

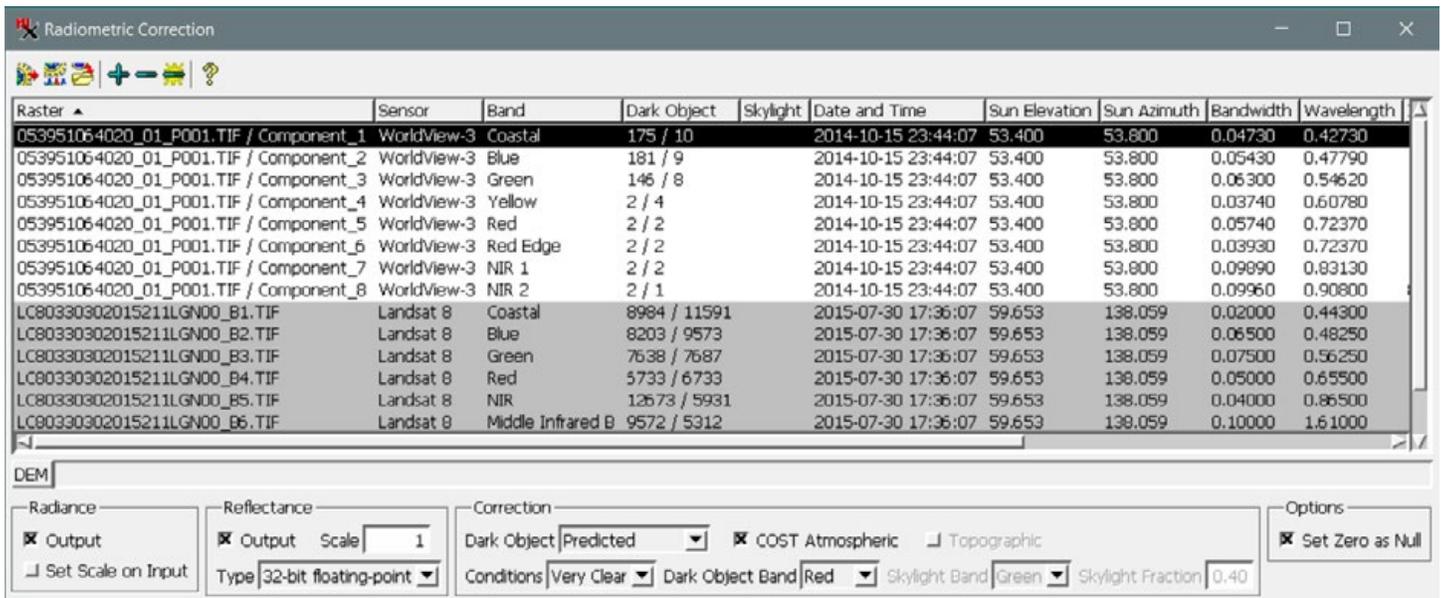
Radiometric Correction of Satellite Images

The Radiometric Correction process in TNTmips (Image / Radiometric Correction) calibrates images acquired by satellite optical sensors to radiance or reflectance values. These corrections allow more accurate assessment of ground surface properties and facilitate comparison between images acquired at different times or for different areas. You can use this process to:

- Convert image digital numbers to at-sensor radiance.
- Convert image digital numbers to top-of-atmosphere reflectance with specified raster data type and scale.
- Apply dark-object (path radiance) correction from image histograms, from a scattering model, by manual entry, or by designating a dark area in the View.
- Apply cosine TZ (COST) atmospheric transmittance correction.
- Apply topographic correction using a DEM.

