F: TASSELED CAP TRANSFORMATION IMAGES

Like *Frequently Asked Questions*, a question is posed, e.g., *F1. What is the Tasseled Cap Transformation?* Then, an answer is given[1] with comments and opinions. For cross referencing, each item is labeled, e.g., *F1*.

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

TASCAP.sml produces a new set of rasters called Tasseled Cap (TC) products. It also produces a set of related n-Space Distance (DS) rasters. Input rasters must have SRFI units (see *FAQs by Jack B.pdf*). SRFI units are integers equal to 100 times percent reflectances. For example, a SRFI value of 6000 is equivalent to a reflectance factor of 60%, and 0 is equal to 0%.

When you run TASCAP.sml, it asks you to select one of 3 Methods:

- Method 1: This method comes the closest to being the traditional Tasseled Cap method. But, it can be applied only to top-of-the-atmosphere (TOA) SRFI-type data only from the Landsat Thematic Mapper (TM) or Enhanced Thematic Mapper Plus (ETM+) imagery. So, you must include all 6 multispectral bands: BL, GL, RL, NA, MB, *and* MC (see *Table 7A*).
- Method 2: This method has more flexibility than Method 1. But, it can be applied only to surface (SFC) SRFI data from TM, ETM+, *or* any four-band imager that covers, at least, BL, GL, RL, and NA (see *Table 7A*).
- Method 3: This method is the most flexible and the most difficult. It may be applied to any SRFI data (TOA or SFC) from any imager that has at least three spectral bands. But, Method 3 requires that you have done specified analyses of the input images **prior** to running it. This tutorial provides guidance about how you can carry out these specific analyses.

The most common use for TASCAP.sml is to produce two or more measures (TC raster values) of specific biophysical properties from multispectral imagery that has more than two spectral bands. Often, the main measure of interest is TC Greenness (a kind of Vegetation Index, VI). But, measures of other properties of vegetation such as (leaf) wetness and (leaf) yellowness are also possible. TC Brightness, usually the 1st TC raster, has less utility.

TASCAP.sml lets you extract quantitative (calibrated) information (having SRFI units) from all existing multispectral bands rather than just from the two NA and RL bands. For example, Landsat TM and Landsat ETM+ each collect

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6 spectral-band images. In this case, the input SRFI rasters would be SRFIBL, SRFIGL, SRFIRL, SRFINA, SRFIMB, and SRFIMC. SPOT 1 and SPOT 2 each collect only 3 spectral bands. But, ASTER collects 9 spectral bands. Many imagers collect 4 bands of multispectral imagery. SRFI data from all of these can be processed by TASCAP.sml.

Method 3 lets you work with a subset of spectral band images with as few as 3 bands. Or, you can work with all bands up to as many as 9 bands. It is best that you select spectral bands that have low cross correlation magnitudes among them. Cross correlation can be analyzed using the Raster Correlation tool that is available in TNTmips' Spatial Data Display. This tool calculates a Correlation coefficient, r, which ranges between -1 and +1. Values of r near zero indicate that the two related spectral bands are independent and therefore may, when both included in an analysis, produce information about at least two biophysical parameters.

If you elect to use Method 1 or Method 2, the output DS and TC rasters will relate to a predefined set of biophysical measures, as follows:

- DS0: This is the distance, in n-dimensional SRFI feature space (also called n-Space), between non-reflecting "BLACK" objects (i.e.,, ones having SRFI values all equal to 0) and the location in n-Space of the set of SRFI values related to the material object (or mixture of objects) in each given pixel. The unit of distance for DS0 is SRFI units.

- TC1 & DS1: TC1 is called TC Brightness. TC1 is a weighted average of the SRFI values. The TC1 coefficients define a unit vector in n-Space. The TC1 unit vector specifies the direction of a line (axis) in n-Space called the 1st TC Brightness axis. This line extends from the origin of n-Space to a typically bright object such as dry bare soil. DS1 is the distance from the 1st TC axis line to each pixel's SRFI-related location in n-Space.

- TC2 & DS2: TC2 is called TC Greenness. The 2nd TC axis is forced to be perpendicular to the 1st TC axis. The two-dimensional plane, defined by the 1st TC axis and the 2nd TC axis, is forced to contain *the* n-Space point that is related to the reflectance spectrum of typical green vegetation. Therefore, TC Greenness is a perpendicular-type Vegetation Index. This is especially true if the TC Brightness axis aligns well with the Line of Bare Soils in n-Space.

Recall that a similar-sounding raster, called PVI, is produced by SRFI.sml and by TERCOR.sml. However, PVI was based on SRFI values in only **2** spectral bands, namely, RL and NA. And the units of PVI are not SRFI units.

Nevertheless, TC Greenness and PVI both indicate the amount of green vegetation present in a way that is somewhat independent of the brightness of the underlying soil, for cases where the amount of green biomass is small.

DS2 is the distance from the Brightness-Greenness plane and each pixel's location in n-Space.

TC Greenness has often been used over the past four decades as a way to track temporal patterns of change over time in vegetation amount for seasonal crops and even for whole biospheres. Temporal patterns of TC Greenness were used extensively in the LACIE and AgRISTARS program for crop identification purposes. You can find many references to these uses on the Internet using a search engine like Google.

The continuing use of Tasseled Cap Greenness is remarkable when you realize that it has been based, in the past, on **uncalibrated** image brightness values (i.e., uncorrected image DNs). But, this error has also plagued other common Vegetation Indices such as Normalized Difference Vegetation Index (NDVI) when it also has been wrongly calculated on the basis of **uncalibrated** image DNs in the RL and NA bands.

- TC3 & DS3: TC3 is called TC Wetness. The 3rd TC axis, i.e., the TC Wetness axis, is mathematically perpendicular to the 1st TC axis *and* to the 2nd TC axis in n-Space. DS3 is the distance from the Brightness-Greenness-Wetness "hyperplane" and each pixel's location – as calculated by mathematical equations that operate in n-Space. It is difficult for anyone to visualize the geometric nature of DS3 (and higher level distances and TC components). However, mathematically, this is an easy task. TC Wetness (TC3) is related to both soil-surface wetness and open water. Historically, TC Wetness has not been widely used. But, it is included in Method 1 and Method 2 due to its being defined as a part of TC theory.

- TC4 & DS4: TC4 is called TC Haze (or TC Haziness). Since dense haze in the atmosphere produces a yellow color shift in natural color imagery, some investigators have referred to TC4 as TC Yellowness. In any case, the 4th TC biophysical indicator (Haze or Yellowness) is a noisy measure that accounts for only a small percentage of the overall variations seen among pixels in n-Space represented by TM, ETM+, or four-band imagers. DS4 is the distance from the Brightness-Greenness-Wetness-Haze hyperplane and each pixel's location.

Regardless of the method being used, the TASCAP.sml process is a set of scale-preserving operations that retain the SRFI units of the input data. Thus, a selected pair of TC rasters may be used as SRFI-like inputs to GRUVI.sml.

This option can produce an optimized final "indicator" raster, e.g., a customized GRUVI raster for vegetation mapping or a customized GRUFI raster for specific non-vegetation feature mapping. When GRUVI.sml is used *following* the use of TASCAP.sml, the final result is an information extraction process that has involved all available spectral bands, rather than just two spectral bands as is normally the case for GRUVI.sml.

When used to produce TC Brightness and TC Greenness, the outputs of TASCAP.sml are similar, in functionality, to the PBI and PVI rasters that are produced by SRFI.sml (and modified possibly by TERCOR.sml). However, these TC rasters have SRFI units rather than PBI and PVI units.

The real power of TASCAP.sml is when a skilled user applies it to situations that address a specific need for a specific information-mapping effort. An example of this kind of non-traditional application is included at the end of this tutorial.

This SML is similar to the Progressive Transformation process that is available in TNTmips as a menu-selectable process. Progressive Transformation has been in TNTmips since Version 4.1. But, having this similar process as a SML script allows you to adapt the process in ways not possible with the hard-coded Progressive Transformation process.

In Brief …

This tutorial discusses key SML functions and model concepts related to **TASCAP.sml**. If you are interested in a particular topic below, please go directly to it.

Quick Guide to Using TASCAP.sml …

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

BEFORE you run TASCAP.sml …

- ☐ You must first run SRFI.sml to produce the SRFI rasters that you will input to TASCAP.sml. See *FAQs by Jack B.pdf* for details about SRFI.sml. You may also run TERCOR.sml, which also produces a set of terrain-corrected SRFI rasters and a related pair of PVI and PBI rasters. TASCAP.sml works best when SRFI data are free of any significant terrain effects.
- ☐ If you are going to use Method 3, you must **first** view and analyze the **input** SRFI images in order to define **a set of line and column locations** related to each **key biophysical object** in the SRFI scene. **How to do this** is explained later in this tutorial.

The script will ask you to provide or to accept specific information items via a series of **Popup Windows**, as follows:

- ☐ **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. Beginning with TNTmips Version 7.1, you only need to adjust this window once. TNTmips remembers the Console Window location and size after that. Click OK to continue.

- ☐ **METHOD-NUMBER ENTRY:** You are presented with three method options (explained on Page 1). Enter **1**, **2**, or **3**. Then, Click OK. Next, go to the instructions associated with the method you selected:

  Method 1: See Page 7
  Method 2: See Page 7
  Method 3: See Pages 8-9

METHOD 1:

- ☐ **RASTER OBJECTS SELECTION:** Method 1 deals only with the 6 SRFI input rasters associated with TM or ETM+. The input rasters must be top-of-the-atmosphere (TOA) SRFI rasters. And, you must select them in the following order: SRFI1 = SRFIBL, SRFI2 = SRFIGL, SRFI3 = SRFIRL, SRFI4 = SRFINA, SRFI5 = SRFIMB, and SRFI6 = SRFIMC.
- ☐ **SELECT OUTPUT OBJECTS FOR DS0, TC1, DS1, …, TC4, and DS4:** TASCAP.sml prints a text report to the Console Window about the number of input rasters, the number of pairs of output rasters, the names (BLACK, Brightness, Greenness, Wetness, and Haze), and offsets or coefficients related to each output product. You can pause to view this information by moving the Select Object window to one side. Then, you should define a new Project File that will contain the new output products. Accept the default names for the output raster objects (DS0, TC1, DS1, …, TC4, and DS4). After that, the script then runs to completion.
- ☐ **SAVING THE REPORT:** To save the text report, Right-Click in the Console Window. Then select the Save As… option. Since TASCAP.sml has many options, it is a good idea to save the related report.

