E: GRAND UNIFIED VEGETATION INDEX IMAGES

Like *Frequently Asked Questions*, a question is posed, e.g., *E1. Why Convert DNs to SRFIs?* Then, an answer is given[1] with comments and opinions. For cross referencing, each item is labeled, e.g., *E1*.

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

GRIVI.sml usually produces a user-controlled pair of calibrated indicator rasters called GRUVI[2] and GRUBI.[2] Inputs to this script usually will be a pair of user-selected SRFI rasters (see SRFI.sml or *FAQs by Jack B.pdf*). However, GRUVI.sml may, instead, take, as input, a pair of TC[2] rasters, which also have SRFI units (see TASCAP.sml or *FAQs by Jack F.pdf*). In this case, the primary output raster is called GRUFI[2] instead of GRUVI as it is likely to not be an indicator of vegetation amount in the traditional sense of Vegetation Indices (VIs). A small Test Area can optionally be used by the script to optimize the value of the Background Noise Parameter, bnp.

With appropriate control parameters, a GRUVI raster will be like one of the several classic Vegetation Indices (VIs)[3]: NDVI, Transformed NDVI, SAVI, TSAVI, or WDVI. In many cases, the user will select GRUVI control parameters that produce unique optimized set of GRUVI and GRUBI rasters.

GRUVI.sml also may provide a solution to the non-linear mixing problem that faces the MS imagery analyst when dealing with mixed vegetation and soil spectra. Non-linear mixing occurs when foreground materials, e.g., vegetation, are partially transparent in one or more of the spectral bands that are involved as inputs to the GRUVI algorithm. In the usual application of GRUVI.sml, the near infrared (NR) band (either NA or NB) is selected as the input SRFIY band (Y-Axis) and another band, e.g., RL, is selected as the input SRFIX band (X-Axis). Partial transparency creates a complex non-linear spectral mixing between foreground vegetation and background materials that have a range of brightness. The GRUVI algorithm is much like the SAVI algorithm (Huete, 1988); however, GRUVI is more flexible than the

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[2] GRUVI stands for Grand Unified Vegetation Index; GRUBI stands for Grand Unified Brightness Index. If the indicator raster is not vegetation related, then the output raster is called GRUFI instead of GRUVI. Here, F is for Foreground materials. Examples would be trees or water as the subject "foreground."

[3] Each classic VI acronym and formula is defined explicitly later in this tutorial. These usually well-known acronyms are referenced here for the sake of brevity.

SAVI algorithm in that GRUVI can be optimized to minimize the disparate effects of variations in background brightness.

Input Data and Input Parameters for GRUVI.sml:

1. A pair of SRFI rasters or rasters having SRFI units (e.g., TC rasters). One input raster is likely to be either SRFINA or SRFINB; the other input raster then would be a visible-region or middle-infrared region raster, e.g., SRFIRL. The generic names of the input rasters are SRFIY and SRFIX, respectively.
2. The location of the Line of Background Materials (LBM) and the location of a Dense Vegetation (or Foreground Materials) Point in a SRFI 2-Space plot. The user provides this information in the form of **five** GRUVI control parameters: srfiX & srfiY for background materials, the slope of the LBM, and srfiX and srfiY for foreground materials (vegetation or possibly some other foreground materials).
3. A value for the GRUVI Background Noise Parameter (**bnp**).
4. An optional Test Raster set, called SRFIXT and SRFIYT. These may be used to optimize the value of bnp.

In addition, there are parameters hard-coded into the GRUVI.sml script that control the range of GRUVI, GRUFI, and GRUBI values and that designate the type of output rasters (16-bit or 8-bit as well as signed or unsigned). Nominally, GRUVI.sml produces 16-bit signed output rasters. GRUVI or GRUFI rasters have a numeric scale from 0 (for LBM materials) to 1000 (for vegetation or designated foreground materials). GRUBI rasters have a numeric scale equal to 20% of the related input SRFI units scale.

Since some pixels in a MS image have non-vegetation, non-foreground materials, and non-background materials as mixtures (or not), the output rasters, GRUVI or GRUFI and GRUBI, can (and will) have negative values. The use of signed integers allows all of the materials in a MS image to be represented by a continuum of numeric values. GRUVI.sml does limit the output numeric values to a range from -3000 to +3000. This also may be changed by changing the hard-coded value of grumax in the script.

If the user desires that the final rasters have only positive values, then the user should add an offset to each output raster value and assign the results of this post-processing operation to unsigned rasters. TNTmips, per se, handles signed rasters very well. However, if the rasters are to be provided to a non-TNTmips user, the output rasters may have to be further processed to create only positive values. There are many advantages for using TNTmips tools to handle rasters such as the outputs from GRUVI.sml.

In Brief …

This tutorial discusses key SML functions and model concepts related to **GRUVI.sml**. The list below is divided into two groups: one for the key SML functions and the other for key model concepts. If you are interested in a particular topic below, please go directly to it.

KEY SML ITEM

There are no new SML functions in GRUVI.sml. Refer to SRFI.sml and DIAG.sml for information about the SUM functions that are in this script.

KEY MODEL-CONCEPT ITEMS

Quick Guide to Using GRUVI.sml …

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

BEFORE you use GRUVI.sml …

- Run SRFI.sml to produce SRFI, PVI, and PBI rasters. These are used by DIAG.sml and TERCOR.sml. If you plan to use both of these, run TERCOR.sml before you run DIAG.sml.
- Select two rasters (SRFI rasters or TC rasters having SRFI units) to use as the two input rasters, called SRFIX and SRFIY in the GRUVI script. Most likely, this pair would be a SRFIY raster from one of the near-infrared bands (SRFINA or SRFINB) and a SRFIX raster from a non-near-infrared band (SRFIRL, SRFIGL, SRFIMC, or SRFIBL). But, two TC rasters will also do.
- You probably need to have used DIAG.sml to produce D rasters for the same two selected bands, e.g., DNA and DRL. Estimating the five GRUVI control parameters may be easier with D rasters than with other rasters. These five parameters are related to:
  - The 2-Space Point <u>on</u> the Line of Background Materials (LBM)
  - The Slope of the LBM in 2-Space
  - The 2-Space Point representing vegetation or some other kind of foreground materials
- If you plan to optimize the output of GRUVI.sml, you <u>must</u> extract a small Test Raster set, called SRFIXT and SRFIYT, from the selected SRFIX and SRFIY rasters before you run GRUVI.sml. GRUVI.sml uses SRFIXT and SRFIYT to find the optimal value of the Background Noise Parameter**,** bnp, i.e., the value of bnp that minimizes the coefficient of variation within the Test Raster set.
- You can, of course, choose to run GRUVI.sml with nominal control parameters and without the bnp optimization routine; however, the results will not be optimal and will likely be like one of the classic Vegetation Indices (VIs) that may be available as TNTmips menu-driven options. GRUVI.sml does allow you to select a set of control parameters that produce some classic or transformed VIs that are not currently in the TNTmips menu selections.

On Pages 5 and 6, you will find GRUVI Workflow & Control Parameters Forms that you can use to prepare for running GRUVI.sml. The sample entries in this form apply only to QuickBird MS SRFI data for Yuma, CO, collected on July 2, 2003. These are not default or generic values that you may use for any scene.

GRUVI Workflow & Control Parameters Form

Use with **REPAIR_RASTER**.sml, **SRFI**.sml, **DIAG**.sml, **TERCOR**.sml, and **GRUVI**.sml.

SAMPLE FORM: Completion Date: 04/26/05

INFO ITEM:	Value	INFO ITEM:	Value	INFO ITEM:	Value
Site Name:	Yuma, CO	Date Code:	20030702	Sun Elevation Angle (deg):	65.34
Imager Name:	QuickBird	Imager Number:	1	Correction Level:	3
hep:	80	msfac:	1.000	icRL:	1.34
Processing Date:	N/A	Product Source Code:	N/A	Gain Code:	N/A
Soil Search PVI Width:	100	Soil Search PBI Max:	1100	Veg Search PVI Min:	1300
Pure Soil Pixel SD Max:	14	Pure Veg Pixel SD Max:	23	Pure Pixel Box Size:	5
Skylight Fraction for GL Band fGL:	0.40	Sun Azimuth Angle (deg):	128.0	Viewing Angle: Off-Nadir Angle (deg):	25.0
Target Azimuth Angle (deg):	207.0	SRFIX Raster:	SRFIRL	SRFIY Raster:	SRFINA
Transformation Option:	Yes	Foreground Materials Point Xf:	305	Foreground Materials Point Yf	3551
Line of Background Materials Slope:	1.0387	Background Materials Point Xb:	1681	Background Materials Point Yb:	2080
Extracted Test Area Available:	Yes	Background Noise Parameter bnp:	0.96	Analyst's Name:	Jack Paris
Comments:	In this case, GRUVI was customized to minimize the effects of wet soil due to irrigation in the agricultural fields.				

GRUVI Workflow & Control Parameters Form

Use with **REPAIR_RASTER**.sml, **SRFI**.sml, **DIAG**.sml, **TERCOR**.sml, and **GRUVI**.sml.

