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Advisors: Paul Evangelista, Jim Graham
Date: January 2011
Software: ArcGIS v9.2, Windows Notepad

Lesson 10: Calculating Vegetation Indices from Landsat 5 TM and Landsat 7 ETM+ Data

Vegetation indices like the Normalized Difference Vegetation Index (NDVI), Soil-Adjusted Vegetation Index (SAVI), and Tasseled Cap transformations are useful measures of vegetation calculated from remotely sensed data. It is relatively straightforward to calculate these indices using data from the Landsat sensors and ArcMap. In this tutorial, a method for doing so is described.

Background:

Landsat data acquired from the USGS Global Visualization Viewer as in the tutorial "Acquiring Landsat Data" has been terrain-, radiometrically-, and geographically-corrected, but has been formatted to fit in an 8-bit number (ranges from 0-255). Data in such a format is referred to as "digital number," or DN data. Before it can be used to calculate vegetation indices, the data must be converted to reflectance, a physical measurement. In addition, if one is interested in calculating the tasseled cap brightness, greenness, and wetness indices, further transformation is needed. As described by Huang et al. (2002), the tasseled cap coefficients for the Landsat 5 TM data were developed for both DN format data (Crist and Cicone, 1984) and for surface reflectance data (Crist, 1985). Reflectances calculated from Landsat data are a so-called "top of atmosphere" (TOA) measurement, however, so the tasseled cap coefficients calculated in the two papers from the 1980s are not applicable to Landsat data unless atmospheric correction is applied, a process that may introduce considerable error. Tasseled cap coefficients are calculated for the TOA reflectance data from the Landsat 7 ETM+ sensor by Huang et al (2002). These coefficients are directly applicable for Landsat 7 ETM+ TOA reflectance data, and can be used with Landsat 5 TM data using a further transformation described in Vogelmann et al. (2001).

Process:

1. Reclassify the Landsat data so that all 0 values are mapped to "NoData" using the method described in step 3 of the "Mosaicking and Clipping Landsat Data." We do not want to calculate reflectances or vegetation indices on the sections where data is missing.

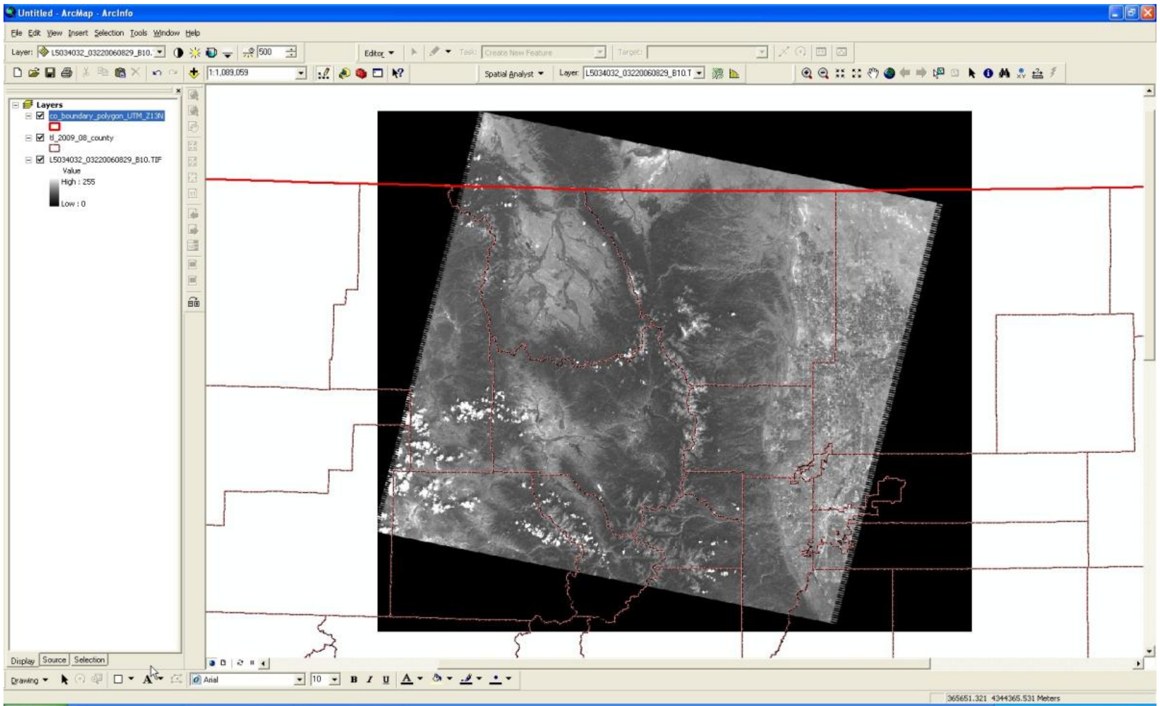


Figure 1. Original Landsat 5 TM DN data with state and county boundaries overlaid

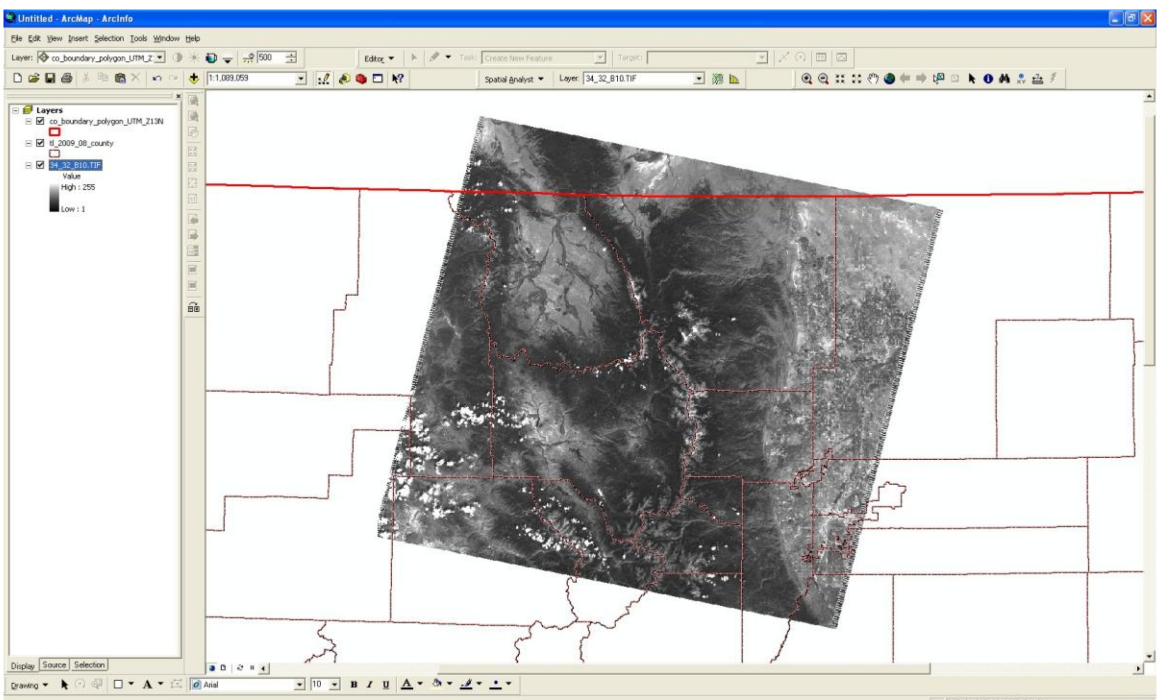


Figure 2. Reclassified Landsat 5 TM data

2. Convert Landsat 5 TM data to the equivalent Landsat 7 ETM+ data
    a. If using Landsat 7 ETM+ data, go to step 3.

b. In order to be able to use the tasseled cap coefficients developed by Huang et al. (2002) for the Landsat 5 TM sensor, one must convert the Landsat 5 TM DN data into data that is equivalent to data recorded by the Landsat 7 ETM+ sensor (because the two sensors have slightly different calibration). This process is described by Vogelmann et al. (2001) in reverse; that is, they converted from Landsat 7 ETM+ data to Landsat 5 TM equivalent. To convert from Landsat 5 TM DN data to Landsat 7 ETM+ DN data, we use the following expression:

$$\mathrm{DN7} = \left(\mathrm{slope}_{\lambda} * \ \mathrm{DN5}\right) + \ \mathrm{intercept}_{\lambda}$$

where DN7 is the Landsat 7 ETM+ equivalent DN data, DN5 is the Landsat 5 TM DN data, and the slope and intercept are band-specific numbers given by the inverse of those found in Vogelmann et al. (2001). The needed values are given in the following table (the inverse has already been performed).