METHOD 2:

- ☐ **SELECT n-Space ORIGIN TYPE:** Accept "dark soil" or change to "BLACK".
- ☐ **NUMBER OF INPUT SRFI RASTERS ENTRY:** Enter 4, 5, or 6 (only). Method 2 processes SRFI rasters that cover, at least, BL, GL, RL, and NA. Optionally, you can processes SRFIMB raster and a SRFIMC raster.
- ☐ **NUMBER OF OUTPUT RASTER PAIRS ENTRY:** Method 2 produces a DS0 raster plus 2 to (NumInputBands – 1) pairs of TC and DS rasters.
- ☐ **RASTER OBJECT SELECTIONS:** Method 2 deals only with 4, 5, or 6 input SRFI rasters referenced to the surface (SFC). Select them in the following order: SRFI1 = SRFIBL, SRFI2 = SRFIGL, SRFI3 = SRFIRL, SRFI4 = SRFINA, (optional) SRFI5 = SRFIMB and (optional) SRFI6 = SRFIMC.
- ☐ **SELECT (OUTPUT) OBJECTS FOR DS0, TC1, DS1, …, TC4, and DS4:** TASCAP.sml prints data to the Console Window about the number of input rasters, the number of pairs output rasters, the names (Dark Soil or BLACK, Bright Soil, Green Veg., Water, and Yellow Veg.), the SRFI values in each input band (in order from 1 to 4, from 1 to 5, or from 1 to 6) that represent the named materials, offsets and coefficients related to the output products. You can pause to view this information by moving the Select Object window to one side. Then, you should define a new Project File that will contain the output products. Accept the default names for the output raster objects (DS0, TC1, DS1, …, TC4, and DS4). The script then runs to completion.
- ☐ **SAVING THE REPORT:** To save the text report, Right-Click in the Console Window. Then select the Save As… option. Since TASCAP.sml has many options, it is a good idea to save the related report.

METHOD 3:

- ☐ **NUMBER OF INPUT SRFI RASTERS ENTRY:** Method 3 deals with a general set of SRFI rasters from an imager that has from 3 to 9 bands. Therefore, Method 3 can handle any set of SRFI data from multispectral imagers in operation today. ASTER is the current MS imager that has the largest number of spectral bands. However, ASTER bands MC, MD, ME, MF, and MG are highly correlated to each other for many scenes. While all of these ASTER bands can be input to TASCAP.sml, doing so may give too much "weight" to the middle infrared part of the spectrum near the 2.2 μm wavelengths. Thus, it is likely that the number of input SRFI rasters being processed will be from 3 to 6, rather than as high as 7, 8, or 9. Nevertheless, TASCAP.sml is designed to handle up to 9 input SRFI rasters.
- ☐ **NUMBER OF OUTPUT RASTER PAIRS ENTRY:** Method 3 outputs 2 to (NumInputBands – 1) pairs of TC and DS rasters plus DS0. However, Method 3 requires that you have already identified (1) a set of biophysical materials and (2) a related set of raster coordinates (LIN, COL values) for each new TC axis that you want TASCAP.sml to define for the production of each new pair of TC and DS output rasters.
- ☐ **RASTER OBJECTS SELECTION:** Method 3 deals only with 3 to 9 input SRFI rasters. The selected input SRFI rasters should be surface (sfc) rasters. They may be selected in any order. This allows Method 3 to deal with imagers, such as SPOT imagers that lack the SRFIBL raster. Or, you can skip rasters (or duplicate rasters) as you wish. You should have an order in mind (one that corresponds to the names and LIN,COL coordinates that will be provided next.
- ☐ **METHOD-3 LINE & COLUMN PARAMETERS ENTRY:** TASCAP.sml will ask you to provide information about "bp" (biophysical) names and the related SRFI raster coordinates (LIN & COL values). It starts with "bp0 NAME." If you specify the bp0 NAME to be "BLACK" then TASCAP.sml will set related SRFI values equal to 0. Then, the script goes on to request the "bp1 NAME," then "bp2 NAME," and so on until it covers all of the number of pairs of output TC and DS rasters that you want to produce. Suggestions about how to get these names and raster coordinates will be explained later in this tutorial. Basically, you need a table of values such as in the following table:

bp Number	bp NAME	bp LIN	bp COL
0	Dark Soil	73	373
1	Bright Soil	276	154
2	Green Veg.	261	40
3	Yellow Veg.	410	65
4	Urban Materials	99	511
5	Open Water	34	528

These values are for the sample image (550 lines by 550 columns) collected by Landsat 7 ETM+ on 9/30/2001 over Stockton, CA. Your values will differ.

METHOD 3 (Continued)

- ☐ **SELECT (OUTPUT) OBJECTS FOR DS0, TC1, DS1, etc.:** TASCAP.sml prints data to the Console Window about the number of input rasters, the number of pairs output rasters, the names (Dark Soil, Bright Soil, Dense Green Veg., Water, and Yellow Veg.), the SRFI values in each input band that represent the named materials, offsets and coefficients related to the output products. You can pause to view this information by dragging the Select Object window to one side. Then, define a new Project File that will contain the output products. Accept the default names for the output raster objects (DS0, TC1, DS1, etc. The script then runs to completion.
- ☐ **SAVING THE REPORT:** To save the text report, Right-Click in the Console Window. Then select the Save As… option. Since TASCAP.sml has many options, it is a good idea to save the related report. This is especially important for Method 3 where you need to record your options.

Examples of all three methods and their variations applications will be discussed later. Now, let's examine the basic ideas behind the Tasseled Cap Transformation.

F1. What is the Tasseled Cap Transformation?

Landsat 1, with its Multispectral System (MSS), was launched successfully in July 1972. At that time, the author was working as a remote-sensing scientist at the NASA Lyndon B. Johnson Space Center (JSC). There, he led one of the initial investigations of Landsat MSS data called the Coastal Analysis Team (CAT) in the Houston Area Test Site (HATS).

Yes … this was the CAT in the HATS investigation!

MSS collected 80-m resolution calibrated digital imagery in four spectral bands, namely, GL, RL, RE, and NB (using the band codes in *Table A7*). For the CAT in the HATS study, atmospheric-scattering simulation software was available at NASA JSC to convert image DNs into accurate estimates of reflectance-factors (RF) at the surface (Paris, 1974). Most investigators, including the author, focused on two key spectral bands, namely, RL and NB.

When viewed as a 2-Space plot of NB vs. RL, it became clear to most investigators that the DNs (and RFs) for bare-soil pixels in many typical MSS scenes had 2-Space locations that fell close to a straight line (see *FAQs by Jack E.pdf* for details). This 2-Space feature is now known as the Line of Bare Soils (LBS).

Unfortunately, most investigators did not take the time and the trouble to convert DNs to RFs. Instead, they wrongly preferred to work directly with the uncalibrated, un-converted image DNs. This tradition carried over to the development of Tasseled Cap transformation ideas.

Soon, researchers began to develop many ways to combine DNs or RFs in the NB and RL bands to create a *single* indicator of vegetation amount and vigor. The combinations were called Vegetation Indices (VIs). [See GRUVI.sml and *FAQs by Jack E.pdf* for more details about VIs.]

The most popular VI was (and still is) the Normalized Difference Vegetation Index (NDVI) developed by Rouse *et al.* (1974). NDVI = (RFNB – RFRL) / (RFNB + RFRL) or NDVI = (RFNA – RFRL) / (RFNA + RFRL). Before NDVI, the Simple Ratio VI (SRVI) was preferred where SRVI = RFNB / RFRL (or SRVI = RFNA / RFRL).

However, SRVI has two flaws. First, it is unstable (undefined or subject to much measurement noise) when RFRL is close to zero. Second, there are no limits on the value of SRVI on its upper end.

The NDVI expression was designed to correct these two flaws, as follows. NDVI has a limited range, which is -1 to +1 (and is often less than even this range). When RFRL approaches zero, NDVI approaches +1. When RFNA approaches zero, NDVI approaches -1. And, there is a one-to-one (albeit non-linear) relationship between SRVI and NDVI.

Using only two spectral bands, namely, NB and RL, NDVI was popular. But, NDVI is not the only approach to the task of formulating a VI (see *FAQs by Jack F.pdf*). Kauth and Thomas (1976) first defined a set of Tasseled Cap (TC) transformation operations to be applied to the DNs in all four MSS bands to create a new set of four TC rasters. These TC coefficients were designed with four specific biophysical properties in mind – one TC raster per biophysical property. In particular, Kauth and Thomas (1976) defined equations that produce TC Brightness, TC Greenness, TC Yellowness, and TC Non-Such indicators from Landsat MSS data as follows:

The Kauth-Thomas equations for MSS are:

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TC Brightness = +0.433 DNGL + 0.632 DNRL + 0.586 DNRE + 0.264 DNNB
TC Greenness  = -0.290 DNGL - 0.562 DNRL + 0.600 DNRE + 0.491 DNNB
TC Yellowness = -0.829 DNGL + 0.522 DNRL + -.039 DNRE + 0.194 DNNB
TC Non-Such   = +0.223 DNGL + 0.012 DNRL - 0.543 DNRE + 0.810 DNNB
```

TC Greenness was used extensively in the LACIE and AgRISTARS programs of the 1970s and 1980s as a reliable and consistent “perpendicular” VI that tracked the temporal patterns of change in annual crops over a season as the crops emerged from bare soil, increased in green biomass. Then, as the crop matured (becoming more yellow after senescence), changes were tracked by the TC Yellowness values. TC Brightness did not play a role in this sequence of growth and change. In fact, for agricultural situations, TC Brightness variations were more like “noise” than like “signal.” In retrospect, the ignoring of TC Brightness was fortuitous: the Kauth-Thomas formulation was based on biophysical indicators from uncalibrated image DNs. Later, they and others suggested that the TC transformation would work better if it had been based on estimates of reflectance factors either at TOA or, better yet, at the surface.

TC raster values are perpendicular indices. How do we know this to be true? First, TC coefficients are components of mutually orthogonal set of unit vectors that performs rotations in n-Space without changes in scale. That is, the magnitude of each TC vector (having TC coefficients as components) is equal to 1.00. Second, the vector dot products of each and every possible pair of TC unit vectors are all equal to zero. The latter condition is a requirement of orthogonality among TC axes.

A useful attribute of the TC coefficients is that each TC transformation is a scale-preserving rotation of DNs from an original n-Space to a new n-Space defined by a new set of measures such as TC Brightness, TC Greenness, TC Yellowness, and TC Non-Such (in the particular case of four-band MSS DN data).

Landsat 4 carried the Thematic Mapper (TM) imager with 6 spectral bands (BL, GL, RL, NA, MB, and MC). Crist and Cicone (1984) developed a different set of TC coefficients to be applied to the DN values in the 6 bands of TM. In a tabular form, the Landsat 4 TM TC coefficients are:

DNBL	DNGL	DNRL	DNNA	DNMB	DNMC
0.3037	0.2793	0.4743	0.5585	0.5082	0.1863
-0.2848	-0.2435	-0.5436	0.7243	0.0840	-0.1800
0.1509	0.1973	0.3279	0.3406	-0.7112	-0.4572
0.8832	-0.0819	-0.4580	-0.0032	-0.0563	0.0130
0.0573	-0.0260	0.0335	-0.1943	0.4766	-0.8545
0.1238	-0.9038	0.4041	0.0573	-0.0261	0.0240

The magnitude of each of these unit-vectors (for each row of this matrix) is equal to 1.0. And, all of the vector dot products are indeed equal to zero. Thus, these Landsat 4 TM DN related TC coefficients perform a scale-preserving rotation from the original 6-Space to a new 6-Space. The new 6-Space components represent the following biophysical materials types and conditions: TC Brightness, TC Greenness, TC Wetness, TC Haze (which is a bit like TC Yellowness), TC5, and TC6 (neither of which was related by Crist and Cicone to any specific biophysical properties).

When Landsat 5 was launched with its TM imager, the TC coefficients had to be redefined again to reflect the differences in DN response between the TM imager on Landsat 4 and the TM imager on Landsat 5. Landsat 7 had a TM-like imager called ETM+ that was very different than the TMs on Landsat 4 or Landsat 5. Again, TC coefficients were redefined to reflect the changes in DNs associated with Landsat 7 ETM+.

Throughout this long period of development, it was sometimes recognized that a more consistent set of TC products would be produced from reflectance-factor data than from uncalibrated DN data. A paper by USGS defines a set of TC coefficients that are applied to reflectance factor data (but from a six band imager like TM or ETM+ consisting of BL, GL, RL, NA, MB, and MC). In this case, the TC components were designed to relate to TC Brightness, TC Greenness, TC Wetness, TC Haze, TC5, and TC6. The TC coefficients for the USGS reflectance-factor related six-band imagery data case are:

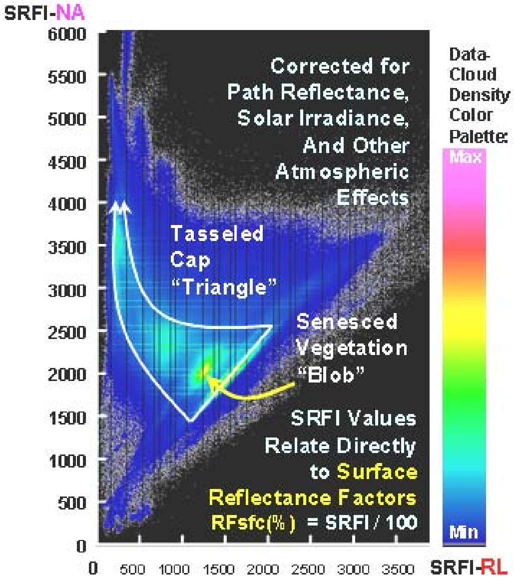
RFBL	RFGL	RFRL	RFNA	RFMB	RFMC
0.3561	0.3972	0.3904	0.6966	0.2286	0.1596
-0.3344	-0.3544	-0.4556	0.6966	-0.0242	-0.2630
0.2626	0.2141	0.0926	0.0656	-0.7629	-0.5388
0.0805	-0.0498	0.1950	-0.1327	0.5752	-0.7775
-0.7252	-0.0202	0.6683	0.0631	-0.1494	-0.0274
0.4000	-0.8172	0.3832	0.0602	-0.1095	0.0985

These same TC coefficients can be applied to SRFI values. Recall that SRFI values are directly proportional to reflectance factor values. However, the USGS coefficients must be applied to TOA reflectances. Thus, they would be applied to SRFItoa values. Again, they are restricted to a six-band system that has BL, GL, RL, NA, MB, and MC bands.

These TC coefficients are also scale-preserving and orthogonal to each other. So, what ever is the scale of the input rasters, the output TC rasters will have the same units, namely, SRFI units.

As was shown in Figures A19G through A19K, many pixels in a typical MS scene have SRFI values that are the result of mixing between variable-brightness background soils and foreground green vegetation. This was also illustrated in *Figure E1D*, which is shown again as *Figure F1* below.

Figure F1: 2-Space Plot of SRFINA vs. SRFIRL.



In most cases, the observed SRFI values of bare soils appear to be the result of a simple linear mixing between (1) a dark-soil "end member" spectrum (i.e., defined by a set of SRFI values in a set of spectral bands) and (2) a bright-soil "end member" spectrum (another set of SRFI values). This is observed to be most true when two specific bands are considered, namely, RL and NA. But, this is often also true when other spectral bands are considered, such as, BL, GL, RL, NA, MB, and/or MC.

If vegetation exists in the foreground of a bare-soil background and if that vegetation has a known spectrum (i.e., set of SRFI values in a set of spectral bands), then the spectra of the mixed pixels occupy a region in n-Space that has the shape of a Tasseled Cap, TC. Working with Landsat MSS data (GL, RL, RE, and NB bands) and annual crops, Kauth and Thomas (1976) first recognized the TC shape in plots of one MSS band versus another MSS band and dubbed this shape as being the shape of an imagined "Tasseled Cap." Furthermore, when they tracked how the spectral properties changed over time due to emergence and growth of crop vegetation (in the foreground) over a background soils, the resulting spectra stayed within the TC distribution.

Typically, a geographically-located pixel of MSS data in an annual-crop field would have the spectral properties of bare soil before emergence. That is, the n-Space location of the pixel resided somewhere on the Brim of the Tasseled Cap. The actual SRFI-defined n-Space location of bare-soil pixels *on* the TC Brim depends on several soil properties, such as, texture (mixtures of sand, silt, and clay), the amount of organic matter, the surface roughness of the soil (e.g., often plowed in furrows), the orientation of plowed row directions with respect to the sun's azimuth, the sun's elevation angle, and, mostly importantly, the wetness of the soil's surface.

As emergent vegetation becomes denser, the n-Space location of the pixel moves off of the Line of Bare Soils, i.e., the TC Brim, and moves toward the

Tip of the TC. If green vegetation becomes dense enough, the n-Space location of the pixel will be at or near a single point that is defined by a set of dense-vegetation related SRFI values.

If dense vegetation changes color, e.g., goes from being green vegetation to yellow vegetation, and if the biomass density of the vegetation also decreases or changes spatially, e.g., wilts, then the n-Space location of the pixel moves away from the dense, green, vegetation point to some other location in n-Space. This late-season change is highly variable among crops. So, the temporal path taken in n-Space was dubbed by Kauth and Thomas (1976) as being TC Tassels extending from the TC Tip. Since the spectral properties of the vegetation change significantly from its vegetative-green stage to later stages, the TC distribution is no longer just a 2-dimensional plane (hyperplane) in n-Space.

With the advent of MS imagers having more than four bands, i.e., Landsat Thematic Mapper (TM), the concept of a TC distribution was extended to 6 bands: BL, GL, RL, NA, MB, and MC.

Woody vegetation has been found to have a special place in the TC distribution. Between the TC Brim and the TC Tip is domain called the TC Badge. The TC Badge is located on the dark side (defined in the non-near-infrared band) of the TC Cap. This is like a badge that a police official might wear on the front of a police cap; though, a police officer would not likely want to wear a TC as it looks a bit like a dunce cap. But, the idea here is that woody vegetation is different than most annual crop vegetation. The woody stems interfere with the multiple scattering of near infrared radiation within the vegetation canopy. This causes the near infrared SRFI values to be significantly lower than for most herbaceous vegetation types of the same density. Some annual crops behave like woody vegetation, e.g., corn that has stalks that also interfere with near-infrared radiation multiple scattering.

F2. Why Aren't Existing Tasseled Cap Transformation Algorithms Adequate?

A basic conceptual error was made when formulating translational (T) and rotational (R) mathematical operations that would operate on MS data having from 2 to 6 spectral bands. The published TC coefficients were defined as operations on the uncalibrated DNs of each of the spectral band images being analyzed. In retrospect, a different set of TC T&R coefficients *should* have been developed for application to *calibrated reflectance factor values*, such as for SRFI values. As we know now from previous discussions, DN values change due to changes in the sun's elevation angle and due to changes in the scattering and absorption properties of the atmosphere. SRFI values are designed to not be changed by changes in the sun's elevation angle nor by changes in the atmosphere.

In addition to this oversight, there is the problem of changing foreground-vegetation "end member" properties in even SRFI-defined n-Space. In a given vegetation pixel, the foreground spectral properties of vegetation affects how the vegetation and soil spectra mix to cause a set of SRFI values.

This type of variability is handled for a 2-Space situation by a Vegetation Index (VI) algorithm such as GRUVI. GRUVI.sml usually takes, as input, the two rasters of SRFIRL and SRFINA. But, it also works with other SRFI pairs such as SRFIGL and SRFINA, SRFIBL and SRFINA, SRFIMB and SRFINA, or SRFIMC and SRFINA. Since GRUVI can be configured to produce any of several classic VIs, the results can mimic or equal the results of NDVI, GNDVI, SAVI, TSAVI, OSAVI, and even a perpendicular VI.

But, GRUVI.sml can work ONLY with two input SRFI rasters (or two rasters having SRFI units).

TASCAP.sml works with any (reasonable) number of input rasters and produces two or more output TC rasters that have SRFI units. Thus, a pair of TC rasters can be used as input to GRUVI.sml. Thus, TASCAP.sml might be used before using GRUVI.sml.

F3. What is the Value of Your Being Able to Construct a Customized TC Transformation?

Any view of the n-Space TC from the perspective of just two spectral band SRFI plots will likely be not optimal. A major purpose of any TC transformation is to re-orient the TC feature, as defined by a new set of TC rasters so that the TC feature (1) can be viewed in a "perpendicular" way directly at the 2-D TC plane or (2) can be viewed along the edge of the TC plane. The TC transformation allows an analyst to identify other materials, e.g., open water, roof materials, road materials, senescent vegetation, that are not ***in*** the TC plane. *Figure E1E* gives a hint of this for a blob of senesced vegetation that is seen in a plot of SRFIGL vs. SRFIRL. However, this kind of separation can be optimized through a properly constructed TC transformation such as is possible by using TASCAP.sml.

F4. What Do I Need to Do Before Using TASCAP.sml?

Since TASCAP.sml is a customized transformation that operates on a set of SRFI rasters, it is necessary to use SRFI.sml before using TASCAP.sml. If the terrain is hilly, you might also use TERCOR.sml to correct SRFI values for terrain slope and aspect effects.

In addition, you need to select one of three methods to provide input parameters to TASCAP.sml. These three methods are explained in separate FAQs below.

The three methods address three situations, as follows:

1. Use default TC coefficients (applied to Landsat TM or ETM+ SRFItoa values to generate pre-defined, specific biophysical measures)
2. Use default SRFI values for specific, pre-defined biophysical end members (applied to 4 to 6 bands of SRFIsfc values to generate specific biophysical measures)
3. Designate the raster coordinates (line and column locations) for desired end-member biophysical features in SRFItoa or SRFIsfc image rasters. In this case, TASCAP.sml will use the SRFI values at the designated locations to compute TC coefficients that are related to the designated biophysical measures.

F5. When Should I Use Default Inputs to TASCAP.sml?

If you are doing a classic TC transformation, you can choose to use default values for TC coefficients or SRFI values for pre-defined materials types, namely, (1) dark soil or BLACK, (2) bright soil, and (3) green vegetation. This classic mode usually works on a set or subset of SRFI rasters in up to six bands, namely, BL, GL, RL, NA, MB, and MC. In this Method 1, it is necessary to pick input rasters in a predefined order (so that default values of SRFI are matched to the appropriate spectral bands). TASCAP.sml allows you to pick a “BLACK” object, rather than a “dark soil” object as the starting point in n-Space. Method 2 uses default SRFI “signatures” as inputs for producing TC coefficients.

F6. How Can I Get the Input Parameters for Method 3?

Here is how.

First, decide what particular biophysical material or property you would like to map vis-à-vis other materials and biophysical properties in the scene. For example, the traditional use of Tasseled Cap is to isolate a perpendicular measure of green vegetation biomass density vis-à-vis bare soil having variable degrees of brightness. Another traditional use would be to isolate a yellow-vegetation indicator vis-à-vis variable-brightness bare soils and various amounts of green vegetation biomass.

The approach that you should make here is to select the main biophysical property of interest to you late in the input-parameters sequence. For Method 3, you must specify the input-parameters sequence by picking on a particular representative pixel by its line and column position for each biophysical property in the sequence.

This will become more obvious in a later “answer” to a later “FAQ.” First, let’s use Method 1 and Method 2 on a TNTlite-compatible sample of Landsat 7 ETM+ data collected near Stockton, CA, on September 30, 2001. [This sample is available on the MicroImages, Inc., Web site.]

F7. What do the Results of Method 1 Mean?

Before you use, Method 1, you need to process the source imagery rasters (having uncalibrated DN values) to create SRFItoa rasters. Here is metadata that you need to know when using SRFI.sml to do this:

- Site Name: Stockton, CA
- Collection Date: 20010930
- Sun-Elevation Angle: 45.18 (degrees)
- Imager Number: 4 (Landsat-7 ETM+)
- Atmospheric-Correction Level: 1 (SRFItoa)
- Processing Date: 20020529
- Source Code: 2 (NLAPS, EarthExplorer)
- Gaincode: HHHLHH
- Selected raster objects (input) in L7_20010930.rvc: BL, GL, RL, NA, MB, and MC
- Output rasters in SRFItoa (.rvc): SRFIBL, SRFIGL, SRFIRL, SRFINA, SRFIMB, and SRFIMC (but not PBI and PVI since this is the SRFItoa option)

Then, you can process the SRFItoa rasters using TASCAP.sml Method 1.

Here are your responses:

- Method Number: 1
- Input SRFI rasters in SRFItoa.rvc: SRFI1 = SRFIBL … SRFI6 = SRFIMC
- Output rasters: DS0, TC1, DS1, TC2, DS2, TC3, DS3, TC4, and DS4

The Console Window (report) lists the sequence of biophysical materials that control (are related) to the TC output rasters. They are (for Method 1):

BPVO: BLACK
BPV1: Brightness
BPV2: Greenness
BPV3: Wetness
BPV4: Haze

The starting point for Method 1 (in 6-Space) is a BLACK object (BP0), i.e., where SRFI = 0 for all bands. All image pixels have a Euclidian distance (in SRFI units) from this starting point that is represented by the DS0 raster.

From that point, the 1st TC unit vector (TC coefficients associated with tc1) are:

tc1: 0.3561 0.3972 0.3904 0.6966 0.2286 0.1596

Note that these coefficients are all positive and are nearly equal to each other (except for the 4th component, related to SRFINA and the 6th component, related to SRFIMC). The square root of the sum of the squares of these components is equal to 1.0000. The relative magnitudes of this tc1 vector are approximately proportional to the brightness of typically bare soil in terms of SRFI units. Thus, a property of overall brightness is captured in TC1. In 6-Space, the distances from the line defined by tc1 to all of the points in 6-Space associated with each pixel is captured in the DS1 raster (having SRFI units). Note that DS1 can be calculated with having defined the higher order TC axes.

The 2nd TC unit vector (TC coefficients associated with tc2) are:

tc2: -0.3344 -0.3544 -0.4556 0.6966 -0.0242 -0.2630

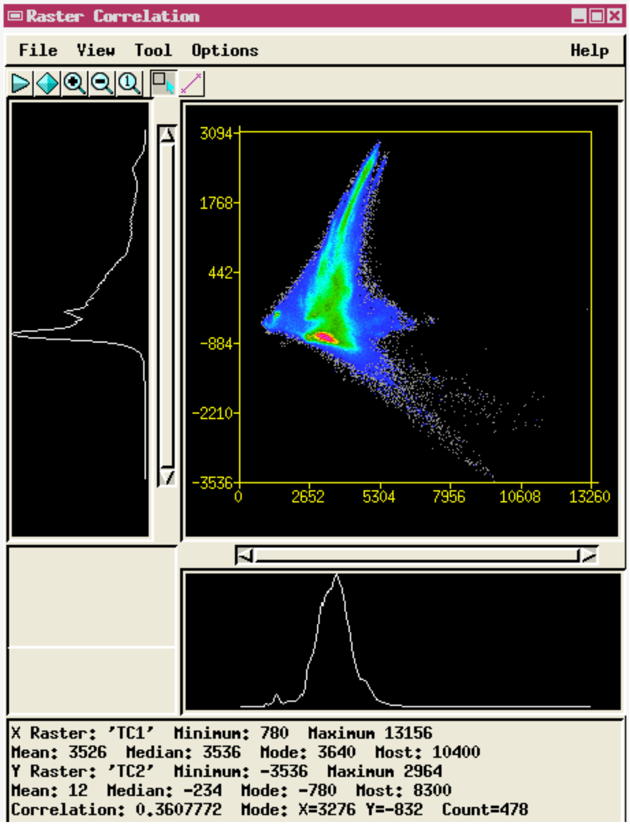
Note that, except for the 4th component, all of these coefficients are negative. And, the 4th component (related to SRFINA) is large in magnitude. In a way, tc2 relates to the difference between SRFINA and a combination of SRFI values in the BL, GL, RL, MB, and MC spectral bands. Green vegetation absorbs radiant energy in all of the non-near-infrared bands while reflecting radiant energy (more than absorption) in the NIR (NA) band. The latter is due to multiple scattering in the leaves and the lack of absorption of radiant energy by leaf chlorophyll, other leaf pigments, and leaf water – in the NIR part of the spectrum only.

These physical spectral characteristics are captured in the TC2 raster as a single number in a way that is not affected by correlated changes in brightness.

DS2 is a raster of distances from the plane defined by tc1 and tc2 for each pixel in the image (as plotted in 2-Space). If a pixel consists of a mixture – linear mixture or non-linear mixture – between bare soil (of variable brightness) and green vegetation, then DS2 will be relatively small.

Examine a typical scatter plot of TC2 vs. TC1 (see Figure F7):

Figure F7. Scatter Plot of TC2 vs. TC1 for Method 1 (from Raster Correlation tool in TNTmips)