BLANK FORM: Completion Date:

INFO ITEM:	Value	INFO ITEM:	Value	INFO ITEM:	Value
Site Name:		**Date Code:**		**Sun Elevation Angle (deg):**	
Imager Name:		**Imager Number:**		**Correction Level:**	
hep:		**msfac:**		**icRL:**	
Processing Date:		**Product Source Code:**		**Gain Code:**	
Soil Search PVI Width:		**Soil Search PBI Max:**		**Veg Search PVI Min:**	
Pure Soil Pixel SD Max:		**Pure Veg Pixel SD Max:**		**Pure Pixel Box Size:**	
Skylight Fraction for GL Band fGL:		**Sun Azimuth Angle (deg):**		**Viewing Angle: Off-Nadir Angle (deg):**	
Target Azimuth Angle (deg):		**SRFIX Raster:**		**SRFIY Raster:**	
Transformation Option:		**Foreground Materials Point Xv:**		**Foreground Materials Point Yv**	
Line of Background Materials Slope:		**Background Materials Point Xb:**		**Background Materials Point Yb:**	
Extracted Test Area Available:		**Background Noise Parameter bnp:**		**Analyst's Name:**	
Comments:					

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

- **CONSOLE-WINDOW ADJUSTMENT:** Use your mouse to adjust the size and placement of the Console Window. You need to be able to view its contents as the script runs and prints data to it.
- **SRFI TRANSFORMATION OPTION:** If you want to produce a Classic VI, answer **No**. Otherwise, answer **Yes**. But, if you answer Yes, you need to have already analyzed the input data to determine key biophysical parameters (listed below and in the **GRUVI FORM** above). The rest of the items here (below) assume that you have answered **Yes** to this question.
- **DENSE VEGETATION POINT: Xv or Xf:** Input the **value associated with dense vegetation** (or **foreground materials**) for the **"X"** raster**.** This comes from **your analysis of the data** in a **2-Space Raster Correlation** plot**.**
- **DENSE VEGETATION POINT: Yv or Yf:** Input the **value associated with dense vegetation** (or **foreground materials**) for the **"Y"** raster**.** This comes from **your analysis of the data** in a **2-Space Raster Correlation** plot**.**
- **LINE OF BACKGROUND MATERIALS SLOPE: slope:** Input the **slope associated** with the **Line of Background Materials.** This comes from **your analysis of the data** in a **2-Space Raster Correlation** plot where you used the **Equation Line**.
- **BACKGROUND MATERIALS POINT: Xb:** Input the **value associated with background materials** for the **"X"** raster**.** This comes from **your analysis of the data** in a **2-Space Raster Correlation** plot**.**
- **BACKGROUND MATERIALS POINT: Yb:** Input the **SRFI value associated with background materials** for the **"Y"** raster**.** This comes from **your analysis of the data** in a **2-Space Raster Correlation** plot**.**
- **BACKGROUND NOISE PARAMETER (bnp) OPTIMIZATION OPTION:** If you have extracted a small test area for this purpose, answer **Yes**. Otherwise, answer **No**.
- **BACKGROUND NOISE PARAMETER (bnp) ENTRY:** Either **accept** the **default bnp** value (from the last step). Or, **override** the default with your own **bnp** value, e.g., **1.0**.
- **SRFIX and SRFIY RASTERS** are **full-sized input rasters** (not test rasters).
- **GRUVI and GRUBI RASTERS** are **full-sized output rasters**. Put them in a **new Project File** (.rvc File).
- **The program runs to completion. Make a note of the type of GRUVI raster set produced in the COMMENTS in the GRUVI FORM.**
- **You may want to use the Right-Button option called Save as… to save the contents of the Console Window to a txt file.**

E1. Why Convert DNs to SRFIs?

Almost without exception, every Classic Vegetation Index (VI) algorithm is based on a pair of selected MS image rasters. In most cases, this pair is a near-infrared (NR) band image (NA or NB) *and* a visible-band image (RL or GL). If available, the second image may be one of the middle-infrared bands (MB, MC, …, MG). Most VI algorithms operate in a 2-Space context (see *A19* and *A20* for details about 2-Space and transformations from one 2-Space context to another 2-Space context).

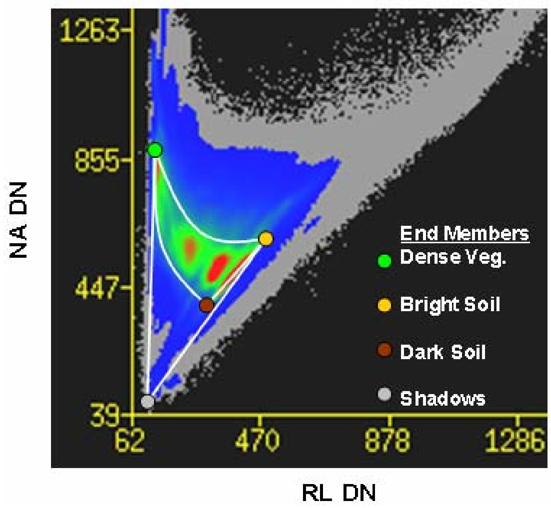
If you want VI data to be consistent from one date to another date and/or from one imager to another imager, the algorithms must use calibrated reflectance-factor based estimates. SRFI.sml produces calibrated SRFI data. SRFI data can be improved by TERCOR.sml or TASCAP.sml. Since the outputs from these scripts are rasters that have SRFI units, you can use them as inputs to GRUVI.sml. In fact, if the terrain is not level, you should also run TERCOR.sml before using GRUVI.sml. In most cases, you would also use DIAG.sml to produce D rasters that you can use to extract key parameters that GRUVI.sml needs as the basis for 2-Space Translation (T) and Rotation (R) transformations (see *A20*).

Warning: If you apply VI algorithms to uncalibrated DNs, e.g., NA vs. RL, the resulting numeric values will also be uncalibrated. This is a fact that seems to be poorly understood in the remote-sensing *user* community. Every software package has one or more VI tools that users can apply to uncalibrated DNs that they get from image-data providers. But, a VI algorithm is not a magic, mystical process that somehow allows you to skip the data calibration step. SRFI.sml and its associated scripts are available to you to use ***before*** you apply any VI algorithm, GRUVI included, to the resulting SRFI rasters.

Consider a 2-Space plot that involves the uncalibrated DNs from a NA raster versus the DNs from a RL raster. The sample data set for this consideration is a portion of QuickBird MS scene that was collected over Yuma, CO, on July 2, 2003. This data set is the same one used for illustrations about SRFI.sml (see *B*).

This sample set is used extensively throughout this tutorial.

*Figure E1A. **2-Space** Plot of **NA DN** vs. **RL DN** for a QuickBird MS Image of Yuma, CO, July 2, 2003.*

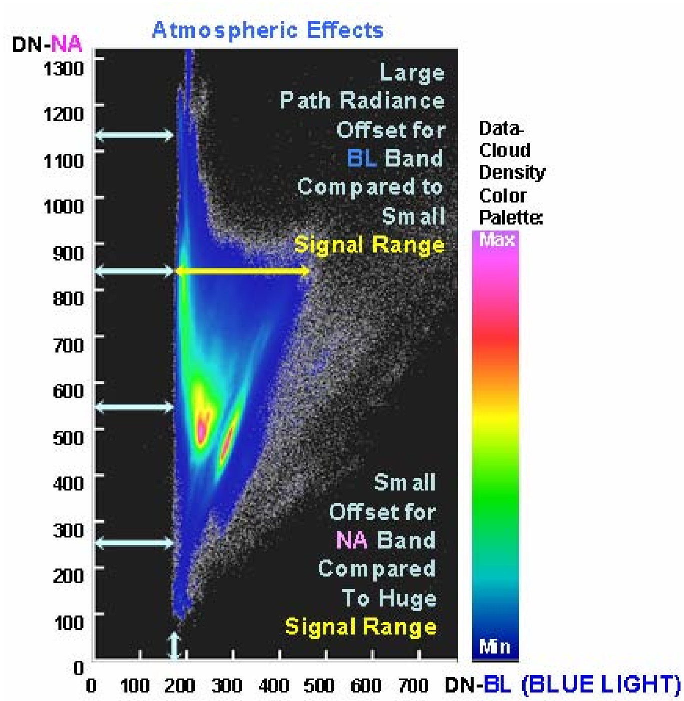


The four colored circles indicate the locations of pure spectral end members. Dense Vegetation is the green circle; Bright Soil, the yellow circle; Dark Soil, brown circle; and Shadows, the gray circle. The curved triangle, outlined by white lines, is called the Tasseled Cap (TC). White lines extend also from the TC area to the Shadow point. The overall area in the white lines shows where mixing among these four types of pure spectra can produce a mixed spectral property for a given pixel.

The line connecting the Dark Soil point to the Bright Soil point defines a Line of Background Materials (LBM) related to bare soils. Some Dense Vegetation pixels extend beyond the indicated Dense-Vegetation point to very high values of NA DN (while RL DN values remain low). Open water is very dark in the NA band and moderately dark in the RL band. Manmade materials tend to be very bright in both bands (tending toward the upper right).

Image pixels on the line between the Dark Soil point and the Bright Soil point are likely to be bare soil. Dense Vegetation pixels are likely to plot out near or above the Dense Vegetation point.

