

TOPOGRAPHIC NORMALIZATION

INTRODUCTION

Use of remotely sensed data from mountainous regions generally requires additional pre-processing, including corrections for relief displacement and solar illumination differences. Specifically, variations in illumination affect land cover discrimination as the same land cover will have different spectral responses among shadowed and non-shadowed areas (Figure 1).

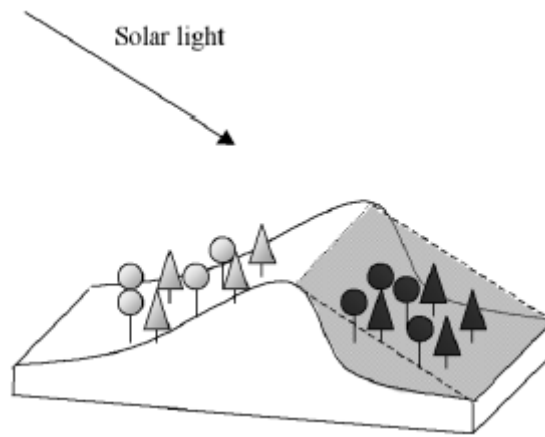


Figure 1. Effect of relief on the spectral response of the same land cover (Riaño et al. 2003).

The correction of illumination variations is referred to as Topographic Normalization or Topographic Correction. Techniques are grouped into two major categories, (1) band ratios and (2) modeling of illumination conditions. Band ratio techniques assume that the spectral response is distorted (increased or decreased) in the same way across all bands. Therefore, the quotient between them will compensate for topographic effects. Their drawback is the loss of spectral resolution. Techniques under group (2) model illumination to compute the flat-normalized radiance of each pixel. They are grouped into two additional subcategories, Lambertian and non-Lambertian, depending on whether they assume a Lambertian or non-lambertian surface behavior.

OBJECTIVES

This lab addresses the topographic normalization techniques that model illumination conditions. Specific objectives include:

- Calculate the illumination surface.
- Perform Topographic Normalization using Lambertian and non-Lambertian techniques. Erdas has a tool to perform the Lambertian Topographic Normalization technique (under **Interpreter** → **Topographic Analysis** → **Topographic Normalize...**). We will be using this technique, but will implement it through the *Erdas model maker*.

DATA

For this lab, an image from south-central California will be used. The image includes 3 of California's distinct bioregions (from west to east): The San Joaquin Valley, the Sierra and the Mojave Desert. Sequoia National Park is included within the Sierra bioregion.

The landcover data dates from 2002 and was published by the California Department of Forestry and Fire Protection. Detailed metadata for this file is included within the lab folder.

Files provided for this lab are:

File	Type	Description
etm_41_35_20000720_reproj	<i>img</i>	Landsat ETM+ scene, path 41/row 35 (southern California), with standard radiometric calibration performed.
illumination	<i>gmd</i>	Erdas model to generate the illumination surface.
p041r035_7x20000720	<i>txt</i>	Image header file.
landcover	<i>img</i>	Landcover data (100 m).
landcover_metadata	<i>txt</i>	Metadata for landcover layer.
ned	<i>img</i>	DEM from the national elevation dataset (1 arc-second ~ 30 m), reprojected to UTM zone 11 north.

PROCESS

Follow the steps outlined below to implement different topographic normalization techniques on the Landsat ETM+ image, and answer the questions presented throughout the lab.

1 ILLUMINATION SURFACE

The illumination value for each pixel is calculated as the cosine of the incident angle γ_i . This angle is defined as that one between the normal to the ground and the sun rays (Figure 2).

Illumination ranges between -1 (minimum) and +1 (maximum), and is computed as follows:

$$IL = \cos \gamma_i = \cos \theta_p \cos \theta_z + \sin \theta_p \sin \theta_z \cos (\phi_a - \phi_o) \quad (1)$$

where:

- γ_i = incidence angle
- θ_p = slope angle
- θ_z = solar zenith angle = (90 – sun's elevation angle)
- ϕ_a = solar azimuth angle
- ϕ_o = aspect angle

The sun's elevation and azimuth angles are obtained from the image header file.

