D: TERRAIN CORRECTION FOR SURFACE REFLECTANCE IMAGES

Like *Frequently Asked Questions*, a question is posed, e.g., *D1. How Do I Make a SHADING Raster?* Then, an answer is given[1] with comments and opinions. For cross referencing, each item is labeled, e.g., *D1*.

This tutorial deals with TERCOR.sml, its uses, and its options.

TERCOR.sml corrects SRFI values for the predictable effects of shading caused by terrain slope and aspect. Terrain shading values are obtained from a digital elevation model (DEM). Based on the corrected SRFI values, TERCOR.sml then produces a new pair of PVI (Perpendicular Vegetation Index) and PBI (Perpendicular Brightness Index) rasters (see *B36*).

Before you run TERCOR.sml, you must make a standardized SHADING raster. You do this by using two TNTmips menu-based processes as defined later in this tutorial in *D1*.

Inputs to TERCOR.sml:

1. A set of SRFI rasters.
- Ideally, the input SRFI values should be accurate within the level-terrain parts of the image. Use DIAG.sml with a level-terrain mask raster (MK) to verify the accuracy of the input SRFI raster values in level-terrain areas.
- If you see grossly inaccurate SRFI values, you should adjust them prior to applying TERCOR.sml. You do this by choosing a different set of icRL and/or msfac parameters when you re-run SRFI.sml.
- Spatial features in the SRFI rasters should be well registered with the same features in the DEM raster. This can be verified by displaying the SHADING raster (from **Process 2** in *D1*) with one of the SRFI rasters in the same display group. The View-in-a-View display option is a good way to verify the excellent registration of the SHADING raster and the SRFI rasters.

2. A digital elevation model (DEM) that covers or exceeds the geographic extent of the SRFI rasters.
- The map projection and cell sizes of the source DEM raster do not have to match that of the SRFI rasters. **Process 1** below addresses this mismatch situation. **Process 1** produces a new DEM raster that matches the SRFI rasters in terms of map projection, datum, orientation, cell sizes, and extent.

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Comment: More sophisticated algorithms, than **Process 2**, exist to produce the required standardized SHADING raster. TERCOR.sml may be improved by the use of one of these more sophisticated algorithms.

In Brief …

This tutorial discusses key SML functions and model concepts related to **TERCOR.sml**. The list below is divided into two groups: one for the key SML functions and the other for key model concepts.

If you are interested in a particular topic below, please go directly to it.

Quick Guide to Using TERCOR.sml …

If you are already familiar with SML functions and syntax … and you just want to Run TERCOR.sml, this Quick Guide will help you.

BEFORE you run TERCOR.sml …

- Run SRFI.sml. It produces the SRFI, PVI, and PBI rasters that TERCOR.sml uses as input rasters.
- From the vendor's metadata, note the following information items: SITE NAME, COLLECTION DATE, SUN ELEVATION ANGLE, SUN AZIMUTH ANGLE, and IMAGING SYSTEM.

AFTER you run the script, the script will ask you to provide or to accept specific information items via a series of **Popup Windows**, in the following order:

- **CONSOLE-WINDOW ADJUSTMENT:** Use your mouse to adjust the size and placement of the Console Window. You need to be able to view its contents as the script runs and prints data to it.
- **SITE-NAME ENTRY:** Type in the SITE NAME, e.g., Stockton, CA
- **IMAGER-NUMBER SELECTION:** From the list, select an Imager Number and type it, e.g., 4 for Landsat 7 ETM+.
- **GL SKY SPECTRAL-IRRADIANCE FRACTION ENTRY:** Accept the default entry, 0.40. If you believe that the sky spectral-irradiance fraction (of the total spectral irradiance) is higher than this, entry a different fraction. This might be the case for hazier atmospheric conditions at low elevations.
- **SUN-ELEVATION-ANGLE ENTRY:** Type in the angle as: NN.NN.
- **SUN-AZIMUTH-ANGLE ENTRY:** Type in the angle as: NNN.NN.
- **SRFI, PVI, and PBI RASTERS** are input rasters.
- A new set of **SRFI, PVI, and PBI RASTERS** are output rasters. You might put them in a new .RVC Project File called TERCOR.RVC.

The script takes a few minutes (up to 15 minutes) depending on the size of the imager file being processed.

