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The effect of topography on radiance measured by a satellite sensor

Center for Biodiversity and Conservation

Biodiversity Informatics Facility

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The Biodiversity Informatics Facility applies information technologies to collect, organize and analyze biological and environmental data from expeditions, remote sensing, natural history collections, modeling and databases. Through research that applies cutting-edge spatial analysis technologies, we aim to discover new insights and develop new methods in ecology, evolution and conservation biology. Through training initiatives and the development and distribution of software and scripts, we aim to strengthen the capacity of students, educators, researchers, conservation practitioners, and the broader public to study and better understand biodiversity.

How to cite this document:
Author(s). Year. Title. Version. American Museum of Natural History, Center for Biodiversity and Conservation. Available from http://biodiversityinformatics.amnh.org. (accessed on date)

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Introduction

The position of the sun in addition to topography can greatly affect how light is reflected off any given point on the Earth's surface. This guide illustrates the effect of change in illumination angle, explains some of the advantages and disadvantages associated with the effects of these angles, and describes ways to reduce these effects through digital processing.

Understanding the effects of uneven illumination due to changing topography and illumination angle can improve our ability to accurately interpret a satellite image. We can reduce the effects of uneven illumination through image pre-processing methods.

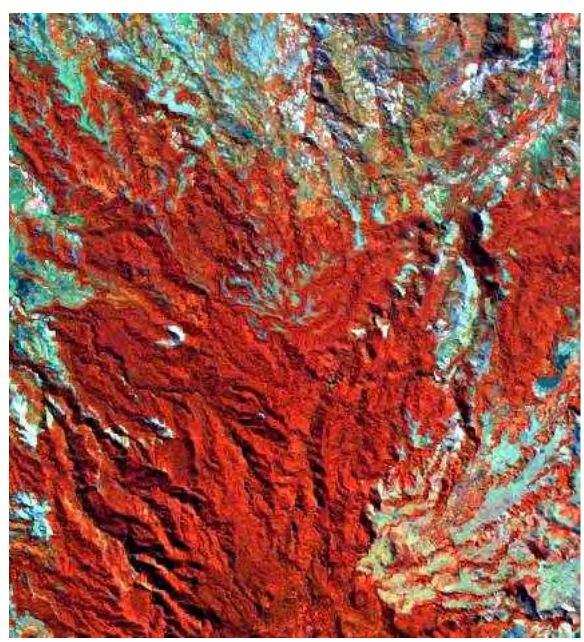
Shadows are often considered a contaminant in an image, but they can actually be quite useful to identify features in an image. The images on the right, for example, were acquired at two different months of the year. In June the sun was high in the sky and in November the sun was much lower and therefore cast longer shadows. These shadows in the November image accentuate the terrain giving a clear indication of the landform. The spatial extent of the shadow also gives an indication to the relative size of a land feature within an image; longer shadows will be cast by taller features.

Unfortunately, shadows tend to cause problems when we use automated methods to identify features on an image. Most automated feature identification approaches work on the assumption that similar feature will have similar reflectance properties. When a feature is partially or entirely covered by a shadow, however, the amount of light reflected to the sensor can change dramatically. In the extreme case when a feature is entirely covered by a dark shadow no light is reflected. This is particularly evident in the shadows associated with the clouds (white puffy features at the top and bottom of the right-side of the image) in the top image. When no or very little light is reflected from a feature it is not possible to remove the shadow.

Another illumination effect, opposite from shadows, occurs when features are oriented in such a way that they become brightly (or overly) illuminated. This can be seen in many mountainous areas when one side of the mountain is in a shadow and the other is brightly illuminated. This over-illumination can cause reflectance values to be higher than what one would expect for a particular feature. This issue of uneven illumination is explained in the following pages.

