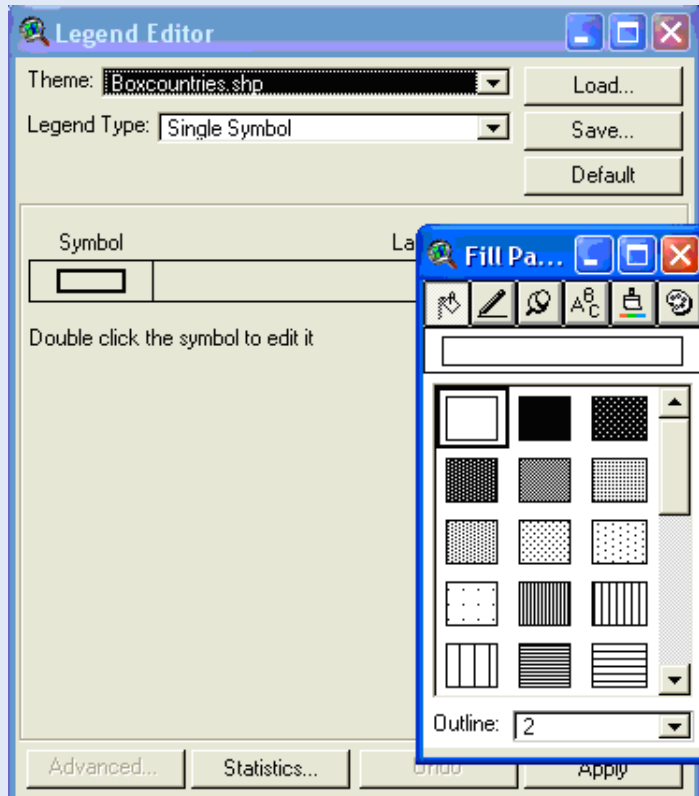
To create a more realistic natural coloring of satellite images demands more advanced programs, or in-depth knowledge about avenue programming, which is beyond the scope of this exercise. Instead I have created naturally looking images for each satellite image used in this exercise. If you want to use these images for the further work they are under the sub-directories "natural color". If you load these pre-processed images as Image Data Sources they will display correctly, if you load them as Image Analysis Data Sources you need to reset the R-G-B bands to 1-2-3 and set stretch to None (all in the Legend Editor). The naturally looking ASTER image was created from the three bands in the VNIR image file at 15 m resolution (the original image is available in the file - uga-rwe_astervnir20050221.img).


Add feature data showing international boundary

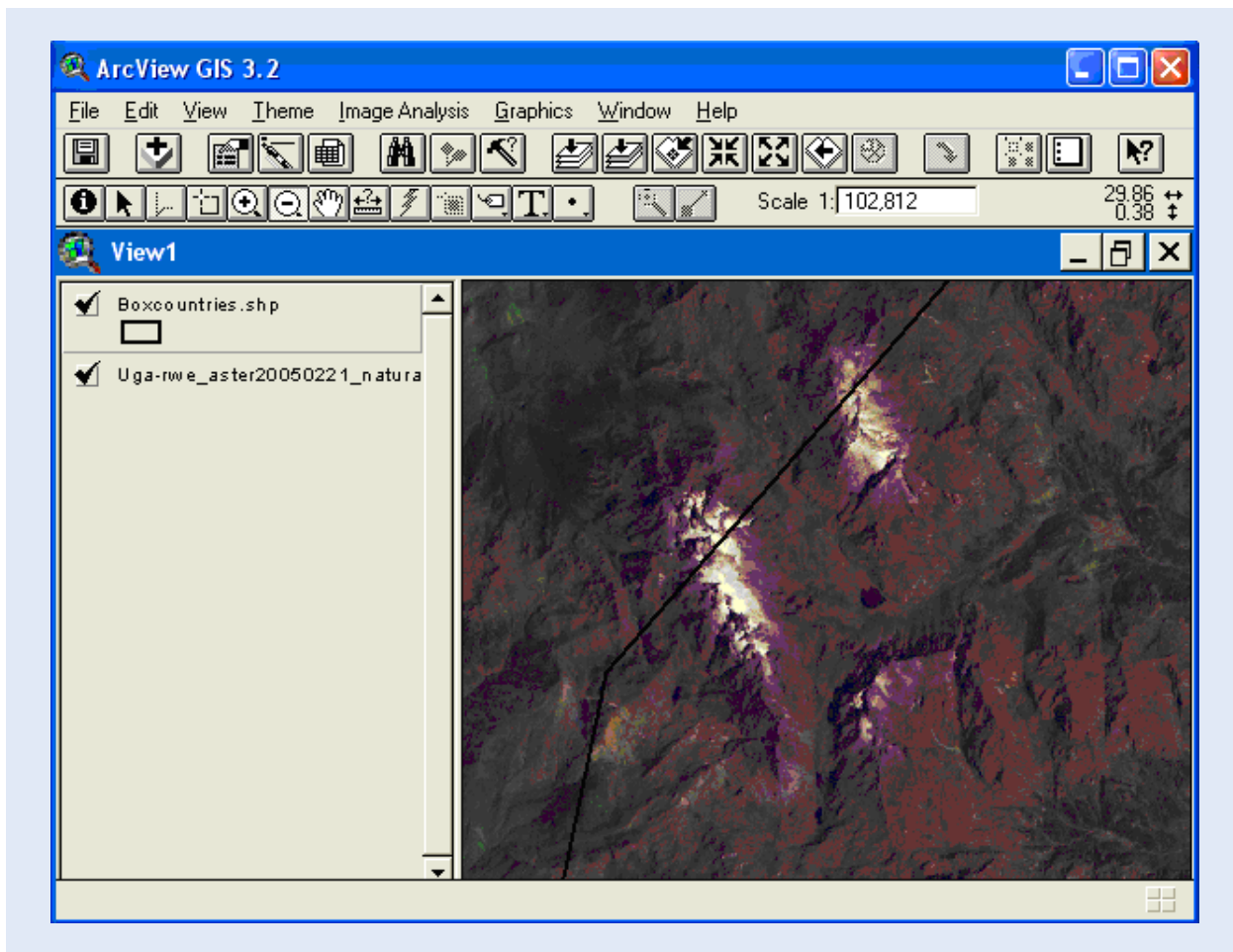
To find your way better in the images we are going to add a feature with international boundaries. Use Add Theme , set Data Source Types to Feature Data Source, navigate to the directory data\NileBasin\Spatial\BaseLayer_NileBasin\Nile_Cnt, and add the theme "boxcountries".



The theme boxcountries is a polygon vector (the two other vector formats are points and lines). The polygon theme covers the images, but we only want to display the boundaries. Hence double click the boxcountries theme in the legend. In the Legend Editor dialogue box click the Symbolizing icon, then Click the Fill Palette , and change the filling to transparent and the Outline width to 2. Click Apply to force the changes to take place.



Use the button for Zoom In , to zoom to the peaks of the Rwenzori, that also straddles the boundary between Uganda and the D.R. of Congo. The boundaries in the database are not made for use at large scales, hence the position of the border between Uganda and the D.R. Congo is not correct at this large scale.

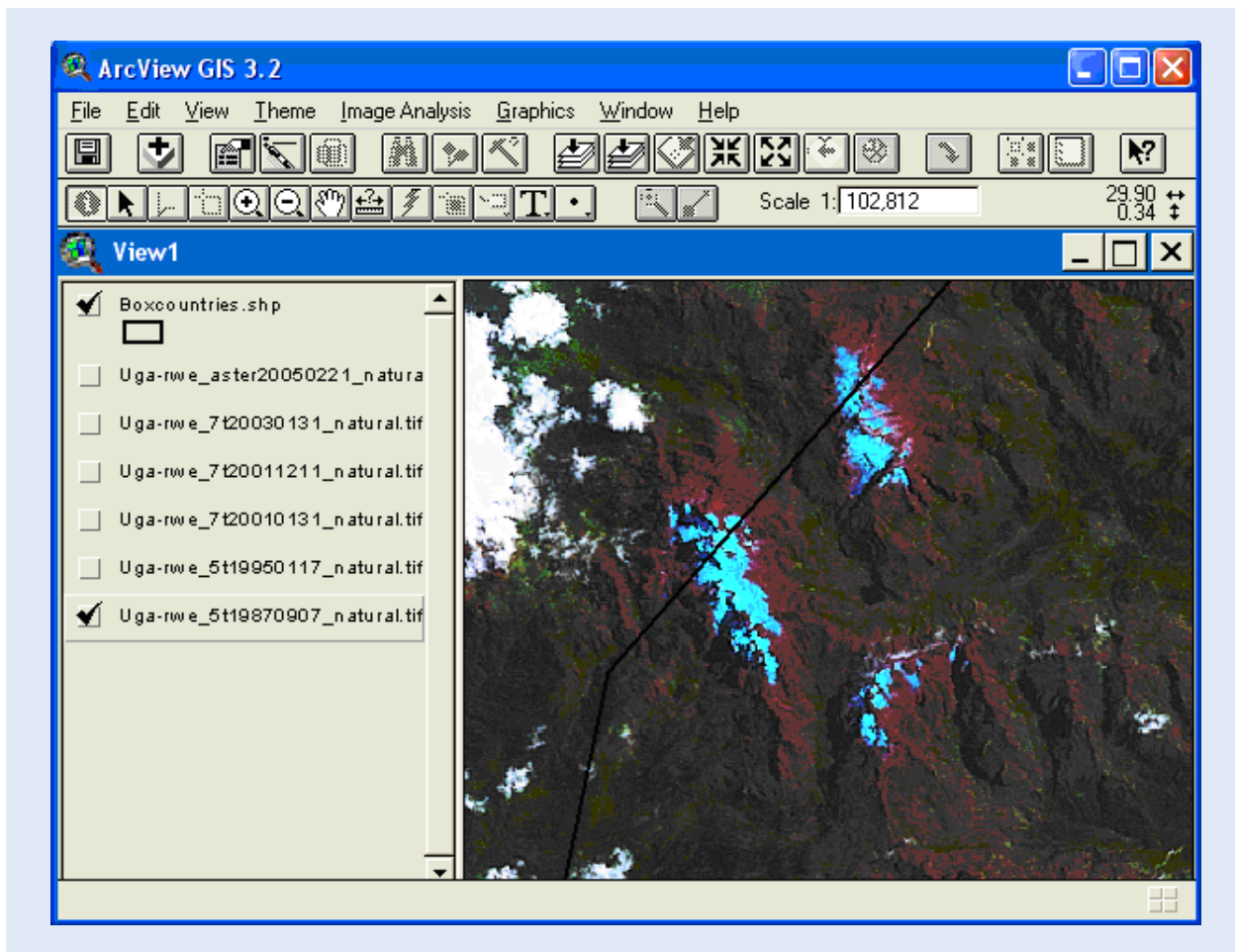


The ASTER images (the image you have used is a composite of two individual scenes) over the Rwenzori Mountains are exceptionally clear. All other images acquired over the last 30 years are more or less cloudy. The peaks, however, are often clear in the mornings, and both Landsat and Terra passes the equator between 10 am and 11 am. So the peaks can usually be seen.

Add a time series of satellite images

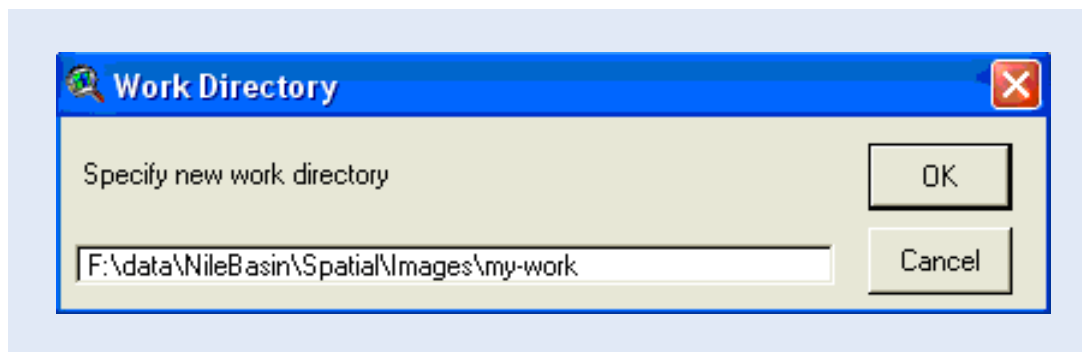
To finish this first part of the exercise you shall add some older images to visually look at the change in the extent of the glaciers on the Rwenzori Mountains. To see the changes add the Landsat TM and ETM images given in Table 1. You can either add the original images, or use the pre-processed natural color images (go to the sub-directory "natural color" instead of "Imagery" as given in table 1).

Arrange the themes by using the mouse to grab them in the legend (click and hold left mouse button) and then slide them up or down in the legend with the mouse before releasing them. Then turn them on and off by clicking the check-box, and you should see the change in the extent of the glaciers since 1987.



Part 2: Band rationing and image classification – mapping the glaciers on the Rwenzori Mountains

In this second part of the exercise you will use the Normalized Difference Snow Index (NDSI) to map out the snow and ice extent in the satellite images. As we will produce several new images in this part, make sure you have set the working directory. In my example I set the working directory to data\NileBasin\Spatial\Images\my-work (I first created the directory my-work).