*D1. How Do I Make the Required **SHADING** Raster?*

Start with a DEM raster. It probably does not match the SRFI rasters in terms of its extent, orientation, map projection, datum, or cell sizes. To produce the required SHADING raster, use two menu-driven processes in TNTmips as follows:

Process 1: Resample the DEM Raster to Match the SRFI Rasters

From the TNTmips main menu:

- Follow the menu path: Process > Raster > Resample and Reproject > Automatic… Button. The Raster Resampling using Georeference control box appears.
- In this box, Select the Rasters Tab.
- Select the Select Rasters…. The Select Objects window appears.
- Navigate to the source DEM raster and select it for processing. Its related .rvc file and raster name are listed in the related panel.
- In the control box, Select the Settings Tab. The Raster Resampling using Georeference control box now displays Settings parameters and choices. You **must** set all of these options as indicated below:
  - **Model**: Choose the From Georeference option.
  - **Method**: Choose the Bilinear Interpolation OR the Cubic Convolution option. The distance between DEM cells is likely not equal to the distance between SRFI cells. Bilinear Interpolation will produce a DEM value that involves a linear interpolation among the four DEM values that surround each output DEM raster point. Cubic Convolution will produce a DEM value that is a non-linear, cubic-weighted function of the 16 DEM values that surround each output DEM point. One choice is not always the right choice in every situation. You could elect to use both choices. Then, you would have two different SHADING rasters to use when performing terrain corrections on a set of input SRFI rasters.
  - **Extents**: Choose Match Reference. When you select this option, TNTmips asks you to Select a reference Object. Select one of the SRFI rasters (e.g., SRFIGL). Click OK to confirm your selection. Note that the .rvc file and raster name that you selected appear in the Reference Raster… panel.
  - **Scale**: Choose To Reference.
  - **Orient**: Should have been automatically changed to To Reference.
  - **Pyramid**: Choose Average. This option is not important.
  - **Null Value**: Select User-Defined. Then, change the value to **-1000**. **Never allow the Null Value to have a default value of "0"** as many elevations in a DEM are, in fact, zero (sea level pixels). In fact, some DEM values may be less than zero, even over land, e.g., Death Valley or reclaimed "ponds."
- Now, Select **Run…** . TNTmips ask you to find a **.rvc** and raster name for this output DEM raster. The author suggests that you call both DEM2.

- You may have noticed that you were not given a choice about the data type for DEM2.
- When this process is finished, you should Exit the process and then view the DEM2 raster that was made. You can display it with a SRFI raster, for example, to verify that the process worked correctly. There are many other good and interesting things you can do with the new DEM2 raster, e.g., using it as the elevation raster in a 3-D display. DEM2 will have the same number of lines and columns as the reference SRFI raster, and it will match in terms of extent, orientation, and cell size. The Null Value of DEM2 should be -1000 (m).

Process 2: Produce a SHADING Raster from the DEM2 Raster

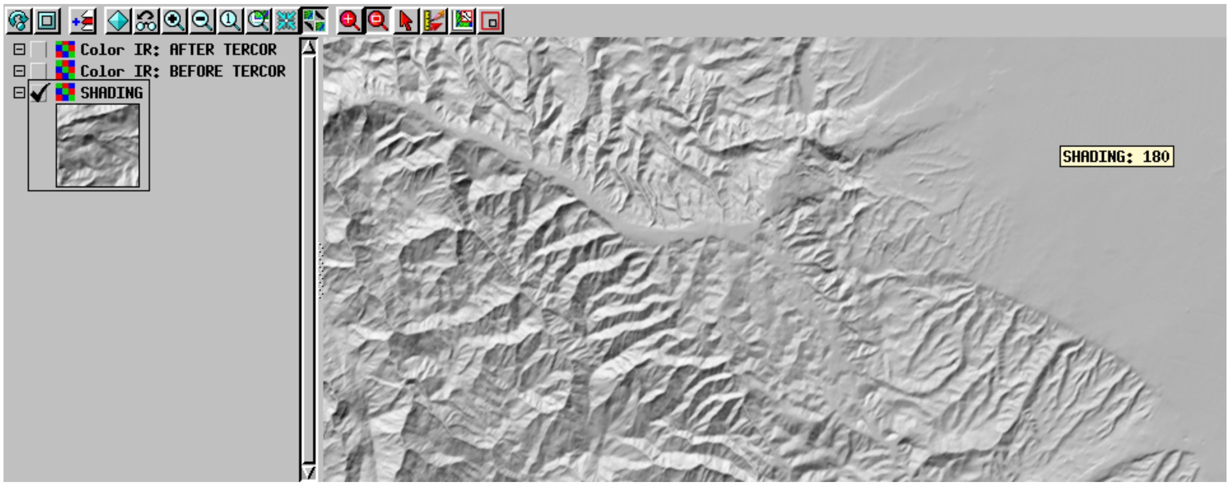
From the TNTmips main menu:

- Select the menu path: Process > Raster > Elevation > Slope, Aspect, and Shading. The Slope, Aspect, and Shading control box appears.
- Select Raster…. Navigate to the location of the DEM2 raster and select it. Again, there are several options. You **must** select the following options:
  - **Slope**: Turn off the "Rescale to range [0…255] radio button. Push in the "Square" Button (default is off). To can leave the units as "Degrees." This applies to the Slope raster that you will not be using.
  - **Aspect**: Turn off the "Rescale to range [0..240]. Again, you will not be using the Aspect raster.
  - **Shading**: Be sure that this is "8-bit unsigned integer." The output SHADING raster will have a value of 180 for level terrain. For non-level terrain, SHADING will be higher than 180 (up to 255) for sun-facing slopes and will be lower than 180 (down to 1) for shadowed slopes. Corrections to the SRFI rasters will be based on the values in the SHADING raster.
  - Referring to information in the metadata file, specify the Elevation angle of the sun (in degrees) and the Direction of the sun (in degrees).
  - Set the Scale for Elevation to its default value of 1.0. Any other value will affect the SHADING value and will lead to wrong corrections to the SRFI rasters.
- Now, Run… the process. Put the output SHADING raster in the project file that contains the related SRFI rasters. You do not need to save the SLOPE or ASPECT rasters. Null-value pixels in DEM2 will have a Null Value of 255 in the SHADING raster.

Smith (2004) describes the TNTmips tool that produces a SHADING raster.

A result of these two processes is shown for an area west of Stockton, CA, in ***Figure D1***.

Figure D1. SHADING for an Area West of Stockton, CA.



D2. What is the Role of **`fGL`**?

In TERCOR.sml, the user specifies the value of the **`fGL`** parameter, which is the part of the total spectral irradiance at the surface that comes from the sky in the GL band. There are 9 possible f-factors: **`fBL`**, **`fGL`**, **`fRL`**, **`fRE`**, **`fNA`**, **`fNB`**, **`fMA`**, **`fMB`**, and **`fMC`** in TERCOR.sml.

The **`fXX`** value for each spectral band, **`XX`**, is predicted using the following power-law model:

`fXX = flr + (fGL – flr) * (wLenGL / wLenXX)^p` **(D1)**

where

- **`flr`** = reference "floor" value for **`fXX`** (default = 0.12)
- **`fGL`** = user specified value (default = 0.40)
- **`wLenGL`** = effective wavelength associated with the GL Band (in μm)
- **`wLenXX`** = effective wavelength associated with Band **`XX`** (in μm)
- **`p`** = exponent of this power-law model (default = 2.0)

When **`wLenXX`** = **`wLenGL`**, then fXX = fGL. When **`wLenXX`** > **`wLenGL`**, then **`fXX`** < **`fGL`**. When **`wLenXX`** < **`wLenGL`**, then **`fXX`** > **`fGL`**. As **`wLenXX`** goes toward very long wavelengths, fXX approaches **`flr`**.

For the default value of **fGL** = 0.40, and at Landsat 7 ETM+ wavelengths, the distribution of **fXX** with **wLenXX** is predicted by this model to be as follows:

BAND	wLen	fBAND
BL	0.482	0.505
GL	0.565	0.400
RL	0.660	0.325
NA	0.825	0.251
MB	1.650	0.153
MC	2.220	0.138

If **fGL** is increased or decreased, all of the other **f**-factors are affected in the same way, i.e., they increase or decrease. One way for the user to select an optimum value for **fGL** is to try different values (on a small extracted SRFI and SHADING raster set) until the results look acceptable. Varying **fGL** affects primarily the shorter spectral band images where the effects of shading are most diminished due to the large sky spectral irradiance component to the overall reflectance.

D3. What is the **TERCOR** *Algorithm?*

The derivation of the TERCOR algorithm is as follows. Let SIp be the predicted spectral irradiance from the sky and the sun at the surface for level terrain. SIp is composed of two additive components:

- **SIsky**: The spectral irradiance **from the sky** *without* attenuated solar radiant energy
- **SIsun**: The spectral irradiance **of the attenuated solar radiant energy**

That is,

SIp = SIsky + SIsun **(D3a)**

On non-level, sun-azimuth-oriented slopes, the *actual* value of SI, denotes as SIa, is not the same as SIa. The standardized SHADING raster produced by TNTmips (see *D1*) is a quantitative raster that expresses the shading and brightening which results from the complex interactions between direct solar spectral irradiance and facets of the terrain having different properties of slope and aspect. The TNTmips SHADING algorithm produces a SHADING raster based on a terrain model that has a nominal (level-surface) brightness of 180 (on a scale from 1 to 254 with 255 being used for null-valued pixels).