Left: Landsat image, northern Madagascar June 3

Right: Landsat image, northern Madagascar, November 30



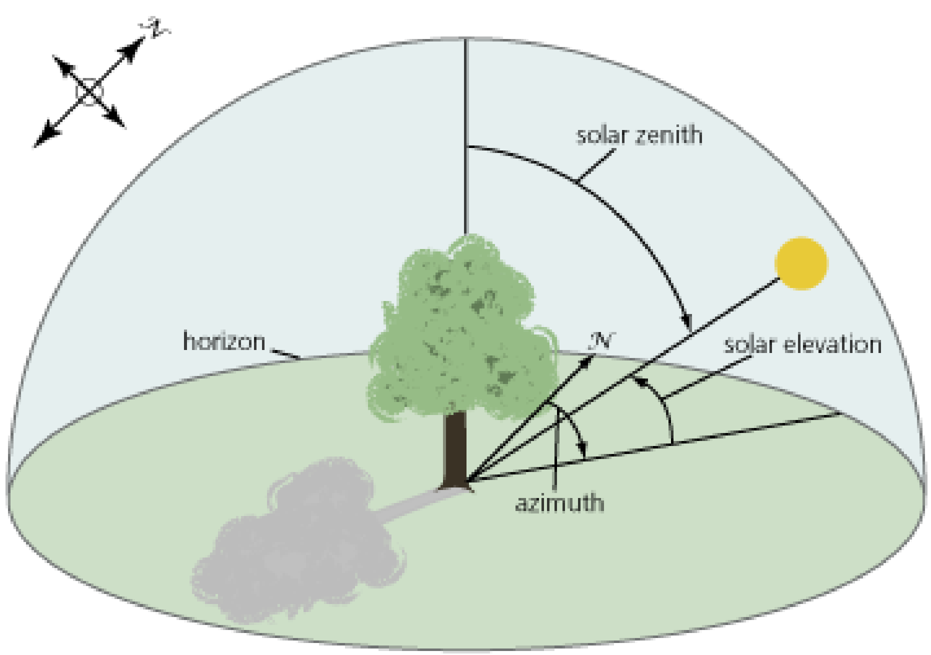
Essential Concepts

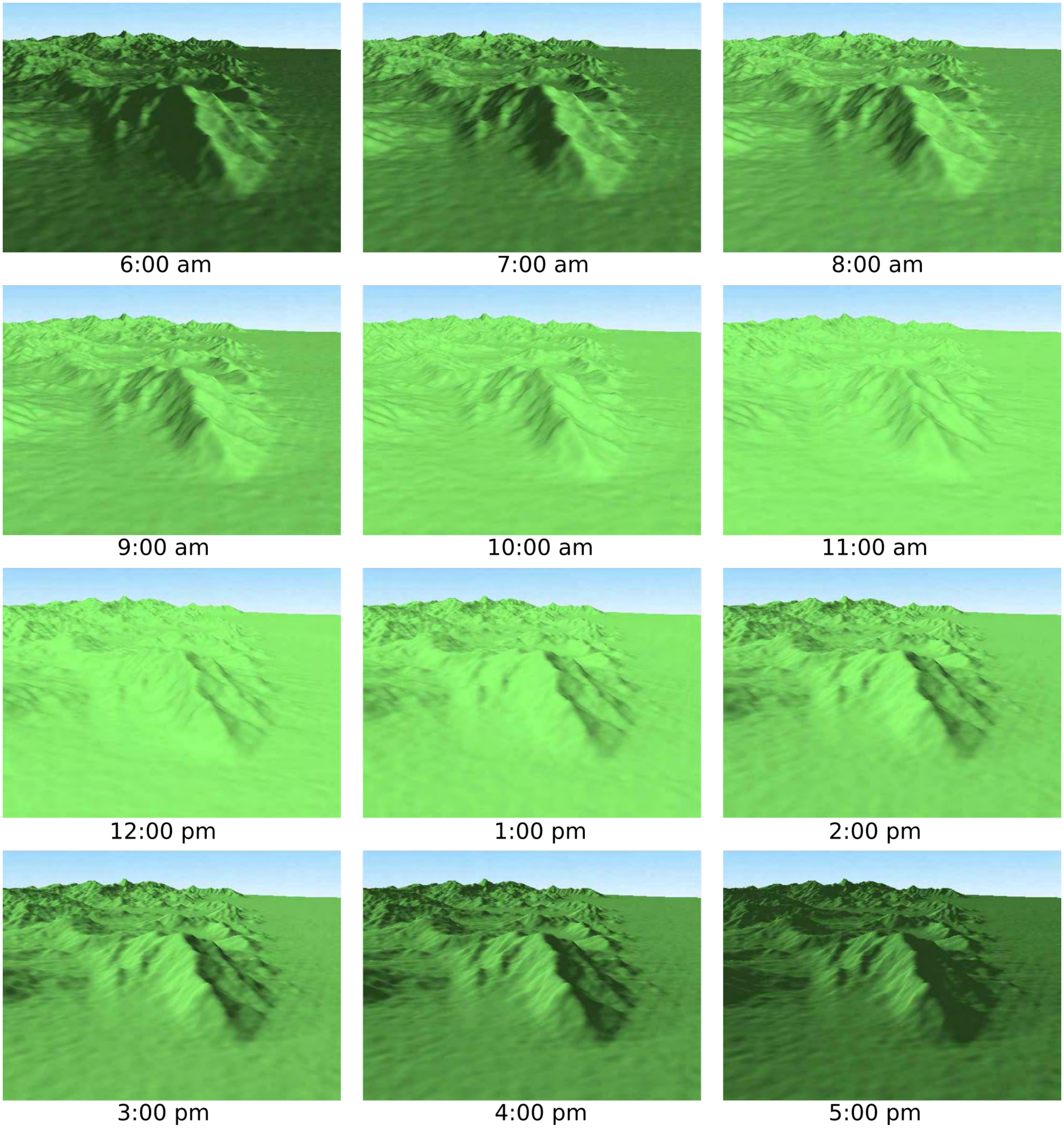
Two principles that must be understood when studying illumination effects are the orientation of a feature of interest and the position of the sun. These principles are illustrated in the figure to the right. The position of the sun is measured relative to the feature being illuminated and is discussed in terms of solar elevation, a solar zenith angle, or azimuth. The sun's elevation (solar elevation) is measured as an angle from the horizontal and the solar zenith angle is measured from vertical. In other words, solar zenith angle = (90 degrees – sun elevation). The sun's azimuth is the compass direction, from the feature of interest, to the sun. Data about the position of the sun can be calculated if the date and time that the image was acquired and the geographic coordinates are known. There are a number of free tools on the Internet that can do this (https://www.esrl.noaa.gov/gmd/grad/solcalc/azel.html). This information is often contained with the image metadata.