```
X Raster: 'TC1'  Minimum: 780  Maximum 13156
Mean: 3526  Median: 3536  Mode: 3640  Most: 10400
Y Raster: 'TC2'  Minimum: -3536  Maximum 2964
Mean: 12  Median: -234  Mode: -780  Most: 8300
Correlation: 0.3607772  Mode: X=3276 Y=-832  Count=478
```

The Tasseled Cap *shape* is quite visible; however, the whole Tasseled Cap feature seems to be rotated from its most optimum position. That is, the Brim of the Cap (marked by red colors) is not quite horizontal. And, the Tip of the Cap looks foreshortened. This lack of perfection is due to the USGS TC coefficients being wrong or being applied to independently calibrated imagery (in terms of SRFI values). The apparent maximum magnitude of TC2 is suspiciously low (only 2964); it should be closer to 6000. This is evidence of significant TC tilt (this result happens only with Method 1).

The 3rd TC unit vector (TC coefficients associated with tc3) are:

tc3: 0.2626 0.2141 0.0926 0.0656 -0.7629 -0.5388

The positive TC coefficients are related to the visible bands (first three TC components). The negative TC coefficients are related to the two middle infrared bands (last two TC components). The 4th TC coefficient is nearly zero (related to SRFINA band). This distribution of coefficients reflects the fact that open water is relative bright in the visible bands and relative dark in the middle infrared bands. tc3 is essentially a weighted difference between the visible bands and middle infrared bands.

DC3 is the distance between each pixel in 6 Space and the hyperplane defined by tc1, tc2, and tc3. The term, hyperplane, is a term used to describe the n-Space domain as a subset of the full higher-dimensional space like 6-Space. If only three spectral bands would have been used for this analysis, then DS3 values would all be zero due to the related pixels being contained in the domain represented by three axes. But, in 6-Space, there is room to have separations between pixels and the hyperplane defined by only 3 TC axes.

The 4th TC unit vector (TC coefficients associated with tc4) are:

tc4: 0.0805 -0.0498 0.1950 -0.1327 0.5752 -0.7775

The magnitudes and signs of these coefficients suggest that TC4 is related to objects that are relatively bright in the RL band and in the MB band, but relatively dark in the MC and NA bands. These are the characteristics of yellow vegetation (relative to soil, green vegetation, and water / wet objects). Historically, the 4th TC component is called Haze (or haziness). But, it could have been just as well called TC Yellowness.

The DS4 raster is the remaining “distance” in 6 Space after the first four TC axes have been defined. An enhanced display of DS4 shows it to be large for materials in the urban areas of the scene. But, some vegetation has surprisingly high values of DS4. The latter may be due to the general nature of Method 1 (operating as it does on SRFI values that have not been matched to the standard USGS coefficients). The situation improves when you use Method 2 or Method 3 (the best of the three methods).

F8. What do the Results of Method 2 Mean?

Before you use, Method 2, you need to process the source imagery rasters (having uncalibrated DN values) to create SRFIsfc rasters. Here is metadata that you need to know when using SRFI.sml to do this:

- Site Name: Stockton, CA
- Collection Date: 20010930
- Sun-Elevation Angle: 45.18 (degrees)
- Imager Number: 4 (Landsat-7 ETM+)
- Atmospheric-Correction Level: 3 (SRFIsfc)
- delcf: 0.05
- msfac: 1.0000
- icRL: 1.45 (low-altitude site like Stockton deserves higher value than default)
- Processing Date: 20020529

- Source Code: 2 (NLAPS, EarthExplorer)
- Gaincode: HHHLHH
- Selected raster objects (input) in L7_20010930.rvc: BL, GL, RL, NA, MB, and MC
- Output rasters in SRFIsfc (.rvc): SRFIBL, SRFIGL, SRFIRL, SRFINA, SRFIMB, SRFIMC, PBI, and PVI (since this is the SRFIsfc option)

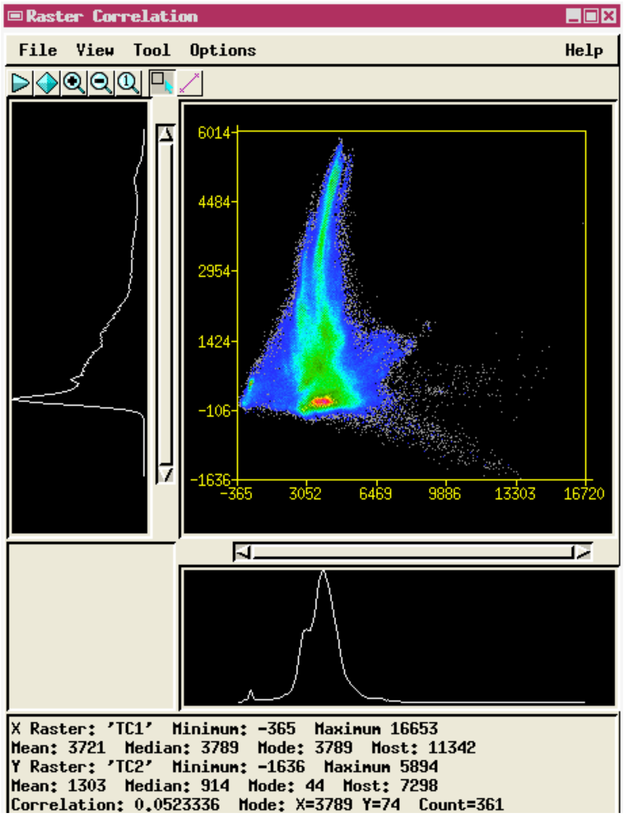
Next, you would run TASCAP.sml with the Method-2 option. When asked to select the n-SPACE ORIGIN TYPE, you have two options: Dark Soil (the default option) or BLACK. Traditionally, historic TC coefficients have been based on an n-Space origin being at the point in n-Space where either image DNs are all equal to 0 *or* where reflectance factors are all equal to 0. If you respond with BLACK (typed exacted as shown in all caps), then Method 2 will produce TC coefficients based on the origin being where SRFI values are all equal to 0. Otherwise, i.e., the Dark Soil (default) option will be used with the corresponding SRFI values associated with dark soil.

The next entry inquiry asks you to declare the number of SRFI rasters to be processed. Your choice must be either 4, 5, or 6. The number of output raster pairs (the next query) can be as high as the number of SRFI rasters less one. That is, if you decided to use 6 input SRFI rasters, then the number of output raster pairs can be as high as 5.

When you select rasters to assign to SRFI1, SRFI2, etc., you must select them in the following order: SRFIBL, SRFIGL, SRFIRL, SRFINA, SRFIMB, and SRFIMC (up to the number requested by the script). TASCAP.sml contains pre-defined sets of SRFI values that are associated with each output pair of rasters being produced by this script by Method 2.

This time, for the same example used to illustrate Method 1, the Raster Correlation between TC2 and TC1 is as shown in *Figure F8* (on the next page). Compare this figure to *Figure F7* (Method 1).

Figure F8. Scatter Plot of TC2 vs. TC1 for Method 2 (from Raster Correlation tool in TNTmips)