Define the floating-point shading factor, **s**, to be:

s = SHADING / 180 **(D3b)**

The value of **s** varies from 0.0 (when SHADING = 0) to 1.0 (when SHADING = 180) to 1.411111 (when SHADING = 254). Thus,

SIa = SIsky + s * SIsun **(D3c)**

Materials on the terrain surface will absorb and scatter a fraction of the **actual spectral irradiance**, SIa. The resulting upwelling radiant energy has a spectral exitance of SE. The relationship between SIa, SE, and RF is as follows:

SE = RF * SIa = RF * (SIsky + s * SIsun) **(D3d)**

RF is the reflectance factor (in fractional units) of the surface materials. Note that RF acts the same way on SIsky and on the term, s * SIsun.

From *Equation (D3d)*, an expression for RF can be derived, namely:

RF = SE / (SIsky + s * SIsun) **(D3e)**

SE is the result of integrating the spectral radiances, SR, associated with all upwelling directions over the upper hemisphere. But, an earth imager observes the value of SR only in one direction – the viewing direction. If we assume that the reflecting surface is a Lambertian surface (where SR is the same in all directions), we can replace the SE in the above equations with SSE, the standardized spectral exitance. The related actual standardized reflectance factor is SRFa. That is,

SRFa = SSE / (SIsky + s * SIsun) **(D3f)**

However, when SRF is calculated in SRFI.sml, the existence of a shading effect was not included. Thus, the predicted value for SRF, called SRFp, is calculated by:

SRFp = SSE / (SIsky + SIsun) = SEE / SIp **(D3g)**

Combining *Equation (D3f)* and *Equation (D3g)*, an expression for SRFa / SRFp can be obtained, as follows:

SRFp / SRFa = (s * SIsun + SIsky) / SIp **(D3h)**

= s * (1 – f) + f **(D3i)**

where

f = SIsky / SIp **(D3j)**

Since SRFIa = SRFa * 100, and since **SRFIp = SRFp * 100**, then the **TERCOR** correction algorithm, as a function of **s** and **f** is:

$$\mathbf{SRFIa = SRFIp \ / \ [s * (1 - f) + f]} \qquad \textbf{(D3k)}$$

The parameters in *Equation (D3k)* are for surface values in a given spectral band, XX. In TERCOR.sml, SRFIp values come from the input SRFI rasters, and SRFIa values are written to the output SRFI rasters.

D4. What is an Example Output from TERCOR.sml?

Figures D4a and D4b show the "before" and "after" images for the same small area that was shown in the SHADING image (***Figure D1***).

Many terrain-shadowing effects are removed by the TERCOR.sml algorithm. What may appear to be uncorrected shadowing effects are not. Real vegetation density differences exist between the south-facing slopes that have a more arid microclimate and north-facing slopes that have a more humid microclimate.

The correction equation becomes somewhat unstable when both **s** and **f** are close to zero. However, **f** is never actually equal to zero, even for the MC band. That is, there is always some significant amount of SIsky present even in the darkest shadows on the northwest sides of steep ridges.

The agricultural area in the northeastern part of these images is on level ground. Therefore, there is no correction – and the images are identical.

The impact of being able to correct surface reflectance data (i.e., SRFI) for terrain slope and aspect effects is profound on subsequent classification and information extraction processes. In commonly-available image-processing algorithms, if two pixels have different absolute reflectance signatures, they will be classified into two different land-cover categories. Due to shading and brightening effects on non-level terrain, identical types of land cover will be seen as spectrally different on various slope and aspect surfaces. TERCOR.sml removes these differences and allows for image processing algorithms to correctly analyze the land cover and its biophysical properties regardless of the terrain slope and aspect (at least up to moderate slopes).

Figure D4a. Original Landsat 7 ETM+ Color Infrared Display with Uncorrected Terrain Shadows.