Band	Slope	Intercept
1	0.943	4.21
2	1.776	2.58
3	1.538	2.50
4	1.427	4.80
5	0.984	6.96
7	1.304	5.76

Use the "Raster Calculator" tool in the Spatial Analyst toolbar to perform the calculation.
After the "Raster Calculator" performs the provided evaluation, it may be wise to save each new evaluated raster by exporting the data. To do this right click on the layer within the table of Contents and select "Export Data." When the window below is visible, change the data format to a GRID and be sure to browse to the correct workspace while naming the raster something memorable.

While calculating, be sure to use the correct slope and intercept values for the band you're working with. Repeat this process for all bands needed for the tasseled cap indices (1-5 and 7).

Figure 3. Raster calculator function to perform the transformation from Landsat 5 TM DN data to the equivalent Landsat 7 ETM+ DN data

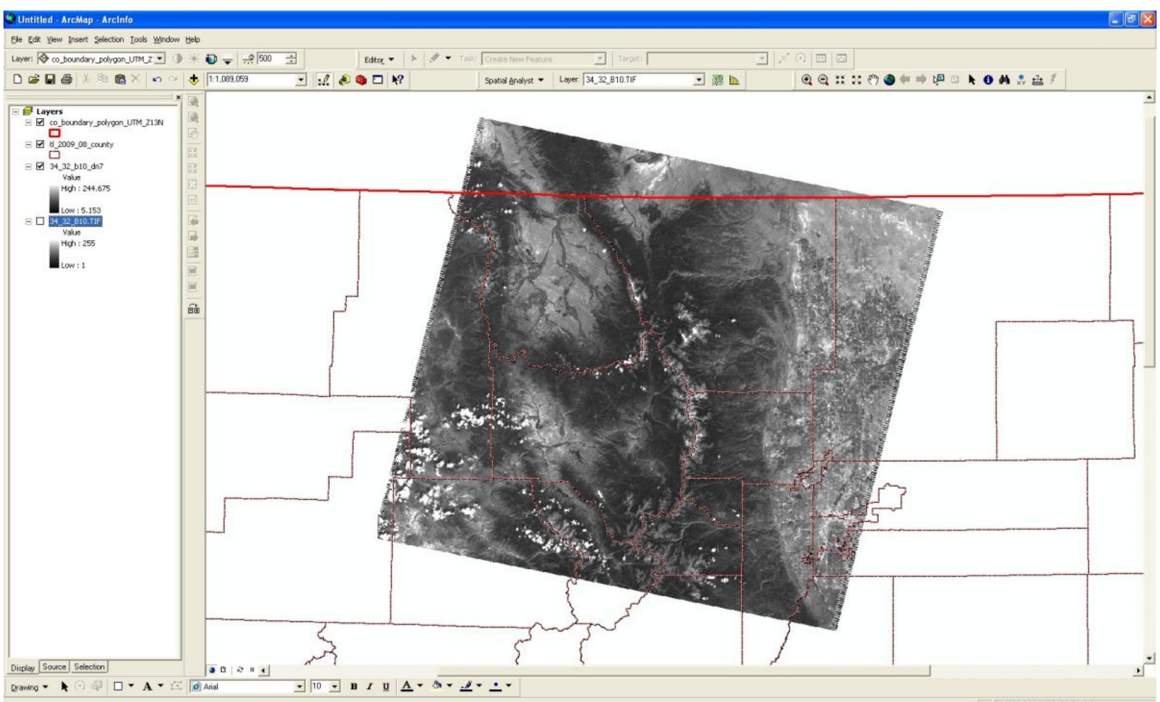


Figure 4. Resulting equivalent Landsat 7 ETM+ DN data

IMPORTANT: Be sure to save the calculations if needed

3. Convert DN data to radiance data
    a. Before converting to reflectance data, one must convert the DN data to radiance. This is done using the following expression:

$$L_\lambda = (\text{gain}_\lambda * \text{ DN7}) + \text{ bias}_\lambda$$

where L_λ is the calculated radiance [in Watts / (sq. meter * µm * ster)], DN7 is the Landsat 7 ETM+ DN data (or the equivalent calculated in step 2), and the gain and bias are band-specific numbers. The latest gain and bias numbers for the Landsat 7 ETM+ sensor are given in Chander et al. (2009) and are shown in the following table.

Band	Gain	Bias
1	0.778740	-6.98
2	0.798819	-7.20
3	0.621654	-5.62
4	0.639764	-5.74
5	0.126220	-1.13
7	0.043898	-0.39

Use the "Raster Calculator" tool in the Spatial Analyst toolbar to perform the calculation, saving the newly created radiance raster as something memorable. Be sure to use the correct gain and bias values for the band you're working with. Repeat this process for all bands needed for the tasseled cap indices (1-5 and 7).

The process of this calculation and following calculations may take a significant amount of time so be sure to save any progress at intervals along the way.