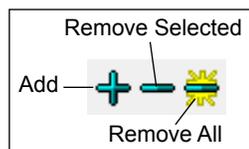
Satellite sensors that are currently supported are listed to the right. TIFF/GeoTIFF and JP2/GeoJP2 images can be used in their original format; correction parameters are read automatically for these images from metadata files in the specified format. Images in other formats (e.g., HDF, NITF) should first be imported to a MicroImages Project File; sensor metadata is automatically imported to a metadata subobject that is also read automatically by the Radiometric Correction process. Default values for missing parameters are provided from a TNTmips reference file. Correction parameters can also be entered manually for these images and for images from other satellite optical sensors.

Supported Satellite Optical Imaging Sensors		
Sensor	Metadata Format	Metadata File Extension
ASTER	HDF	embedded in HDF
DMC	DIMAP	*.dim
GeoEye1	Digital Globe	*.xml
IKONOS	GeoEye	*_metadata.txt
KOMPSAT-3	KOMPSAT	*_aux.xml
KOMPSAT-2	KOMPSAT	*.eph, *.txt
Landsat 8 OLI	ODL	*.mtl
Landsat 7 ETM+	ODL	*.mtl
Landsat 4,5 TM	ODL	*.mtl
Pleiades	DIMAP	DIM_*.xml
RapidEye	RapidEye	*_metadata.xml
QuickBird2	Digital Globe	*.xml
SPOT 6,7	DIMAP	DIM_*.xml
WorldView 2,3	Digital Globe	*.xml



Radiometric Correction Window

Press the Add icon button on the Radiometric Correction window toolbar to select image bands to process. You can select TIFF or JP2 files (one file per band or multiple bands from a single file) or raster objects from a MicroImages Project File. All selected image bands are shown in the columnar list (see illustration above). You can select and process more than one image at a time; listings for different images are automatically grouped

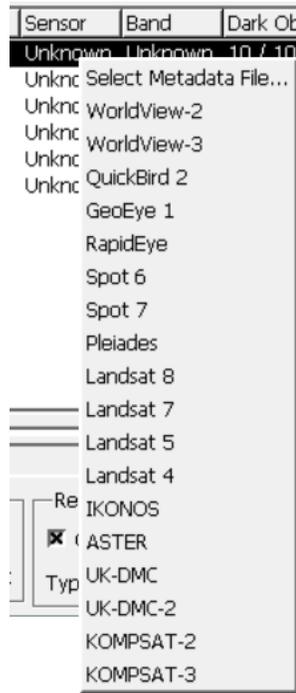


with alternate background colors. Images are also automatically displayed in the View window. You can remove any band(s) that were incorrectly selected by left-clicking on the entry in the list to highlight it, then pressing the Remove Selected icon button. (You can hold down the shift key to highlight a range of entries or the control key to toggle highlighting on/off for an entry). Press the Remove All icon button to remove all bands.

The sensor name, band assignments, and correction parameters are automatically read from the accompanying metadata if

(continued)

available and shown in the various columns in the list. If the sensor metadata file or object is not found automatically, the value “Unknown” is shown in the Sensor and Band columns. If a metadata file in the supported format is available, left-click in the Sensor column for any of the image bands, choose Select Metadata File from the popup menu, and use the Select File window to navigate to and select the file. If a metadata file in the proper format is not available, you can use the Sensor column popup menu to choose the sensor, which is assigned to all bands in the image. For each band, left-click in the Band column and choose the spectral band from the popup menu. Correction parameters that are not scene-specific are filled in automatically from the TNTmips sensor reference file.



Values for correction parameters not found in the metadata are listed as “Unspecified”. These values can be filled in manually for each band and parameter.

The Options box (lower right corner of Radiometric Correction window) provides a Set Zero as Null toggle button. When this toggle is on, 0 values in the input image bands are interpreted as non-image (null) values if the band lacks a null mask or does not have a null value set. The corresponding cells are set as null in the output rasters.