*Figure E1B. **2-Space** Plot of **DN NA** vs. **DN BL** for a QuickBird MS Image of Yuma, CO, July 2, 2003.*

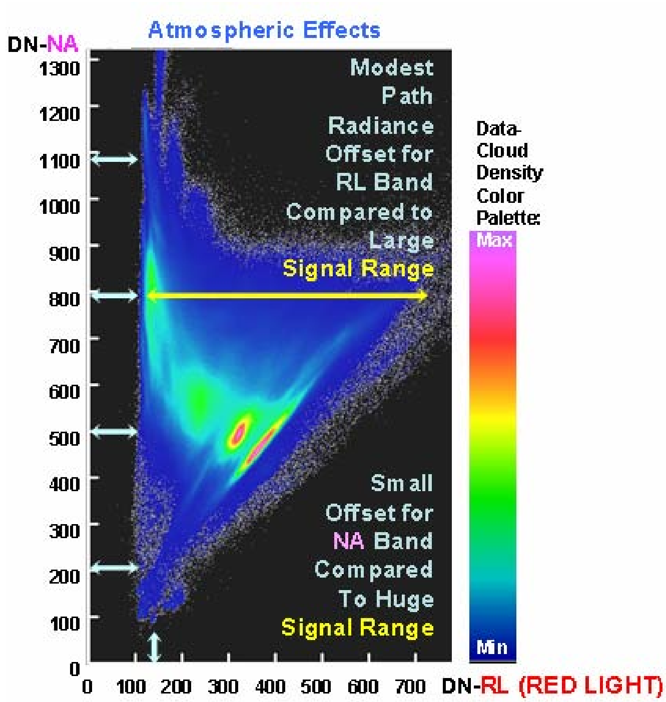


This 2-Space plot is not exactly what you see when you use the **TNTmips** Raster Correlation tool. The author created this plot with a special SML script. Being zero based on both axes, this plot shows better the fact that atmospheric reflectance (Path Radiance) creates a significant offset, in the BL band. In this band, the scene's Signal Range is only about twice the Path Radiance Offset range. In addition, the scales of the two 2-Space axes are unequal.

Thus, this 2-Space plot, which involves image DNs, is distorted and uncalibrated.

A similar situation exists for the 2-Space defined by DN NA vs. DN RL (see *Figure E1C* on the next page).

*Figure E1C. **2-Space** Plot of **DN NA** vs. **DN RL** for a QuickBird MS Image of Yuma, CO, July 2, 2003.*



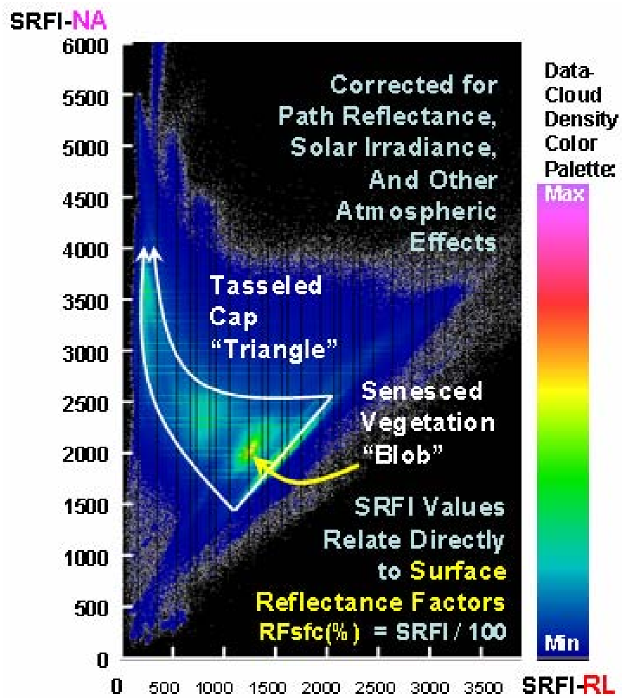
The Path Radiance Offset (related to atmospheric reflectance) for the RL band is much smaller than the Signal Range. The highest density of data-cloud points are indicated by reddish colors. One feature that stands out is an elongated cluster of points related to bare soil pixels. This feature is close a line, called the Line of Background Materials (LBM), that is near the diagonal of the plot, i.e., where DNNA = DNRL. LBM has a slope of 1.25. If the **NA** scale were reduced, the slope might be 1.00. And, LBM might intersect at DNNA = 0.

In the early history of Vegetation Index (VI) algorithm development, simple empirical equations were devised to combine DNRL data and DNNA data into a single numeric indicator (index) of the relative density of vegetation in each image pixel. The most famous empirical VI is the Normalized Difference Vegetation Index (NDVI). In terms of uncalibrated DN values,

$$\mathbf{NDVI = (DNNA - DNRL) / (DNNA + DNRL)} \qquad \textbf{(E1A)}$$

Lines of constant NDVI (called isoveg lines) radiate the origin of the related 2-Space, i.e., from the point where DNNA and DNRL are both 0. Fortuitously, one of these isoveg lines runs close to LBM. In this case, the corresponding uncalibrated NDVI value is about 0.1111. At the tip of the Tasseled Cap distribution (see *Figure E1A*), the uncalibrated NDVI value is about 0.8000.

*Figure E1D. **2-Space** Plot of **SRFINA** vs. **SRFRL** for a QuickBird MS Image of Yuma, CO, July 2, 2003.*



Converting DNs to SRFI values adds value by:

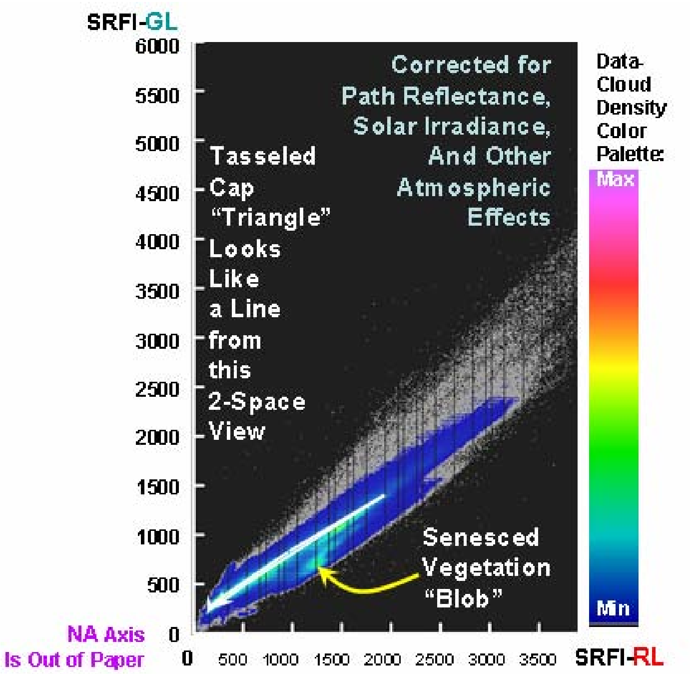
- Correcting the data for atmospheric reflectance effects (path reflectance effects)
- Correcting the data for sun elevation angle effects, and
- Correcting the data for atmospheric transmission loss effects.

The Tasseled Cap feature is still present in this SRFI-related 2-Space plot.

But, now the LBM and the Dense Vegetation Point have been moved to locations defined by calibrated SRFI values. The calibrated NDVI values, based on calibrated SRFI values, are now are 0.1076 for bare soil and 0.8471 the selected Dense Vegetation.

The use of a physically-based VI, such as the Soil Adjusted Vegetation Index (SAVI, see *A20*) or GRUVI, requires that the input data have calibrated reflectance-factor related units (like SRFI). Otherwise, the resulting VI values are unpredictable and have no physical relationship to biophysical variables in the vegetation being assessed.

*Figure E1E. **2-Space** Plot of **SRFIGL** vs. **SRFRL** for a QuickBird MS Image of Yuma, CO, July 2, 2003.*



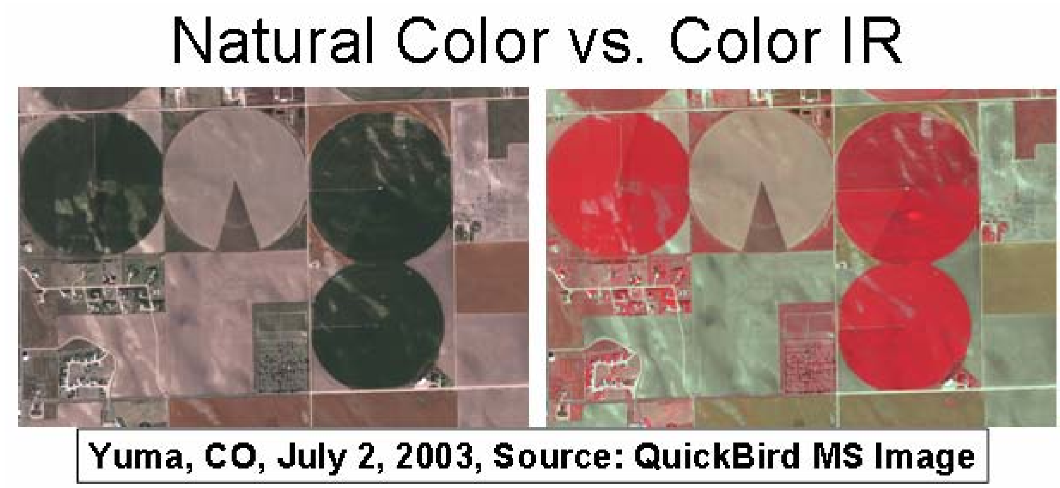
This 2-Space plot of SRFIGL vs. SRFIRL shows that the Tasseled Cap triangle appears to be a single line; however, this view is across the edge of the TC distribution. A benefit of this view is that a Senesced Vegetation "blob" is now seen as being a separate cluster that is not located within the domain of the TC triangle.