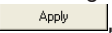


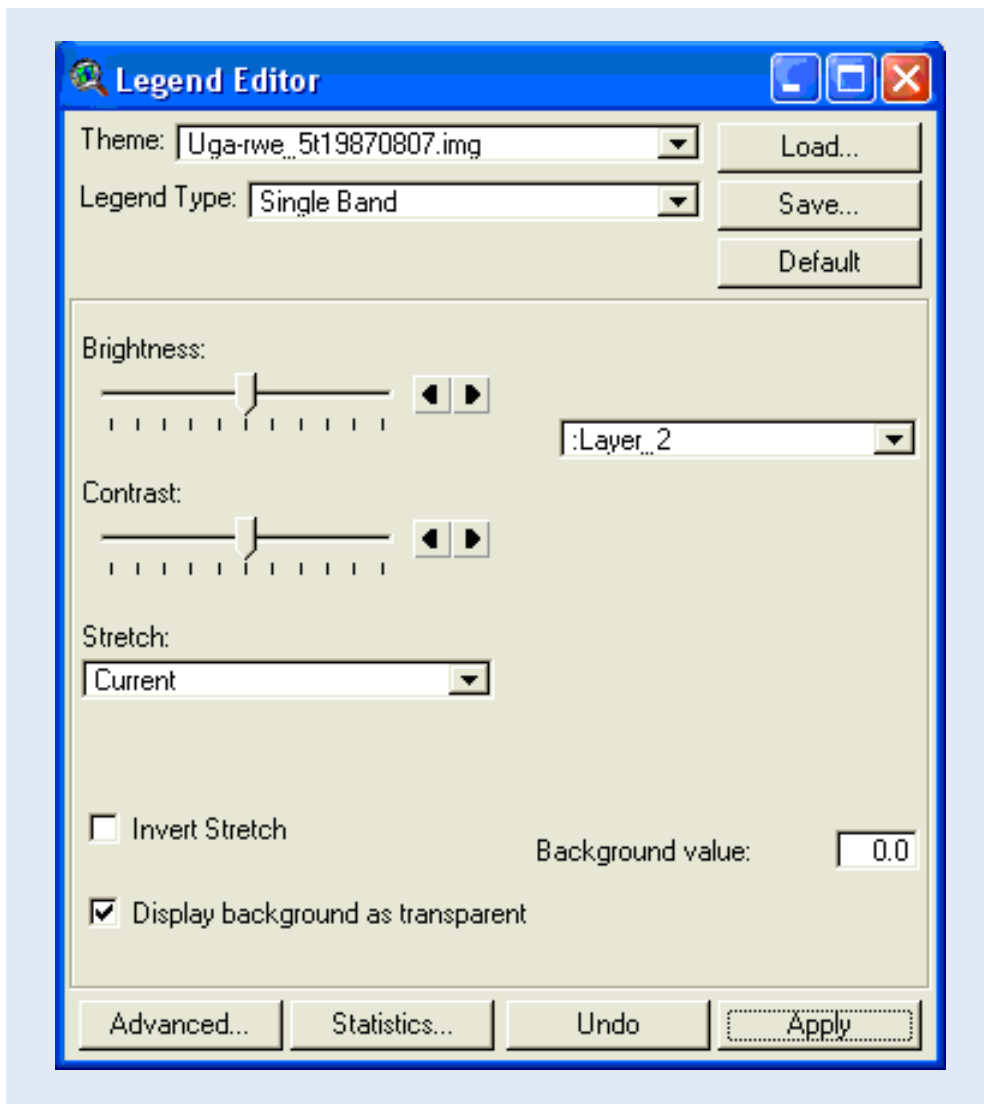
Using band rationing is very common in remote sensing, and because it uses a ratio of two or more bands, it overcomes some of the calibration problems that hamper older satellite images. Modern sensors (including ASTER and MODIS on TERRA) have internal calibration that can remove noise and errors stemming from varying atmospheric conditions, sensor drift and degradation.

NDSI uses a ratio between red and middle infrared to map out ice and snow cover of the ground:

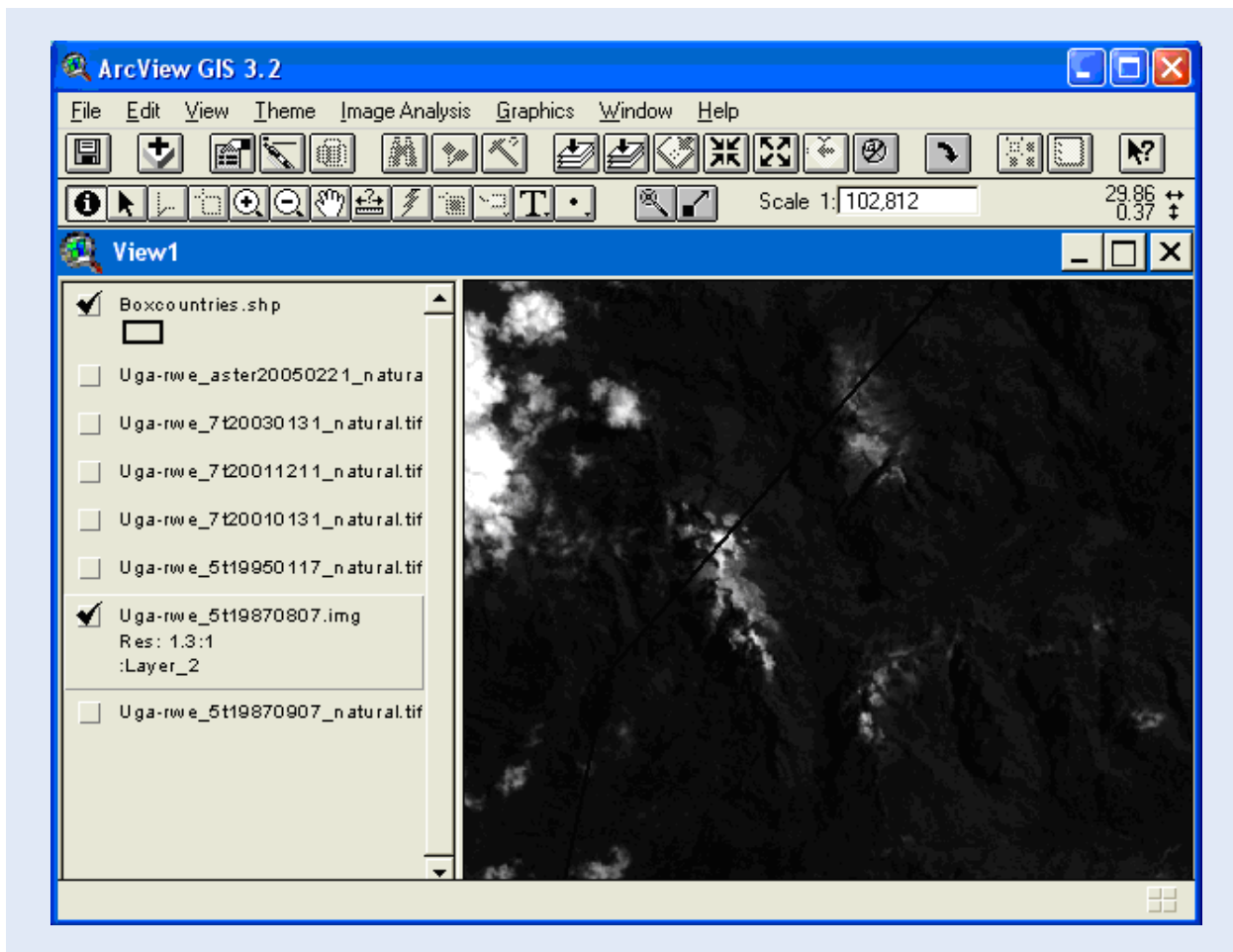
$$\text{NDSI} = (\text{Red} - \text{Middle InfraRed}) / (\text{Red} + \text{Middle InfraRed})$$

For Landsat (E)TM the Red band is band 2 (0.56 μm) and Middle InfraRed band is band 5 (1.65 μm). As snow strongly reflects visible light (e.g. red) but absorbs middle infrared light, NDSI is high over snow and ice.

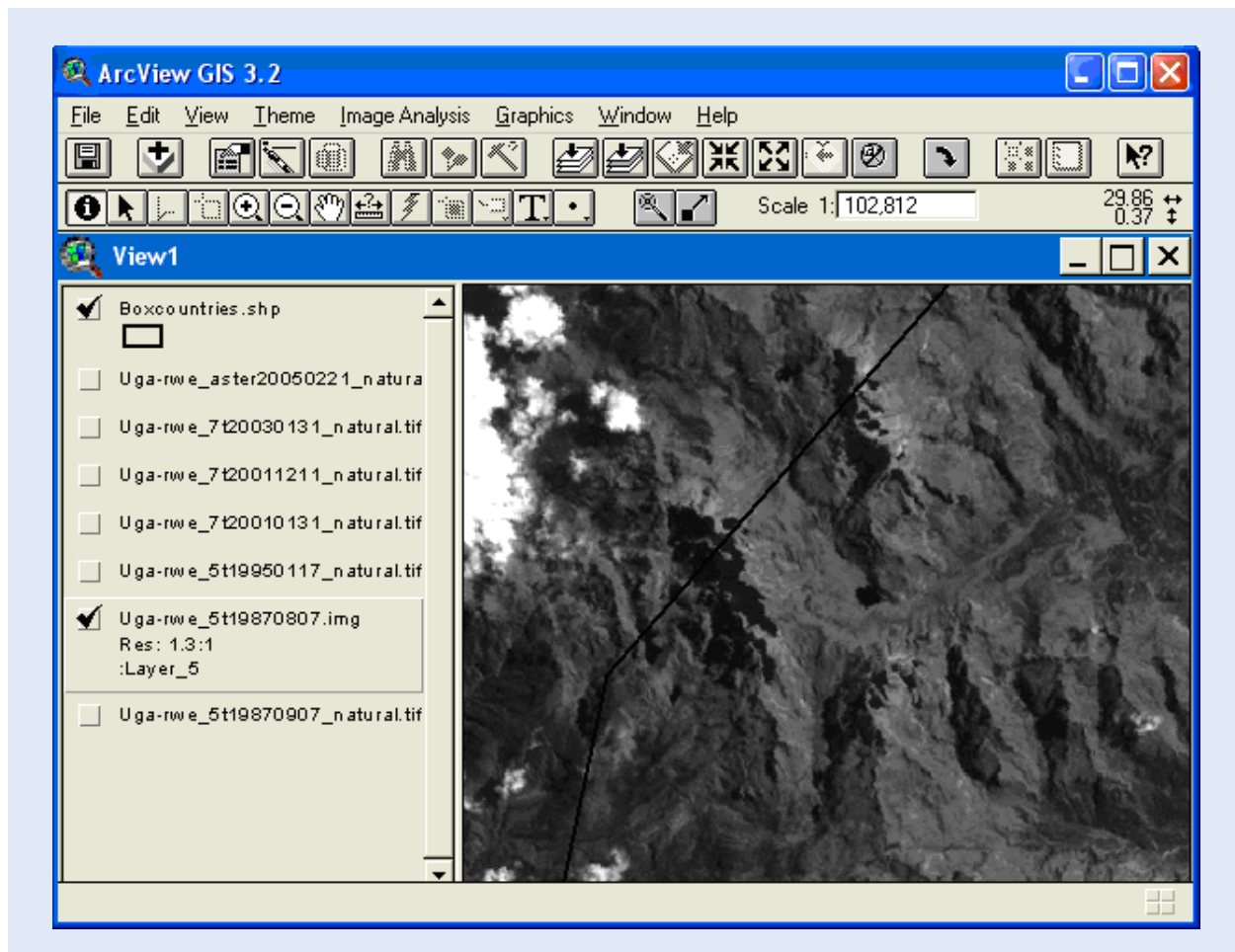
As you need the original image data for doing the calculations, add the Landsat (E)TM and Aster imagery themes (see table 1). First you should have a look at the individual bands that we are going to use. Open the Legend Editor for any of the images - double click the theme in the legend, or click the button for Edit Legend . Use the drop down menus to change the Legend Type to Single Band and then select the red layer (Layer 2 for the TM sensor) to be displayed. Remember to click apply , to force the changes to take place.



Now you should see the strong reflection of snow and ice (and clouds) in the red band.

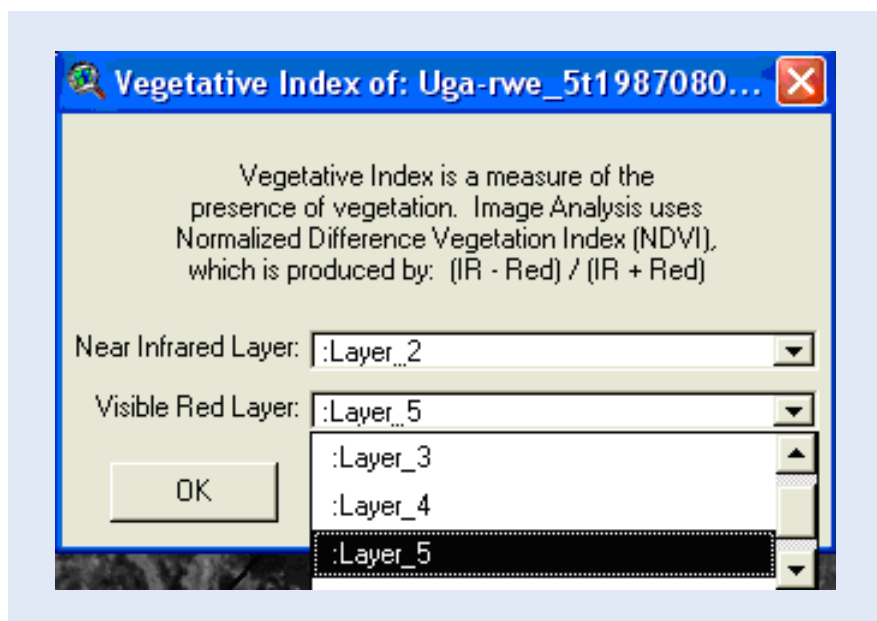


Use the Legend Editor to display the middle InfraRed band (Layer 5 for TM) instead. As you can see the snow and ice on the peaks of the Rwenzori Mountains strongly absorbs radiation in the middle IR range (they appear black), however clouds strongly reflect also in middle IR. Hence we can safely use the NDSI also in our rather cloud contaminated images, the NDSI will easily discriminate between snow and ice on the one side and clouds on the other.