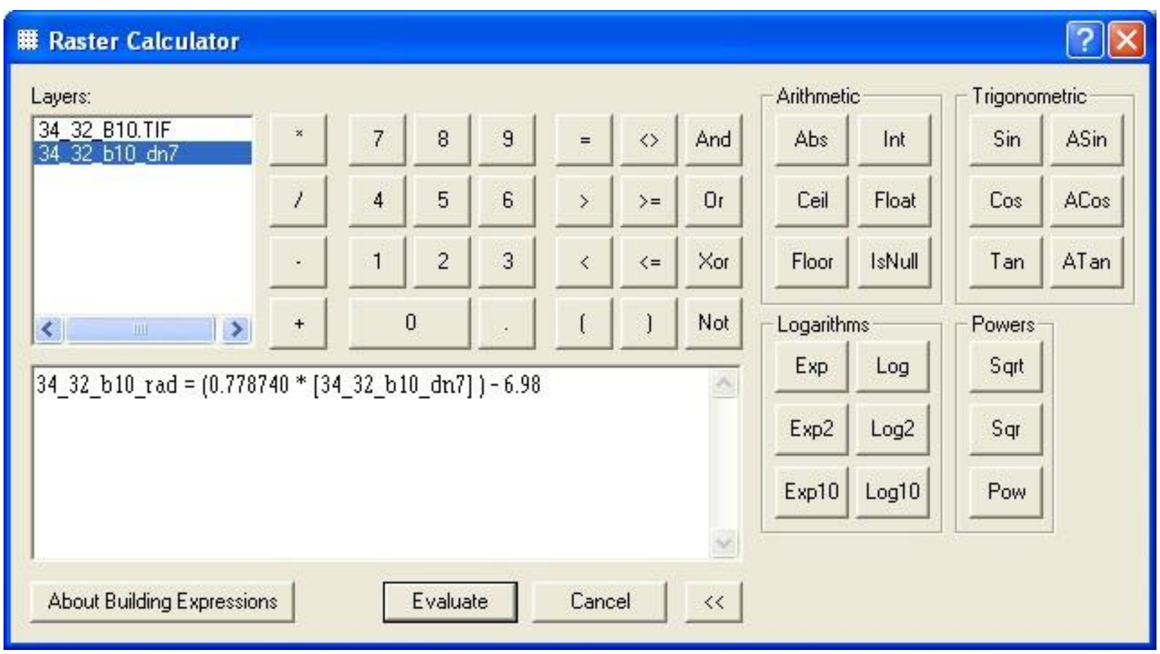


Figure 5. Raster Calculator function to perform radiance calculation

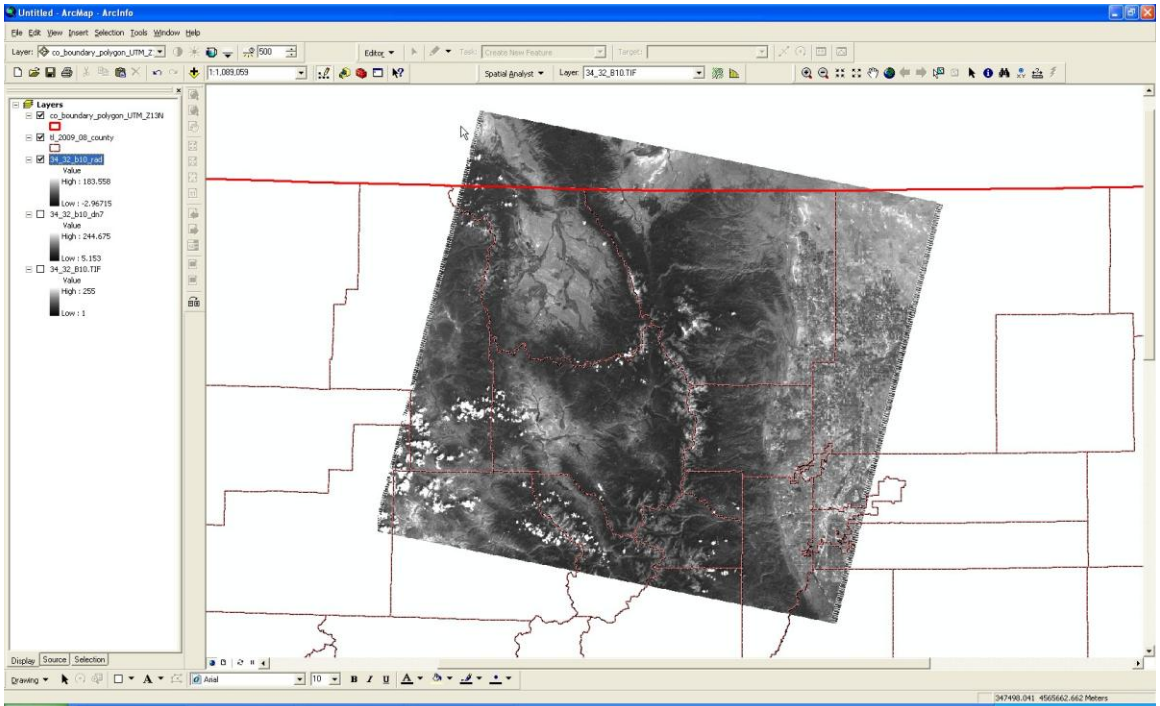


Figure 6. Radiance data resulting from the Raster Calculator calculation

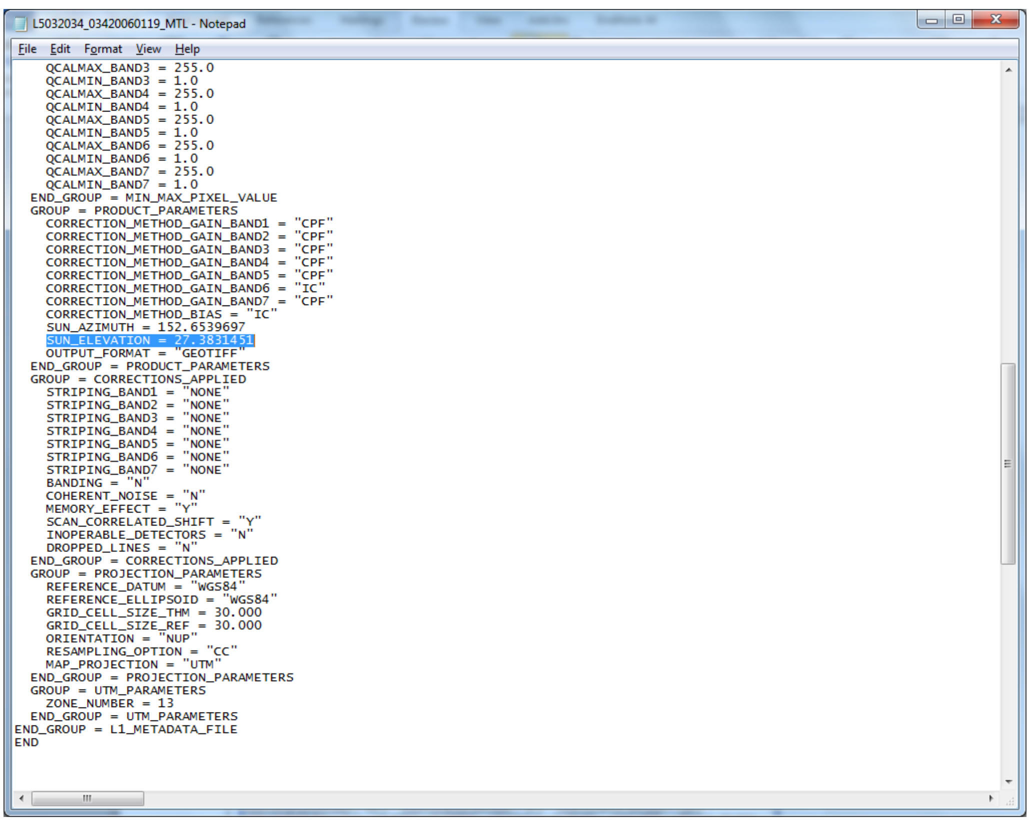
4. Convert radiance data to reflectance data
   a. While radiance is the quantity actually measured by the Landsat sensors, a conversion to reflectance facilitates better comparison among different scenes. It does this by removing differences caused by the position of the sun and the differing amounts of energy output by the sun in each band. The reflectance can be thought of as a "planetary albedo," or fraction of the sun's energy that is reflected by the surface. It can be calculated using the following expression:

$$R_\lambda = \frac{\pi * L_\lambda * d^2}{E_{sun,\lambda} * \sin(\theta_{SE})}$$

where R_λ is the reflectance (unitless ratio), L_λ is the radiance calculated in step 3, d is the earth-sun distance (in astronomical units), $E_{sun,\lambda}$ is the band-specific radiance emitted by the sun, and θ_{SE} is the solar elevation angle. One needs three pieces of information (in addition to the radiance calculated in step 3) in order to calculate the reflectance. The first is the band-specific radiance emitted by the sun. These values are given in Chander et al. (2009) and are repeated in the following table.

Band	$E_{sun,\lambda}$ [Watts / (sq. meter * µm)]
1	1997
2	1812
3	1533
4	1039
5	230.8
7	84.9

The second and third pieces of information are *d*, the earth-sun distance, and $\theta_{SE,}$ the solar elevation angle. These two values are dependent on the individual scene, specifically the day of the year and the time of day when the scene was captured. The solar elevation angle and the day of year are listed in the header file for each scene. This file is included with the data and ends with "_MTL.txt". Search the file for the solar elevation angle labeled "SUN_ELEVATION" and the day of the year labeled "DATE_HOUR_CONTACT_PERIOD". The solar elevation angle is given in degrees and the date is in the format "YYDDDHH" where the 3 "D" digits denote the day of the year. For example, "0624117" means the 241st day of 2006 at 17 UTC. Once the day of the year is acquired, use the table reproduced from Chander et al. (2009) to find the earth-sun distance. For example, for day 241, the earth-sun distance is 1.00992 astronomical units.



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END
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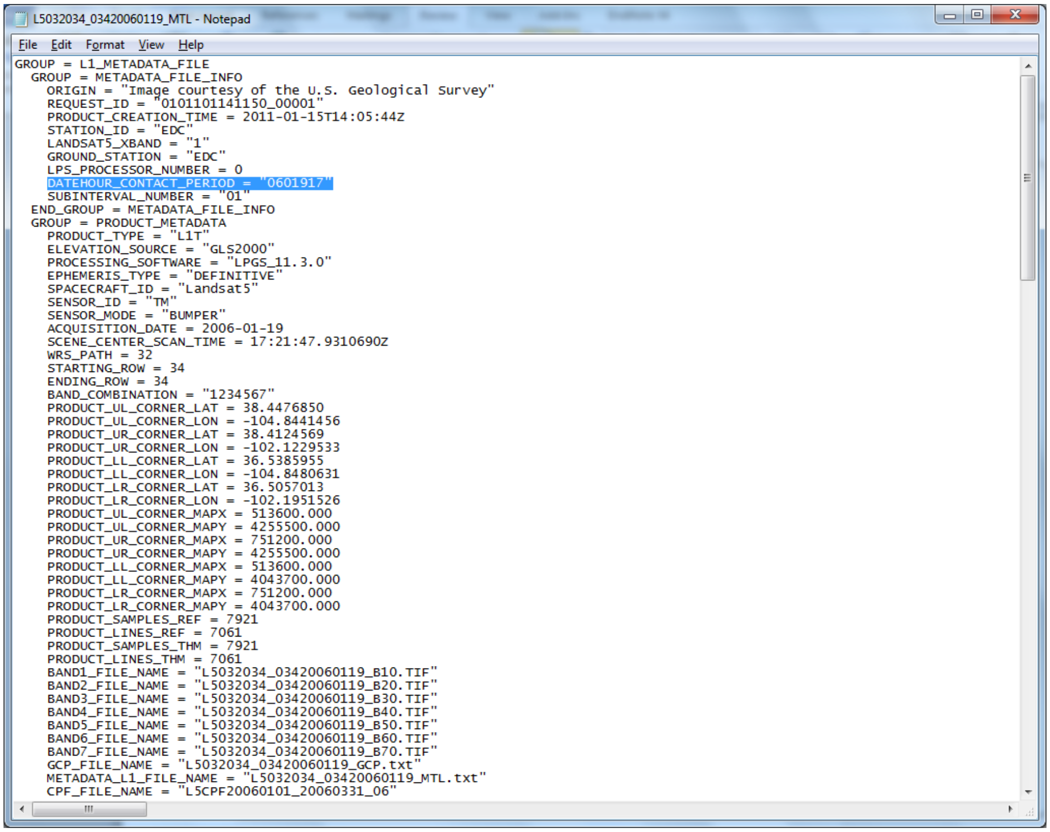
Figure 7. An example of where the solar elevation angle is found within the header file.