```
X Raster: 'TC1'  Minimum: -365  Maximum 16653
Mean: 3721  Median: 3789  Mode: 3789  Most: 11342
Y Raster: 'TC2'  Minimum: -1636  Maximum 5894
Mean: 1303  Median: 914  Mode: 44  Most: 7298
Correlation: 0.0523336  Mode: X=3789 Y=74  Count=361
```

Note that the Brim of the TC is more horizontal than it was for Method 1. Also, the Correlation between TC2 and TC1 (for this Method 2 case) is almost zero (0.05). When Method 1 was used, the Correlation between TC2 and TC1 was large: 0.36. This is evidence that Method 2 produces a better set of TC rasters than did Method 1. However, the best set of TC rasters will come from Method 3, which is discussed next.

F9. What do the Results of Method 3 Mean?

Before you use, Method 3, you need to process the source imagery rasters (having uncalibrated DN values) to create SRFIsfc rasters. Here is metadata that you need to know when using SRFI.sml to do this:

- Site Name: Stockton, CA
- Collection Date: 20010930
- Sun-Elevation Angle: 45.18 (degrees)
- Imager Number: 4 (Landsat-7 ETM+)
- Atmospheric-Correction Level: 3 (SRFIsfc)
- delcf: 0.05
- msfac: 1.0000

- icRL: 1.45 (low-altitude site like Stockton deserves higher value than default)
- Processing Date: 20020529
- Source Code: 2 (NLAPS, EarthExplorer)
- Gaincode: HHHLHH
- Selected raster objects (input) in L7_20010930.rvc: BL, GL, RL, NA, MB, and MC
- Output rasters in SRFIsfc (.rvc): SRFIBL, SRFIGL, SRFIRL, SRFINA, SRFIMB, SRFIMC, PBI, and PVI (since this is the SRFIsfc option)

Then, you need to **find and record specific pixels (by line and column position) that are related to specific key biophysical materials**. To do this, you need to use TNTmips standard (menu-driven) Display Spatial Data tools.

Process: Spatial Data Display

From the TNTmips main menu:

- Menu path: Display > Spatial Data… The Spatial Data Display menu bar appears.
- Select New 2D Group. The Group 1 – Group Controls box appears and the Group 1 – View 1 window appears.
- In the Group 1 – Group Controls box, select Add Raster… . From the list, select Add RGB Raster … .
- Navigate to the location of the SRFIsfc.rvc file. Assign SRFINA to Red, SRFIRL to Green, and SRFIGL to Blue. When the Raster Layer Controls box appears, disable the DataTips (under each color label) and Click OK.
- A color infrared (CIR) depiction of the scene appears.

You can easily recognize many of the key biophysical materials in this small scene. Bare soil has shades of gray with dark bare soil being dark gray and bright bare soil being bright gray. Dense green vegetation is red. Yellow vegetation is yellow or brown. Urban materials are bright gray to white. Open water is dark blue or black.

You need to select specific pixels, by line and column position, that well represent these key biophysical (bp) materials.

- Turn on the Object Coordinates… tool (go through the Tool icon next to the layer in the Group 1 – Group Controls box to find the icon that turns on this tool).
- As you move the cursor around the image, you will see the Line: and Column: coordinates of the cursor's location. It is a floating point number. When you have selected a bp object, round up to the nearest integer and record the Line: and Column: in your notebook. This is like the list on Page F8. There

are many pixels to select from regarding being a representative of each biophysical material type.

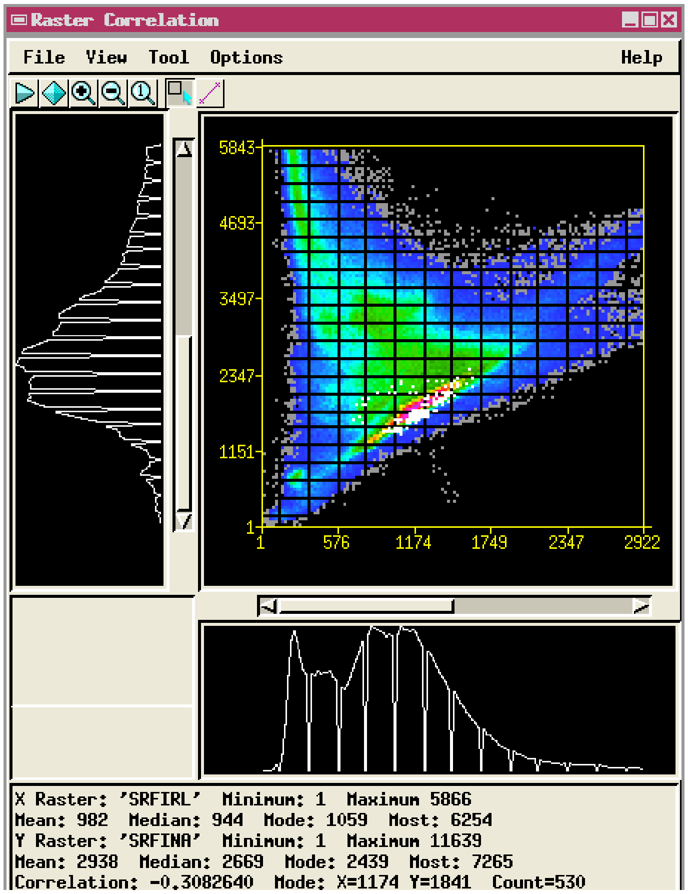
Process: Raster Correlation

From the Group 1 – Group Controls box:

- Select Raster Correlation from the Tools drop-down list. A default scatterplot is displayed of SRFIRL vs. SRFINA.
- Click File then New. Then, assign SRFIRL to the X Axis and SRFINA to the Y Axis. The scatter plot changes.
- As you move the cursor around the CIR image, you will see white pixels appear in the Raster Correlation window. This is called the “dancing pixels” feature. It shows you where the pixels near the cursor’s location plot out in the 2-Space plot in the Raster Correlation tool.
- If the “dancing pixels” don’t dance, try leaving TNTmips altogether and repeating the above sequence. “Dancing pixels” requires memory on the graphics board – memory that might be saturated when TNTmips is used too much. This is an on-again / off-again tool that takes patience to have it appear.
- Sometimes, you have to Restart the computer to gain back the memory needed to make the pixels “dance.” When you are successful, you can see how certain pixels map over into SRFI 2-Space.
- *Figure F9A* (next page) shows the locations of bare soil pixels – dark and bright – in SRFINA vs. SRFIRL 2-Space.
- Raster Correlation is a useful tool for viewing n-Space from different perspectives – two coordinate axes at a time.

In any case, you will need to find Line: and Column: coordinates for each pixel that will represent each biophysical material type for using Method 3 of TASCAP.sml.

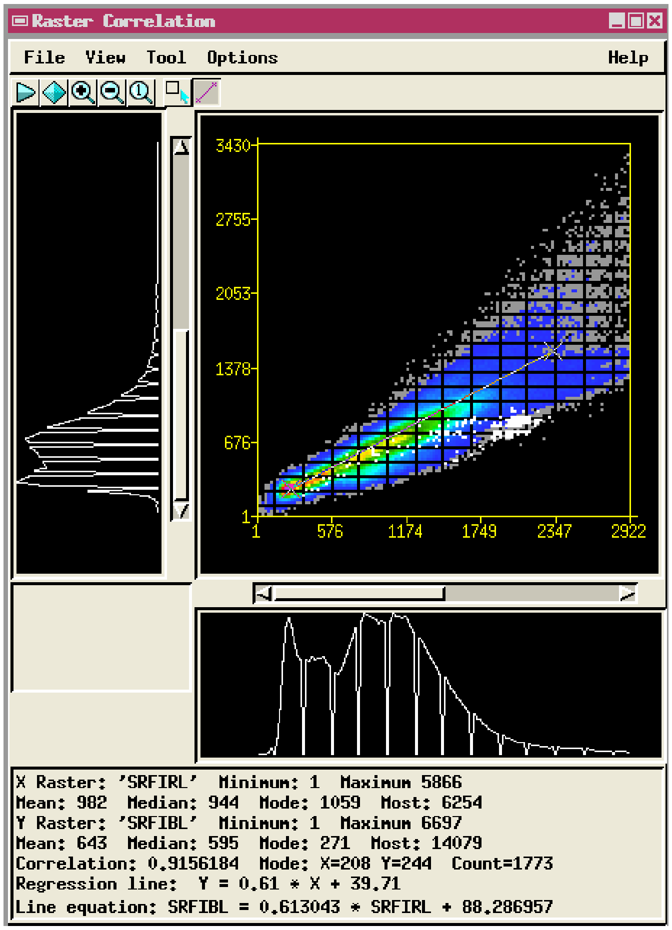
Figure F9A. SRFINA vs. SRFIRL with Dancing Pixels (White).