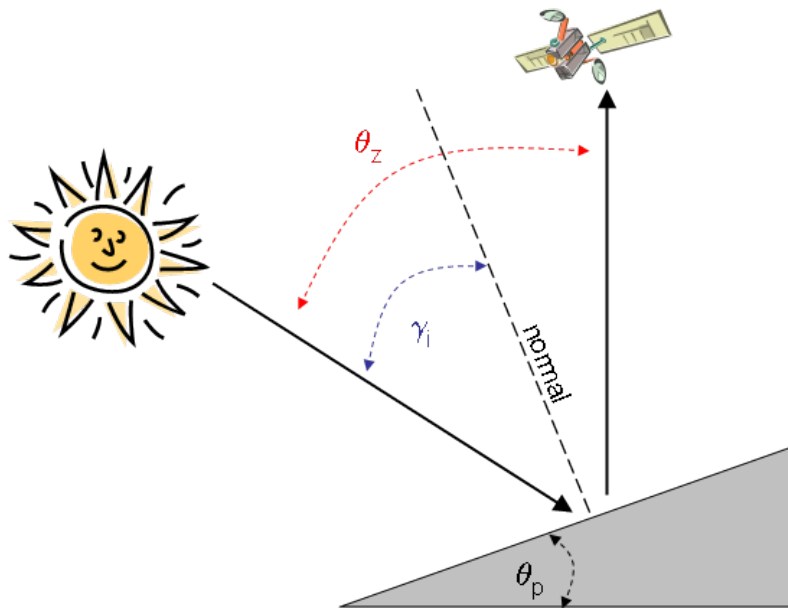


Figure 2. Representation of the Sun's angle of incidence (γ_i), zenith angle (θ_z), and terrain slope (θ_p).

1.1 Calculate slope and aspect surfaces

- Launch *Erdas* and *click* on **Interpreter** → **Topographic Analysis...** → **Slope...**
 - Select the DEM (`ned.img`) and keep all other options as default. Output units should be in **degrees**.
 - *Click* **OK** and name the output file as `slope.img`.
- *Click* on **Interpreter** → **Topographic Analysis...** → **Aspect...**
 - Select the DEM (`ned.img`) and keep all other options as default.
 - Name the output file as `aspect.img`.

1.2 Calculate the illumination surface

- Launch *Erdas model maker* and create a model to calculate illumination, based on the equation (1) (see Appendix). You can also use the model provided (`illumination.gmd`).
 - Name the output file as `illum.img`. Its **data type** should be set to floating.
- ⓘ *Notice that the cosine function in Erdas requires that input angles be in radian units (not degrees).*
- Open the *illumination* surface and check its range of values. Remember that they should be between -1 and +1.

The illumination surface will look like a 3D representation of the relief:

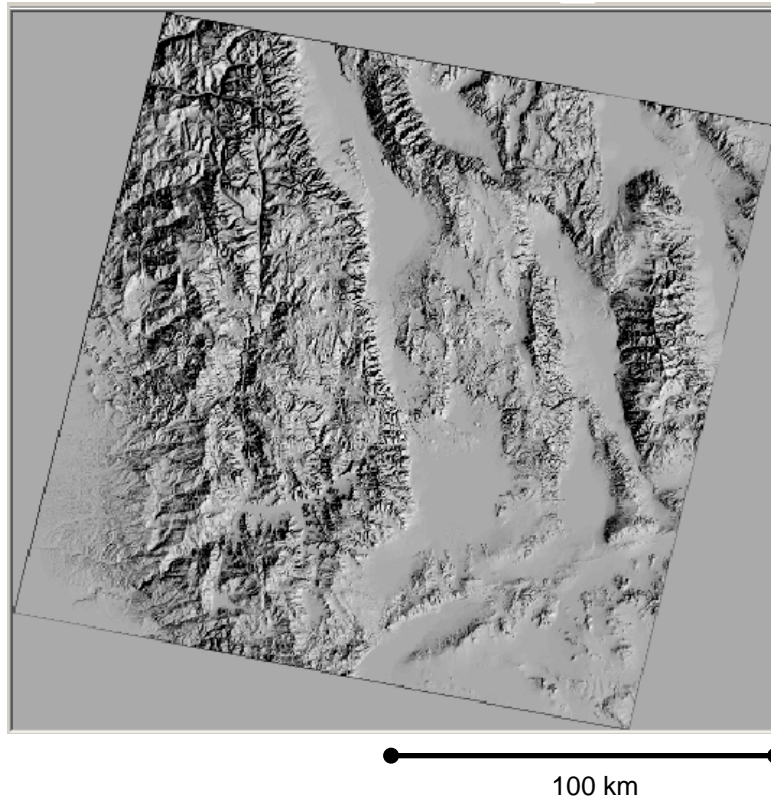


Figure 3. Illumination surface.

2 LAMBERTIAN TECHNIQUES

These techniques are the easiest to implement, but are based on somewhat unrealistic assumptions, such as: (1) the surface reflects energy equally in all directions, (2) the correction is wavelength independent, (3) constant distance between the Earth and the Sun, and (4) constant amount of solar energy illuminating the Earth.

2.1 Cosine correction

This method is computed as:

$$L_H = L_T \frac{\cos \theta_z}{IL} \quad (2)$$

where: L_H = radiance of a horizontal surface
 L_T = radiance of an inclined surface

This method is known for resulting in overcorrection of weakly illuminated areas as it does not take into account sources of illumination other than the direct irradiance (e.g. diffuse skylight or light reflected from surrounding pixels).

To compute this correction:

- Create a model in *Erdas model maker* to calculate the corrected value of each pixel based on equation (2).
 - Name the output file as `etm_41_35_20000720_cosinecorr.img`.
- Open the corrected image and compare it with the original one:

Do you see any areas of overcorrection?

Do they coincide with areas of low or high illumination values?

2.2 Modified cosine correction

This method seeks to improve the above equation by taking into account average illumination conditions, and reducing the overcorrection effect. It is computed as:

$$L_H = L_T + \left[\frac{(IL_m - IL)}{IL_m} \right] \quad (3)$$

where: IL_m = average IL value for the study area

To compute this correction:

- Compute the average illumination value for the image. You can do this by looking at the file statistics using the image information tool.

Be careful however, as it is possible that while computing illumination, the border pixels (value of 0 in the image) were assigned a value. If this is the case, you will need to recompute the statistics only within the image area. To do this:

- Create an AOI (polygon) delimiting the image area (and excluding the border pixels) and make sure it is selected.
- Within the *Image Info* window: Click on **Edit** → **Compute Statistics...** → **Use AOI...** → **Viewer** → **OK** → **OK**
- Create a model in *Erdas model maker* to calculate the corrected value of each pixel based on equation (3).
 - Name the output file as `etm_41_35_20000720_cosinecorr_mod.img`.

- Compare the resulting image with the previous one to see if there are any improvements.

3 NON-LAMBERTIAN TECHNIQUES

These techniques try to model the roughness of the surface, or the degree to which it is Lambertian. Usually, they require the calculation of correction coefficients which are wavelength dependent. Therefore, each band is processed separately.