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GROUP = L1_METADATA_FILE
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    REQUEST_ID = "0101101141150_00001"
    PRODUCT_CREATION_TIME = 2011-01-15T14:05:44Z
    STATION_ID = "EDC"
    LANDSAT5_XBAND = "1"
    GROUND_STATION = "EDC"
    LPS_PROCESSOR_NUMBER = 0
    DATEHOUR_CONTACT_PERIOD = "0601917"
    SUBINTERVAL_NUMBER = "01"
  END_GROUP = METADATA_FILE_INFO
  GROUP = PRODUCT_METADATA
    PRODUCT_TYPE = "L1T"
    ELEVATION_SOURCE = "GLS2000"
    PROCESSING_SOFTWARE = "LPGS_11.3.0"
    EPHEMERIS_TYPE = "DEFINITIVE"
    SPACECRAFT_ID = "Landsat5"
    SENSOR_ID = "TM"
    SENSOR_MODE = "BUMPER"
    ACQUISITION_DATE = 2006-01-19
    SCENE_CENTER_SCAN_TIME = 17:21:47.9310690Z
    WRS_PATH = 32
    STARTING_ROW = 34
    ENDING_ROW = 34
    BAND_COMBINATION = "1234567"
    PRODUCT_UL_CORNER_LAT = 38.4476850
    PRODUCT_UL_CORNER_LON = -104.8441456
    PRODUCT_UR_CORNER_LAT = 38.4124569
    PRODUCT_UR_CORNER_LON = -102.1229533
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    BAND6_FILE_NAME = "L5032034_03420060119_B60.TIF"
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    CPF_FILE_NAME = "L5CPF20060101_20060331_06"
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Figure 8. An example of where the day of the year is found within the header file

Table 6
Earth–Sun distance (*d*) in astronomical units for Day of the Year (DOY).

DOY	*d*	DOY	*d*	DOY	*d*	DOY	*d*	DOY	*d*	DOY	*d*
1	0.98331	61	0.99108	121	1.00756	181	1.01665	241	1.00992	301	0.99359
2	0.98330	62	0.99133	122	1.00781	182	1.01667	242	1.00969	302	0.99332
3	0.98330	63	0.99158	123	1.00806	183	1.01668	243	1.00946	303	0.99306
4	0.98330	64	0.99183	124	1.00831	184	1.01670	244	1.00922	304	0.99279
5	0.98330	65	0.99208	125	1.00856	185	1.01670	245	1.00898	305	0.99253
6	0.98332	66	0.99234	126	1.00880	186	1.01670	246	1.00874	306	0.99228
7	0.98333	67	0.99260	127	1.00904	187	1.01670	247	1.00850	307	0.99202
8	0.98335	68	0.99286	128	1.00928	188	1.01669	248	1.00825	308	0.99177
9	0.98338	69	0.99312	129	1.00952	189	1.01668	249	1.00800	309	0.99152
10	0.98341	70	0.99339	130	1.00975	190	1.01666	250	1.00775	310	0.99127
11	0.98345	71	0.99365	131	1.00998	191	1.01664	251	1.00750	311	0.99102
12	0.98349	72	0.99392	132	1.01020	192	1.01661	252	1.00724	312	0.99078
13	0.98354	73	0.99419	133	1.01043	193	1.01658	253	1.00698	313	0.99054
14	0.98359	74	0.99446	134	1.01065	194	1.01655	254	1.00672	314	0.99030
15	0.98365	75	0.99474	135	1.01087	195	1.01650	255	1.00646	315	0.99007
16	0.98371	76	0.99501	136	1.01108	196	1.01646	256	1.00620	316	0.98983
17	0.98378	77	0.99529	137	1.01129	197	1.01641	257	1.00593	317	0.98961
18	0.98385	78	0.99556	138	1.01150	198	1.01635	258	1.00566	318	0.98938
19	0.98393	79	0.99584	139	1.01170	199	1.01629	259	1.00539	319	0.98916
20	0.98401	80	0.99612	140	1.01191	200	1.01623	260	1.00512	320	0.98894
21	0.98410	81	0.99640	141	1.01210	201	1.01616	261	1.00485	321	0.98872
22	0.98419	82	0.99669	142	1.01230	202	1.01609	262	1.00457	322	0.98851
23	0.98428	83	0.99697	143	1.01249	203	1.01601	263	1.00430	323	0.98830
24	0.98439	84	0.99725	144	1.01267	204	1.01592	264	1.00402	324	0.98809
25	0.98449	85	0.99754	145	1.01286	205	1.01584	265	1.00374	325	0.98789
26	0.98460	86	0.99782	146	1.01304	206	1.01575	266	1.00346	326	0.98769
27	0.98472	87	0.99811	147	1.01321	207	1.01565	267	1.00318	327	0.98750
28	0.98484	88	0.99840	148	1.01338	208	1.01555	268	1.00290	328	0.98731
29	0.98496	89	0.99868	149	1.01355	209	1.01544	269	1.00262	329	0.98712
30	0.98509	90	0.99897	150	1.01371	210	1.01533	270	1.00234	330	0.98694
31	0.98523	91	0.99926	151	1.01387	211	1.01522	271	1.00205	331	0.98676
32	0.98536	92	0.99954	152	1.01403	212	1.01510	272	1.00177	332	0.98658
33	0.98551	93	0.99983	153	1.01418	213	1.01497	273	1.00148	333	0.98641
34	0.98565	94	1.00012	154	1.01433	214	1.01485	274	1.00119	334	0.98624
35	0.98580	95	1.00041	155	1.01447	215	1.01471	275	1.00091	335	0.98608
36	0.98596	96	1.00069	156	1.01461	216	1.01458	276	1.00062	336	0.98592
37	0.98612	97	1.00098	157	1.01475	217	1.01444	277	1.00033	337	0.98577
38	0.98628	98	1.00127	158	1.01488	218	1.01429	278	1.00005	338	0.98562
39	0.98645	99	1.00155	159	1.01500	219	1.01414	279	0.99976	339	0.98547
40	0.98662	100	1.00184	160	1.01513	220	1.01399	280	0.99947	340	0.98533
41	0.98680	101	1.00212	161	1.01524	221	1.01383	281	0.99918	341	0.98519
42	0.98698	102	1.00240	162	1.01536	222	1.01367	282	0.99890	342	0.98506
43	0.98717	103	1.00269	163	1.01547	223	1.01351	283	0.99861	343	0.98493
44	0.98735	104	1.00297	164	1.01557	224	1.01334	284	0.99832	344	0.98481
45	0.98755	105	1.00325	165	1.01567	225	1.01317	285	0.99804	345	0.98469
46	0.98774	106	1.00353	166	1.01577	226	1.01299	286	0.99775	346	0.98457
47	0.98794	107	1.00381	167	1.01586	227	1.01281	287	0.99747	347	0.98446
48	0.98814	108	1.00409	168	1.01595	228	1.01263	288	0.99718	348	0.98436
49	0.98835	109	1.00437	169	1.01603	229	1.01244	289	0.99690	349	0.98426
50	0.98856	110	1.00464	170	1.01610	230	1.01225	290	0.99662	350	0.98416
51	0.98877	111	1.00492	171	1.01618	231	1.01205	291	0.99634	351	0.98407
52	0.98899	112	1.00519	172	1.01625	232	1.01186	292	0.99605	352	0.98399
53	0.98921	113	1.00546	173	1.01631	233	1.01165	293	0.99577	353	0.98391
54	0.98944	114	1.00573	174	1.01637	234	1.01145	294	0.99550	354	0.98383
55	0.98966	115	1.00600	175	1.01642	235	1.01124	295	0.99522	355	0.98376
56	0.98989	116	1.00626	176	1.01647	236	1.01103	296	0.99494	356	0.98370
57	0.99012	117	1.00653	177	1.01652	237	1.01081	297	0.99467	357	0.98363
58	0.99036	118	1.00679	178	1.01656	238	1.01060	298	0.99440	358	0.98358
59	0.99060	119	1.00705	179	1.01659	239	1.01037	299	0.99412	359	0.98353
60	0.99084	120	1.00731	180	1.01662	240	1.01015	300	0.99385	360	0.98348