Radiance

At-sensor spectral radiance for values in each image band is computed from image digital numbers by applying band-specific gain and offset values. This computation has the general form:

$$Radiance = gain * cell\ value + offset$$

The exact form of the computation varies from sensor to sensor depending on the form of the stored radiance calibration factors (for example, a scale factor that is the reciprocal of the gain or needing to divide the raw result by the bandwidth of the spectral band). Spectral radiance is expressed in units of Watts / (m² * steradian * μm).

Two mutually-exclusive options are provided in the Radiance box. Turning on the *Output* toggle creates an output raster with radiance values for each input image band. Turning on the *Set Scale on Input* toggle instead sets scale and offset values for the input image bands so that the raw cell values are expressed as radiance. (The scaled and offset values are used automatically in many raster processes in TNTmips.)

Reflectance

Spectral reflectance is the ratio of the radiance reflected from a surface at a particular wavelength to the radiant energy incident on the surface (irradiance) at that wavelength. The irradiance value for an image band is calculated from the solar irradiance for the particular wavelength band (*ESUN*), the earth-sun distance (*d*) on the imaging date, and the sun elevation angle (*θ*) at the time of image acquisition.

$$Reflectance = \frac{\pi * Radiance * d^2}{ESUN * \sin \theta}$$

Landsat 8 image metadata includes reflectance scale and offset values that encapsulate all factors except the sun elevation angle. The reflectance computation for Landsat 8 images is:

$$Reflectance = \frac{reflect.\ scale * cell\ value + reflect.\ offset}{\sin \theta}$$

Turn on the *Output* toggle in the Reflectance box to compute a reflectance raster for each input band. If no Dark Object or COST atmospheric correction is applied, the result is *top-of-atmosphere reflectance* or *apparent reflectance*, which includes atmospheric effects.

Since reflectance is a ratio, raw reflectance values can vary from 0 to 1.0. The default raster data type for reflectance rasters is therefore 32-bit floating-point. If you prefer to work with scaled integer reflectance values, you can choose an integer data type from the Type menu and set an appropriate scaling value in the Scale field.

Dark Object Correction

Solar radiation interacts with water vapor, other gas molecules, and small particles in the atmosphere, and some portion of this radiation is scattered in all directions. The amount of scattering is strongest for shorter wavelengths (blue band) and diminishes exponentially as wavelength decreases. Scattering also increases with the amount of water vapor and dust (haze) in the atmosphere. Light scattered upward toward the satellite sensor by this means contains no information about the surface properties, but is simply atmospheric noise. This *path radiance* is added to the radiance received from the ground surface by the sensor in each image band.

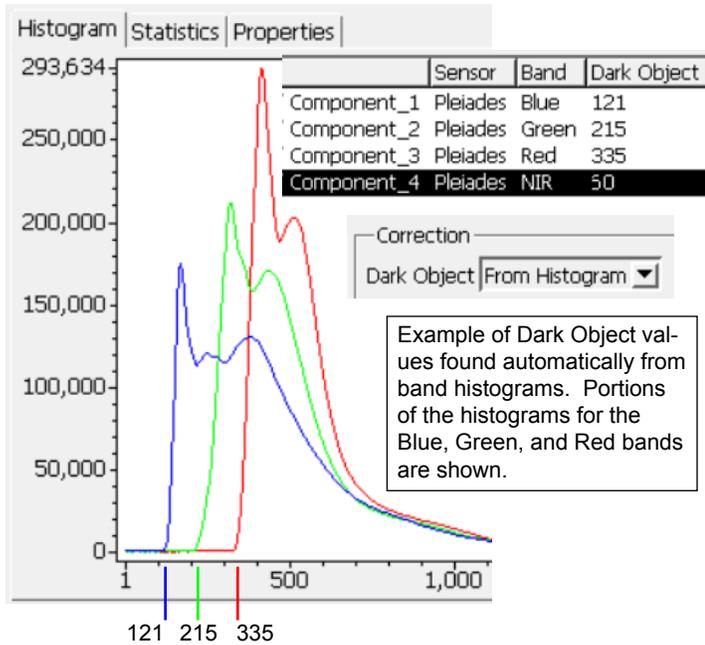
The Dark Object correction attempts to remove band-specific path radiance effects using image values for dark objects in the scene. Most satellite images contain at least some cells that should be effectively black, with near zero reflectance, such as deep shadows cast by topography or structures, or deep clear water bodies. These areas should not contribute any surface radiance to the image, so any measured values are assumed to be due to atmospheric path radiance. The “dark object value” in each band can then be subtracted from all image values to produce a path-radiance corrected image. The Dark Object correction can be applied to reflectance and/or output radiance rasters.