```
X Raster: 'SRFIRL'  Minimum: 1  Maximum 5866
Mean: 982  Median: 944  Mode: 1059  Most: 6254
Y Raster: 'SRFINA'  Minimum: 1  Maximum 11639
Mean: 2938  Median: 2669  Mode: 2439  Most: 7265
Correlation: -0.3082640  Mode: X=1174 Y=1841  Count=530
```

When you point the cursor at yellow ag fields (in the CIR image), the related location in SRFINA vs. SRFIRL space is in the continuum between the Line of Bare Soils (white pixels above) and the Point of Dense Green Vegetation (off the plot at the upper left). But, this location is an illusion. If you view, for example, a plot of SRFIBL vs. SRFIRL for the same spatial pixels, they can be seen as being clearly not in the mixture between bare soil and dense green vegetation. This is shown in *Figure F9B* (next page).

Figure F9B. SRFIBL vs. SRFIRL Scatterplot.



```
X Raster: 'SRFIRL'  Minimum: 1  Maximum 5866
Mean: 982  Median: 944  Mode: 1059  Most: 6254
Y Raster: 'SRFIBL'  Minimum: 1  Maximum 6697
Mean: 643  Median: 595  Mode: 271  Most: 14079
Correlation: 0.9156184  Mode: X=208 Y=244  Count=1773
Regression line:  Y = 0.61 * X + 39.71
Line equation: SRFIBL = 0.613043 * SRFIRL + 88.286957
```

The white pixels (dancing pixels) show the location of brown and yellow ag fields in this 2-Space plot. The thin gray line is the location of the edge of the Tasseled Cap that represents a mixture between bare soils and dense green vegetation.

The TC process aims at defining an axis to represent the property of being like Yellow Vegetation vis-à-vis being like a mixture of bare soil and green vegetation. Ultimately, an axis will be defined as a unique indicator of being like open water vis-à-vis all non-water materials in the scene.

F10. How Can Method 3 be Used for a Customized Mapping of Something Other than Brightness, Greenness, Wetness, and Yellowness?

Suppose that you want to map Open Water with the help of a customized TC index.

First, consider the general spectral properties of Open Water. In most cases, Open Water is darker than most other objects in a scene. This is true for all bands and is especially true for the NA, MB, and MC bands. This implies that TC Brightness alone might be used to map Open Water. You would need only to define a ceiling value for TC Brightness such that all water pixels would have a TC Brightness below that ceiling value.

But, in some cases, Open Water, might be brighter than land materials due to the water being shallow, being high in sediment content, and/or being partly vegetated (e.g., floating algae). In these cases, the otherwise useful property of being darker than a ceiling value in the TC Brightness image would not be valid. Other biophysical properties would be needed to avoid erroneous classifications.

Let's consider the use of Method 3 with the line and column values on Page F8 with the goal of constructing a TC Open Water raster (which will be called TC5).

The responses you would make, in this case, when running TASCAP.sml with this goal in mind are:

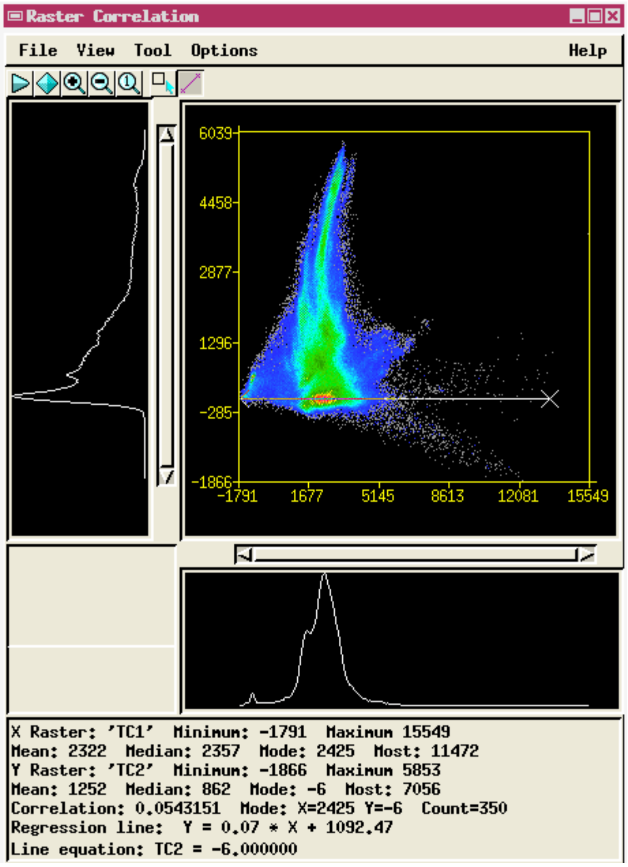
- Method Number: 3
- Number of Input SRFI Rasters: 6
- Number of Output Raster Pairs: 5
- Select (input) raster objects:
  - SRFI1: select SRFIBL
  - SRFI2: select SRFIGL
  - SRFI3: select SRFIRL
  - SRFI4: select SRFINA
  - SRFI5: select SRFIMB
  - SRFI6: select SRFIMC
- bp0 Name: Dark Soil
  - LIN: 73
  - COL: 373
- bp1 Name: Bright Soil
  - LIN: 276
  - COL: 154
- bp2 Name: Green Veg.
  - LIN: 261
  - COL: 40

- bp3 Name: Yellow Veg.
  - LIN: 410
  - COL: 65
- bp4 Name: Urban Materials
  - LIN: 99
  - COL: 511
- bp5 Name: Open Water
  - LIN: 34
  - COL: 528
- Output Rasters: accept each of the default raster names. Put the output rasters in new TNTmips Project File called Method_3_Open_Water (.rvc).

This approach will produce, as TC5 values, a good measure of how likely it is that a pixel is Open Water. In this case, the intermediate biophysical measures (TC1, TC2, TC3, and TC4) serve only to capture land features so that the TC5 indicator clearly relates only to Open Water.

One way to see this fact this is to examine at scatterplots for the various pairs of TC rasters. The best TNTmips tool for this purpose is the Raster Correlation. Scatterplots and correlation data are shown on the following pages in *Figures F10A through F10F*.

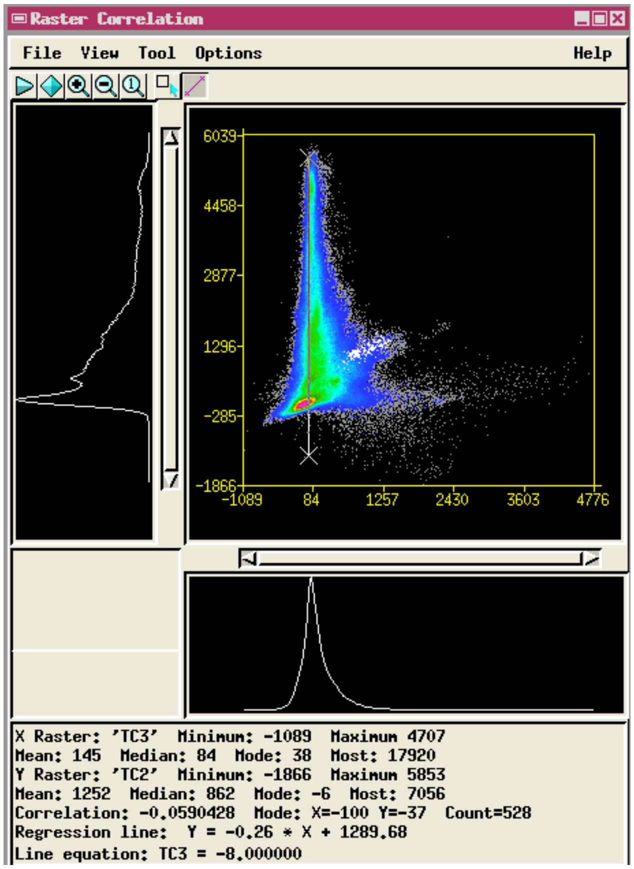
Figure F10A: TC2 (TC Greenness) vs. TC1 (TC Brightness).