Figure 9. Table from Chander et al. (2009) showing the earth-sun distance as a function of day of the year

Use the “Raster Calculator” tool in the Spatial Analyst toolbar to perform the calculation, saving the newly created reflectance raster as something memorable. Be sure to use the correct $E_{sun,\lambda}$ for the band you’re working with and the correct earth-sun distance and solar elevation angle for the scene. Keep in mind that the sine function within ArcMap requires the solar elevation angle to be in radians instead of degrees. Convert from degrees to radians using

$$\text{radians} = (\text{degrees} * \pi)/180°$$

Below, this conversion has been incorporated into the calculation. Repeat this process for all bands needed for the tasseled cap indices (1-5 and 7). If an error occurs while the “Raster Calculator” attempts to evaluate this expression, it may be a simple syntax error. Before doing anything extravagant to fix the problem, try counting parentheses () to make sure that all are present. Another remedy may include adding parentheses () around the numerator and denominator.

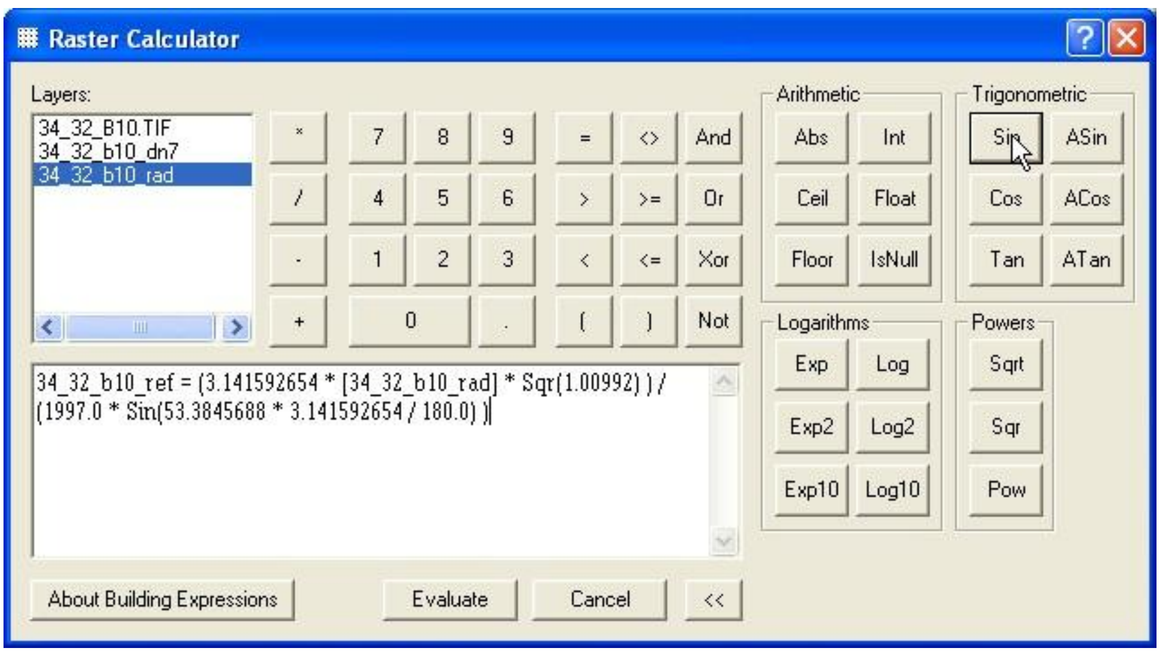

Figure 10. Raster Calculator function for calculating the reflectance

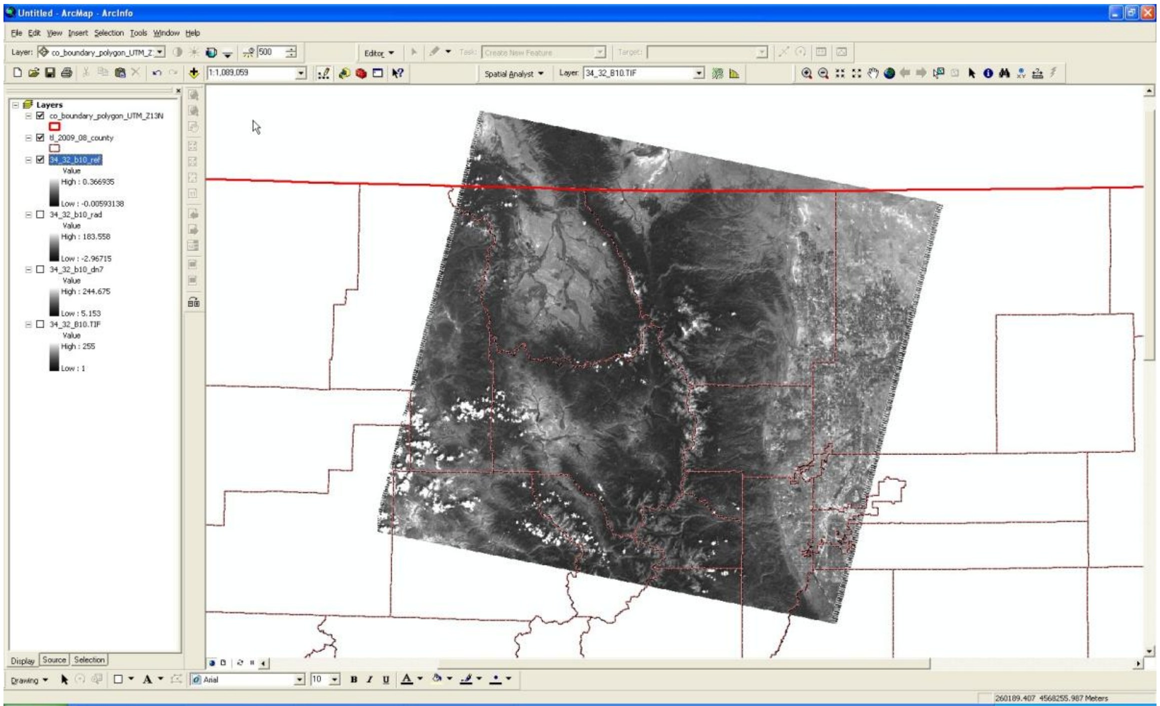

Figure 11. Reflectance data resulting from the Raster Calculator function

5. Enforce positive reflectances

   a. During the conversion from DN data to reflectance, it is possible to create small negative reflectances. These values are not physical and should be set to zero. It should be noted that only very small negative numbers should be produced with this procedure. If large negative numbers are calculated, this may signify a problem with the implementation of this procedure. Use raster calculator to check for negative values and replace them with zero.

      corrected_reflectance = CON([reflectance] < 0.0, 0.0, [reflectance])

   The CON () statement can either be utilized by directly typing it into the "Raster Calculator" or by clicking the appropriate function button within certain versions of ArcMap.