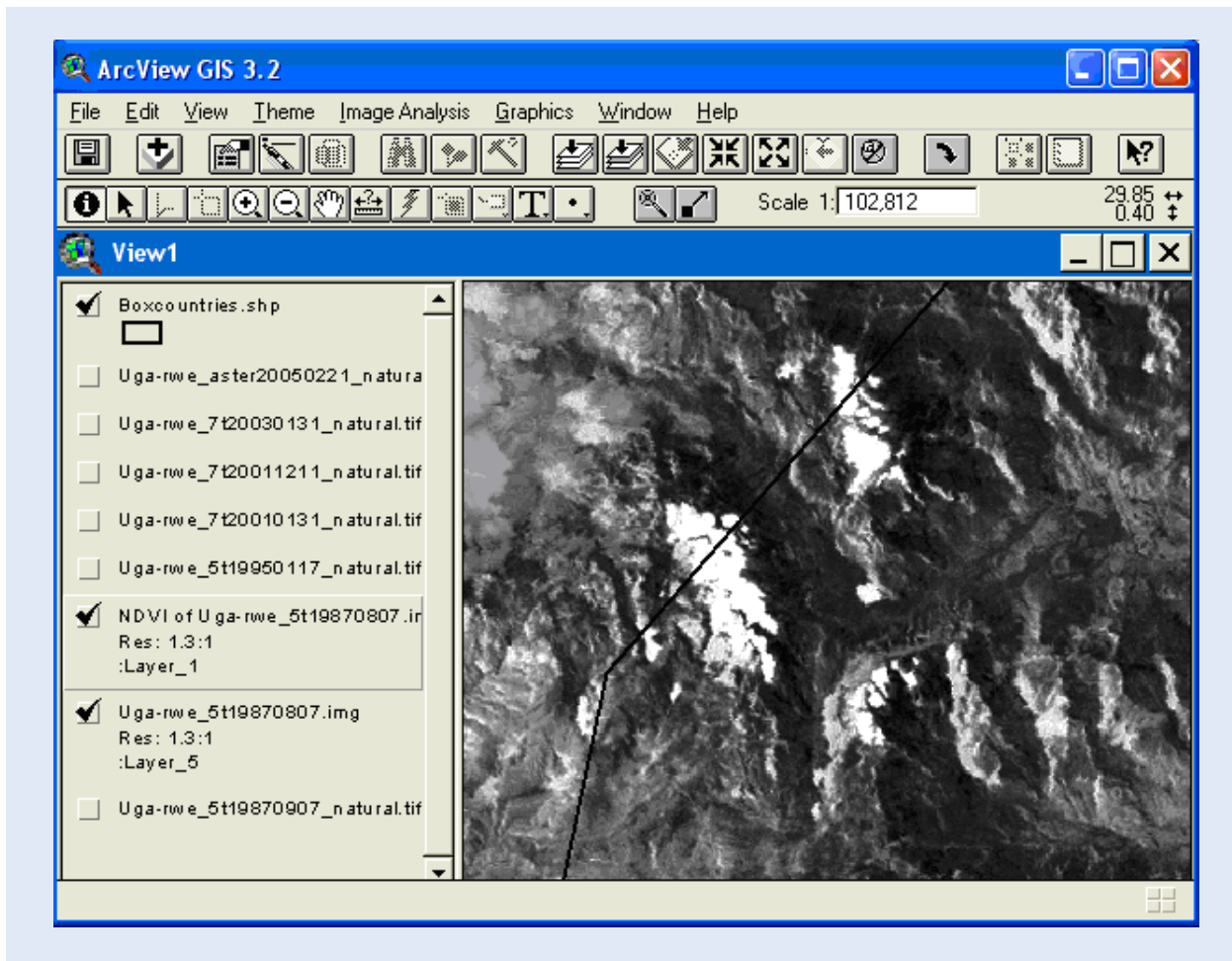


Calculate the NDSI (Image analyst)

With the Imagery theme as the active theme (appears lifted in the legend) use the legend menu: Image Analysis - Vegetative Index (the Vegetative Index is calculated using the same formula as NDSI, but with other bands as input – you will use it in part 3). In the dialogue window of Vegetative Index use the dropdown menus to set the first Layer to Red (Layer 2 for TM) and the second Layer to Middle InfraRed (Layer 5 for TM), then click OK.



The resulting image will distinguish snow and ice from other features in the image.



To avoid getting confused by the now erroneous title of your NDSI theme, use the menu: Theme – Properties, and change the title of the theme.

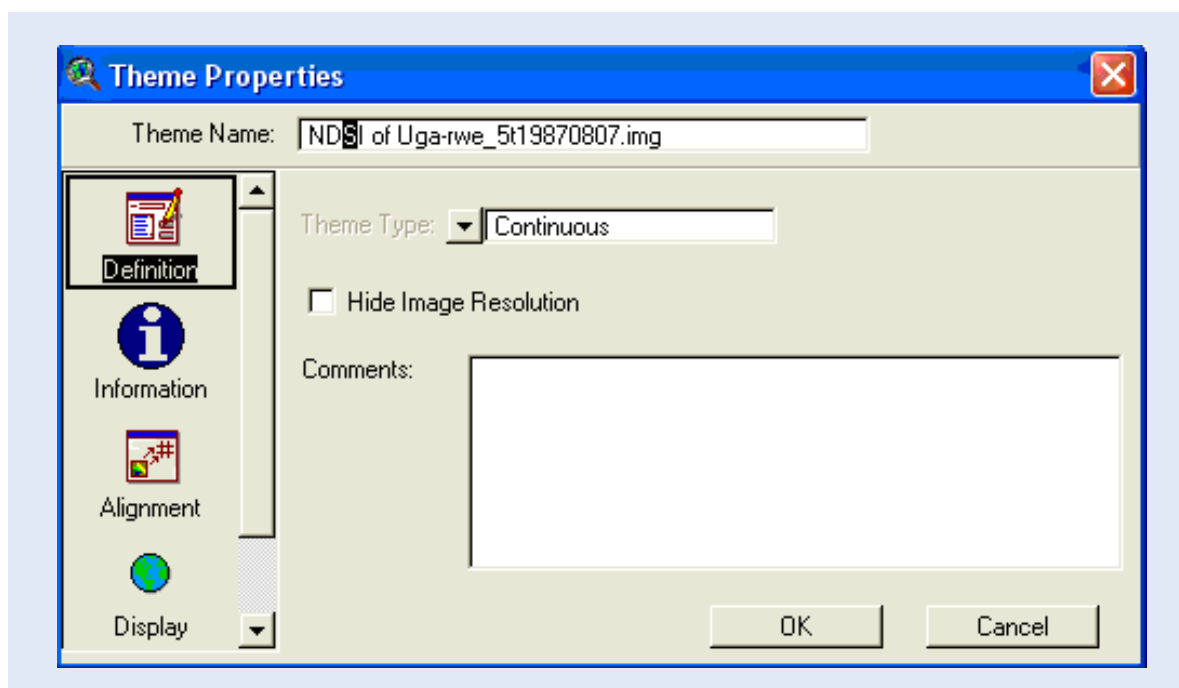


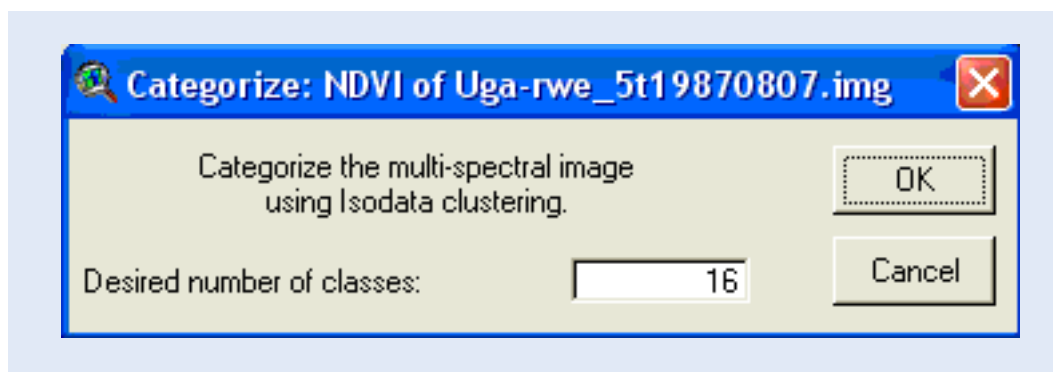
Image classification (Image Analyst)

Hitherto you have used stretching and band combinations (part 1) and band rationing (part 2) to enhance the information content of the satellite images. Now it is time to classify the raster images into objects. There are two main processes for classifying images – unsupervised classification and supervised classification.

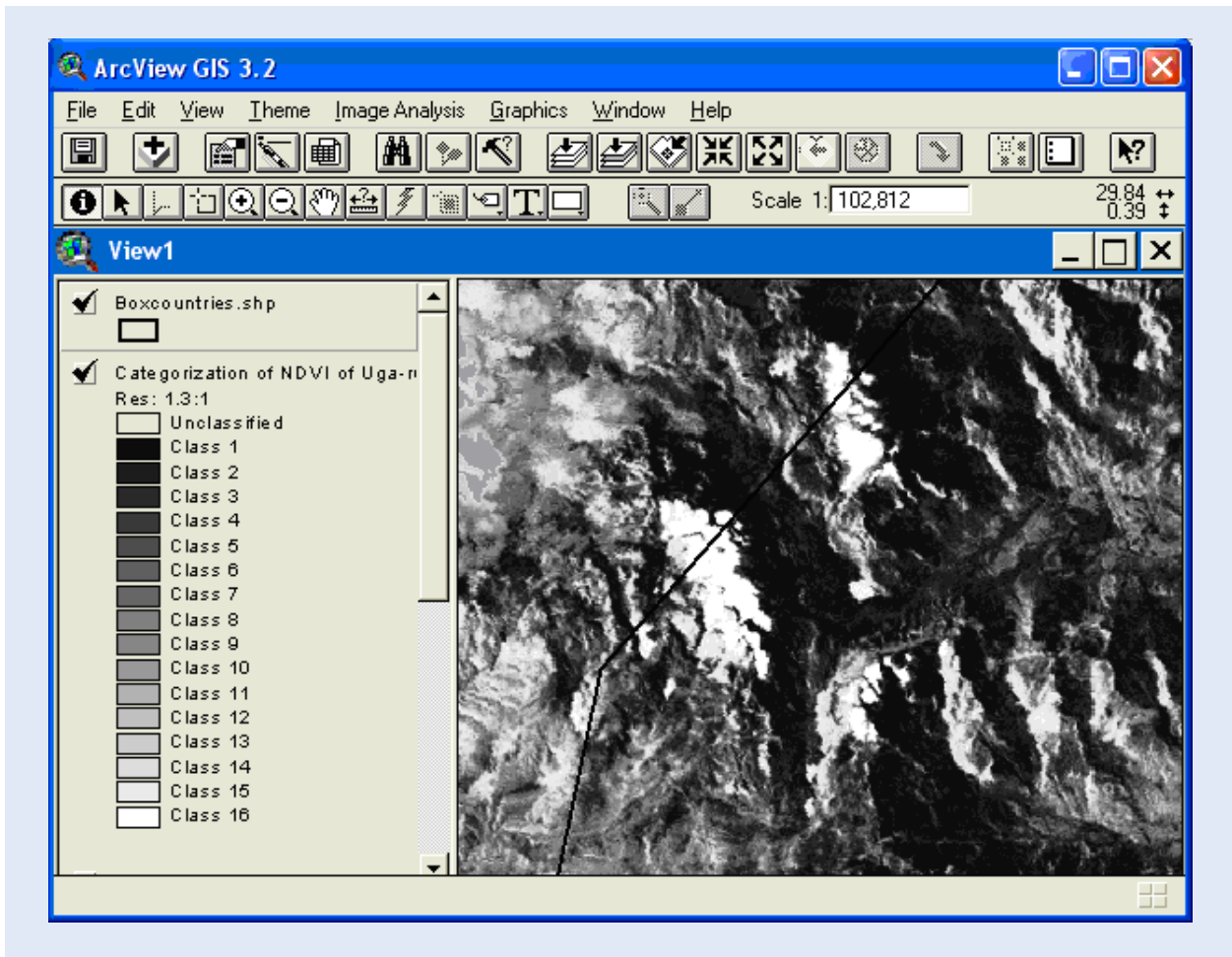
Unsupervised classification (Image Analyst)


Unsupervised classification is done without any ground-controlled data as input; it is a statistical classification that aims at finding clusters of pixels with similar characteristics. The classification is done as a post-processing, where the user assigns classes to each statistical cluster found. There are numerous clustering algorithms available, but for us it is enough just to try out the default unsupervised classification in ArcView.

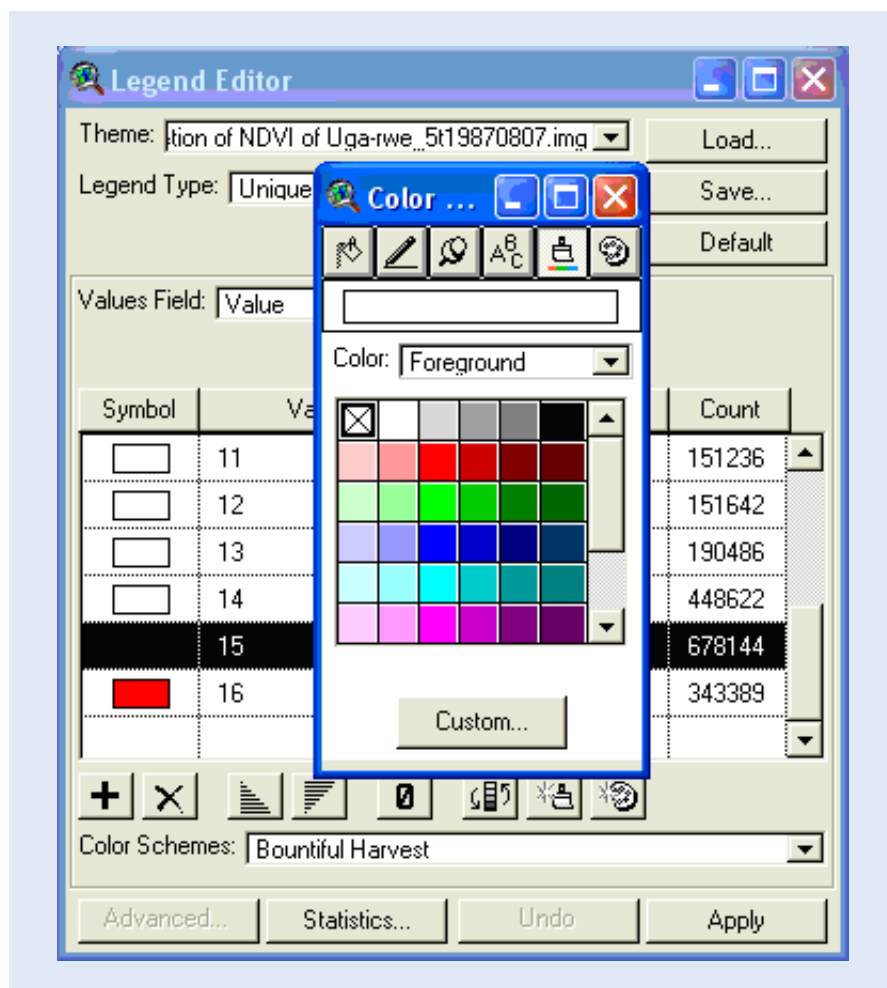
As we want to classify the glaciers, make sure the NDSI is the active theme, then perform the unsupervised classification via the menu: Image Analysis – Categorize. In the Categorize dialogue set the Desired number of classes (e.g. accept the default of 16), then click OK to start the classification.