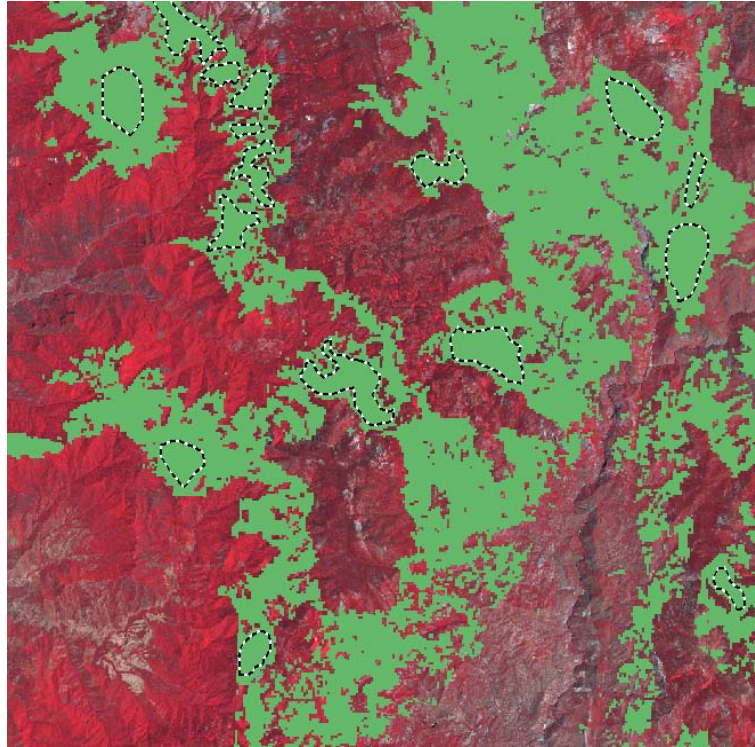
The computation of the correction factors will be done using a subset of pixels from the same land cover class. First, we will extract the pixel values from the image bands and illumination layers, and then, we will compute the correction factors.

3.1.1 Data extraction

- In a new viewer, open the landsat image and the land cover grid.
 - Use the raster attribute table to assign colors to different land cover classes.
 - Use the swipe tool to get familiar with the different land cover classes.

The land cover data comes from a statewide multisource land cover layer, with a 100 m pixel resolution, so keep this in mind when interpreting your results. It also has a different projection than the image, but this should not be a problem in carrying out the following steps.

- Select a land cover class spread over rugged terrain (e.g. Sierran mixed conifer):
 - Create several AOIs covering this class and a wide range of illumination conditions.
 - Save the AOI layer.



10 km

Figure 3. AOIs (dashed black-white lines) created over same land cover class (Sierran mixed conifer, in green).

- Extract the pixel values (bands 1 through 7, and illumination) using the AOI layer:
 - In *Erdas* main menu: *Click* on **Utilities** → **Convert pixels to ASCII...**
 - Name the output file as `sample.asc`. This text file will have the XY coordinates of the sampled pixels, plus their respective DN and illumination values.
- Open the generated file in excel and clean it up, so that it looks like:

	A	B	C	D	E	F	G	H	I
1	X	Y	illum	B1	B2	B3	B4	B5	B7
2	341154	4072835	0.801466	24	37	31	129	53	30
3	341154	4072805	0.797593	25	38	34	149	75	34
4	341184	4072925	0.744247	23	42	35	127	63	33
5	341184	4072895	0.70461	24	38	34	124	74	35
6	341184	4072865	0.691175	25	40	33	131	67	34
7	341184	4072835	0.699665	28	46	45	159	84	40
8	341184	4072805	0.699665	25	39	39	149	81	42
9	341184	4072775	0.680019	25	37	33	133	74	40
10	341184	4072745	0.648291	22	37	33	122	57	29
11	341214	4073045	0.63738	25	33	29	122	53	27
12	341214	4073015	0.686579	25	41	38	147	70	37
13	341214	4072985	0.722766	26	44	39	129	76	41
14	341214	4072955	0.717656	28	37	37	124	64	33
15	341214	4072925	0.715369	26	34	33	129	55	25
16	341214	4072895	0.676498	24	38	34	124	74	35

- Copy the data to a statistical program such as SPSS in order to calculate the correction factors.
- Create scatter plots of illumination (X axis) versus bands 1-7 (Y axis). These will provide you with an idea on how affected are DN values by illumination conditions.