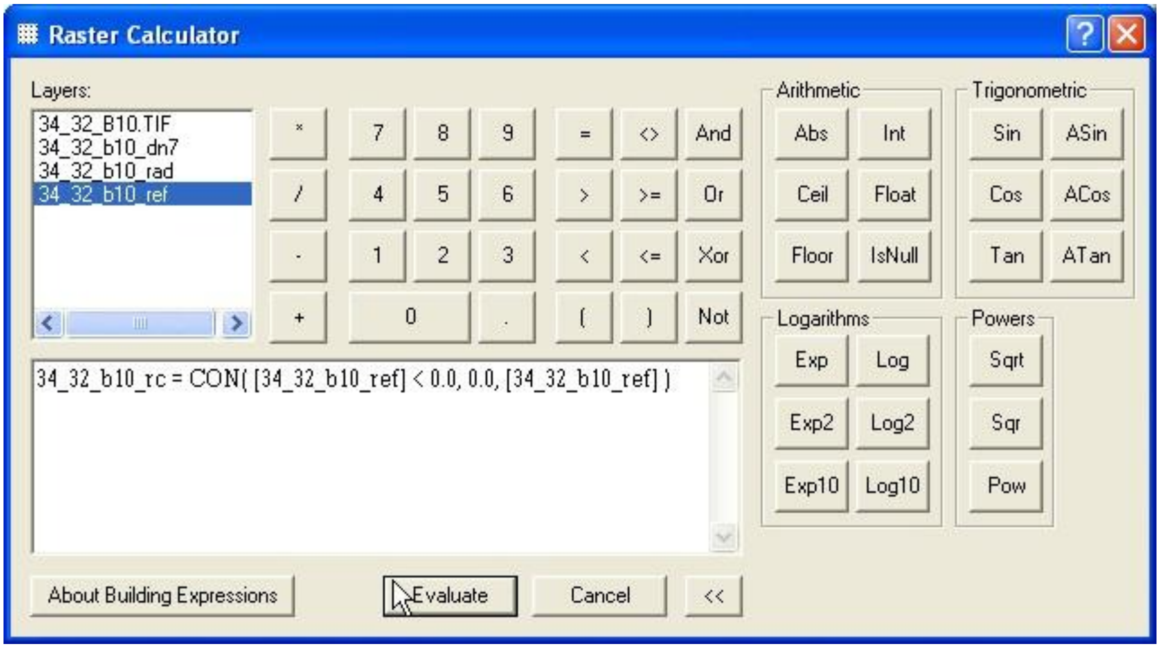

Figure 12. Raster Calculator function for enforcing positive reflectance values

6. Calculate NDVI
    a. With TOA reflectances calculated for each band, one can now calculate vegetation indices. NDVI is given by

NDVI = (band 4 – band 3) / (band 4 + band 3)

where the TOA reflectances are used for each band. Use Raster Calculator to calculate the index.

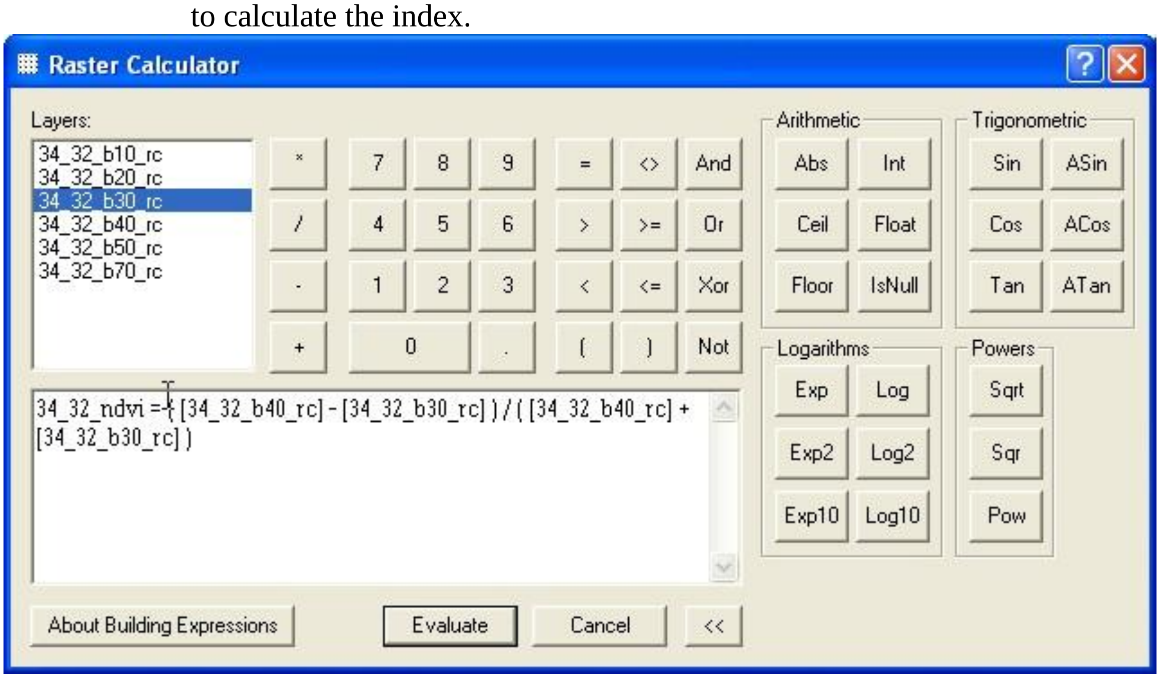

Figure 13. Raster Calculator function for calculating NDVI from reflectance data

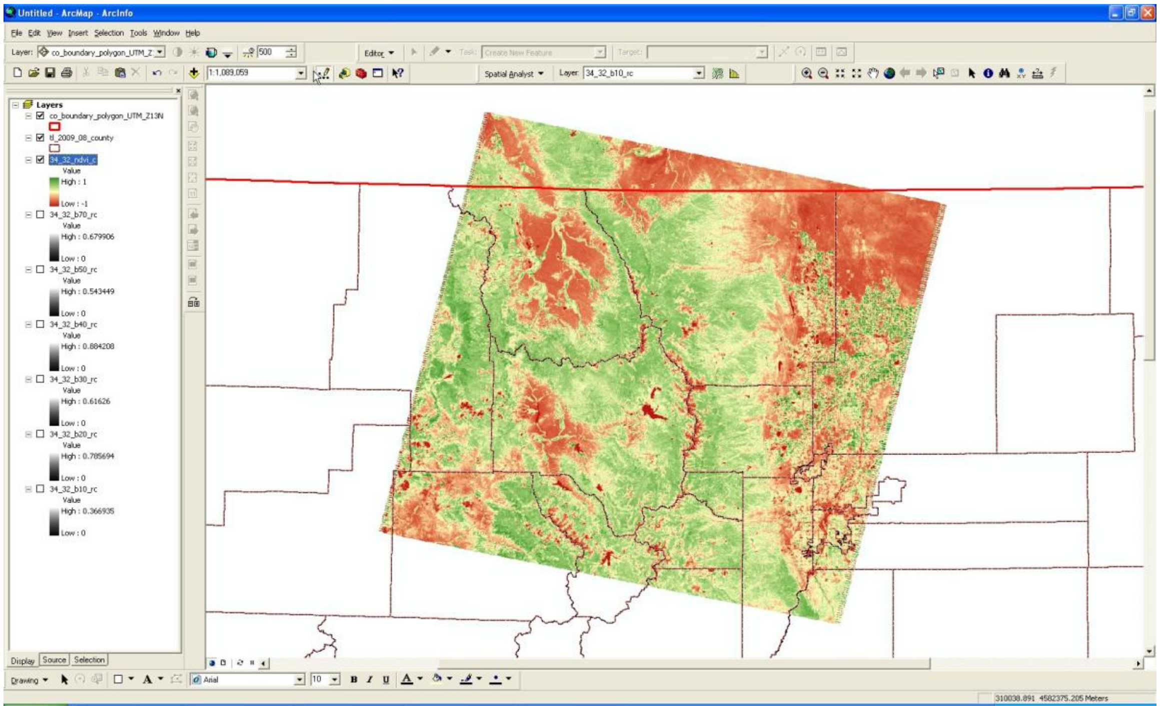

Figure 14. NDVI calculated from the Raster Calculator calculation

7. Calculate SAVI
    a. SAVI is similar to NDVI, but attempts to account for the background soil conditions. SAVI is given by

$$SAVI = (1+ L)*(band\ 4 – band\ 3) / (band\ 4 + band\ 3 +L)$$

where the TOA reflectances are used for each band and L is a soil brightness correction factor. From Huete (1988), L=0.5 is used in most conditions. Use Raster Calculator to calculate the index.