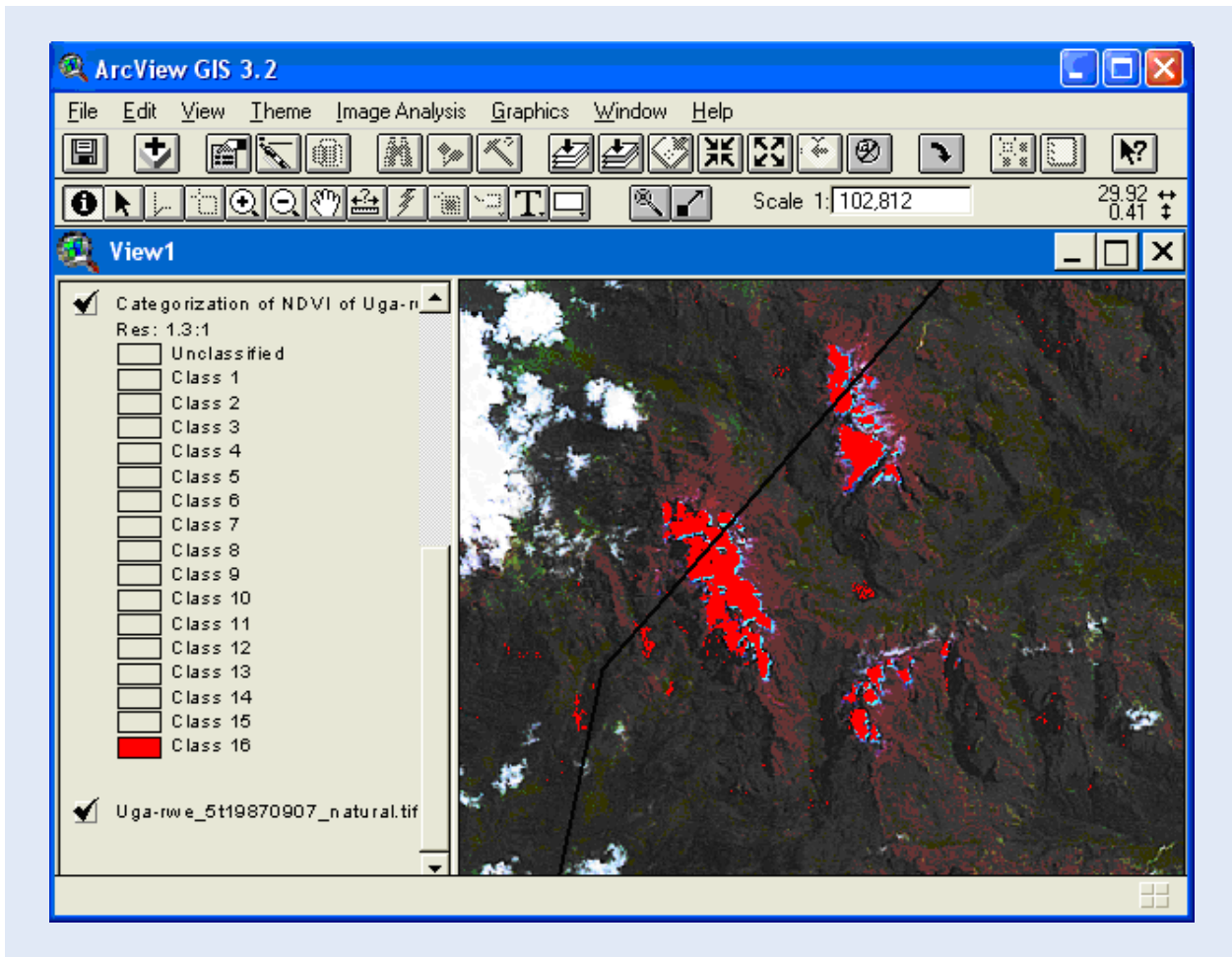
The classification result is automatically added to the project, with categories displayed in grayscale.



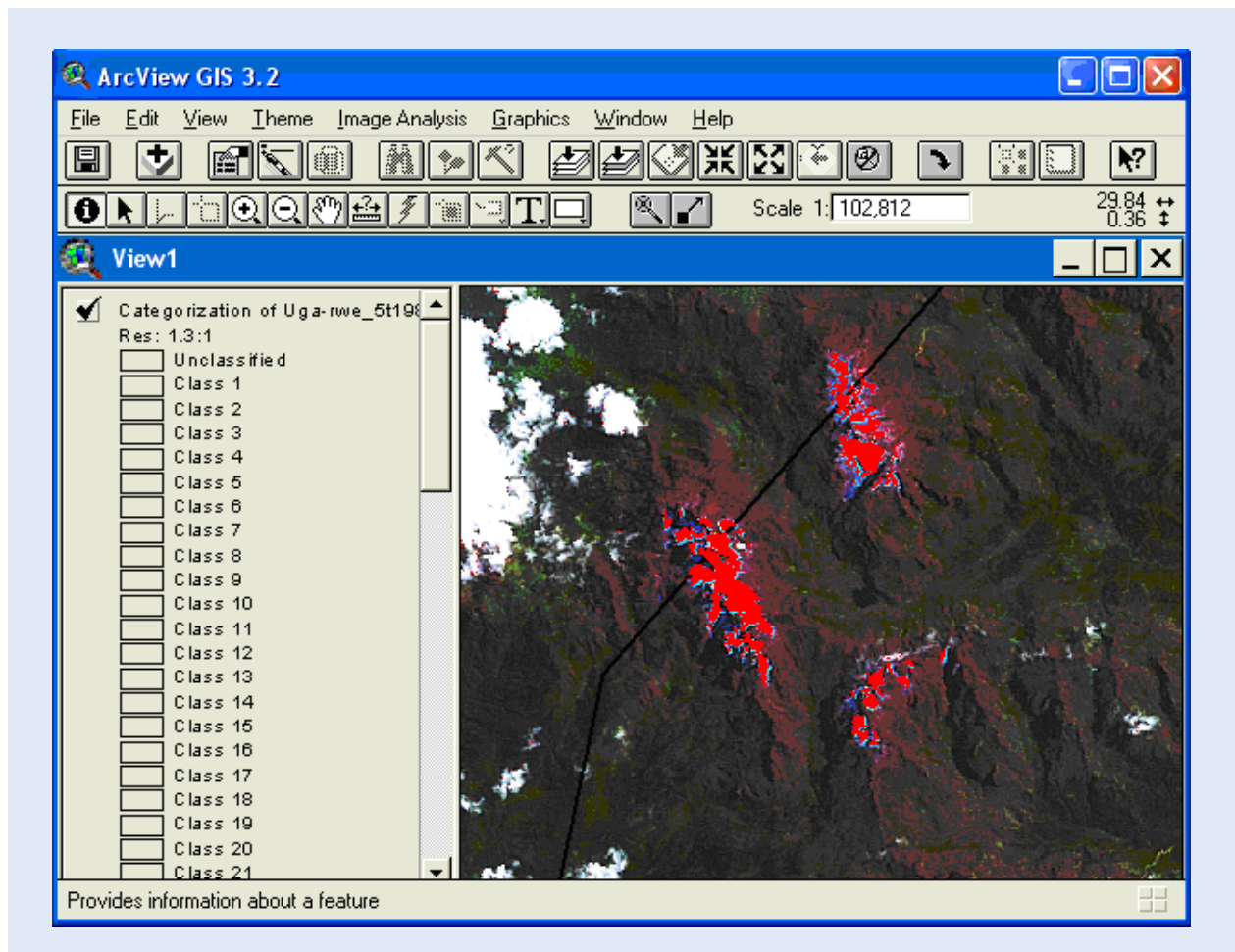
Use the Information Tool , to find out the class assigned to the glaciers (should be the highest class(es)). Then use the Legend Editor to change the Color Palette, and set all layers to transparent except the glacier class category (that I set to red).



You can now display the glacier classification on top of the natural color image used for creating the NDSI and the unsupervised classification.



If you examine the image closely you will notice that the categorization needs to be fine-tuned, areas outside the glaciers were classified as glaciers (including the small lake between the peaks, plus some shadow areas). It is typical for image classification that the process must become iterative in order to derive at a satisfactory result. The alternatives you can use for improving the unsupervised classification include: 1) assigning a larger number of classes for the categorization, 2) using a multi-band image with more information as input, 3) stratifying the images using some a-priori information (e.g. elevation), and 4) combining these alternatives. The glacier classification below was created using the natural color image as input in a categorizing yielding 32 categories.

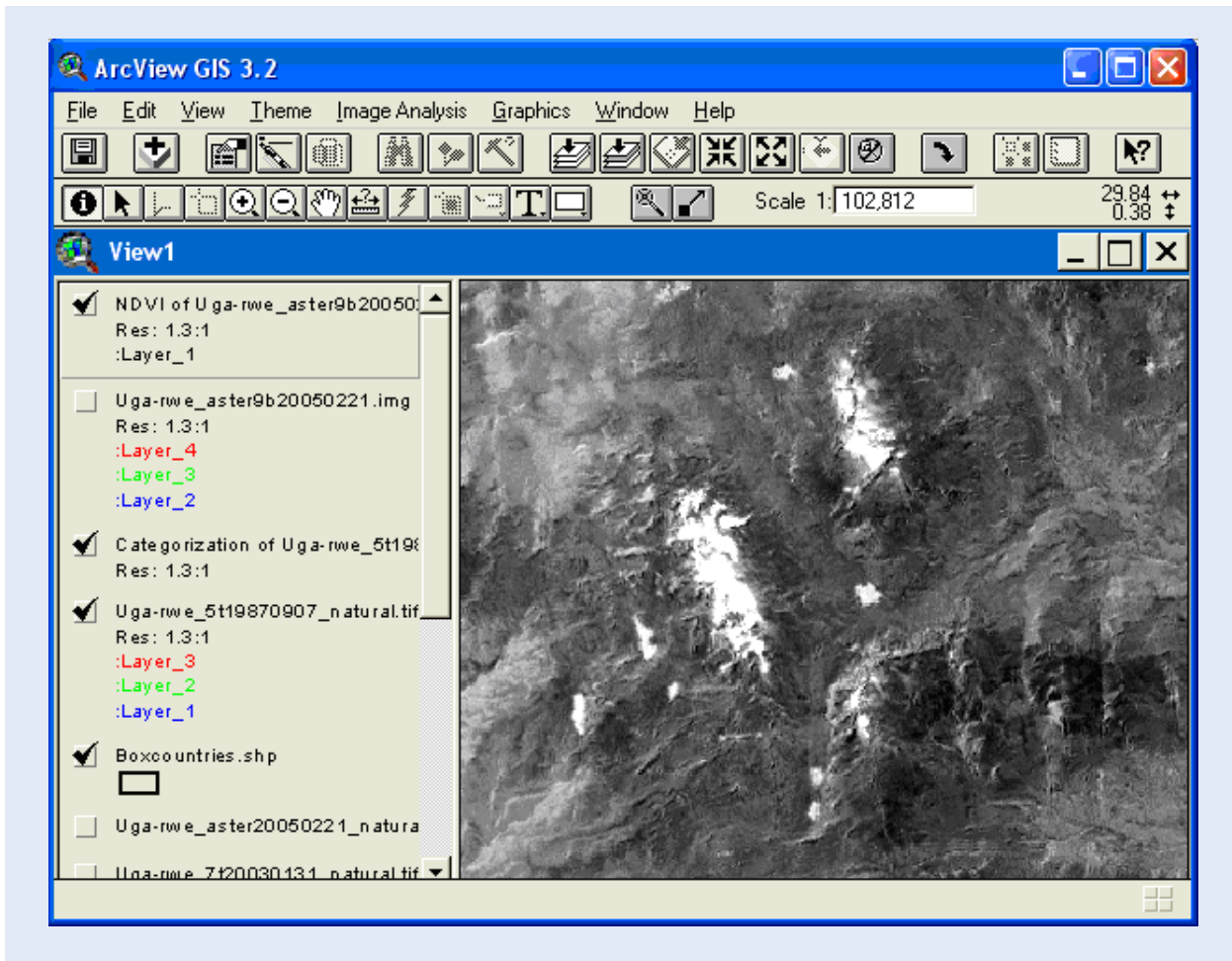


Supervised classification (Image Analyst)

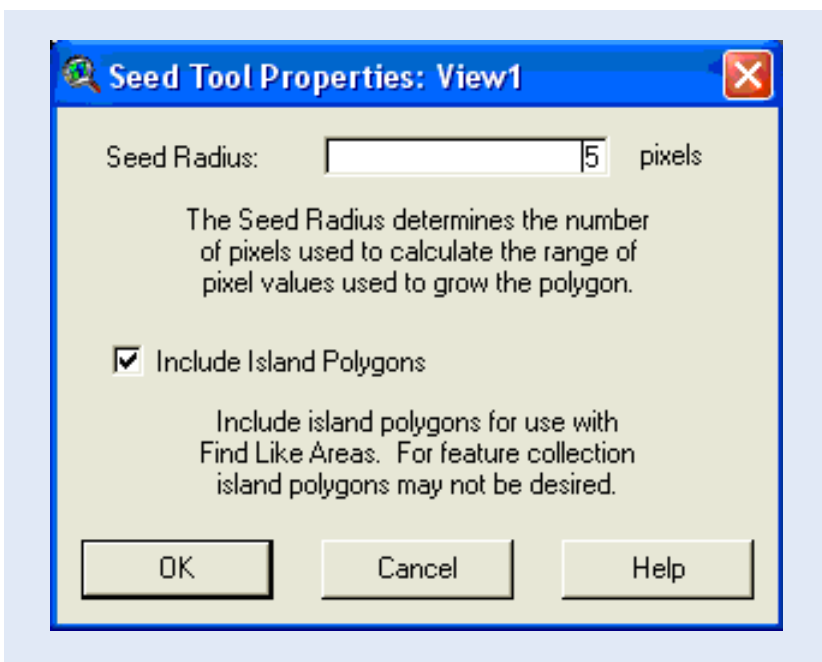
Supervised classification is based on training areas – areas with known characteristics, identified by the user and used for inferring statistically rules that seek out similar areas throughout the image. In ArcView Image Analyst there are two alternatives for supervised classification; the first is to digitize polygons as training areas, and the second is to use a mouse click as a seed tool. The latter is most appropriate when you want to find the boundary of just one contiguous area of pixels with a particular characteristic – exactly what we want to do for delineating the glaciers.