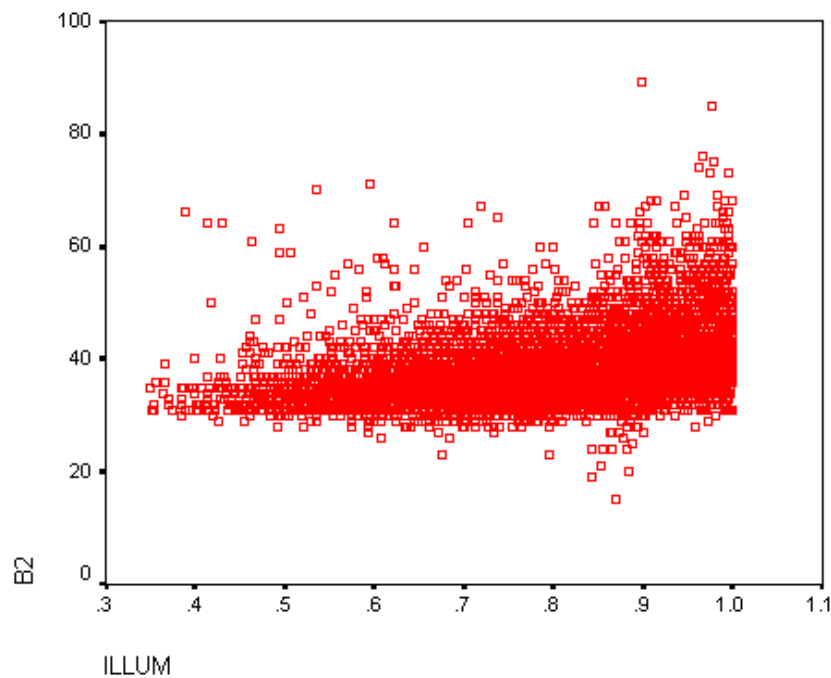


Figure 4. Scatter plot of illumination (X) vs. original Band 2 DN values for AOIs (Sierran mixed conifer land cover class).

3.2 Minnaert Correction

This method was proposed by Minnaert, who modified the cosine correction by including a factor which measures the extent to which a surface is Lambertian. This method is computed as:

$$L_H = L_T \left[\frac{\cos \theta_z}{IL} \right]^{K_k} \quad (4)$$

where: $K_k =$ Minnaert constant for band k

K ranges between 0 and 1. If K=1, then the equation becomes the same as the cosine correction, meaning that the surface behaves as a perfect Lambertian reflector.

The value of K is computed by linearization of the above equation:

$$\ln(L_T) = \ln(L_H) + K_k \ln \left[\frac{IL}{\cos \theta z} \right] \quad (5)$$

where: $\ln(L_H) =$ intercept of the regression
 $K_k =$ slope of the regression for band k

To compute K for Band 2:

- Run a linear regression analysis using equation (5) and data for Band 2. Check the regression coefficient section:

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	3.664	.002		2346.572	.000
	ln_il/cosz	.309	.007	.407	44.539	.000

a. Dependent Variable: LN_B2

In this example, the regression slope = 0.309. This is the value of the Minnaert constant (K) for Band 2.

- Within the statistical program, create an additional column with the corrected values for Band 2, using equation (4).
- Create a scatter plot of illumination (X axis) versus Band 2 Minnaert corrected values (Y axis). Compare it with the original plot.