Thus, it is possible to construct a special GRUVI product that focuses on senescent vegetation in a way that is not confused by the presence of mixtures of emerged green vegetation and background soils of variable brightness.

E2. Is There an Example of GRUVI Compares to other VIs?

Consider the extracted image of an agricultural area near Yuma, CO, as shown in Figure E2A.

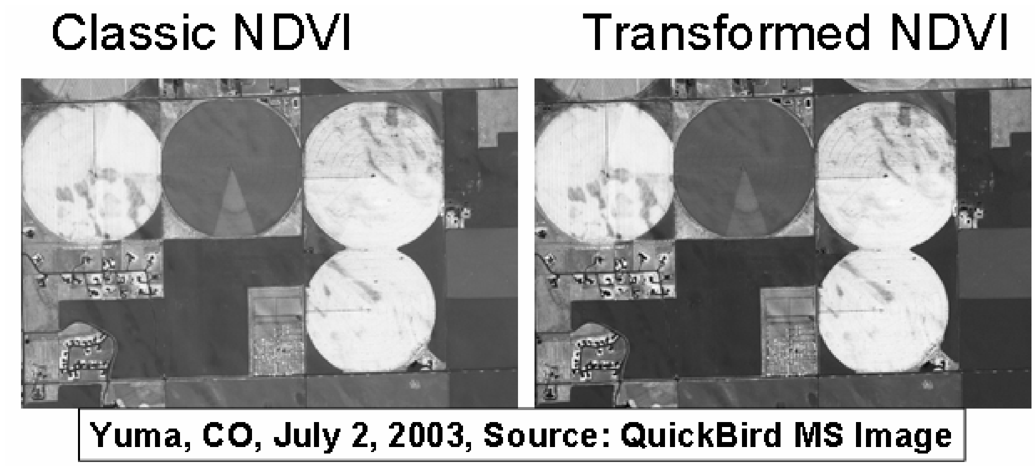
Figure E2A. Natural Color and Color IR Images of Yuma, CO, on July 2, 2003, Based on QuickBird MS.



There are four center-pivot irrigated fields in this extracted scene. All of them are being affected by variations in surface soil brightness caused by the irrigation system. Wet plants also contribute to this effect. The effect of plant and soil wetness is most obvious in the south part of the top center circular field. The other three circular fields are corn fields near maximum biomass density. Variations in these fields are due to both wetness and biomass density. Some patches in these fields have poor soil, especially in the northern half of the upper right corn field. Residential areas, a cemetery, and other crops are also in this image (square and rectangular fields).

In general, it is difficult, if not impossible, to manually analyze these standard color images for the purpose of mapping out biomass density patterns in the presence of soil-wetness "noise." VIs are designed to address this dilemma by providing a single indicator of biomass density that is not affected by soil-brightness / wetness "noise."

Figure E2B. Classic NDVI and Transformed NDVI Maps of Yuma, CO, on July 2, 2003, Based on QuickBird MS.

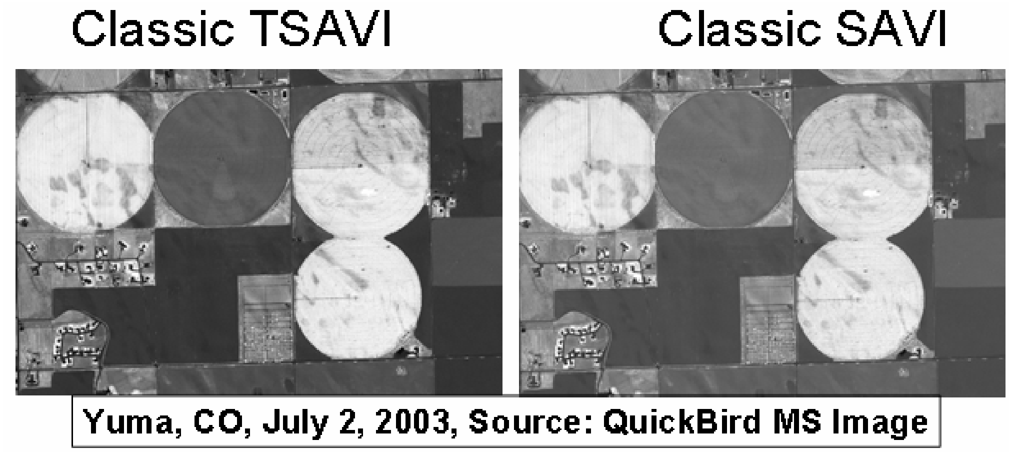


Classic NDVI is based on non-transformed values of SRFIRL and SRFINA. Thus, the Line of Background Materials (LBM) is not located on the line where SRFINA = SRFIRL. As a result, the SRFINA values are disproportionately higher than the SRFIRL values along the LBS. This causes the NDVI value to increase as the soil wetness (soil brightness) decreases. This is a significant noise effect that makes the wet part of the field appear to have a higher biomass density than it actually has.

An R and T transformation of the SRFINA and SRFIRL values moves the LBM to a position where Transformed SRFINA = Transformed SRFIRL. While this kind of transformation makes the Transformed NDVI have a zero (and constant) value for bare pixels, whether wet or dry, there still remains a significant effect of soil wetness in fields that are partly vegetated, e.g., the top center center-pivot field. The problem with the NDVI algorithm is that it produces isovegetation lines that are not parallel to the effects of soil wetness.

Huete (1988) addressed this basic defect in the NDVI algorithm by developing the Soil Adjusted Vegetation Index (SAVI). Baret (1989) modified SAVI to allow for the actual location of the LBM in a 2-Space plot of NR reflectance vs. RL reflectance. This modified version is called the Transformed SAVI (TSAVI). Other variations on SAVI and TSAVI are defined at the following Web site: http://www.yale.edu/ceo/Documentation/rsvegfaq.html

Figure E2C. Classic TSAVI and Classic SAVI Maps of Yuma, CO, on July 2, 2003, Based on QuickBird MS.



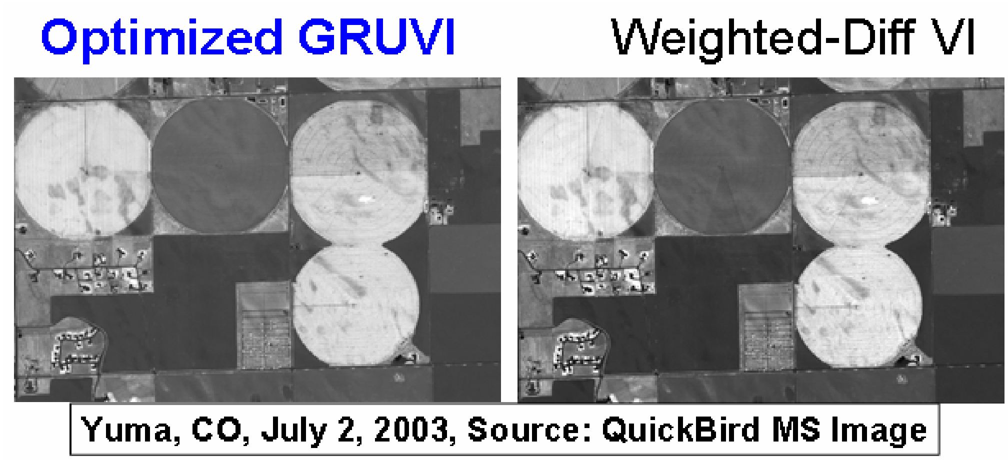
Both TSAVI and SAVI use formulas similar to NDVI. TSAVI involves a coordinate stretch transformation of the RL reflectance axis *and* a translation shift of the NR reflectance axis. While this transformation moves the LBM to a desired diagonal position in the transformed 2-Space, this kind of transformation causes a scale change in the 2-Space.

SAVI uses a SAVI soil noise parameter, L, which has a fixed value of 0.5. This is often too low for many cases. And, the axes of NR reflectance vs. RL reflectance are not transformed in the SAVI algorithm.

A way to view SAVI and TSAVI is that fixed displacement reflectance values are added equally to both the NR and RL reflectances before a NDVI-like formula is applied to the displaced (translated) data. The displacement is 0.25 (25% reflectance) for the NR data and 0.25 (25% reflectance) for the RL data. The total of these two displacements is equal to 0.5, which expressed as the SAVI L factor. In the case of TSAVI, the displacement depends on the LBS slope and the LBS NR intercept. A typical value of these LBS parameters leads to an effective value of L = 0.15. This is way too low for many cases.

A careful examination of *Figure E2C* shows that a small, but significant effect of soil wetness still exists in the top center pivot-irrigation field.

Figure E2D. Optimized GRUVI and Weighted-Difference VI Maps of Yuma, CO, on July 2, 2003, Based on QuickBird MS.