Delineation of glacier extent in 2005 using the seed tool (Image Analyst)

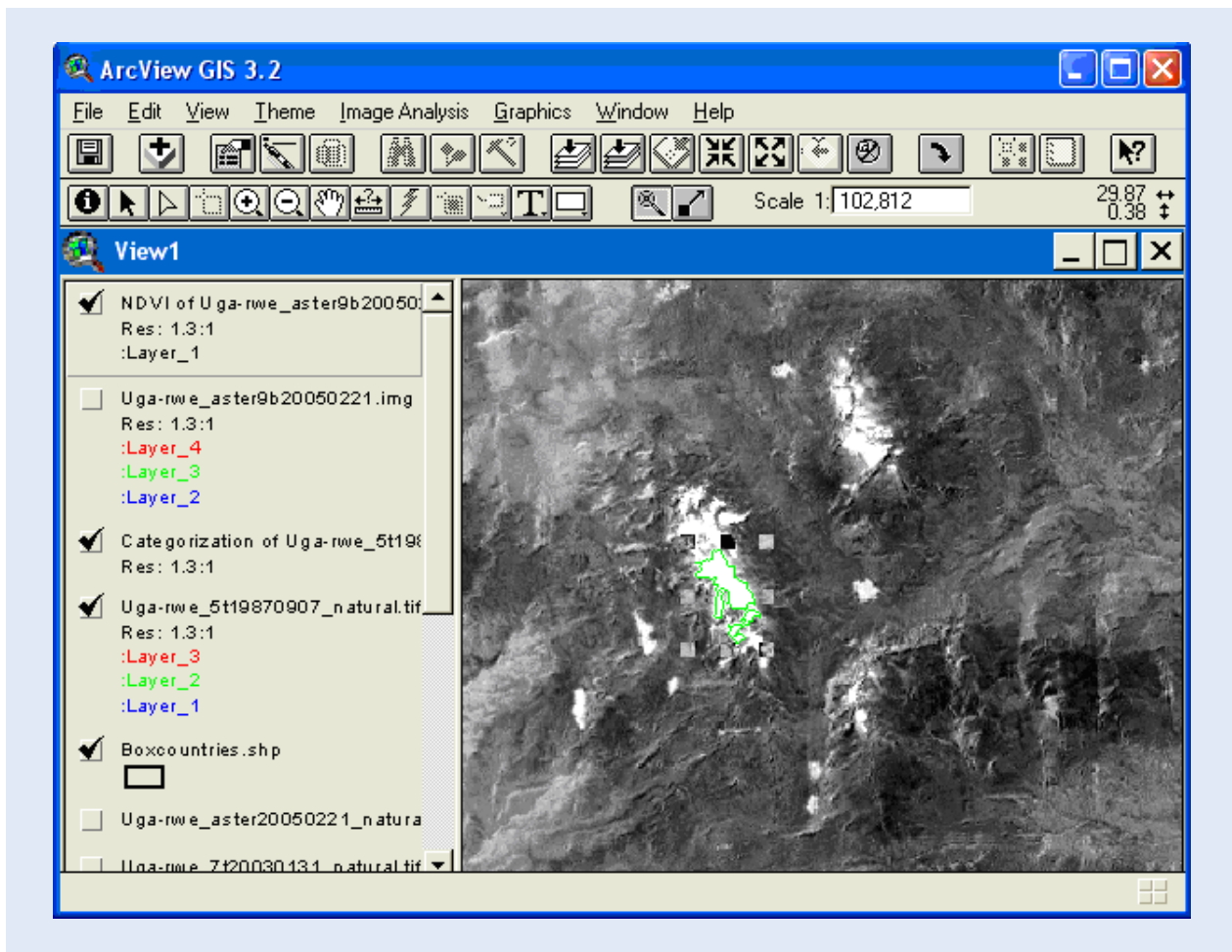
First you need to create a Normalized Difference Snow Index image using the ASTER image from 2005. Consult table 2 to select the appropriate bands to use.




To set the properties of the Seed Tool use the menu: Image Analysis – Seed Tool Properties. As the glaciers are rather small, you might need to decrease the default radius of 5 pixels.



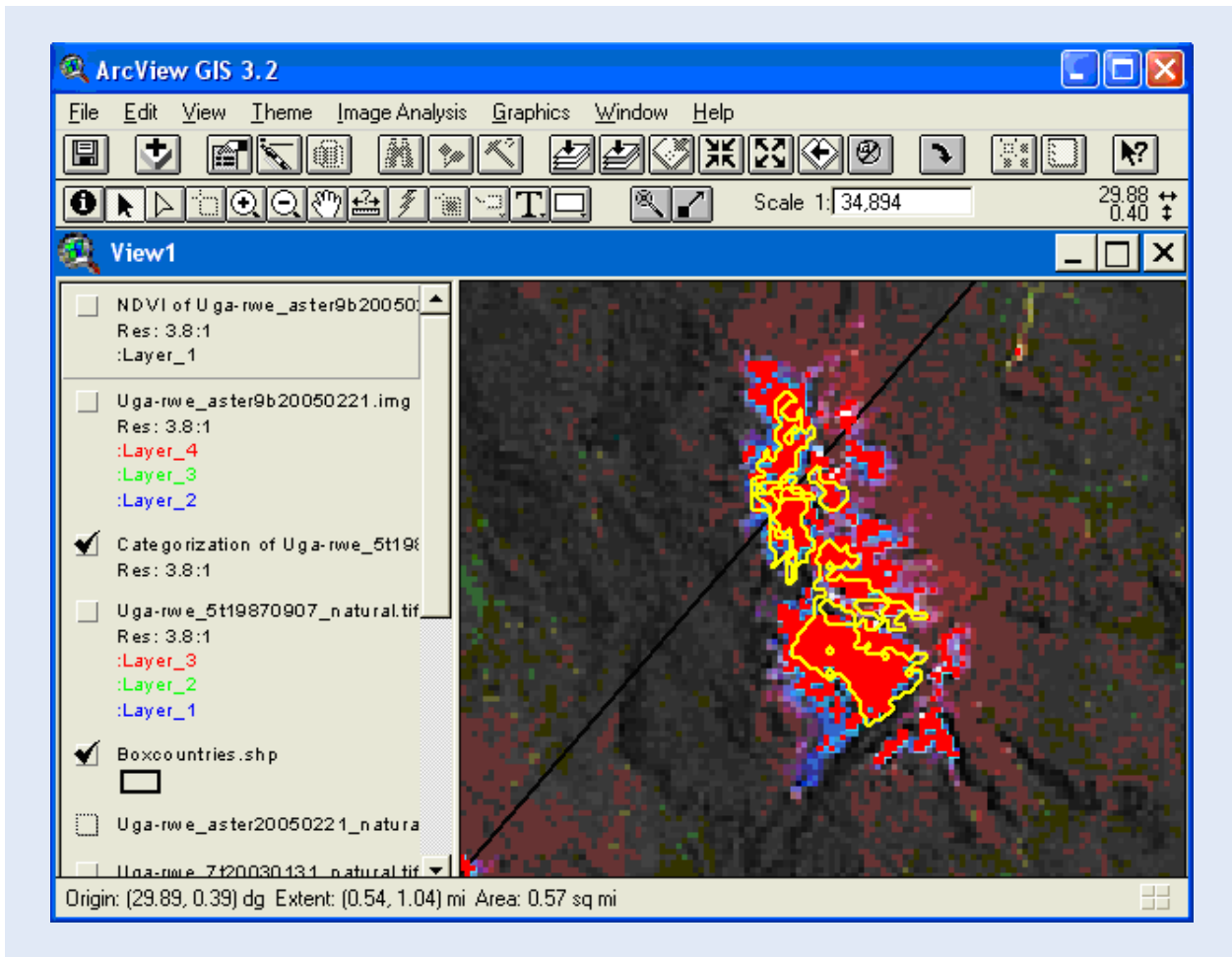
Click the Seed Tool , and then click in one of the larger glaciers (e.g. the one Mount Stanley, as shown below).



Supervised classification will usually demand even more iterations than unsupervised classification, and using the seed tool in ArcView is no exception. If you are not happy with the classification, just use the Delete key and redo the seeding until you are satisfied. As the glaciers on the Mount Stanley (and Mount Speke to the NE and Mount Baker to the SE) are divided into several individual glaciers, you will need to use the seed tool for each individual glacier. If you tend to get to large polygons using the seed tool, you must decrease the Seed Radius in the Seed Tool Properties dialogue window. The Seed Tool uses a growth function to create a polygon vector (as a graphic, not a shape file) enclosing pixels that correspond to the area identified by the Seed Tool.

When you have mapped out all the glaciers, use the menu: Edit – Select All Graphics. You can also select/deselect individual graphics vectors with the Pointer Tool . With one or more graphic vectors selected you can change the properties of the graphics vector much the same as you do for shape vectors – go via the menu: Graphics – Properties.

The graphics produced by the Seed Tool are associated with the image theme from which they were derived, and will only be displayed when this image theme is displayed. To put the graphics vectors in association with the view, make sure they are all selected (Edit – Select All Graphics), then use the menu: Edit – Copy Graphics (Ctrl-C), then Edit – Paste (Ctrl-V). Now the graphic vectors will always be displayed in the view. In the image below, showing Mount Speke, I have displayed the glacier extent vectors for 2005 displayed over the glacier extent in 1987 (from the unsupervised classification above), using the natural color image from 1987 as a back drop.



Analyze glacier retreat 1987 to 2005

Above you used both supervised and unsupervised classification to map out the glacier extent. To make a time series analysis of the glacier retreat 1987 to 2005 you should use the same method applied to each image. To finish part 2 you need to apply the same method consistently to each image in the time-series. You can choose if you want to use supervised or unsupervised classification.

Part 3: Vegetation changes around the Rwenzori Mountains 1973-2005

From Parts 1 and 2 it is evident that the glaciers of the Rwenzori Mountains have retreated over the last 20 years. The present extent of the glaciers (2005) is around 1 km². The first mapping of the glaciers was done in 1906, by an Italian scientific expedition led by Luigi of Savoy the Duke of Abruzzi (De Filippi, 1907). The map produced by the Abruzzi expedition shows that the glacier extent one hundred years ago was around 6.5 km².

The cause of the retreat of the glaciers is debated, with an Austrian research team from the University of Innsbruck favoring a drier atmosphere (Mölg et al., 2003), and an international team led by R. Taylor from University College London, favoring temperature increase (Taylor et al., 2006). Studies of the glacier retreat on Mount Kilimanjaro, indicate that local changes in vegetation might have a large impact on the mass balance of glaciers (Agrawala et al., 2003). With increasing losses of Mountain forests, illegal logging, charcoal production and land conversion, the local evapotranspiration in and around Mt Kilimanjaro have been greatly reduced, leading to a local drier climate. A drier climate impacts the glaciers in several ways. Primarily less precipitation is falling, meaning that less ice and snow are added to the glaciers. Simultaneously cloudiness decreases which leads to increased solar insolation, and a faster loss of ice and snow both through ablation (direct evaporation of snow and ice to water vapor) and by increased melting.

In the third part of this exercise you shall study the vegetation changes around the Rwenzori Mountains, using time series of satellite images.