```
X Raster: 'TC1'  Minimum: -1791  Maximum 15549
Mean: 2322  Median: 2357  Mode: 2425  Most: 11472
Y Raster: 'TC2'  Minimum: -1866  Maximum 5853
Mean: 1252  Median: 862  Mode: -6  Most: 7056
Correlation: 0.0543151  Mode: X=2425 Y=-6  Count=350
Regression line:  Y = 0.07 * X + 1092.47
Line equation: TC2 = -6.000000
```

This TC Greenness vs. TC Brightness scatter plot shows the Tasseled Cap distribution feature "full on," i.e., with no tilt distortion or tilt reduction. Note that the Line of Bare Soils (indicated by the gray Line equation) is in an ideal orientation (i.e., horizontal at TC2 ≅ 0). Note also that the range of TC2 is up to nearly +6000, as expected.

Figure F10B: TC2 vs. TC3 (TC Greenness vs. TC Yellowness).



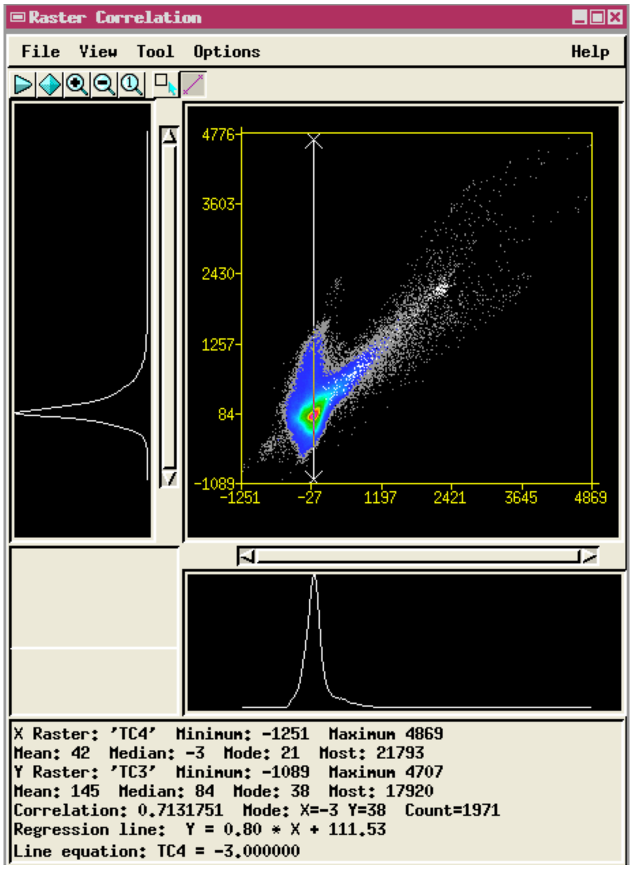
```
X Raster: 'TC3'  Minimum: -1089  Maximum 4707
Mean: 145  Median: 84  Mode: 38  Most: 17920
Y Raster: 'TC2'  Minimum: -1866  Maximum 5853
Mean: 1252  Median: 862  Mode: -6  Most: 7056
Correlation: -0.0590428  Mode: X=-100 Y=-37  Count=528
Regression line:  Y = -0.26 * X + 1289.68
Line equation: TC3 = -8.000000
```

In this scatterplot, we can see how the soil-green-veg mixture-related TC plane looks across its "edge." The Tasseled Cap triangular Feature is in a plane that is represented in *Figure F10B* by the vertical gray Equation Line (i.e., where TC3 ≅ 0). The "dancing" white pixels show that pixels dominated by yellow (and brown) colored crops have large positive values for TC3. It also shows that some pixels (not bare soil, not green vegetation, and not yellow vegetation) have negative values for TC3.

This width of the distribution of TC3 in this plot also indicates that the soil-green-veg mixture-related TC plane is a "fat" plane, not a "thin" plane. But, there are two more TC components, i.e., TC4 and TC5, that may explain spectral variations that here are displayed as variations in TC3.

Note: At times, the "dancing pixels" feature does not work in TNTmips. The author has found that it is helpful to reset clipboard memory and TNTmips' use of memory (that is essential to the functioning of this feature). You can do this by (1) copying a small item (such as a single text letter) into clipboard memory by using <Control><C> and/or (2) exiting TNTmips and re-launching TNTmips. In some cases, it is necessary to restart your computer.

Figure F10C: TC3 vs. TC4 (TC Yellowness vs. TC “urban materials” ness).

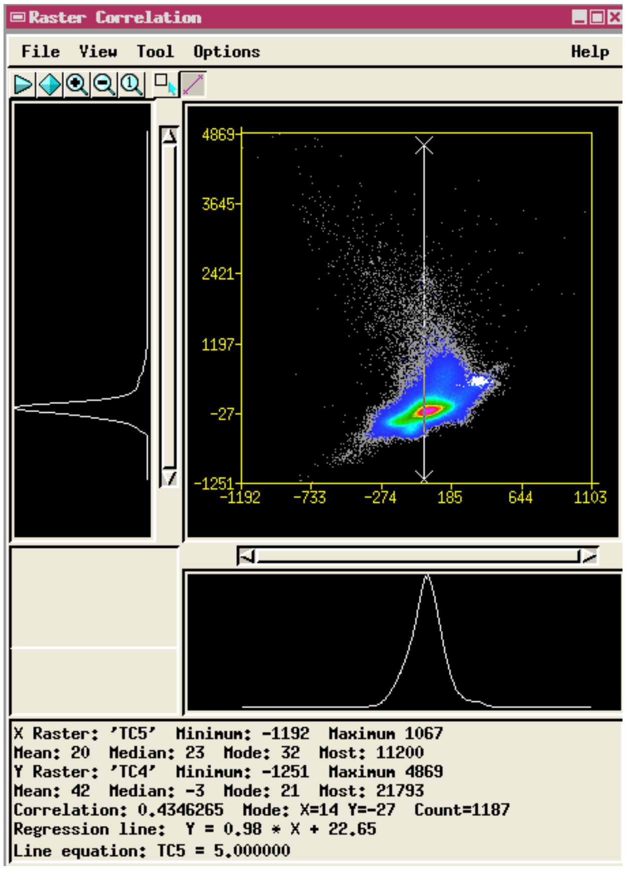


```
X Raster: 'TC4'  Minimum: -1251  Maximum 4869
Mean: 42  Median: -3  Mode: 21  Most: 21793
Y Raster: 'TC3'  Minimum: -1089  Maximum 4707
Mean: 145  Median: 84  Mode: 38  Most: 17920
Correlation: 0.7131751  Mode: X=-3 Y=38  Count=1971
Regression line:  Y = 0.80 * X + 111.53
Line equation: TC4 = -3.000000
```

This plot shows that TC4 (the measure of being like “urban materials”) stands away from the hyperplane defined by TC1, TC2, and TC3 axes (represented in this figure by the vertical gray Equation line). The high concentration of pixels (red colors) at a point (where TC3 ≅ 0 and TC4 ≅ 0) in this plot shows that most of the pixels in this scene consist of mixtures between bare soil and green vegetation. However, the vertical extension concentration (on the gray line where TC4 = 0) represents the pixels that are dominated by yellow vegetation.

The white colors show were urban materials are (as shown by the “dancing pixels” in the Raster Correlation tool).

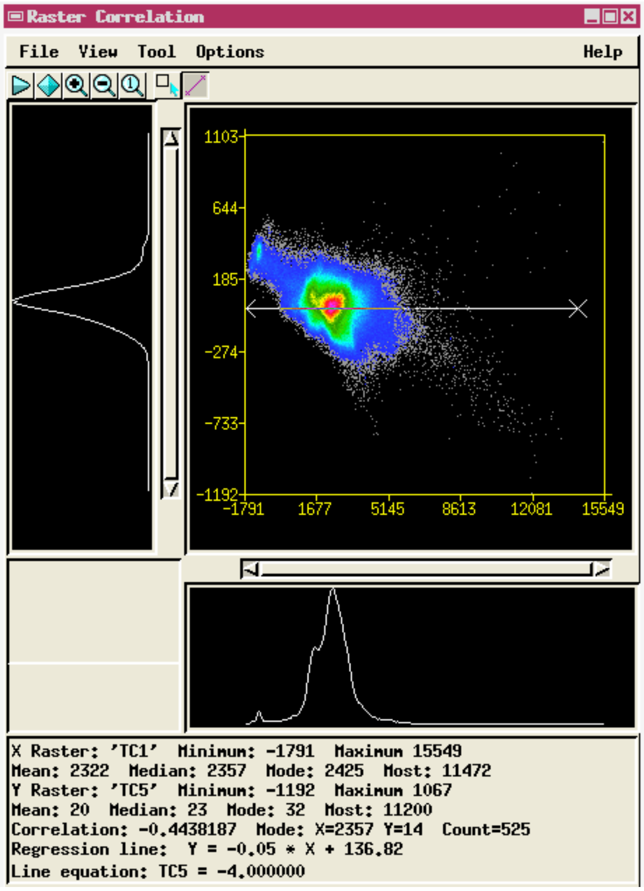
Figure F10D: TC4 vs. TC5 (from the Open-Water Method 3 Run).