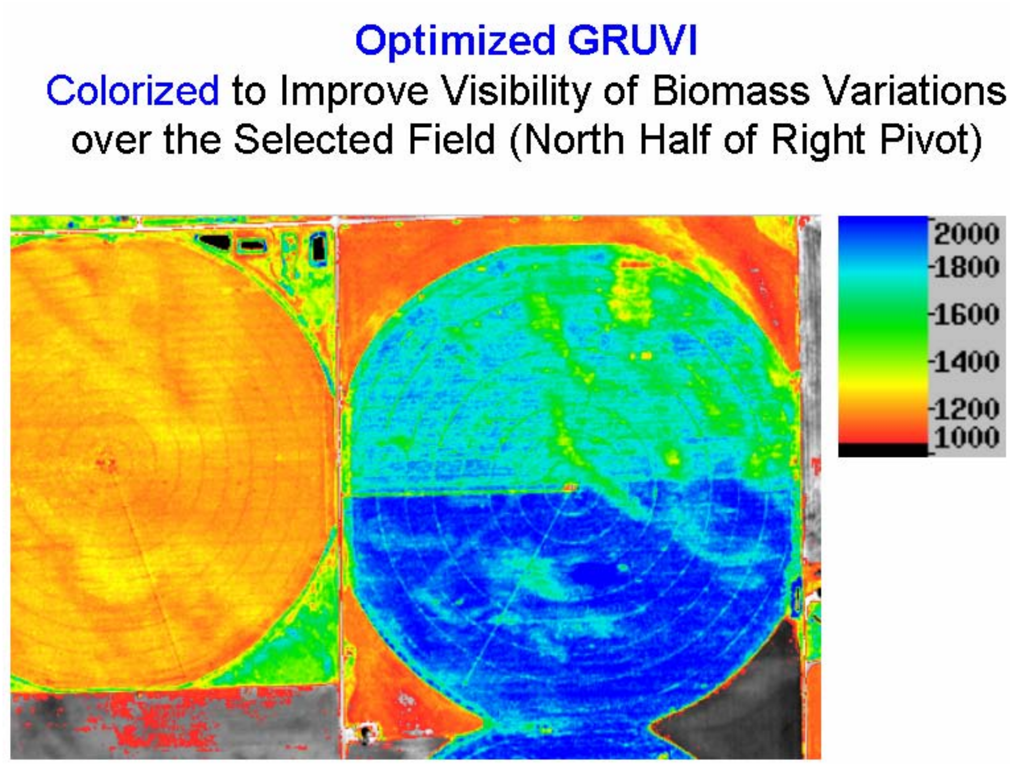


GRUVI addresses the flaws of NDVI, Transformed NDVI, SAVI, and TSAVI by first performing a translation (T) and rotation (R) transformation to SRFI values before applying a SAVI-type formula with a value of L that is optimized for the scene being analyzed. The T and R transformation preserves the SRFI scale of the input data (see *A20*); the RL scale expansion of all of the other classic transformed VIs does not preserve the scale of the input data. In addition, GRUVI determines the optimal value for its background noise parameter, bnp, through a process of optimization using a test area in the image being analyzed. bnp plays a role similar to L in the SAVI algorithm. In the case of the map above, the optimized bnp value was 0.96 (as opposed to the value of L = 0.5 or = 0.15). If the slope of the LBS and its NR intercept change, bnp changes also.

The Weighted Difference VI (WDVI) is a perpendicular-type VI. Effectively, if bnp is allow to take on a very large value, e.g., 20.00, the isovegetation lines become parallel to the LBS – a primary main characteristic of all perpendicular type VIs. Clearly, this value of bnp is not optimal. The effects of soil wetness are over-corrected in the WDVI image, i.e., the vegetation biomass density is underestimated.

The best of all of the VIs is the Optimized GRUVI. A full-resolution, colorized map of Optimized GRUVI is shown on the next page in *Figure E2E*.

Figure E2E. Optimized GRUVI, with Color Scale Enhancement, for Yuma, CO, Based on QuickBird MS collected on July 2, 2003.



This close-up and colorized map product shows that the effects of wet soil are completely removed by the optimization process available in the GRUVI algorithm.

In addition, the algorithm produces a VI map that has extended sensitivity to higher levels of biomass density. The top half of the right-hand pivot field is an R&D field that was receiving variable amounts of nitrogen applications. There are also poor soils in this half (due to iron chlorosis). The red patch in this field was a plot of corn that received no nitrogen application (as a control).

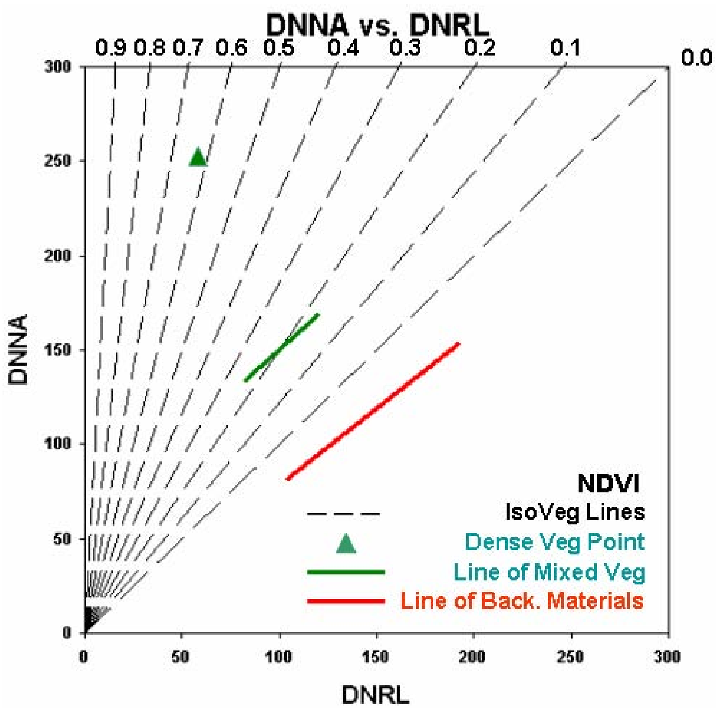
E3. How Does GRUVI Optimize the Structure of 2-Space?

While the maps above show that the Translation (T) and Rotation (R) operations associated with GRUVI.sml seem to produce an optimized Vegetation Index (VI) map, it may still not be clear why this happens. This FAQ "answer" should make this clearer.

Let's start with structure of the usual 2-Space that involves the NA and RL bands (as Y and X data). This time, plots of 2-Space will be shown in a sequence from the original DNs to the final optimized transformed SRFI values.

Suppose that you have an image set consisting of 8-bit unsigned integers, e.g., from a Landsat 5 TM image. A plot of 2-Space might look like *Figure E3A*:

Figure E3A: Hypothetical NA vs. RL 2-Space for Image DNs.



The range of DNs runs potentially from 0 to 255 for each axis. Three biophysical features are shown in this figure:

- Line of Background Materials, LBM (the red line)
- Line of Mixed Vegetation and Soils, LMVS (the green line)
- Dense Vegetation Point, DVP (the green triangle)

From place to place, the actual locations of these three biophysical features (LBM, LMVS, and DVP) will change due to differences in soil type, degree of mixing between vegetation and soil, and type of vegetation. When DNs are used to define a 2-Space plot, many other effects are involved including the gain of the sensor, the sun elevation angle, the atmospheric conditions, and terrain conditions.

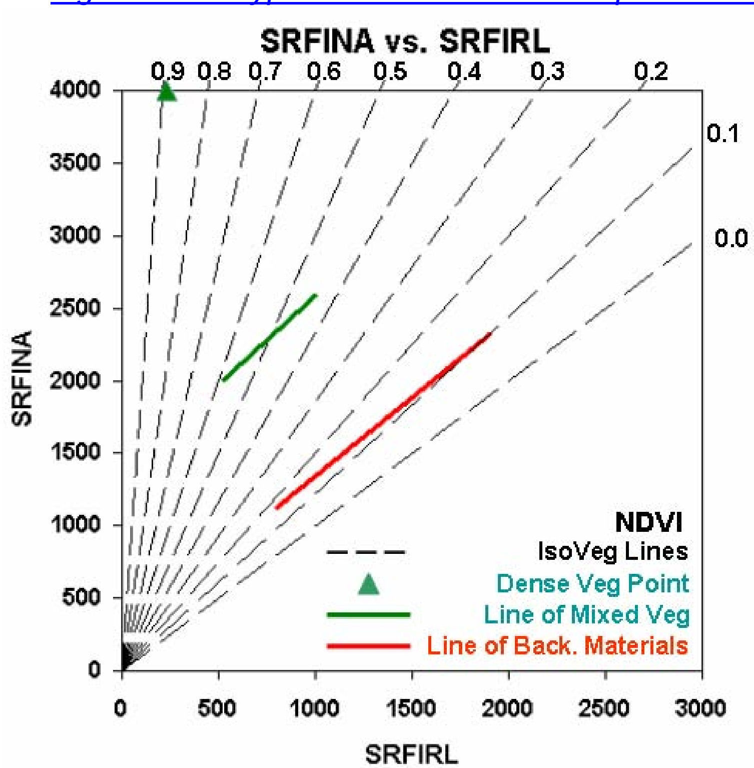
An image DN is an arbitrary brightness scale that varies from one spectral band to another spectral band and that does not, without conversion to reflectance, relate to any physical property.

Often, an analyst will apply the NDVI algorithm to DNs perhaps with the vague (and unfounded) hope that it somehow deals successfully with the uncalibrated nature of DN data.

The dashed lines show lines of constant NDVI values in this uncalibrated 2-Space. The value of NDVI along each dashed line is denoted at the upper end of each line by a number, such as 0.0, 0.1, … or , 0.9. These dashed lines are called isovegetation lines since NDVI (an indicator of vegetation amount) is constant (iso) for all locations in 2-Space *on* each isovegetation / NDVI line. Since it is common practice to use only positive values of NDVI for an output NDVI product raster, no isovegetation lines are shown for negative values of NDVI. Thus, all of the pixels that plot on or near the LBM (bare soil pixels and some sparely-vegetated pixels above it) would have a NDVI value of 0.0 in an output raster. This explains why some analysts have said that they cannot detect small amounts of emergent vegetation in a NDVI map that is based on uncalibrated DNs. Vegetation has to "grow" for a while for it to reach the isovegetation line associated with NDVI = 0.0.