Dark object values can be determined in several ways, specified by the selection on the Dark Object menu in the Correction box. The options are None, From Histogram, Manual, and Predicted.

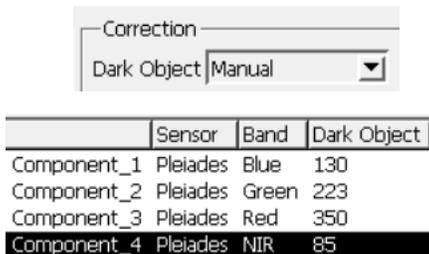
(continued)

The resulting value for each band is shown in the Dark Object column in the image list.

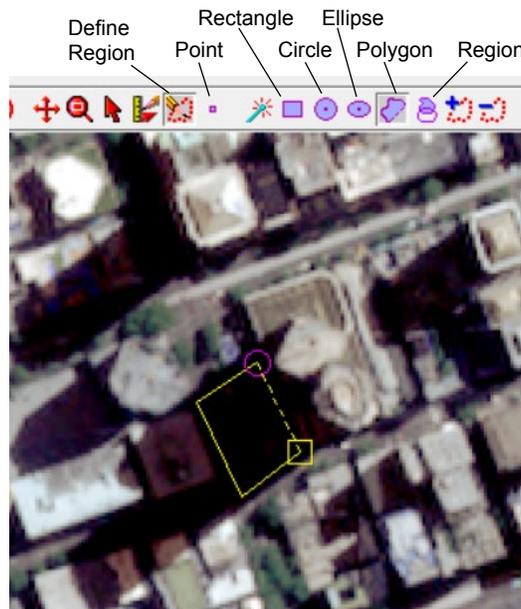
From Histogram: this method automatically determines dark object values from the band histograms by attempting to identify the inflection point on the lower end of the value range where the cell count begins to rise rapidly with increasing cell value. The assumptions are that dark object cells are far less numerous than other image cells and there is a range of dark object values due to sensor noise. The method attempts to identify the upper end of this dark object value range. An example for the Red, Green and Blue bands of a Pleiades image is illustrated below.



Manual: this method lets you set dark object values manually in two ways. If you have separately determined dark object values (such as by your own examination of the band histograms), you can enter the values directly in the Dark Object column in the image list. Alternatively, you can use the Define Region tool set in the View window to draw one or more points or shapes to define a region identifying dark features. (See the Technical Guide entitled *Define Region Toolset* for instructions on the use of these tools). Average band values from the defined region are then auto-



Dark Object value set manually by drawing a polygon outlining the dark shadow of a building.

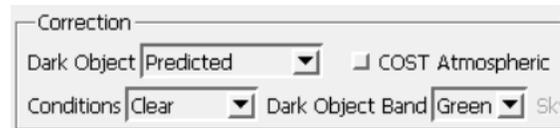


atically computed and shown in the Dark Object column (see illustration at the bottom of the previous column using a region in an urban building shadow to define the dark object values).

Predicted: a drawback of the previous methods is that the dark object value for each band is determined independently, whereas atmospheric scattering is wavelength-dependent. Radiance-corrected dark object values should conform to a negative exponential function with increasing wavelength.