The orientation of a feature is noted as a slope and aspect. Slope is measured as the angle of the surface relative to the horizon and aspect is the compass direction of the slope's orientation. Slope and aspect information is often derived by processing digital elevation models (DEMs). Most image processing and GIS software have the capability to calculate slope and aspect from DEMs.

Although not covered in detail in this guide it is important to know that in addition to topographic effects the properties of individual features on the Earth's surface also affect how light is reflected. For example, on a smooth surface, such as a lake, sunlight can result in specular reflection where the light is reflected at an angle equal to the angle of reflection.

This can be demonstrated by shining a light on a mirror. The light bounces off the mirror at the same angle (although in the opposite direction) that it hits the mirror. The opposite of specular reflection is diffuse reflection. This is when light is reflected equally in all directions independent of the orientation of the surface or the angle of incoming light. This can be demonstrated by shining alight on a piece of cloth. The light is reflected in all directions creating an ambient light off of the cloth rather than a directional light that bounced off of the mirror.

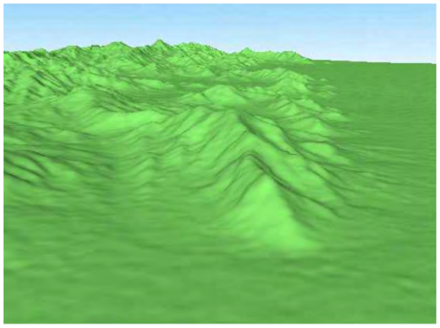




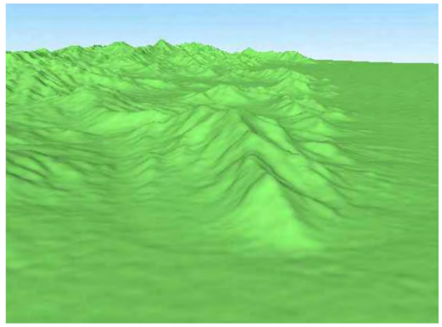
Changing Solar Elevation and Azimuth throughout a day

This montage illustrates how the illumination of a mountainous area changes throughout a single day. This example is based on actual elevation and illumination data as seen in the foothills of the Chiricahua mountains of Southeastern Arizona.

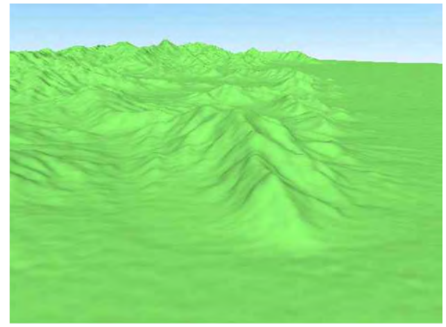
Location of Viewer: 31 53' 48.76" N, 109 08' 01.37" W
Date: 1 September 2005
1000m above ground level



