University of Massachusetts Boston – Department of Environmental, Earth, and Ocean Sciences

EEOS 383 - GISCIENCE FOR WATER RESOURCES RESEARCH – Spring 2010

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Exercise 09: Creating LST and NDVI from Brightness Temperature and Reflectance Data

Introduction

Before we can begin making use of remotely-sensed data to assess the surface moisture condition of the landscape, we must first become familiar with the data itself, and the sorts of operations required to convert the data from its raw form to a form that will be useful for our purposes.

In order to describe the surface moisture condition in terms of the relationship between sensible and latent heat fluxes in the region of interest, we will require two sorts of values derived from remotely-sensed data. Land surface temperature (LST) will be derived using the split-window technique developed by Price (1984), which requires brightness temperature information in two thermal infrared bands. Normalized difference vegetation index (NDVI; Nemani and Running, 1989 for our purposes, and in many preceding references elsewhere) will be derived using red and near-infrared reflectances, a technique that takes advantage the unique response of vegetative matter to energies in these wavelengths.

Data

The exercises in the remainder of the course will use remotely-sensed data in the vicinity of North Carolina Climate Division 3. This geographic unit is an agglomeration of 13 counties in north-central North Carolina, which includes the cities and towns of Durham, Chapel Hill, Greensboro, Burlington, and Winston-Salem. This particular exercise will make use of 4 bands of an Advanced Very High Resolution Radiometer (AVHRR) 14-day composite image (composited by taking 14 individual daily images, and for each pixel finding the data of maximum NDVI, and then using reflectance and brightness temperatures from the day of maximum NDVI to populate the bands), collected May 17 – 30, 2002:

- band1 – This GRID contains red reflectance data (0.58 – 0.68 μm), recorded as an 8-bit number
- band2 – This GRID contains near infrared reflectance data (0.72 – 1.10 μm), recorded as an 8-bit number
- band4 – This GRID contains thermal infrared (10.3 – 11.3 μm) brightness temperature data in degrees K, recorded as an 8-bit number after shifting and scaling the values has been applied to allow the values to fit in the 0-255 range
- band5 – This GRID contains thermal infrared (11.5 – 12.5 μm) brightness temperature data in degrees K, recorded as an 8-bit number after shifting and scaling the values has been applied to allow the values to fit in the 0-255 range
- mask – This GRID contains an analysis mask for North Carolina Climate Division 3

Procedure and Questions

Calculating Brightness Temperatures

- The equation we will use to calculate land surface temperature LST is:

  $$LST = BT4 + 3.33\ (BT4 – BT5)$$

  where BT4 and BT5 are the brightness temperature values in degrees Kelvin for channels 4 and 5 respectively. However, these are not the values that are actually stored in the channels.

- The data file used for this AVHRR image provides an 8-bit number for each pixel for each channel. That is to say that it is possible to store a value between 0 and 255 for each cell for each channel. The problem is that values of brightness temperatures in degrees Kelvin do not fit inside that range: Temperatures in degrees Kelvin have a value that is 273.15 degrees less than the equivalent temperature in degrees Celsius. Thus, for a typical temperature of 20 degrees C, the equivalent in the Kelvin scale is 293.15 degrees K, and this is a value that will not fit in the 8-bit range provided.

- The solution to this common, which is commonly applied in remotely-sensed imagery of various sorts, is to transform the actual values using both a scaling factor and shift. In this case, the brightness temperature in degrees K is subjected to a negative shift of 202.5, and then multiplied by 2. This allows the temperature to still be stored in the 8-bit number with half a degree precision. For example, given a brightness temperature of 280 degrees K:

  $$280 – 202.5 = 77.5$$

  $$77.5 * 2 = 155$$

  Thus, the example brightness temperature is stored using the digital number 155. To turn the digital numbers stored in the bands back into brightness temperatures, we need to reverse the process: We divide the digital numbers stored in the bands by 2, and then add 202.5 to get the brightness temperatures in degrees K.

- It should be straightforward for you to figure out a *Raster Calculator* expression that you can use to recover the brightness temperatures in degrees K from channels 4 & 5. One detail you must take into account is the need to use the Float() operator appropriately: If you divide an integer GRID (like band4) by 2, without first converting it a floating point GRID, the result will be rounded to the nearest integer, which is not what you want. So, make sure that when you form your *Raster Calculator* expression, it includes Float([bandX]) so decimal places are maintained using floating point math (you can check that you did this right by looking at the attribute table of the result; some of the values should be NNN.5 in form).