The difficulties associated with a 2-Space plot based on DNs is somewhat resolved when the DNs are converted to reflectance units, e.g., to SRFI values (say with SRFI.sml).

Figure E3B: Hypothetical NA vs. RL 2-Space for SRFI Values.

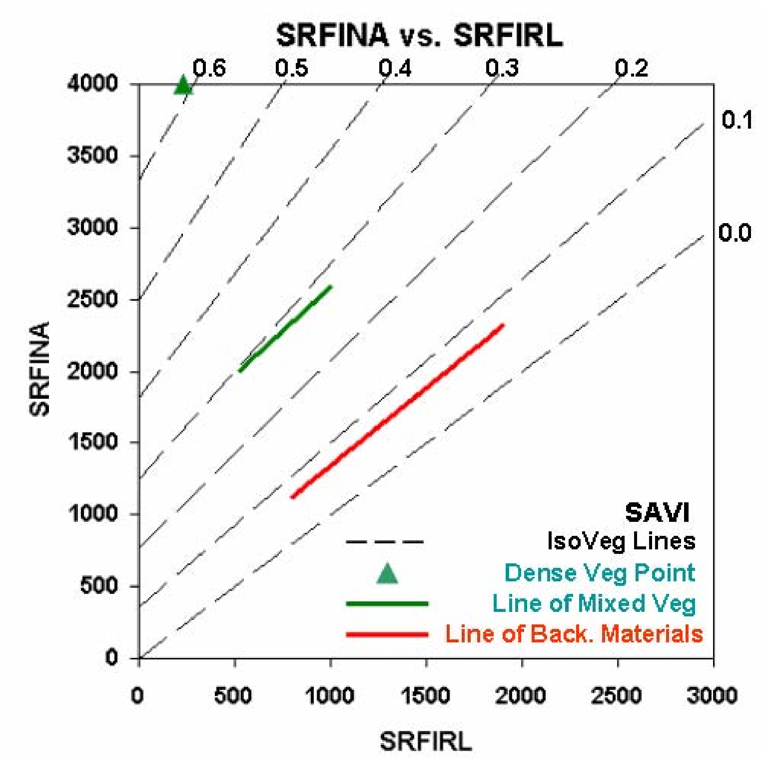


In a SRFI-based 2-Space plot like this, all three biophysical features (LBM, LMVS, and DVP) are in the domain of positive values of NDVI. But, the LBM and the LMVP do not run parallel to the NDVI isovegetation lines. And, the location of the LBM is not near the isovegetation line where NDVI = 0.

It would make more sense to have a VI be equal to zero where no vegetation exists, i.e., along the LBM. And, it would be desirable that variations in the brightness of mixed vegetation and soils have a constant value for the associated VI. Therefore, it is obvious that NDVI, even based on SRFI values, still suffers from noise caused by variations in soil brightness (both for bare soil and for a mixture of foreground vegetation and background vegetation).

The Classic SAVI algorithm simply moves the convergence point of the isovegetation lines from (SRFIRL = 0 and SRFINA = 0) to SRFIRL = -2500 and SRFINA = -2500). This equal translation of the two SRFI axes is controlled by the L factor in the SAVI equation.

Figure E3C: Hypothetical NA vs. RL 2-Space for SRFI Values with Isovegetation Lines Associated with the Classic SAVI Algorithm.

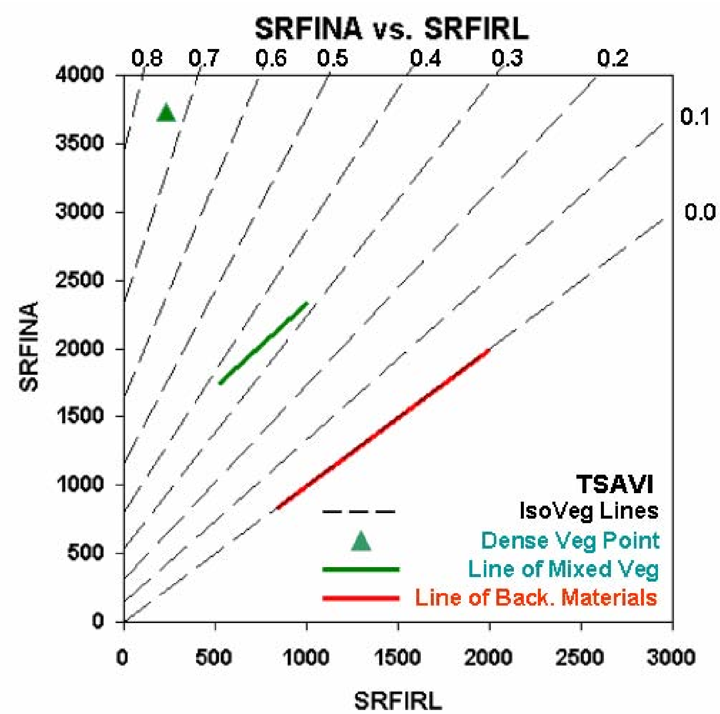


This change has improved the alignment of the resulting SAVI isovegetation lines with the LBM and LMVS. But, the alignment is not perfect. And, the BLM is still located on an isovegetation line where SAVI is not equal to 0.

One way to fix the problem of NDVI values or SAVI values not being zero on the LBM is to transform the SRFI values by first performing a Translation offset equal to the intercept of the LBM on the SRFINA axis and second by performing a Rotation that aligns the VI = 0 isovegetation line with the LBM (where bare-soil pixels are found).

Figure E3D (next page) shows the results of this T and R transformation for an algorithm called TSAVI. The L factor for TSAVI is only about 0.15 (rather than 0.5 as it was for SAVI).

Figure E3D: Hypothetical NA vs. RL 2-Space for SRFI Values with Isovegetation Lines Associated with the Classic TSAVI Algorithm.



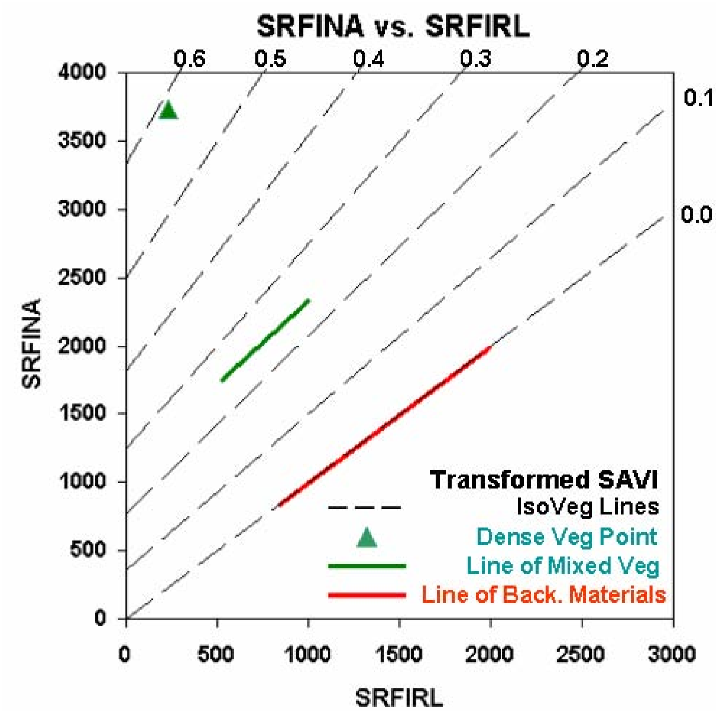
While the transformation associated with TSAVI fixed the alignment problem for the LBM, it did not fix the alignment problem for the LMVS.

The obvious problem lies with the location of the convergence point associated with Classic TSAVI, SRFIRL = -750 and SRFINA = -750. This convergence point is too close to (0,0) to flatten out the slopes of the isovegetation lines in this T & R transformed 2-Space.

This suggests that SAVI's larger L-factor (0.5) might work better with the transformed SRFI axes. This idea is used for the Transformed SAVI data in *Figure E3E*. Note that this Transformed SAVI is not the same as TSAVI.

The Transformed SAVI benefits from the fact that it includes a scale-preserving T & R transformation and the more optimum value for L, which is 0.5.

Figure E3E: Hypothetical NA vs. RL 2-Space for SRFI Values with Isovegetation Lines Associated with a Transformed SAVI Algorithm.