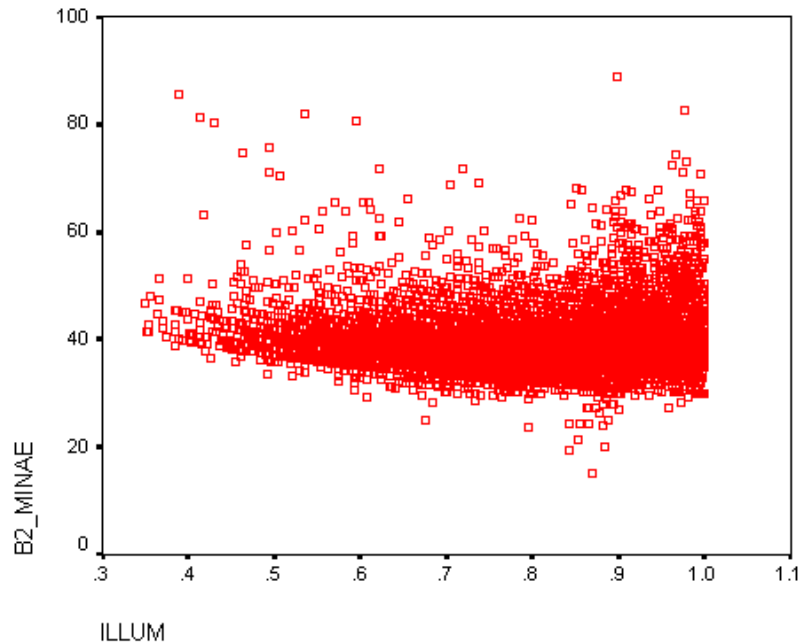


Figure 5. Scatter plot of illumination (X) vs. Band 2 Minnaert corrected for AOIs (Sierran mixed conifer land cover class).

Do you notice any changes with the uncorrected Band 2 data?

- Now, you can implement this correction by creating a model in *Erdas model maker* to calculate the corrected value of each pixel based, using equation (4).
 - Name the output file as `etm_41_35_20000720_minaertcorr.img`.
- Compare the resulting image with the previous ones.

3.3 C Correction

This technique was introduced by Teillet et al. (1982) and includes the calculation of the parameter “c”, as follows:

$$L_H = L_T \left[\frac{\cos \theta_z + c_k}{IL + c_k} \right] \quad (6)$$

where: $c_k = \frac{b_k}{m_k}$

and b_k and m_k are the regression coefficients (for band k) of:

$$L_T = b_k + m_k IL \quad (8)$$

To compute c for Band 2:

- Run a linear regression analysis using equation (8) and data for Band 2. Check the regression coefficient section:

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	24.251	.312		77.682	.000
	ILLUM	17.084	.385	.406	44.383	.000

a. Dependent Variable: B2

In this example, and for Band2, $m = 17.084$ and $b = 24.251$.

- Calculate the value of c using equation (7).
- Within the statistical program, create an additional column with the corrected values for Band 2, using equation (6).
- Create a scatter plot of illumination (X axis) versus Band 2 c-corrected values (Y axis). Compare it with the previous plots.

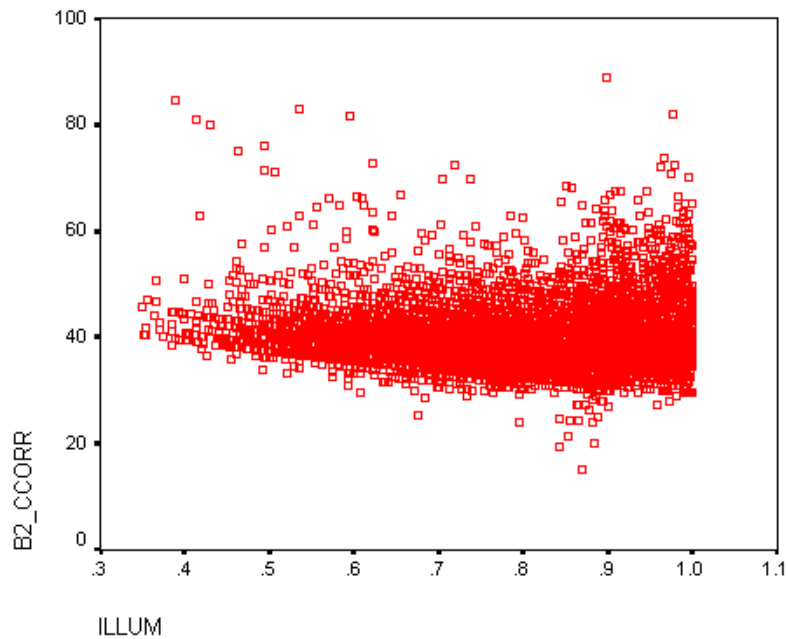


Figure 6. Scatter plot of illumination (X) vs. Band 2 c-corrected for AOIs (Sierran mixed conifer land cover class).