Normalized Difference Vegetation Index

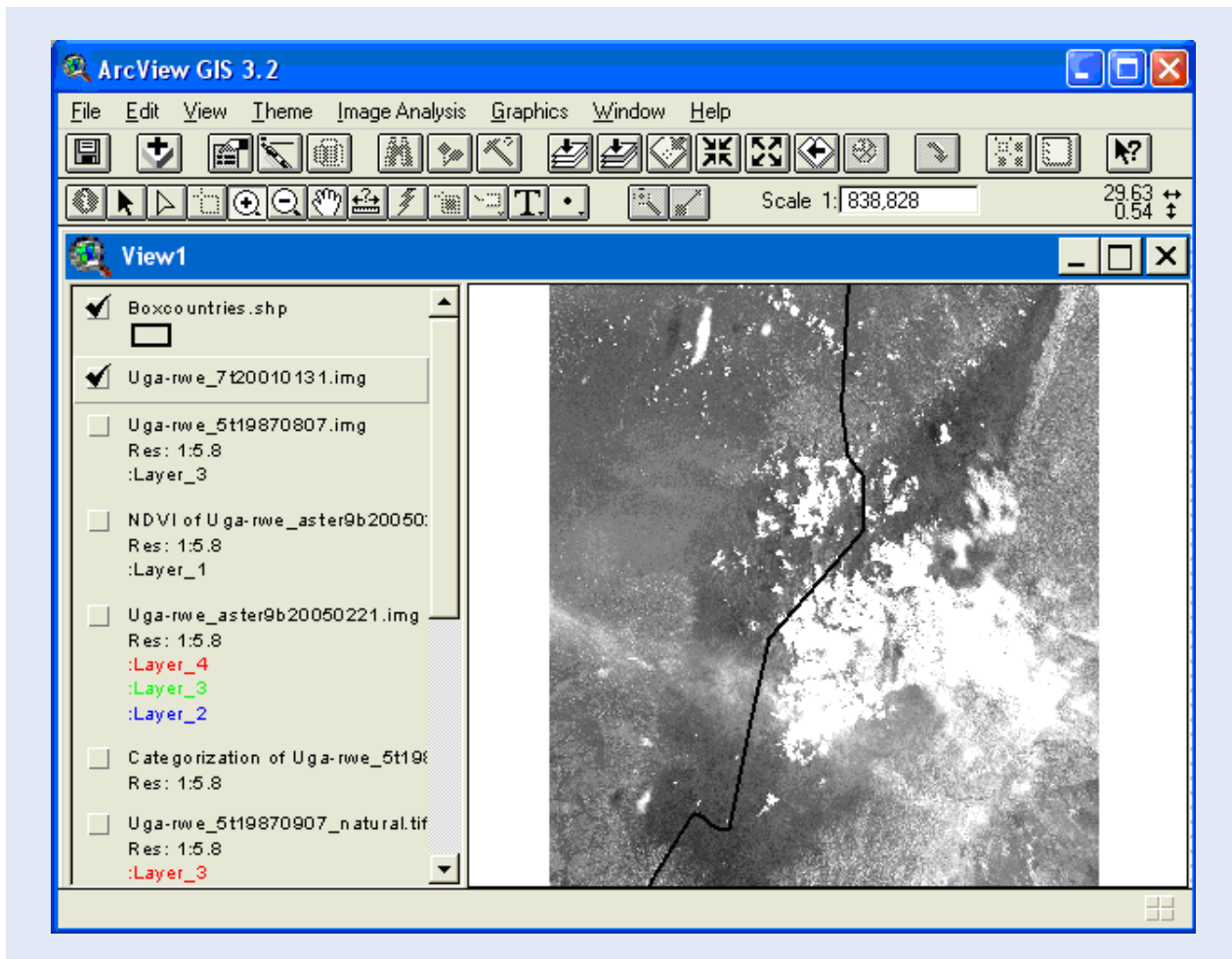
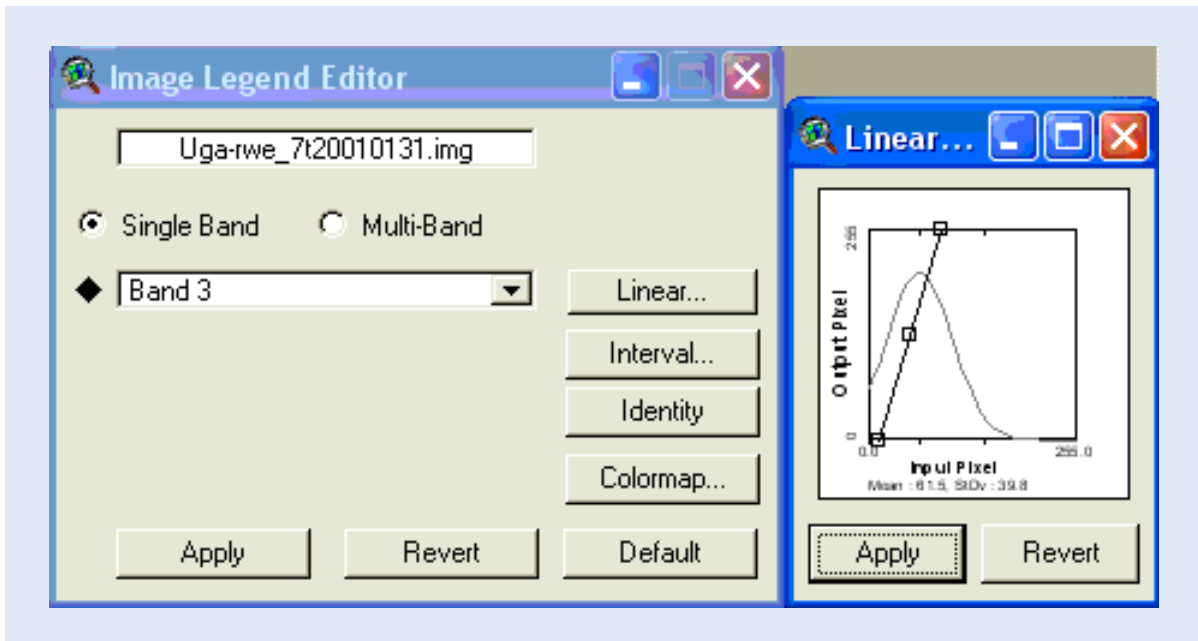
The Normalized Difference Vegetation Index (NDVI) is a widely used index for studying vegetation and vegetation changes in satellite images. NDVI is defined as

$$\text{NDVI} = (\text{Near InfraRed} - \text{Red}) / (\text{Near InfraRed} + \text{Red})$$

Vegetation strongly absorbs red light, as red light is used for driving the process of photosynthesis. The energy level in infrared light is lower, and can not be harnessed by plants for driving photosynthesis, and is hence reflected. This difference between the ratio in absorption and reflection of red and infrared light is used for mapping vegetation.

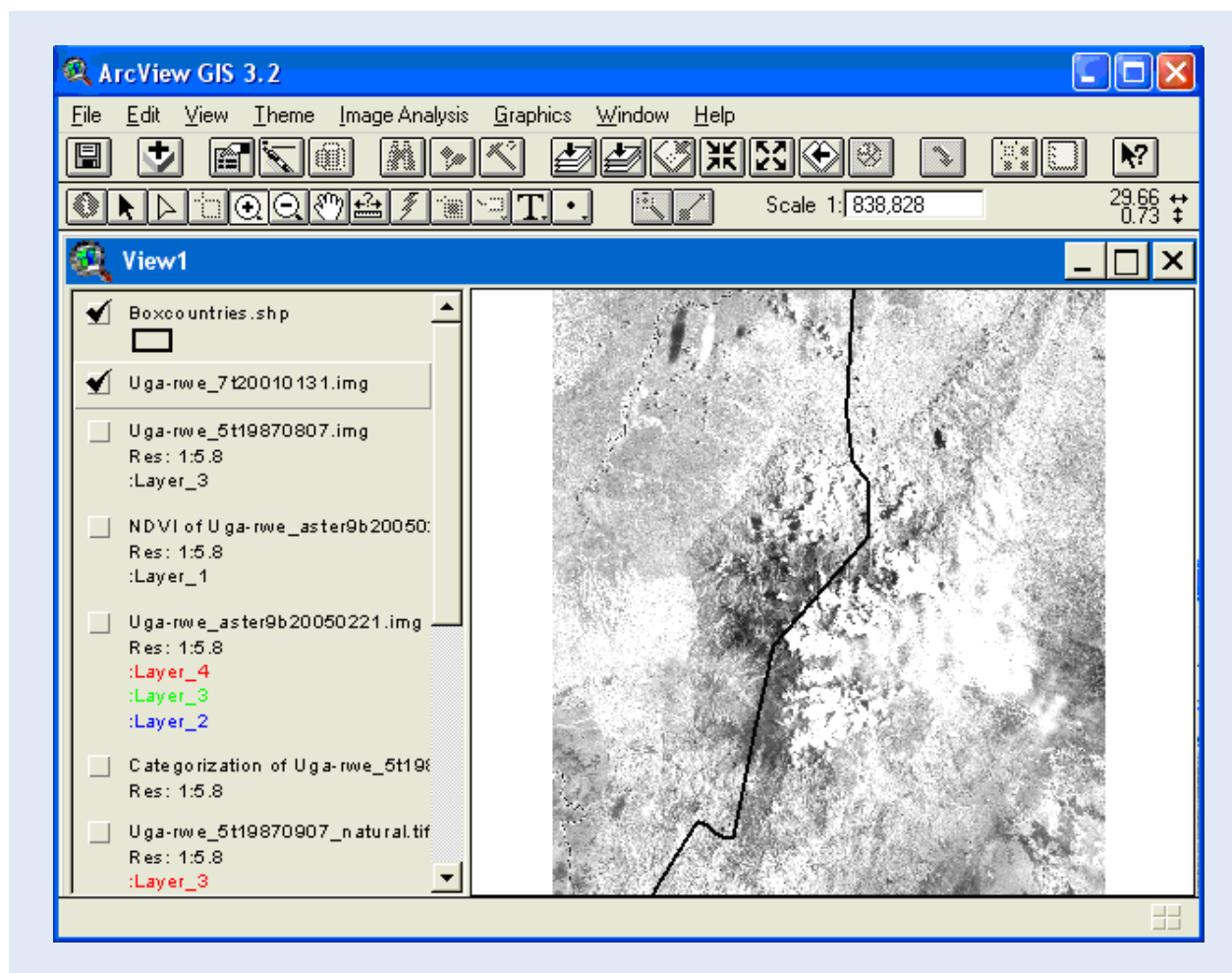
To illustrate the difference in absorption and reflection you can use any of the supplied satellite images to look at the red (R) and near infrared (NIR) bands (see table 2).

Below is band 3 (red) from the Landsat ETM image acquired 20010131. I have loaded the image as Image Data Source and then used the Legend Editor to display the image as a single band, with a stronger linear stretch (to enhance the grayscale distribution in the image).



You can see the stronger absorption of red over the mountain (darker) compared to the surrounding agricultural landscapes and the clouds that reflect most of the red light (brighter).

Use the Legend Editor to change the display to show band 4 (NIR) instead.

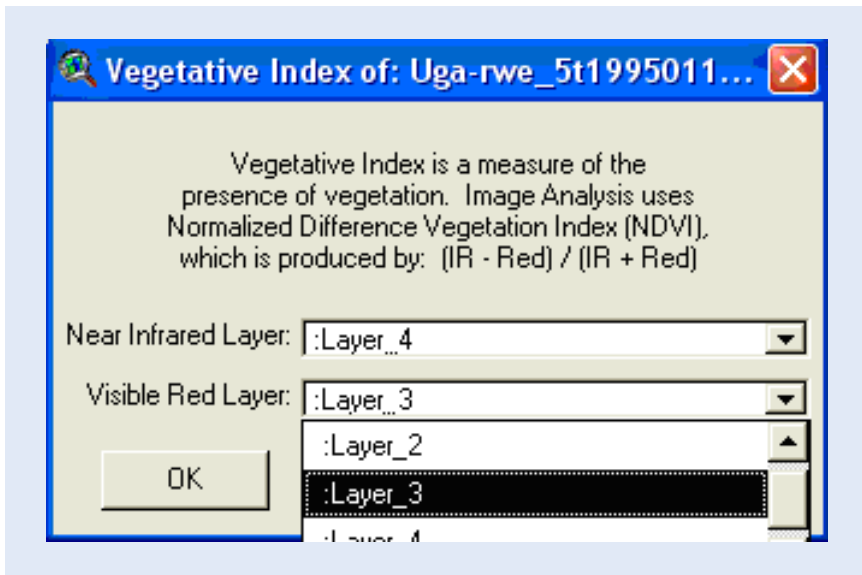


In the Near Infrared the vegetation reflects a much larger portion of the incoming radiation. The clouds are still the strongest reflectors. The dark streaks on the mountain western slopes are valleys that lie in the shade.

Calculate NDVI (Image analysis)

To calculate the Normalized Difference Vegetation Index (NDVI) you need the extension Image Analysis. If you do not have image analysis the pre-processed NDVI datasets for all the images are available in the database under the subdirectories "NDVI". These NDVI images can be opened as Image Data Source files.

With Image Analysis installed, make sure the Imagery file is loaded as an Image Analysis Data Source, and is the active theme. Calculate NDVI from the Image Analysis menu: Image Analysis – Vegetative Index.. Select the bands to use for calculating NDVI (see table 2) and click OK.

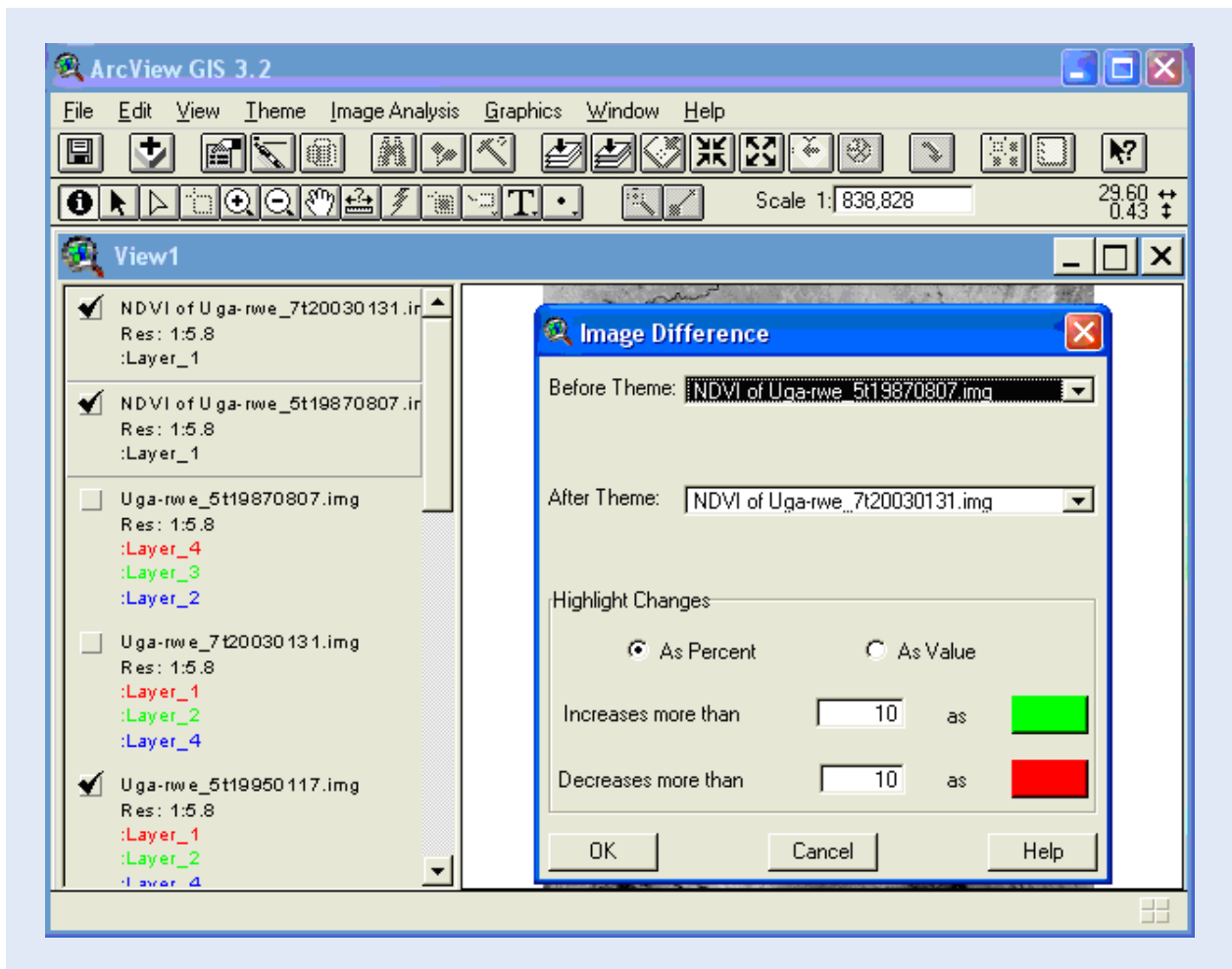


The resulting NDVI image is (except for the ASTER derived NDVI) strongly contaminated by clouds, and also the valleys in shadow will have distorted values. Calculate the NDVI for some (or all) of the images available in the database (table 1), use at least one Landsat MSS image, one Landsat (E)TM and the Aster image. To find out which bands to use for the NDVI calculations, use table 2.