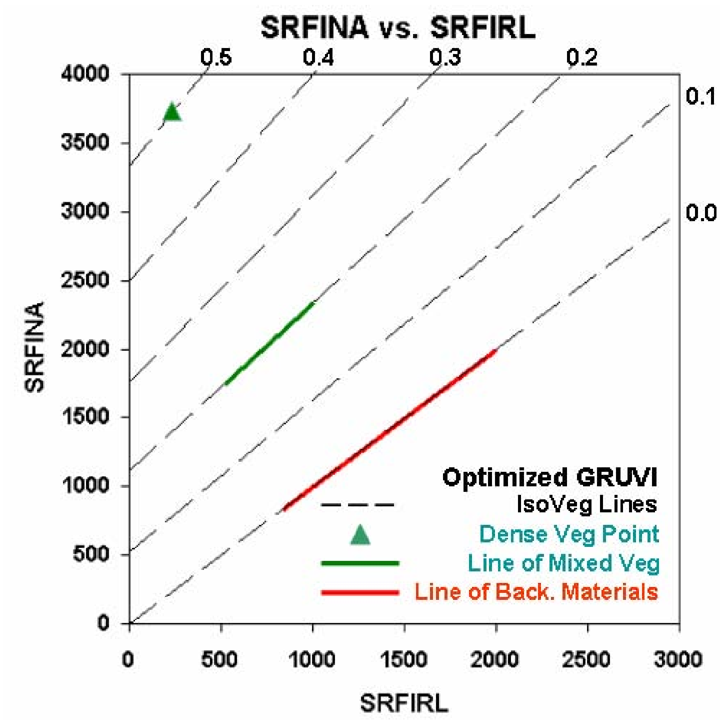


This non-classic SAVI is an improvement over all of the foregoing VIs. It puts the LBM on isovegetation line where Transformed SAVI = 0. And, it has a good alignment for the LMVS, better than TSAVI or Classic SAVI.

The isovegetation lines for this Transformed SAVI are the same as they are for the GRUVI algorithm with a Background Noise Parameter, bnp, of 0.5.

GRUVI.sml has a routine that optimizes the bnp based on a Test Area where the effect of background noise is very evident for a partly-vegetated field (like the green line in this 2-Space plot). For this hypothetical data set, the optimized value of bmp turns out to be 1.0. Figure E3F (next page) shows the results of using bnp = 1.0, rather than bnp = 0.5 (as in Figure E3E).

Figure E3F: Hypothetical NA vs. RL 2-Space for SRFI Values with Isovegetation Lines Associated with the Optimized GRUVI Algorithm.



As indicated, both the LBM and the LMVS features are perfectly aligned with the isovegetation lines from the Optimized GRUVI (where bnp = 1.0).

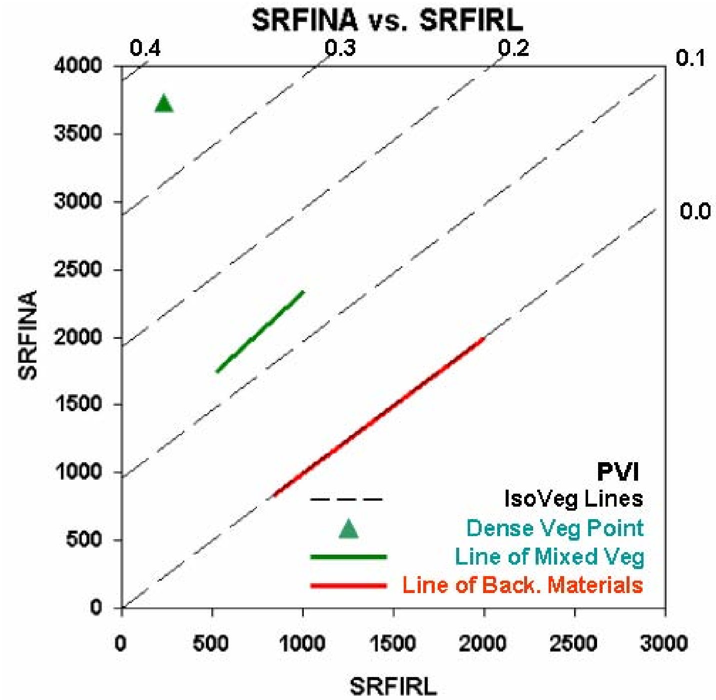
The isovegetation lines here converge to a point where SRFIRL = -5000 and SRFINA = -5000. These negative offsets are each equal to minus bnp * 5000.

As bnp is allowed to increase to large values, say up to 20.0, the isovegetation lines become parallel to each other and to the LBM. This property is characteristic of the Perpendicular Vegetation Index (PVI) as shown in *Figure E3G* (next page).

This initial floating-point value of the Optimized GRUVI is rescaled so that the Dense Vegetation Point has a final GRUVI value of 2000 and the LBM has a final GRUVI value of 1000. With this rescaling, features that plot out below the LBM will have values of GRUVI between 0 and 1000.

GRUVI.sml also produces a GRUBI raster that has a set of GRUBI isobrightness lines that are perpendicular to the GRUVI isovegetation lines.

Figure E3G: Hypothetical NA vs. RL 2-Space for SRFI Values with Isovegetation Lines Associated with the PVI Algorithm.



Using bnp = 20.0 (the value associated with PVI), the LMVS feature is again poorly aligned to the isovegetation lines.

GRUVI.sml contains a routine that optimizes the value of bnp for each scene based on a selected small Test Area where the effects of background brightness noise on SRFIX and SRFIY are evident (for a partly vegetated field.

Since calibration errors vary from scene to scene and since soil and vegetation structure varies from field to field, there is not a universal value for bnp that is optimal for all situations. GRUVI.sml addresses this reality by optimizing on the scene being analyzed.

E4. How do I Get the GRUVI Control Parameters?

If you elect to optimize the GRUVI algorithm, you must provide five GRUVI control parameters: srfiXb, srfiYb, slope, srfiXv, and srfiYv.

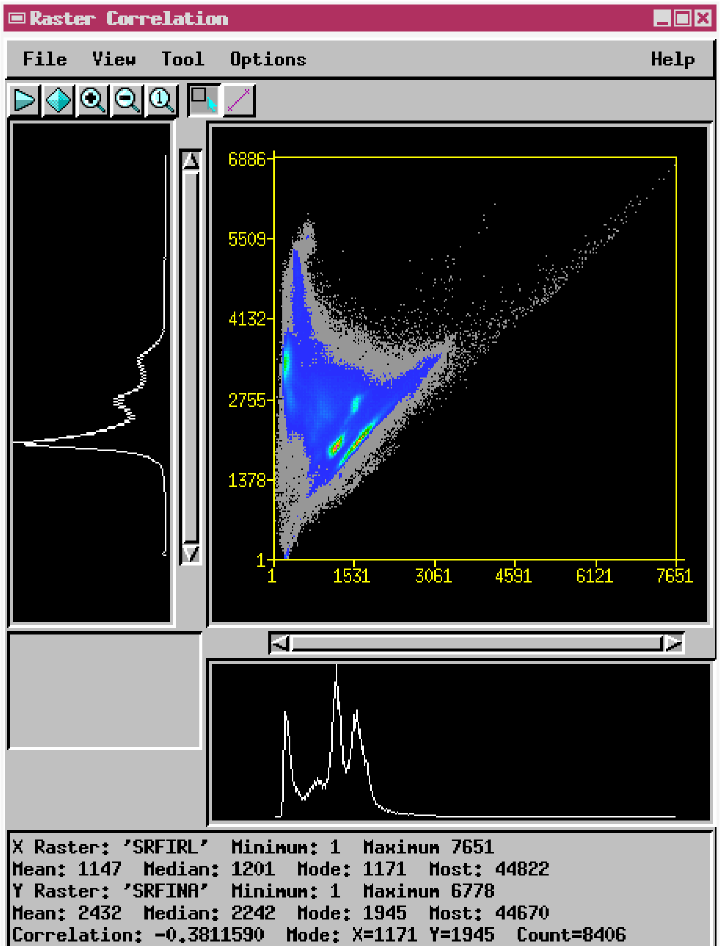
- srfiXb and srfiYb: These are the coordinates of any selected point near the center of the Line of Background Materials (LBM) in the 2-Space defined by a plot of SRFIY vs. SRFIX.
- The slope of the LBM in the 2-Space defined by a plot of SRFIY vs. SRFIX.
- srfiXb and srfiYb: These are the coordinates of a cluster of dense vegetation in the 2-Space defined by a plot of SRFIX vs. SRFIY.

All five of these GRUVI control parameters can be estimated by using the TNTmips Raster Correlation tool. Here is the step-by-step procedure for using this tool for this purpose.

From the TNTmips main menu:

- Follow the following menu path: Display > Spatial Data… > New 2D Group. The Group 1 – View 1 and Group 1 – Group Controls windows appear.
- Now Add (a new Single) Raster to Group 1. This should be one of the two SRFI or SRFI type rasters that you will be in the GRUVI process. Suppose that this is the SRFINA raster from the QuickBird scene used above. It will appear in the Group 1 – View 1 window as a grayscale image. An item will appear in the Group 1 – Group Controls window that is related to this single raster.
- Click on the Tools icon associated with the single raster item. Select the Raster Correlation… option. The Raster Correlation window opens with a blank (black) screen.
- Under the File menu, select New. A Select Objects window opens. It needs for you to select a raster to assign to the X Axis and one to assign to the Y Axis. Navigate to the TNTmips Project File (.rvc) that has the SRFI rasters for the scene being analyzed.
- Select an appropriate raster for the X-Axis. For example, you can select the SRFIRL raster or the SRFIGL raster or the SRFIMB raster. This is the raster that is paired up with the SRFINR raster (SRFINA or SRFINB) to define the SRFI-type 2-Space being used as inputs to GRUVI.sml.
- Select an appropriate raster for the Y-Axis. For example, you can select SRFINA or SRFINB. When this selection (when you click OK) is done, TNTmips produces a 2-Space plot of the Y raster vs. the X raster, e.g., SRFINA vs. SRFIRL. You may get a plot that looks like *Figure E3A* (next page). This is a color-coded data-cloud density plot (see *A19*) of the data in this defined 2-Space. The palette of colors used in this figure (and remaining figures) as associated with TNTmips Version 7.1. Prior versions of TNTmips use a standard color palette that is less optimum (compared to Version 7.1) – but still is quite adequate.