Question 1 – *What is the Raster Calculator expression required to turn the digital numbers stored in the band4 GRID to the original brightness temperatures in degrees K (**Hint: Make sure you use float(), and be careful with brackets [you need some!]**)?*

Question 2 – *What are the minimum and maximum and maximum brightness temperatures in degrees K in channels 4 & 5 in the provided image?*

Calculating Land Surface Temperature

- Now that we have calculated the brightness temperatures for channels 4 & 5, we can use those values to calculate the land surface temperatures, using the formula:

  $$LST = BT4 + 3.33\ (BT4 - BT5)$$

  where BT4 and BT5 are the brightness temperature values in degrees Kelvin for channels 4 and 5 respectively. Strictly speaking, this expression should also include some emissivity information (as described in Price, 1984), but for simplicity, we will leave it out (the effect being that resulting temperatures are somewhat higher than they should be, since we are effectively assuming 100% emissivity everywhere).

  Note that since your BT4 and BT5 GRIDs were produced using floating point calculations, we don't have to worry about that in this next *Raster Calculator* expression (since all the inputs to this expression are going to be floating point GRIDs, floating point arithmetic will automatically be used).

- Come up with appropriate *Raster Calculation* expression (based on the equation above) to calculate land surface temperature in degrees K for the whole image.

*Question 3 – What is the Raster Calculator expression required to calculate the land surface temperatures in degrees K (****Hint: Again, be careful with brackets [you need some!]****).*

- Now, use a further *Raster Calculation* expression to convert the LST values from degrees K to degree C (that is, subtract 273.15) and multiply the result by the mask GRID so you end up with a GRID of LST values in degrees C within North Carolina Climate Division 3.

Question 4 – What are the minimum and maximum land surface temperatures (expressed in degrees C) within North Carolina Climate Division 3 in this particular composite image? Include a printed map of the LST in degrees C inside NC CD3 GRID with your exercise, and make sure it has the following characteristics: It should have an appropriate title, north arrow, scale, and legend (be sure to use the Layout View for this). An appropriate symbology would be a classified color ramp ideally with hotter cells symbolized using a hotter color.

Question 5 – Compare your resulting land surface temperature GRID to the map of North Carolina Climate Division 3 land-use land-cover that can be found in the last slide of the accompanying lecture PDF. Are there any common features that can be found? What are they and why would you expect them to be expressed in a GRID of land surface temperature?

Calculating Normalized Difference Vegetation Index

- We can now move on to calculating the normalized difference vegetation index (NDVI) from the reflectance data stored in channels 1 & 2. Again, these reflectances are stored as 8-bit numbers, but in this case, they have not been subjected to the same kind of scaling and shifting as was the case for the brightness temperatures. Here a value of 0 indicates minimum reflectance at that pixel in that part of the spectrum, and 255 indicates maximum reflectance.
- For this reason, we do not have to modified the digital numbers before including them in an equation to calculate NDVI:

  NDVI = (NIR - Red) / (Red + NIR)

  where the Red reflectance is stored in band1 and the NIR reflectance is stored in band2.
- In forming the required *Raster Calculator* expression to create an NDVI GRID, we must again make use of the float() operator: The digital numbers stored in the channels are stored as integer GRIDs, but we must use floating point calculations to produce NDVI. Note that parts of the equation can sit inside of float(), e.g. float([band1] + [band2]).

*Question 6 – What is the Raster Calculator expression required to calculate NDVI from the band1 and band2 reflectances (**Hint: Make sure you use float()**)?*

- Again, multiply the resulting NDVI GRID by mask to produce a GRID of just the NDVI values within North Carolina Climate Division 3.

Question 7 – What are the minimum and maximum NDVI values within North Carolina Climate Division 3 in this particular composite image? Include a printed map of the NDVI inside NC CD3 GRID with your exercise, and make sure it has the following characteristics: It should have an appropriate title, north arrow, scale, and legend (be sure to use the Layout View for this). An appropriate symbology would be a classified color ramp ideally with lower NDVI values symbolized by brown and higher NDVI values symbolized by green.