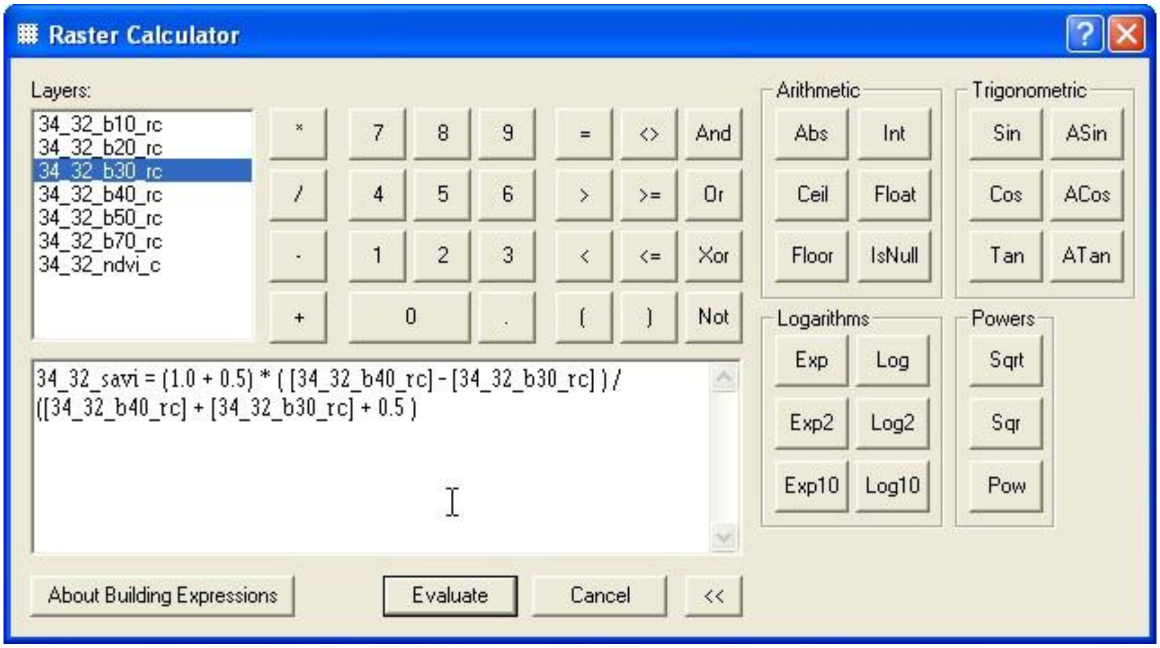

Figure 15. Raster Calculator function for calculating SAVI from reflectance data

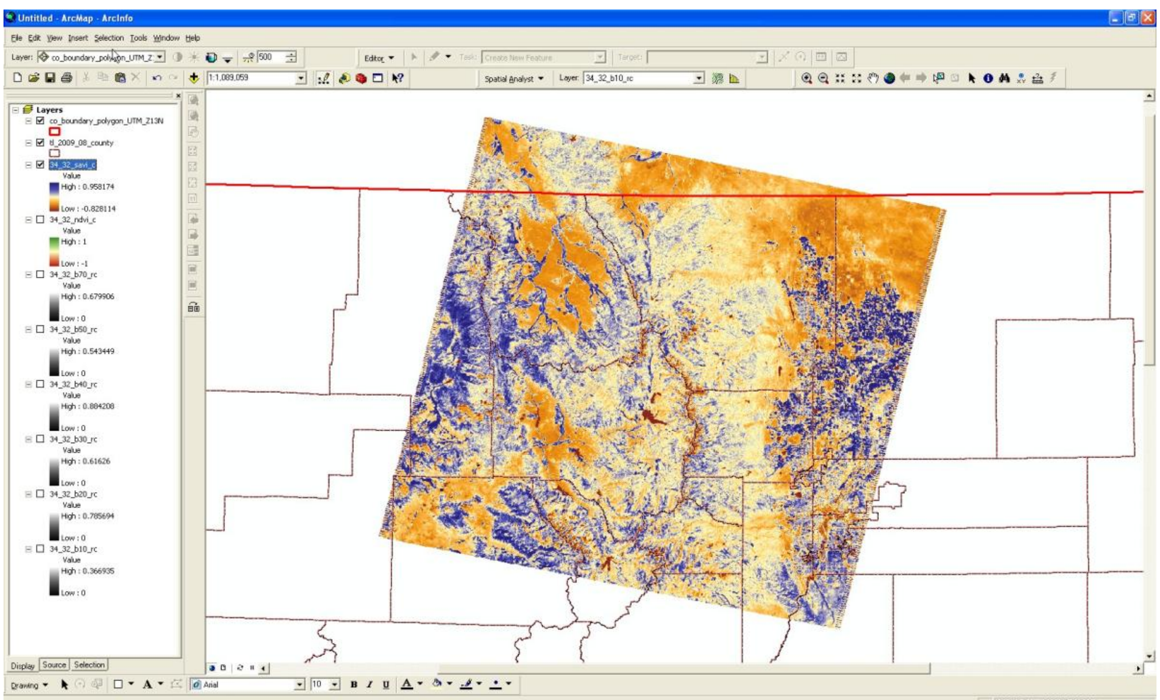
Figure 16. SAVI calculated from the Raster Calculator expression

8. Calculate tasseled cap indices
    a. Tasseled cap indices give a measure of the brightness, greenness, or wetness of a pixel and utilize a linear combination of 6 of Landsat's frequency bands. Each of the brightness, greenness, and wetness indices can be calculated using the expression

$$\text{tas. cap}_i = (\text{coeff}_1 * \text{band}_1) + (\text{coeff}_2 * \text{band}_2) + (\text{coeff}_3 * \text{band}_3) + (\text{coeff}_4 * \text{band}_4) + (\text{coeff}_5 * \text{band}_5) + (\text{coeff}_7 * \text{band}_7)$$

where tas. cap_i is the calculated tasseled cap index for brightness, greenness, or wetness depending on the coefficients used, the bands are the TOA reflectances calculated in this tutorial, and the coefficients are given by Huang et al. (2002):

Index	Band 1	Band 2	Band 3	Band 4	Band 5	Band 7
Brightness	0.3561	0.3972	0.3904	0.6966	0.2286	0.1596
Greenness	-0.3344	-0.3544	-0.4556	0.6966	-0.0242	-0.2630
Wetness	0.2626	0.2141	0.0926	0.0656	-0.7629	-0.5388

Use Raster Calculator to calculate the desired index. Outputs will be displayed with a black-white color ramp. The color ramp can be changed within the layer's properties like Figures 18-20.

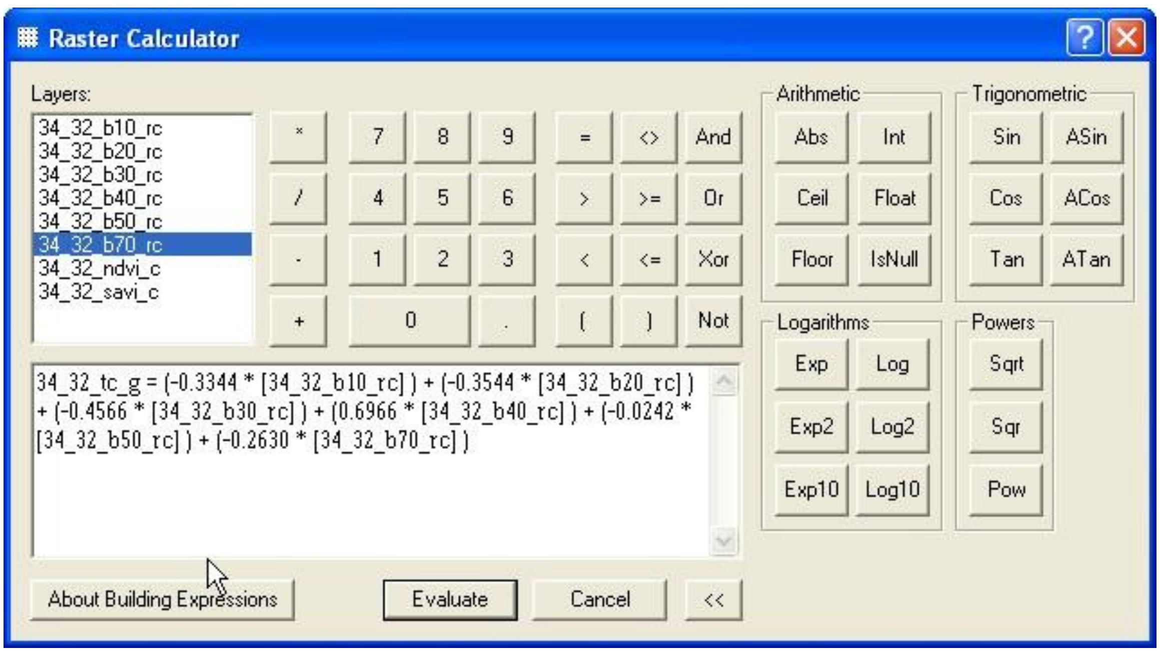

Figure 17. Raster Calculator function for calculating the tasseled cap greenness index