- Implement this correction by creating a model in *Erdas model maker* to calculate the corrected value of each pixel based, using equation (6).
 - Name the output file as `etm_41_35_20000720_ccorr.img`.

How does this image compare with the previous ones?

3.4 Comparison with cosine corrected values

- Within the statistical program, create an additional column and calculate the cosine corrected values for the same pixels, using equation (2).
- Create a scatter plot of illumination (X axis) versus Band 2 cosine corrected values (Y axis).

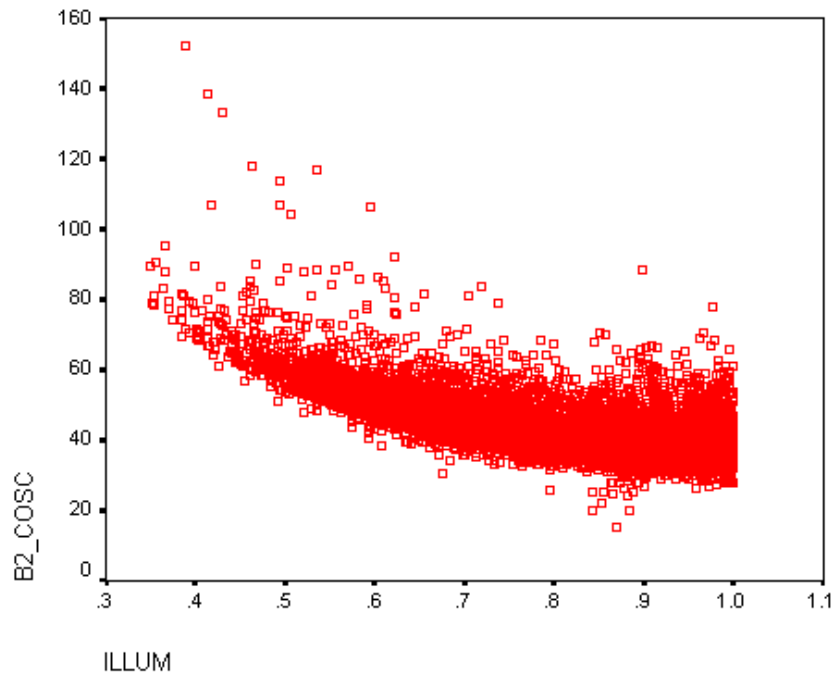


Figure 7. Scatter plot of illumination (X) vs. Band 2 cosine corrected for AOIs (Sierran mixed conifer land cover class).

- Make a visual assessment of all plots and determine which techniques are most effective in reducing the illumination effects.

4 FINAL REMARKS AND QUESTIONS

The effectiveness of each method can also be assessed by performing a linear regression analysis between illumination and the corrected values, and comparing regression coefficients among methods.

However, since these corrections are usually performed in order to improve classification accuracy, their effectiveness would be ultimately tested by their improvement on land cover classification.

Questions:

Under what conditions do you think these techniques would be more helpful? Think about geographic conditions, seasonality, sensor, etc.

What advantages and disadvantages do you find for each technique?

Can you think of other ways to deal with different illumination conditions in an image?

Further work:

Implement different corrections methods for an image you're familiar with, and perform a classification to compare the effectiveness of these techniques.

REFERENCES

Meyer P., Kl Itten, T. Kellenberger, S. Sandmeier and R. Sandmeier. 1993. Radiometric corrections of topographically induced effects on Landsat TM data in an alpine environment. ISPRS Journal of Photogrammetry and Remote Sensing 48(4): 17-28.

Riaño D., E. Chuvieco, J. Salas and I. Aguado. 2003. Assessment of different topographic corrections in Landsat-TM data for mapping vegetation types (2003). IEEE Transactions on geoscience and remote sensing 41(5): 1056-1061.

Teillet PM., B. Guindon and DG Goodenough. 1982. On the slope-aspect correction of multispectral scanner data. Canadian Journal of Remote Sensing 8(2): 84-106.

ILLUMINATION MODEL