Choosing the Predicted method activates the *Conditions* and *Dark Object Band* menus in the Correction box. Use the *Conditions* menu to choose a relative scattering model to define the wavelength dependence of the dark object values, based on your qualitative visual assessment of the atmospheric conditions in the scene. The choices on the menu are Very Clear, Clear, Moderate, Hazy, and Very Hazy. Each of these choices sets a different value for the wavelength function exponent in the relative scattering model. Use the *Dark Object Band* menu to choose either the Green or Red band as the starting dark object value to anchor the wavelength function. For details of the methodology, see the following reference:

Chavez, Pat S., 1988, An Improved Dark-Object Subtraction Technique for Atmospheric Scattering Correction of Multispectral Data. *Remote Sensing of Environment*, vol. 24, pages 459-479.



Sensor	Band	Dark Object
Landsat 8	Coastal	8984 / 9013
Landsat 8	Blue	8203 / 8303
Landsat 8	Green	7638 / 7638
Landsat 8	Red	5733 / 7307
Landsat 8	NIR	12673 / 7162
Landsat 8	Middle Infrared B	9572 / 7509
Landsat 8	Middle Infrared C	7106 / 8987

When you use the Predicted method, the Dark Object column shows the histogram-derived values on the left and the predicted values on the right.

When you use the Predicted method, the Dark object column in the image list shows both the histogram-derived and the predicted values for each band for comparison. The predicted values shown are in raw digital image values, but radiance-corrected values are used by the method when fitting the exponential function. You can change your selections from the *Conditions* and *Dark Object Band* menus if the current selections appear to over-correct the other bands.

COST Atmospheric Correction

The COST Atmospheric correction applies a first-order correction to reflectance values to account for atmospheric absorption effects. A portion of the sunlight illuminating

(continued)

a scene may be absorbed by gases during its passage through the atmosphere. For a given set of atmospheric conditions, the amount of attenuation of the incoming radiation is dependent on the length of the path through the atmosphere. A correction for this effect on reflectance values can be made by multiplying the values in each band by the cosine of the *solar zenith angle* (TZ), the angle between the vertical (zenith) and the sun's position in the sky at the time of image acquisition. The solar zenith angle is equal to 90 degrees minus the sun elevation angle recorded in the image metadata. For a technical discussion of this correction see the following reference:

Chavez, Pat S., Jr., 1996. Image-Based Atmospheric Corrections — Revisted and Improved. *Photogrammetric Engineering & Remote Sensing*, vol. 62, pages 1025-1036.

Topographic Correction

The Topographic correction in the Radiometric Correction process normalizes image reflectance values for terrain effects using a digital elevation model (DEM). To activate the Topographic correction toggle, press the DEM pushbutton below the image list and select a DEM raster that covers the entire extents of the image(s) being corrected. The DEM raster does not have to match the cell size or exact extents of the images, but it should have a cell size roughly equal to or less than that of the images.

The Earth's surface is illuminated in part by direct sunlight and in part by diffuse light from all parts of the sky, another consequence of atmospheric scattering. The amount of the direct sunlight reflected from a local surface varies depending on its orientation with respect to the direction to the sun, introducing a terrain dependence to the reflectance values calculated from image values. To a first approximation, the diffuse skylight can be assumed to be equal in all directions and thus the portion of the surface reflectance originating from skylight is not dependent on the terrain orientation.