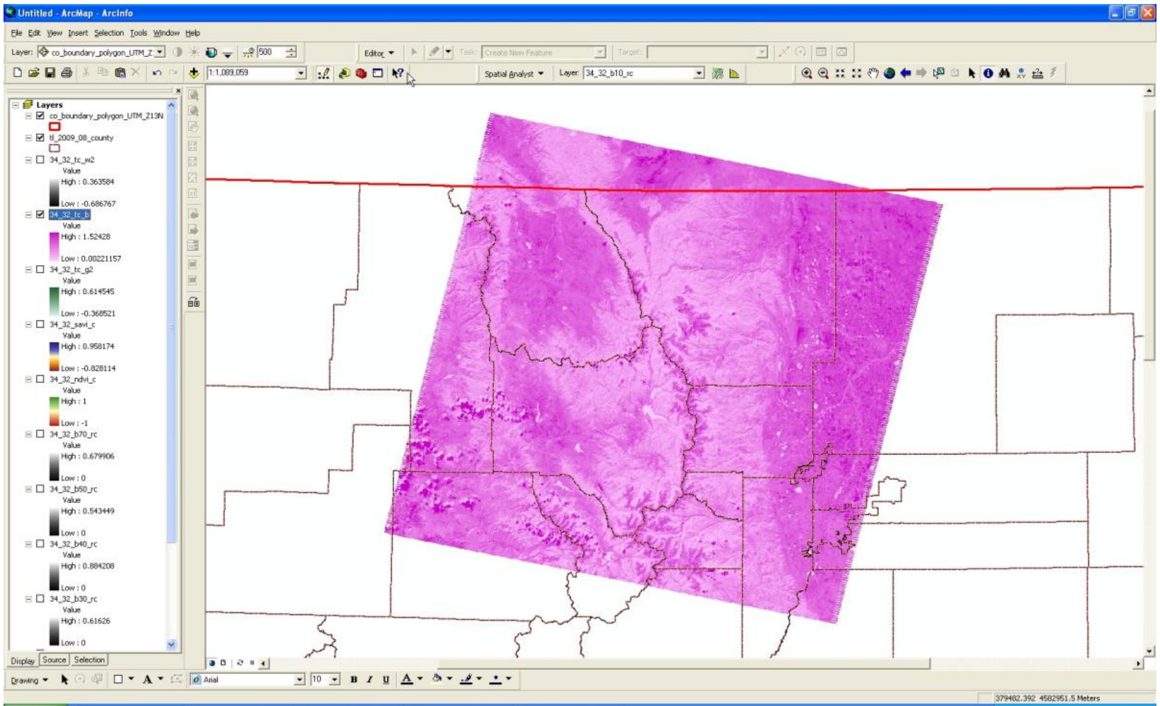

Figure 18. Tasseled cap brightness index

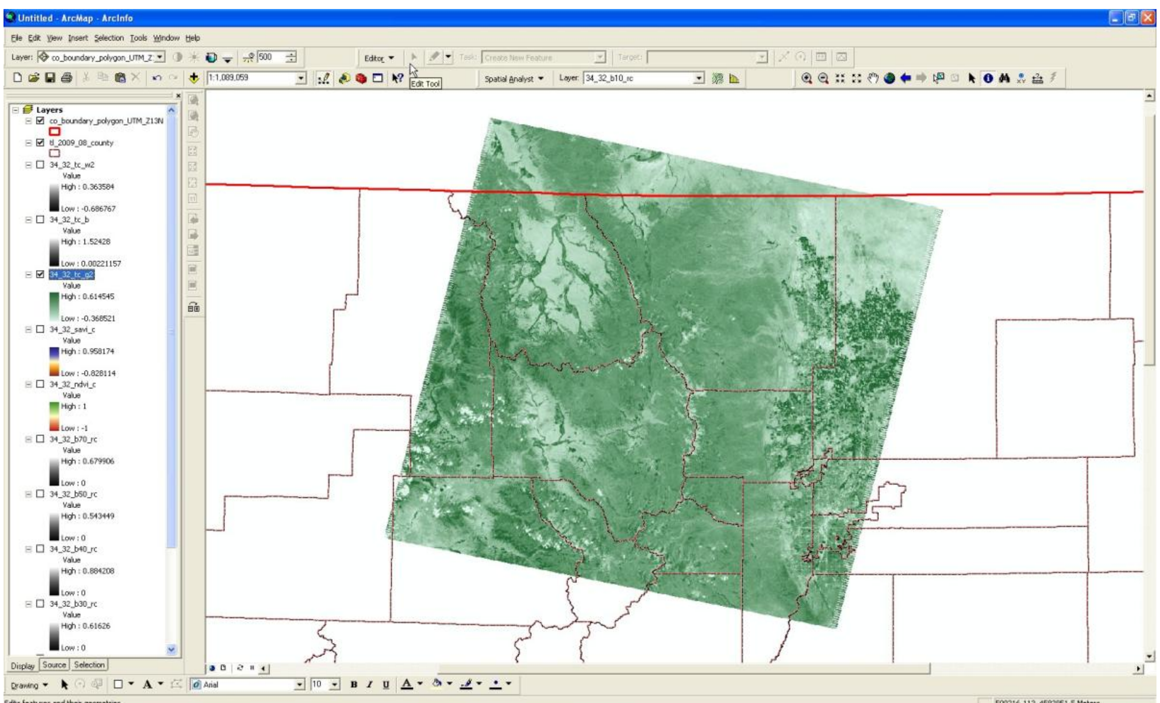

Figure 19. Tasseled cap greenness index

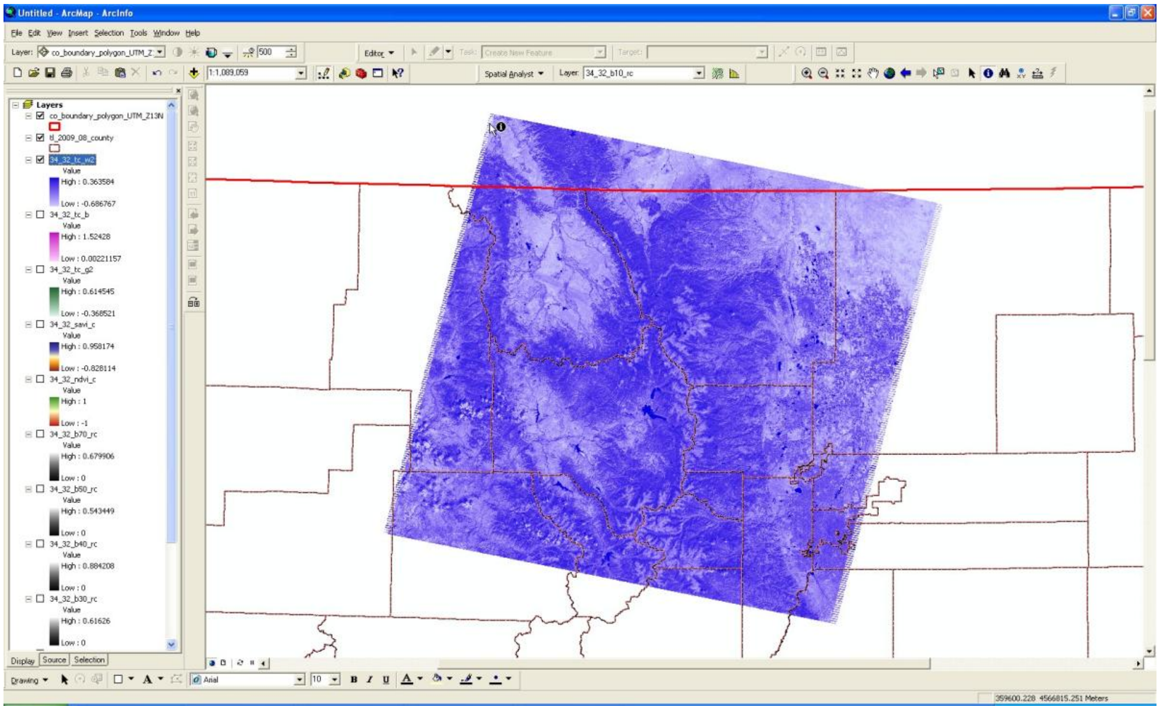

Figure 20. Tasseled cap wetness index

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