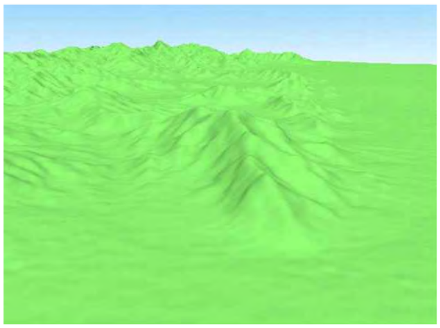
January 15



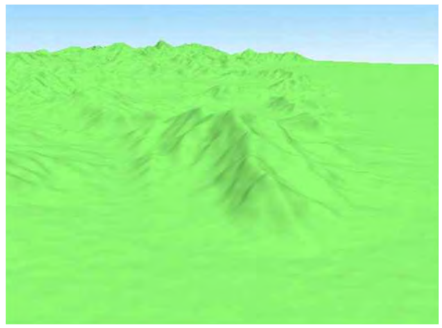
February 15



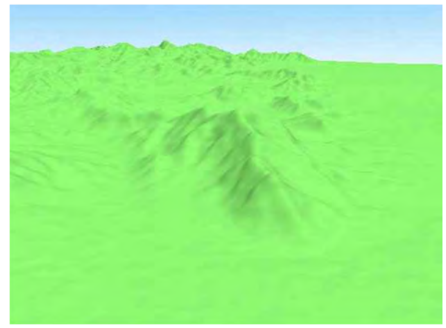
March 15



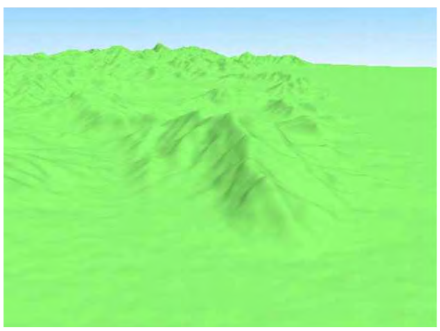
April 15



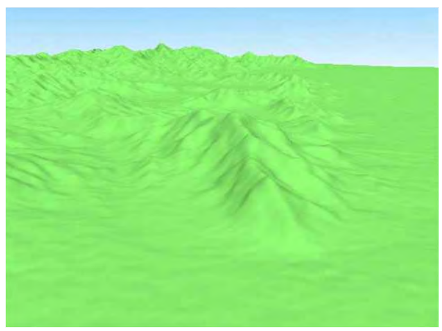
May 15



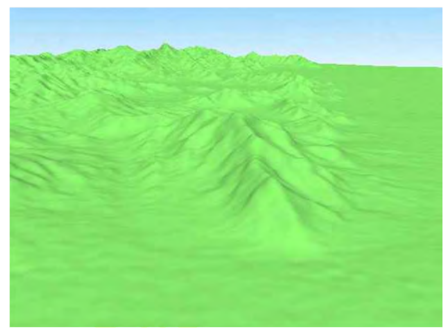
June 15



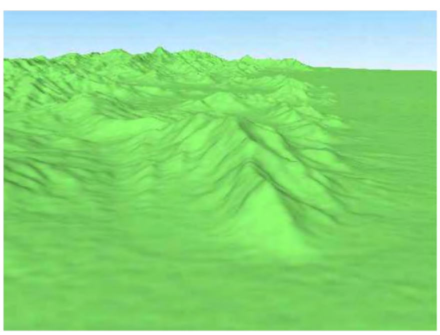
July 15



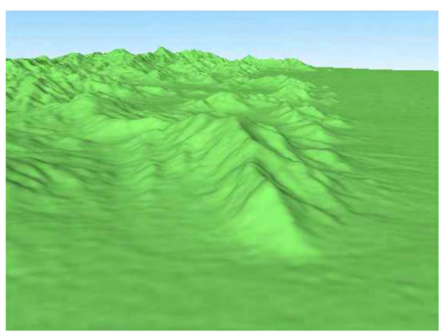
August 15



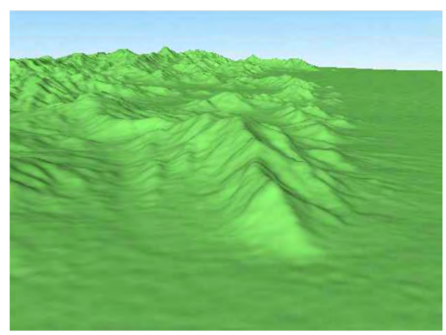
September 15



October 15



November 15



December 15

Changing Solar Elevation and Azimuth throughout a year

This montage illustrates how the illumination of a mountainous area changes throughout the year at 10:45AM, the local time that Landsat acquires imagery in this area. You will see how the image brightens and tends to look flatter as northern hemisphere summer arrives (June) because the sun is highest in the sky this time of the year. Around winter (December) the sun is much lower and this causes the scene to appear darker and the terrain is more accentuated.