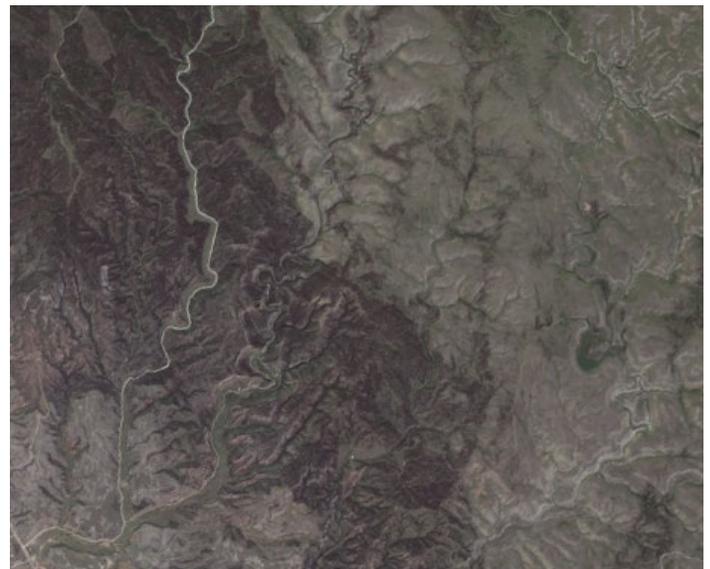
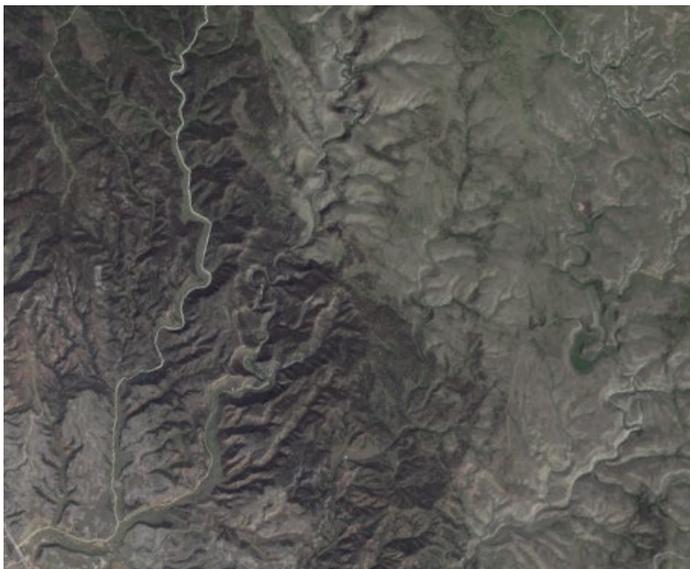
The Topographic correction adjusts reflectance values using relief shading values computed from the DEM. The relief shading value for each DEM cell is the cosine of the *incidence*

angle, the angle between the sunlight direction (calculated from the sun elevation angle and sun azimuth angle from the image metadata) and the normal to the local surface. Reflectance values are corrected by multiplying the relief shading value and the fraction of the reflectance value assumed to be due to direct solar illumination.

Because the skylight fraction is a result of atmospheric scattering, it is assumed to vary with band wavelength using the same relative scattering model you chose for the predicted Dark Object correction. Use the Skylight Band menu to choose the band (Green, Red, or None) to which to assign the value in the Skylight Fraction field (default 0.40). The computed values for individual bands are listed in the Skylight field in the image list.

Sensor	Band	Dark Object	Skylight
Landsat 8	Coastal	8984 / 9013	0.64
Landsat 8	Blue	8203 / 8303	0.54
Landsat 8	Green	7638 / 7638	0.40
Landsat 8	Red	5733 / 7307	0.30
Landsat 8	NIR	12673 / 7162	0.17
Landsat 8	Middle Infrared B	9572 / 7509	0.05
Landsat 8	Middle Infrared C	7106 / 8987	0.03

The Topographic correction brightens image cells on slopes that are not oriented toward the sun. (Applying the Topographic correction without incorporating the skylight adjustment tends to overcorrect [overly brighten] these cells). Reducing or removing the terrain influence on reflectance produces an image that appears “flatter”, providing a better starting point for image classification than an uncorrected image. However, natural vegetation patterns are also strongly influenced by terrain orientation, so vegetation differences may reveal topographic features even in a terrain-corrected reflectance image.



Natural-color display of Landsat 8 image bands: reflectance with topographic effects (left) and reflectance after terrain correction (right).