```
X Raster: 'TC5'  Minimum: -1192  Maximum 1067
Mean: 20  Median: 23  Mode: 32  Most: 11200
Y Raster: 'TC4'  Minimum: -1251  Maximum 4869
Mean: 42  Median: -3  Mode: 21  Most: 21793
Correlation: 0.4346265  Mode: X=14 Y=-27  Count=1187
Regression line:  Y = 0.98 * X + 22.65
Line equation: TC5 = 5.000000
```

This figure shows that the indicator of being like Open Water, i.e., TC5, is well separated from the other the other indicators (as again represented by the vertical gray Equation line where TC5 ≅ 0.

Figure F10E: TC5 vs. TC1 (from the Open-Water Method 3 Run).



```
X Raster: 'TC1'  Minimum: -1791  Maximum 15549
Mean: 2322  Median: 2357  Mode: 2425  Most: 11472
Y Raster: 'TC5'  Minimum: -1192  Maximum 1067
Mean: 20  Median: 23  Mode: 32  Most: 11200
Correlation: -0.4438187  Mode: X=2357 Y=14  Count=525
Regression line:  Y = -0.05 * X + 136.82
Line equation: TC5 = -4.000000
```

The best 2-Space combination of TC values for mapping Open Water is TC5 vs. TC1. The scatterplot above shows that two main clusters of points exist in this 2-Space. The largest cluster is near where TC1 = 2257 and TC5 = 14 (which are the Mode: values for X and Y related to the Correlation: stats of the text report below the figure). These are all of the land pixels. The smaller cluster is near where TC1 = -1179 and TC5 = 365. This is the location of the water pixels in this 2-Space plot.

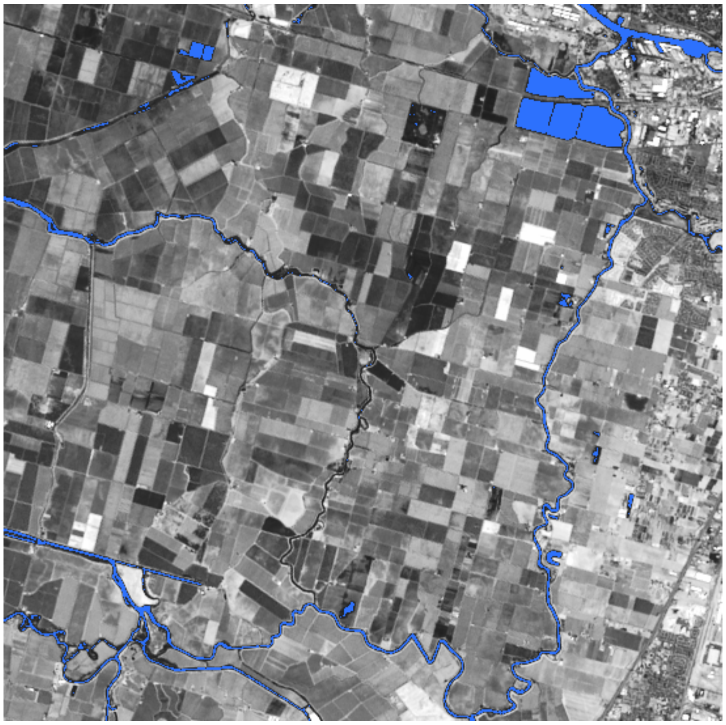
There is a clear separation between the land-pixels cluster and the water-pixels cluster. It appears that a diagonal "decision" line (not shown) drawn between these two clusters could serve well as a means for classifying water pixels from land pixels. An ideal tool for determining the best position of this diagonal "decision" line is GRUVI.sml. In this case, the GRUVI.sml SRFIX raster would be assigned to TC1 and the GRUVI.sml SRFIY raster would be assigned to TC5. The Line of Background Materials (LBM) would be the horizontal gray Equation line shown above. In this case, LBM has a slope of 0.0. A logical value for the GRUVI.sml Xorg parameter is the minimum value of TC1, which is -1171. Selecting a GRUVI.sml bnp value of 0.02 causes the lines of constant GRUFI values to be like the spokes of a wheel, in the scatterplot of TC5 vs. TC1. These GRUFI isolines extend in radial directions from a hub where TC1 equals to about -1200 and TC5 = 14. One of these isolines (one of the values of GRUFI) can serve as a decision point in the distribution of GRUFI values. Water pixels would have values of GRUFI greater than the decision point; land pixels would have values of GRUFI less than the decision point.

Try using GRUVI.sml with the following inputs:

- GRUVI "Way" Selected: 2
- Foreground Materials Name: Open Water
- Background Materials Name: Non Open Water
- Foreground Materials Point, Xf: -1179 (typical TC1 for water)
- Foreground Materials Point, Yf: 365 (typical TC5 for water)
- Line of Background Materials (LBM), slope: 0.0 (where is TC5 ≈ 0)
- Background Materials Point, Xb: 2257 (typical TC1 for background)
- Background Materials Point, Yb: 14 (typical TC5 for background)
- Line of Background Materials X Origin, Xorg: -1791 (minimum TC1)
- Test Area: No
- bnp Value: 0.02 (makes GRUFI like a ND algorithm)
- Input SRFIX Raster: TC1
- Input SRFIY Raster: TC5
- Output Rasters: GRFBI & GRUFI. GRUFI serves as an indicator of being Open Water.

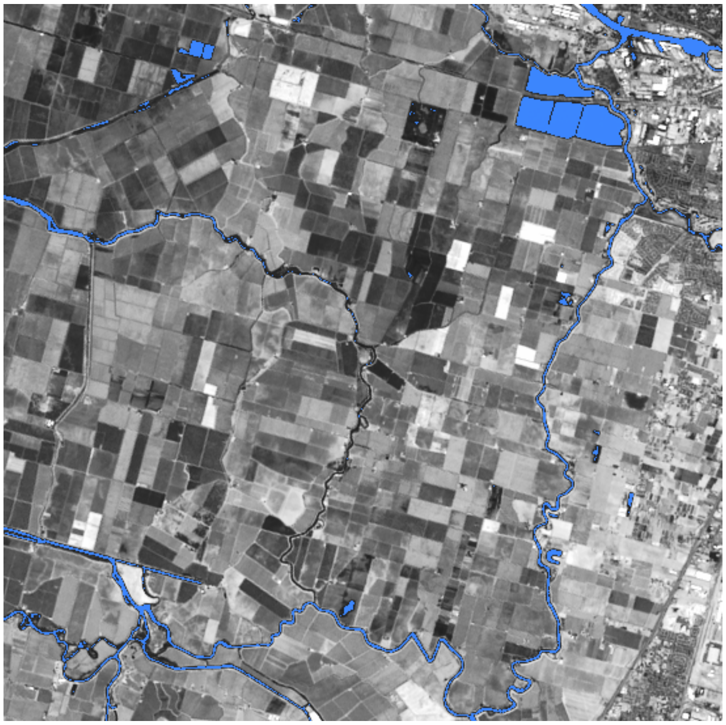
Now, a map of Open Water can be made by setting a threshold on GRUFI (see the next page).

Figure F10F: Map of Open Water (Light Blue) Using a Threshold (630) on GRUFI Values.



It is possible that a threshold value of -200 for TC1 could have served as an indicator that a pixel is Open Water. The corresponding TC1 only related Open Water map is shown on the next page.

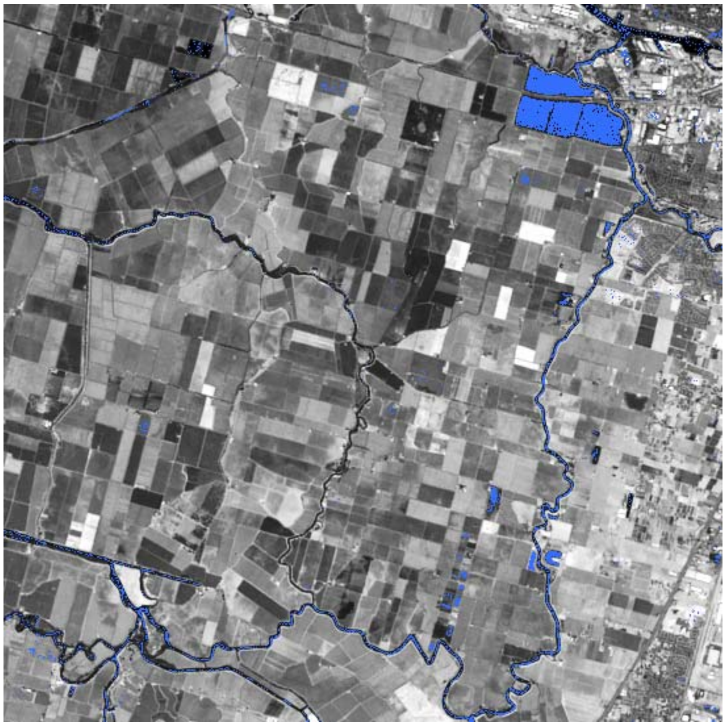
Figure F10G: Map of Open Water (Light Blue) Using a Threshold (-200) on TC1 Values.



In this case, a simple threshold on TC1 seems to work well. In a different scene, bright water pixels would be misclassified.

Using simple threshold on TC5 (see next page) to produce a map of Open Water does not work as well as the TC1 threshold or the GRUFI threshold.

Figure F10H: Map of Open Water (Light Blue) Using a Threshold (+300) on TC5 Values.



The author of this script hopes that you will try complex approaches like the one presented in this section in order to use a combination of TASCAP.sml and GRUVI.sml processes to obtain good maps of specific biophysical features. At the end of the day, the information content of the multispectral images will determine what biophysical data can be extracted – regardless of the technique being used.

TASCAP.sml and GRUVI.sml also will have important roles as a way to prepare image data (converted to SRFI values) prior to using the script called OBJECT.sml. This script breaks a scene up into a large number of polygons with one polygon for each scene object. Scene objects are entities such as each agricultural field, each body of water, each urban area, each forest stand, etc. OBJECT.sml will process source rasters to extract attributes attached to each scene-object polygon as a database table. The source rasters may be biophysical rasters produced by TASCAP.sml.

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