Figure E3A. SRFINA vs. SRFIRL 2-Space Plot with Data-Cloud Density Shown by the Default Raster Correlation Color Palette (as of TNTmips Version 7.1).



- The location of the elongated cluster (brown colors) related to the Line of Background Materials (LBM) associated with bare soil can be seen near the brim of the Tasseled Cap feature. If you click the Zoom-In icon, you will be able to see this LBM feature better (see *Figure E3B* on the next page).
- Move your mouse to the center of the LBM feature. The X and Y coordinates for this position will be displayed in the gray area of the plot (lower left). These are the values for the srfiXb and srfiYb parameters needed by GRUVI (when you run this script). In this case, srfiXb = 1681 and srfiYb = 2080.
- Now, move your mouse to the center of the Dense Vegetation feature (See *Figure E3C* on the next page). These are the values for the srfiXv and srfiYv parameters needed by GRUVI (when you run this script). In this case, srfiXb = 305 and srfiYb = 3551.
- To estimate the slope of the LBM, turn on the Equation Line tool by clicking the right-most icon in the Raster Correlation tool above the 2-Space plot. Use your mouse to draw a line in the 2-Space plot area. Then, use the handles at the ends of this Equation Line to position it along the center of the elongated cluster of LBM points. This is shown in *Figure E3D* (on the next page).

Figures E3B (left) and E3C (right). SRFINA vs. SRFIRL 2-Space Plot with Data-Cloud Density Shown by Raster-Correlation Standard Palette (Version 7.1) with Mouse Cursor Pointing to the Center of the Line of Background Materials (left) and to the Dense Vegetation Point (right).

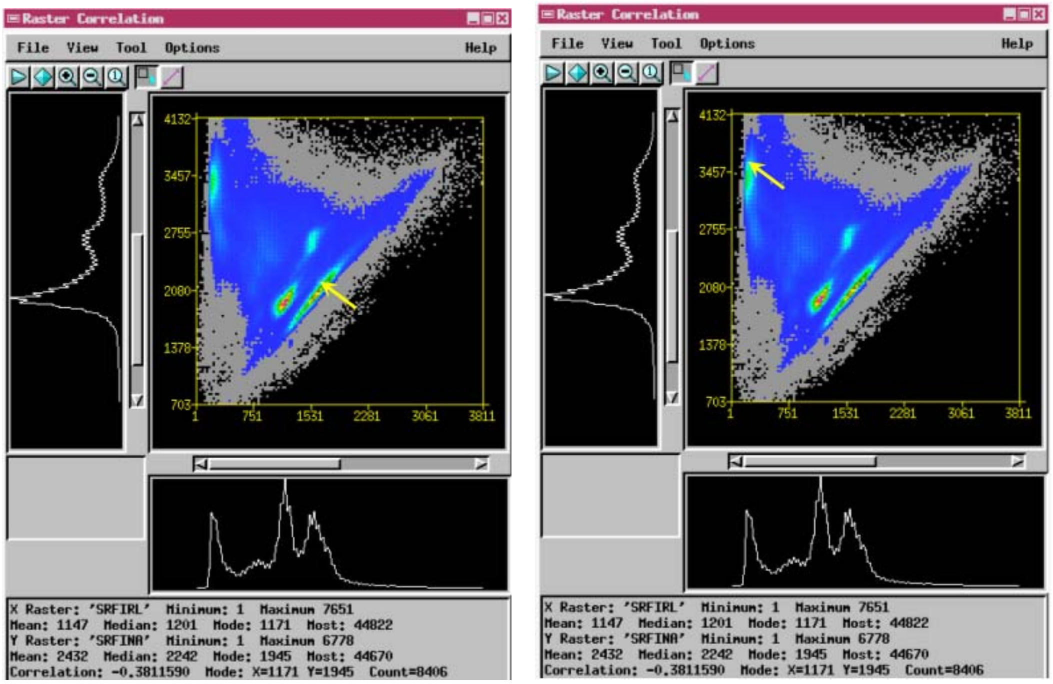
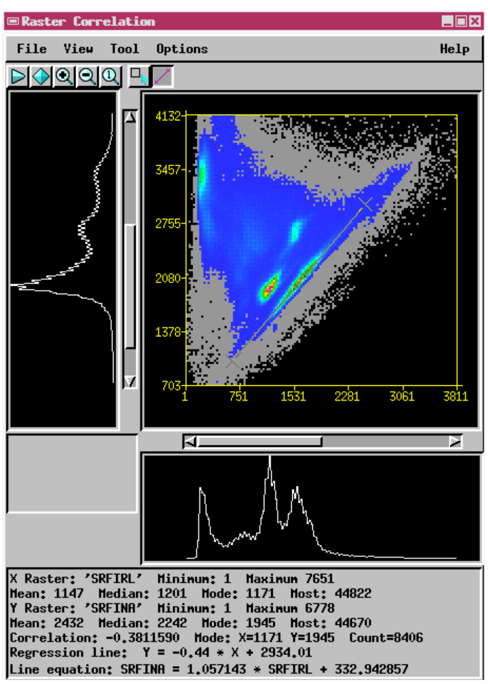


Figure E3D. Using the Equation Line Tool to Estimate the Slope of the LBM in the 2-Space Defined by SRFINA vs. SRFIRL.



The slope of the LBM is reported in the information below the plot as the Line equation: SRFINA = 1.057143 * SRFIRL + 332.942057. So, slope = 1.0571.

With these parameters, you are almost ready to run GRUVI.sml.

See the next FAQ for the final preparation: Extraction of a Test Raster that GRUVI.sml will use for optimization of the GRUVI bnp control parameter.

E4. Where do I get the GRUVI Test Rasters?

You use the Raster Extract tool to extract a small raster set that will be used by GRUVI.sml to optimize the GRUVI bnp control parameter.

Here is how you do this with TNTmips.

From the TNTmips main menu:

- Follow the following menu path: Process > Raster > Extract… . The Select Objects window appears.
- Navigate to the locations of the SRFI rasters that you plan to use as inputs to the GRUVI.sml. For example, you probably would pick two rasters: SRFIRL and SRFINA. If you plan to produce a set of GRUVI & GRUBI rasters for more than one pair of input rasters, go ahead and select all of the available SRFI rasters for the scene being analyzed. When you confirm your selection (by clicking OK), the Raster Extract window appears.
- There are many tabs in the Raster Extract window. You need to examine each to ensure that all of the options are right for the present purpose. Do this in the following order:
  - Rasters tab: Should list the SRFI rasters that you selected for extraction. If not, Exit and re-select the rasters.
  - Map Extents tab: Don't change anything in this tab.
  - Zoom/Orient tab: Zoom Lines by 1.000 and Columns by: 1.000. Rotate: 0.00000 degrees. Method: Nearest Neighbor. Transfer Georeference: Enabled (pushed in).
  - Values tab: Output type: Same as input. Rescale: None. Null Value: Default.
  - Insert tab: All options disabled (not pushed in)
  - Special tab: Pyramid Output: Sample. Copy Metadata: Enabled. Default Raster Names: Polygon Name and Raster Name. Compression: Standard Lossless.
  - Extract tab: Change Select: to Range. When you do this, the Raster Extract Object View and Raster Extract – Layer Manager windows appear. The first raster on your extract list appears in the View window. Zoom into a part of the image that has a vegetated field that is obviously affected by background noise, e.g., a dark wet field. If you are unsure of whether or not the field is vegetated, you can add the PVI image to the Layer Manager and look for PVI values that are intermediate in value between 1000 and 2000. A PVI value of 1000 is for bare soil (no vegetation); you want a field that is partly vegetated.
  - The Range button is pushed in. You next need to pull out a green box with your mouse and reposition it over the wet field. Ideally, you want about half of the green box to be dry (light) and the other half to be wet (dark).

- o Try to avoid parts of the field where the vegetation density is highly variable; you what the main source of variability in the green box to be caused by variations in the brightness of the background materials (in this case, wet soils). You will see something like what is shown in *Figure E4A* below:

Figure E4A. Raster Extract View Window after Selecting a Small Test Area for Extraction. Yuma, CO, SRFIRL Data, July 2, 2003.

- When you are satisfied with the position of the green box, click the Run… button in the Raster Extract window. A Select Objects window appears.
- Navigate to the location of a new Project File. Name that file: Test_Rasters (.rvc). Name the rasters as SRFIXT and SRFIYT (if you have only two extracted rasters); alternatively, use the default names (if you have three or more extracted rasters).

You are now ready to run GRUVI.sml. See the QUICK GUIDE at the beginning of this tutorial to do this (using GRUVI parameters you have put in the BLANK FORM).

E6. Is There an Example of the Use of GRUVI.sml for Non-Vegetation?

Yes. But, this example will be given at the end of *FAQs by Jack F.pdf*, which is the tutorial for TASCAP.sml. This example will address the use of GRUVI.sml to produce a GRUFI raster that relates to open-water pixels in a ASTER image over Stockton, CA (May 9, 2001). TC4 (designed to emphasize water) will be the "Y" raster and TC3 (a collection of non-water materials) will be the "X" raster.

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