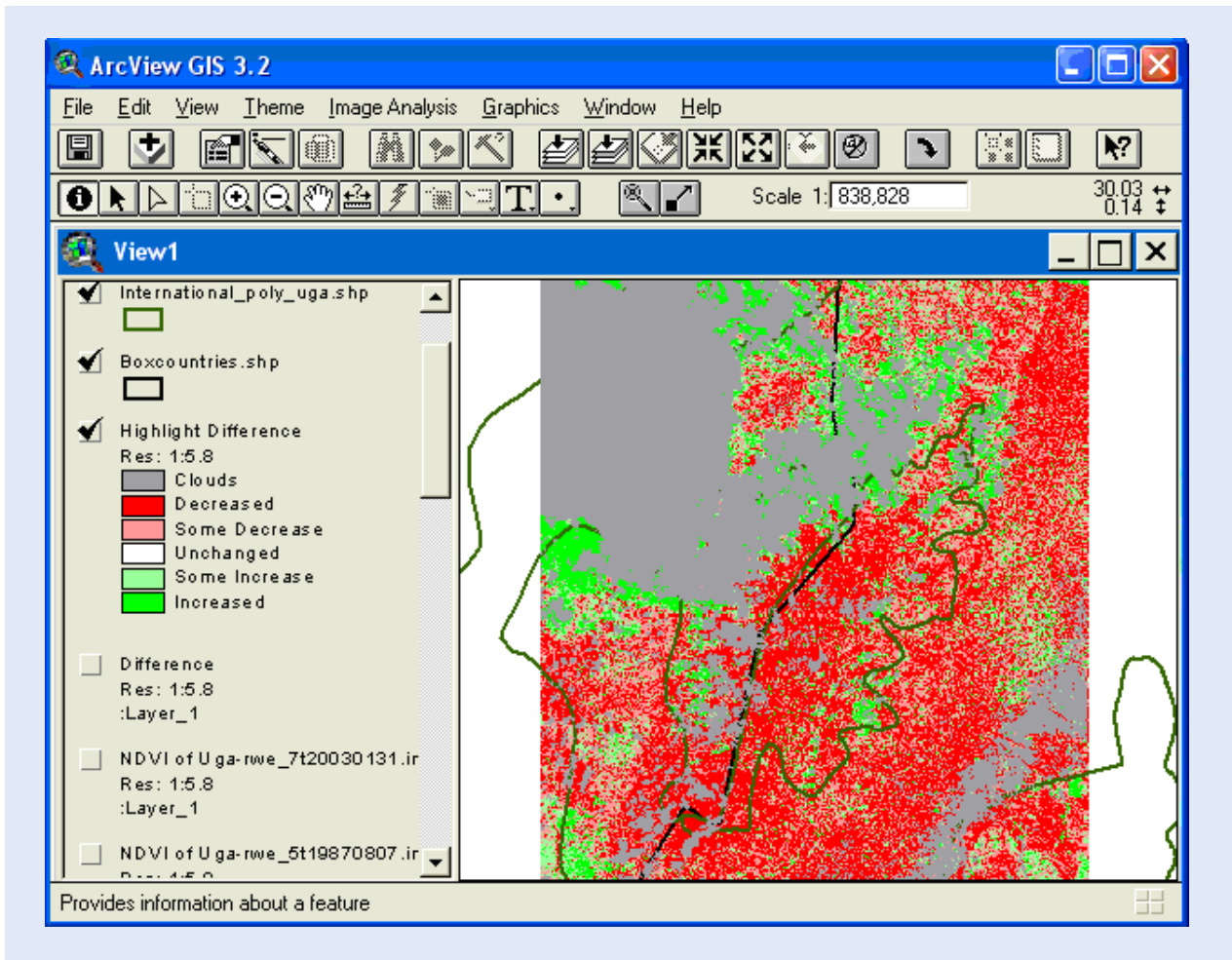
Time trend study of NDVI changes (Image Analysis)

Use two of the derived NDVI layers for analyzing the vegetation changes over time. In my example I have used the oldest and the most recent Landsat (E)TM scenes, as the analysis will then be less affected by changes in sensor type (albeit the 1987 scene is from Landsat 5, and the 2004 scene from Landsat 7).

Make both images you want to use for the change study active (hold down the Shift+Ctrl keys and click the legends, both legend entries will then appear lifted). Then use the Image Analysis menu: Image Analysis – Image Difference. Set the older image as the Before Theme, and the more recent as the After Theme. Set the thresholds you want to use for displaying changes.



The cloud contamination will make it difficult to interpret the vegetation changes correctly. In the example below I used unsupervised classification to mask out the cloudy areas of both images used in the difference study. I also added the theme showing the boundaries of the national parks in the Rwenzori - data\NileBasin\Spatial\Conservation Areas\NileBasin_ProtectedAreas_IUCN/international_poly_uga. I then used the Legend Editor for all these themes to create a layout that shows areas with increases and decreases in vegetation between 1987 and 2003.



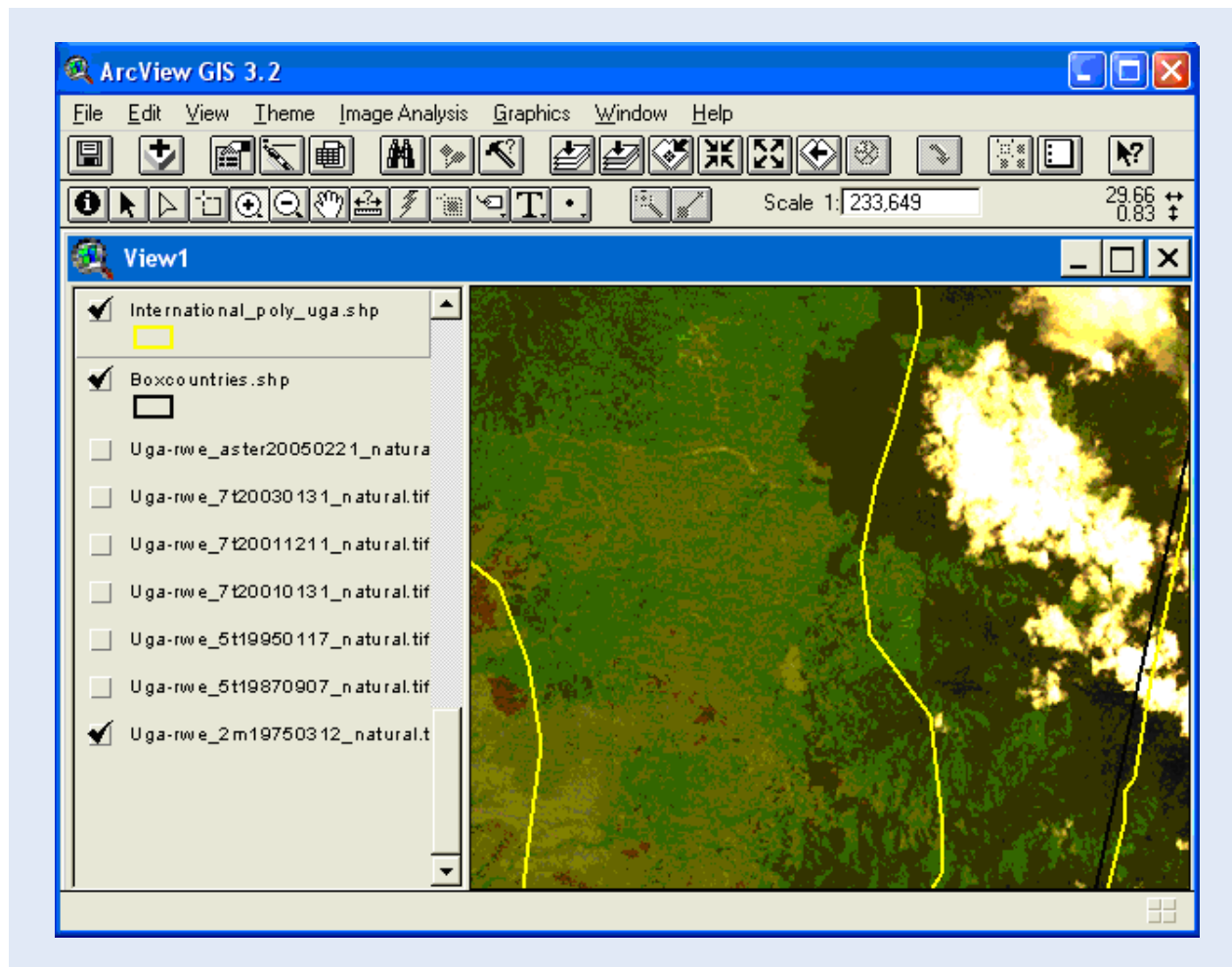
If the Image Difference analysis is correct, the Rwenzori and its surroundings must have experienced large decreases in vegetation cover over the last 20 years. The two images used in the analysis were acquired with same type of sensor (Thematic Mapper), but with two different instruments. The images are also acquired at different seasons, and apart from differences in the vegetation this also means differences in the Earth-Sun distance and the radiation received at the Earth's surface. The differences seen in the analysis are hence only indications of what might have happened; more detailed studies are needed before any definitive conclusions can be drawn.

As the last part of this exercise, we will use the full time series of satellite images to search for changes in land cover and vegetation.

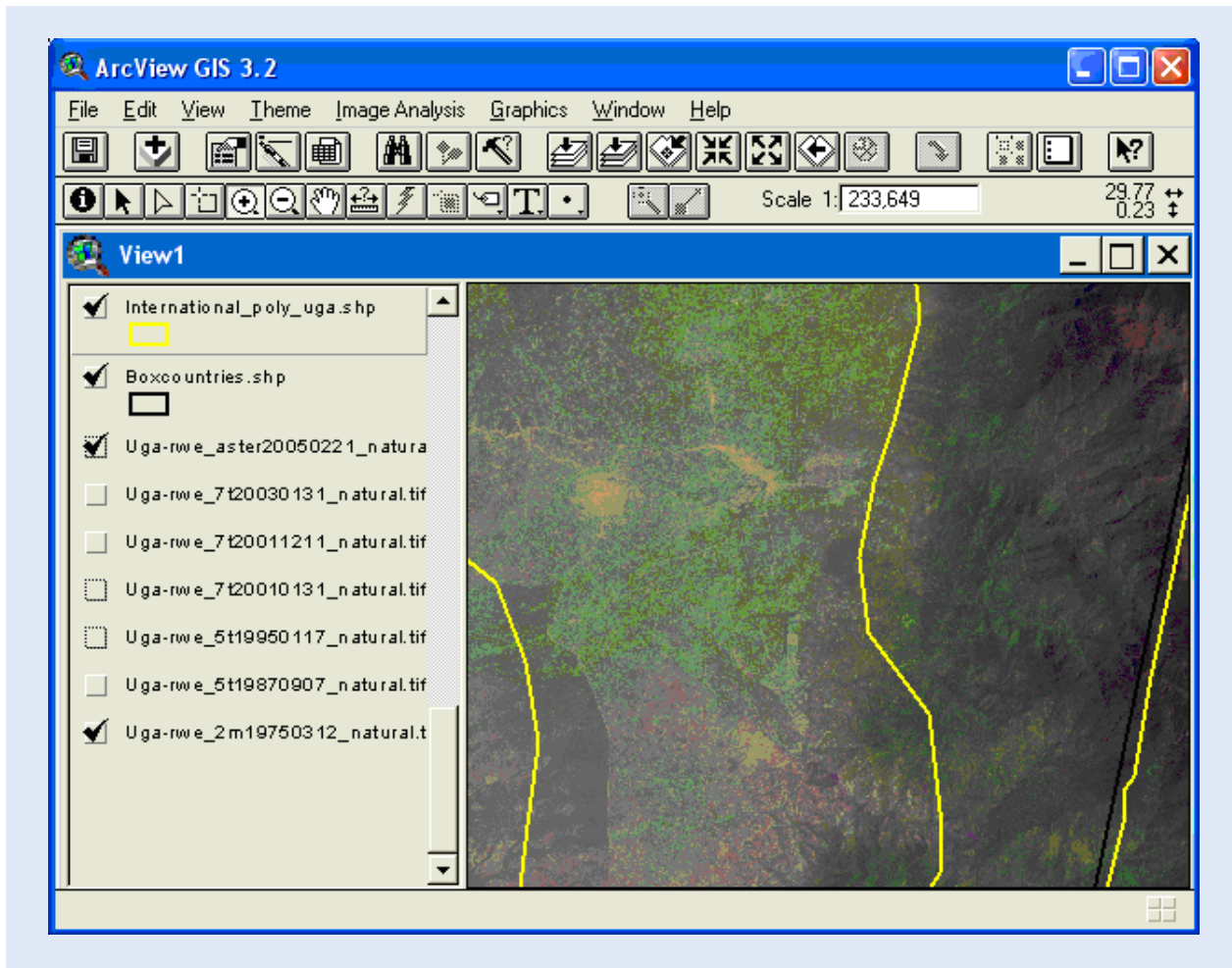
Land cover changes 1975-2005

A large part of the image area is covered by National Parks, including the Rwenzori Mountains National Park in Uganda, and the Virunga National Park in the D.R. Congo. In my example I choose to look more closely at the land cover changes to the SW of the peaks in the Rwenzori Mountains. The area covers part of the National Parks areas, but a large section is also forming a corridor inside the Virunga National Park.