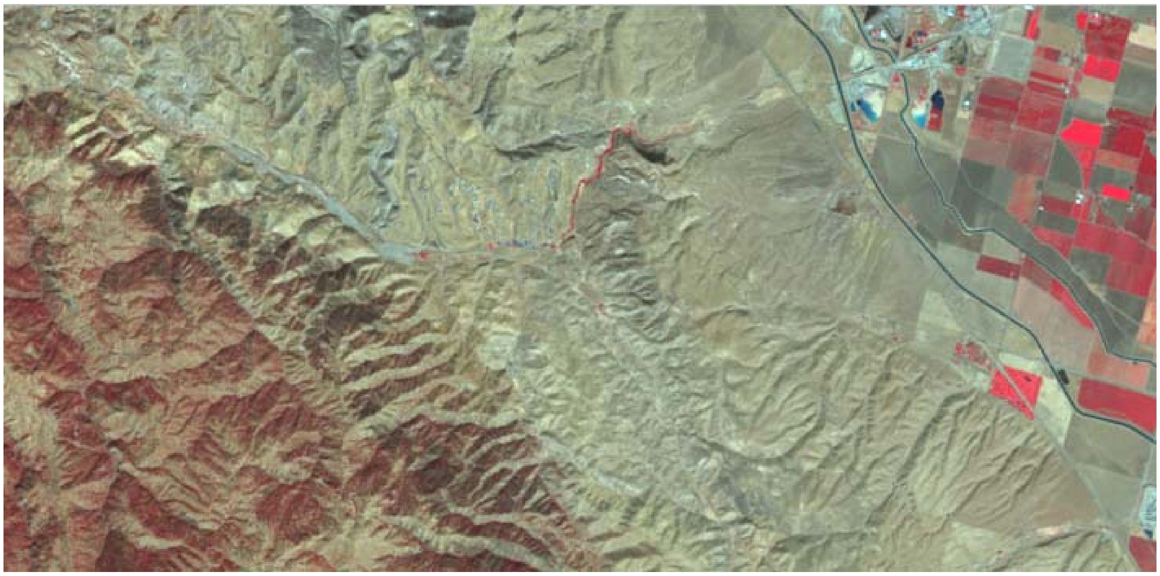
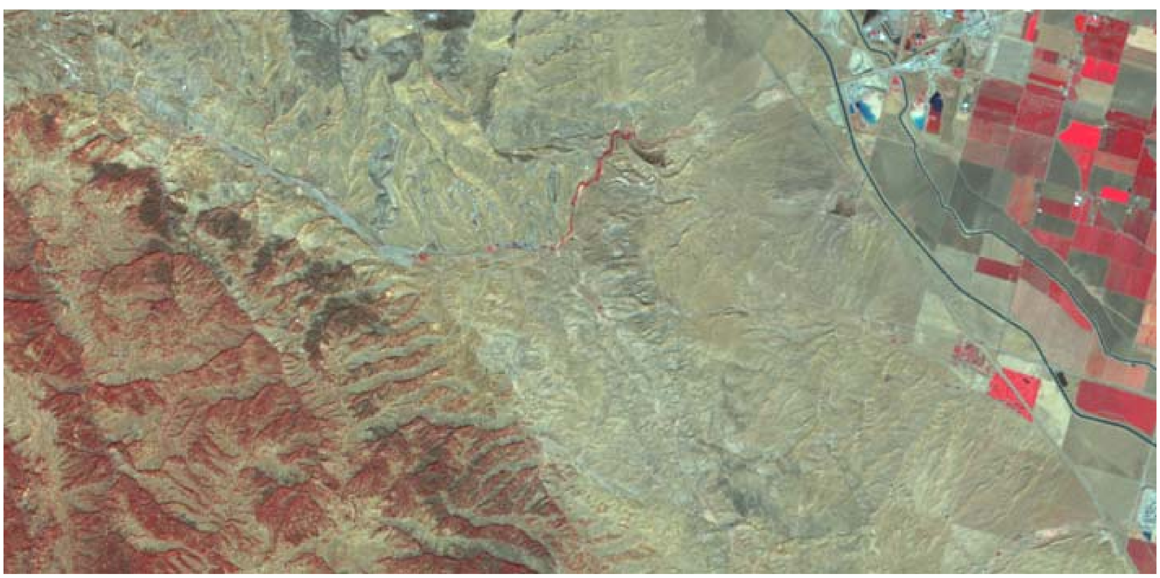


Figure D4b. Corrected Landsat 7 ETM+ Color Infrared Display without Terrain Shadows: Corrected by TERCOR.sml.



TERCOR.sml preserves the SRFI scale. Thus, the output SRFI products from TERCOR.sml may be used as inputs to GRUVI.sml or to TASCAP.sml (see *E* and *F*; TASCAP.sml and *F* have not yet been written).

REFERENCES

Smith, R. B., 2004: Analyzing Terrain and Surfaces. MicroImages, Inc., 11th Floor – Sharp Tower, 206 South 13th Street, Lincoln, NE 68508-2010, available on www.microimages.com