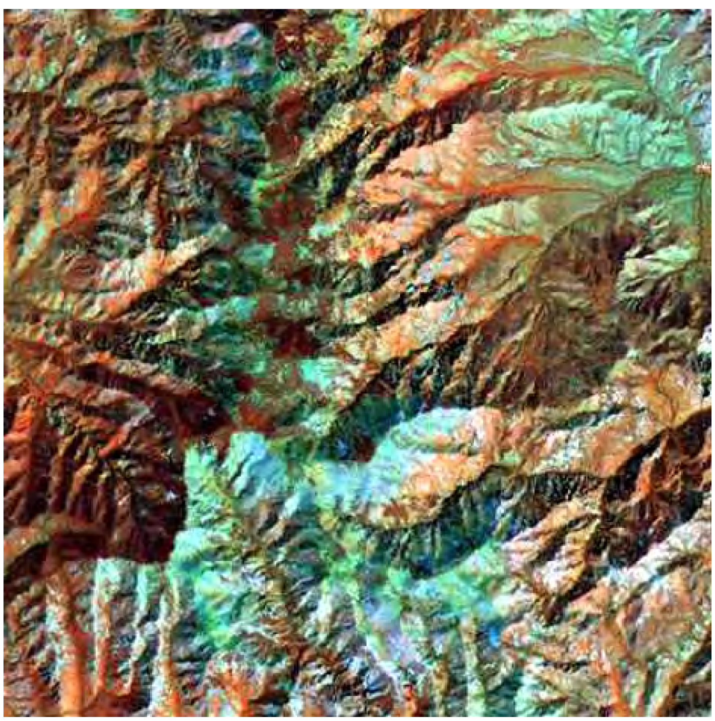
Location of Viewer: 31 53’ 48.76” N, 109 08’ 01.37” W
Year: 2005
1000m above ground level

Shadow Correction

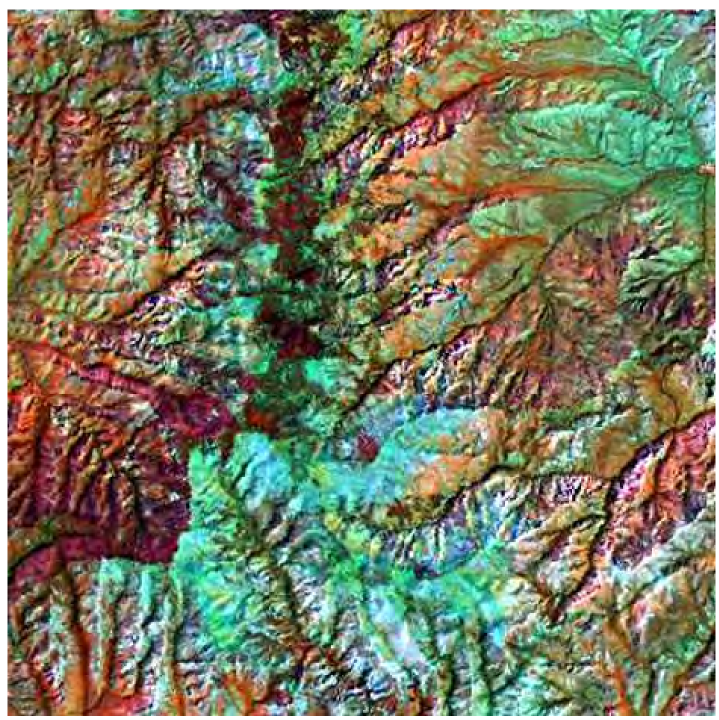
The goal in reducing the illumination effects caused by shadows is to make similar features look the same regardless of their illumination configuration. One common and relatively simple way to do this is to approximate the way the feature would be illuminated if it had a level orientation.

The formula is: Corrected value = radiance recorded by the satellite * (cosine of the solar zenith angle / cosine the sun's angle of incidence). The angle of incidence is the angle between the incoming light measure from an imaginary line perpendicular (normal) to the feature's slope.
It is can be calculated by subtracting the slope of the feature from the solar zenith angle. This algorithm works on the assumption that the features on the surface are perfect diffuse reflectors (a Lambertian surface) and this is never the case.

More complex algorithms have been created to compensate for the limitations of the simple cosine correction approach described above. One algorithm, called the Minnaert correction multiplies the result of the above algorithm by a constant between 0 (specular) and 1 (perfectly Lambertian) to different types of land cover to account for the fact that features have varying degrees of diffuse reflection.



Uncorrected Landsat ETM+ image



Terrain corrected Landsat ETM+ image