In the earliest image available for this area (1975) the landscape looks homogenous, and no boundaries can be seen in the satellite image.



As you look through the time series of images, you will notice how the urban centers grow steadily, how infrastructure develops and how land is converted. And in the last image in the time series – the Aster image from 2005, the landscape is largely changed; the boundaries to the national park stand out sharply, and the loss of vegetation is seen already in the natural color image.



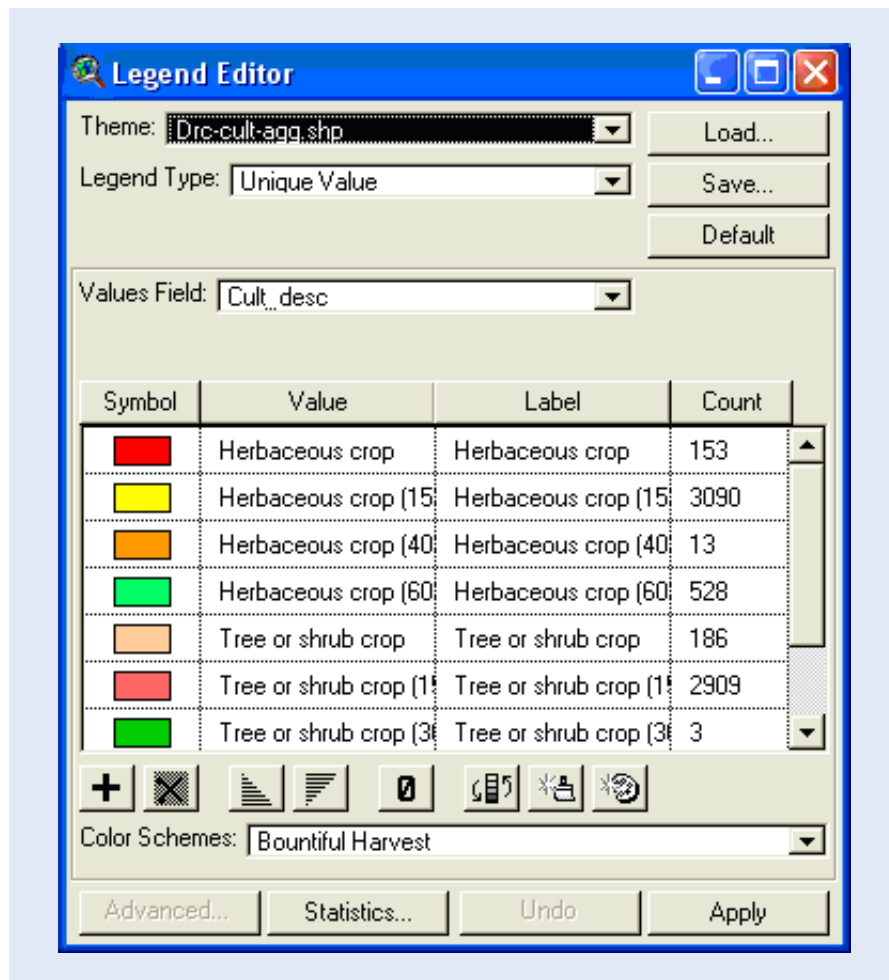
The discrepancies between the boundaries of the national parks on the one side, and the international boundaries and boundaries seen in the image data on the other are due to inaccuracies in the data.


Land cover map

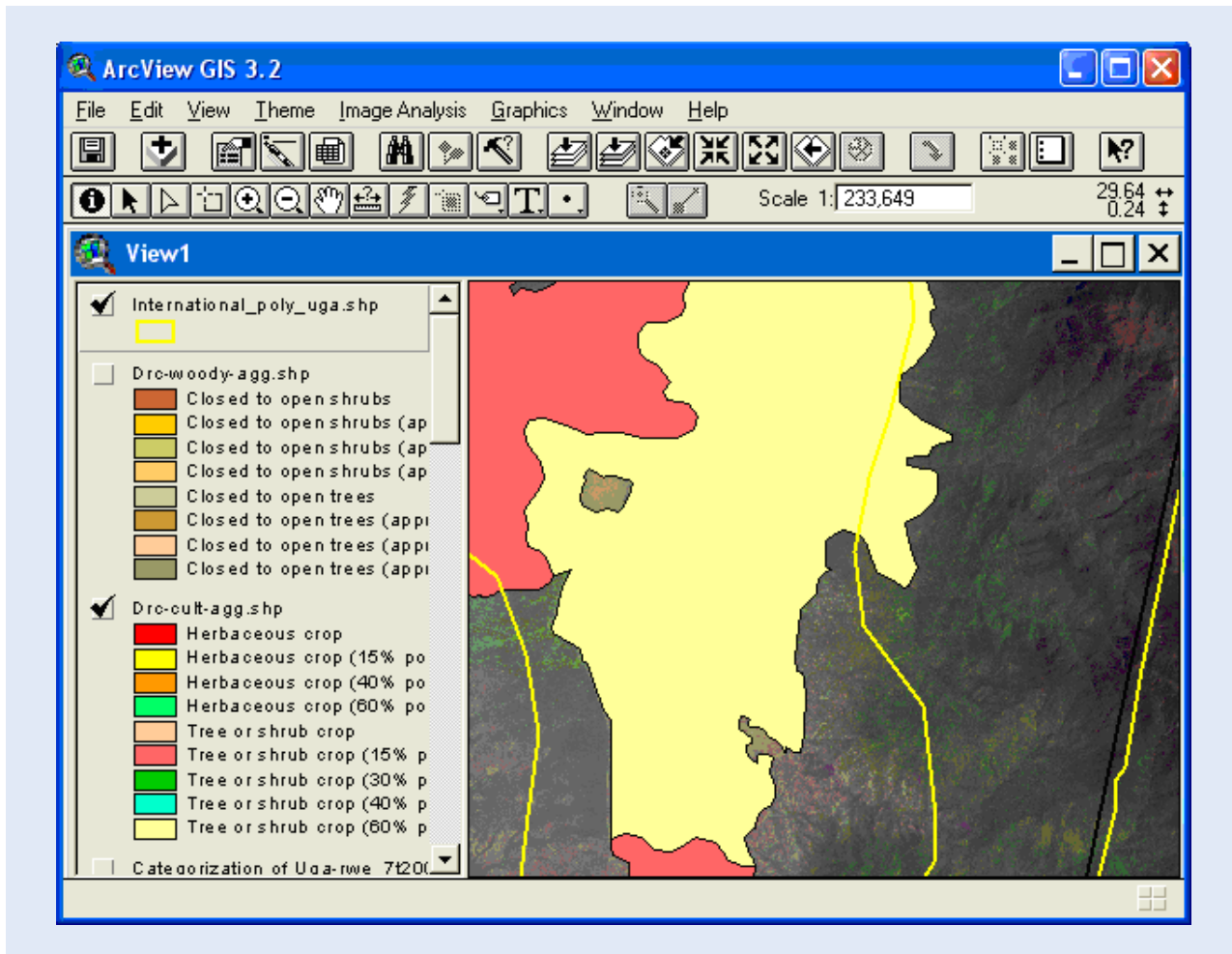
To have an idea about the land cover in the area that you have looked at, you are going to use the africover database, also available in the NileBasin database. If you looked at the same area as in the example you need to add africover for the D.R. Congo, if you looked at other areas, you might need to add africover for either the D.R. Congo or Uganda, or both.

You find the Africover for each country in the Nile Basin under the sub-directory data\NileBasin\Spatial\Africover. You need to add the aggregated data for forests (e.g. drc-woody-agg) and agriculture (e.g. drc-cult-agg).

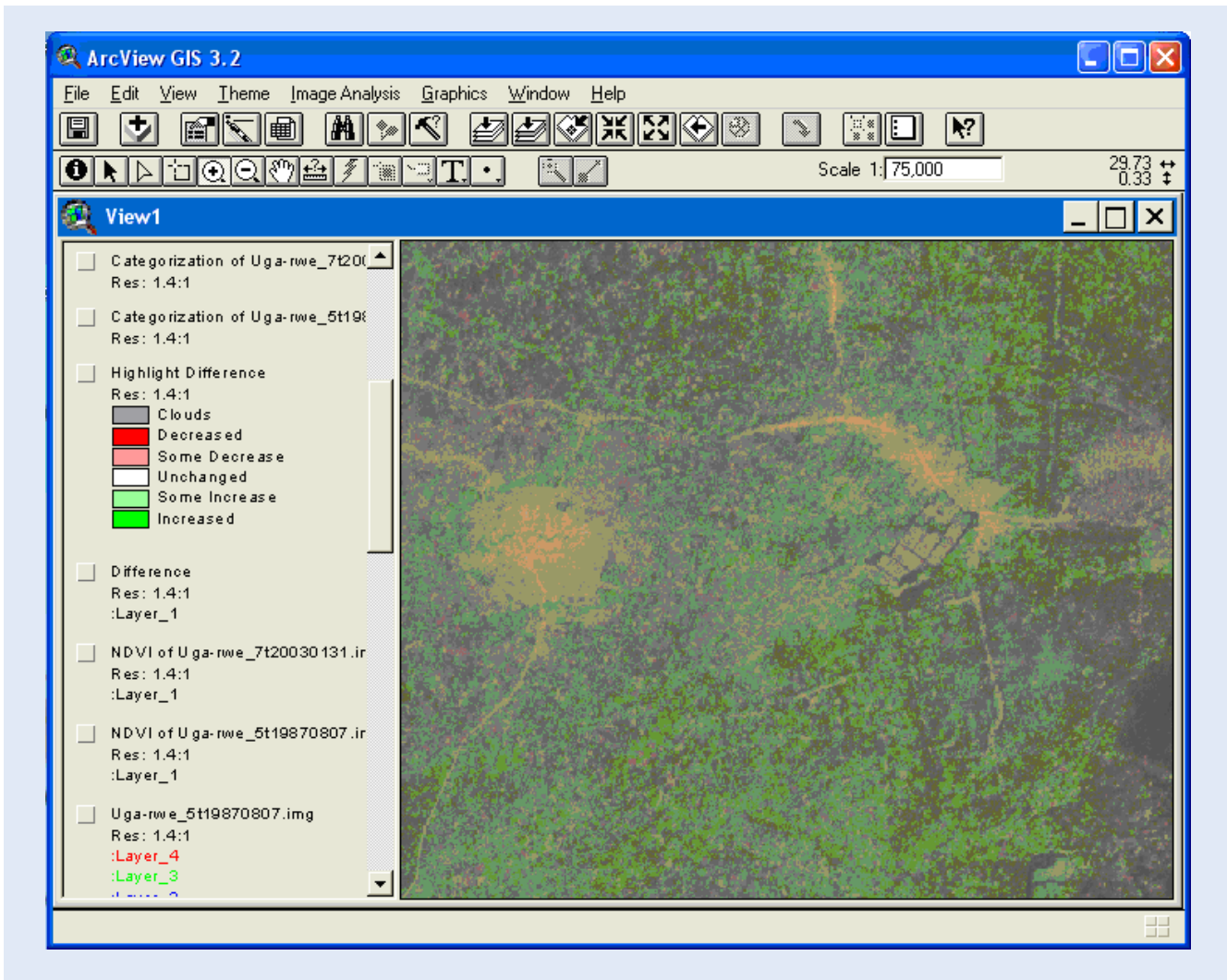
For the africover themes Use the Legend Editor and set the Legend Type to Unique Value, select a Values Field for the legend and then select a Color Scheme. Remember to click Apply to force the changes to take place.



Use the Identify Tool , to get query the africover database for what the landcover is over the area you have just studied in the time series of satellite images. Detailed descriptions of the Africover data are available as pdf files in each country directory.



The Africover thematic land cover map is made from Landsat (ETM) data from around year 2000. The TERRA satellite, carrying the ASTER sensor, was launched in December 1999. If you zoom in to a larger scale (1:50000 – 1:100000) you will see how much more detailed the ASTER image is. In the image below it is obvious that land cover in large part of the area differs from the category given in the africover data set.



If the changes in vegetation and land cover around Mountain Rwenzori have affected the glaciers or not, we can not yet tell. If they have had an influence it is most likely accelerating the decrease. To quantify the influence of the changes, a model of the water cycle of the Rwenzori Mountains would have been needed. Satellite images have many applications in hydrological modeling, including for estimating soil moisture, and both precipitation and evapotranspiration. But that will have to be another exercise.

References

Agrawala, S., A. Moechner, A. Hemp, M Aalst, S. Hitz, H. Meena, S Mwakfwamba, T. Hyera and O. Mwaipopo, 2003. Development and climate change in Tanzania: Focus on Mount Kilimanjaro. Organisation for Economic Co-operation and Development (OECD), Paris, 72 pp.

De Filippi, F. (Ed), 1909. Der Ruwenzori. Erforschung und erste Besteigung seiner höchsten Gipfel. Von L.A. v. Savoyen, Herzog der Abruzzen, F.A. Brockhaus.

Mölg, T., C. Georges and G. Kaser, 2003. The contribution of increased incoming shortwave radiation to the retreat of the Rwenzori glaciers, East Africa, during the 20th century. *International Journal of Climatology* 23: 291-303.

Taylor, R., L. Mileham, C. Tindimugaya, A. Majugu, A. Muwanga and B. Nakileza, 2006. Recent glacial recession in the Rwenzori Mountains of East Africa due to rising air temperature. *Geophysical Research Letters*, 33:, L10402, doi: 10.1029/2006GL025962.