A FAQ on Vegetation in Remote Sensing

Written by Terrill W. Ray
Div. of Geological and Planetary Sciences
California Institute of Technology
email: **terrill@mars1.gps.caltech.edu**

Snail Mail: Terrill Ray
Division of Geological and Planetary Sciences
Caltech
Mail Code 170-25, Pasadena, CA 91125

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Revision History:

Version 1.0.	major revision. Discussion of radiance vs. reflectanceadded. Addition of vegetation indices designed to minimize atmospheric noise (GEMI, ARVI, etc.). Addition of SPOT HRV bands. Numerous minor changes. Cautions regarding the use of SAVI, MSAVI, etc. added.
Version 0.7	numerous minor non-substantive typos fixed. Addition of question 14a. Some stylistic and grammatical problems dealt with.
Version 0.6	major typo in TSAVI equation fixed and minor typo in MSAVI2 fixed.
Version 0.5	original version posted

Conventions:

In most cases, reflectance, apparent reflectance and radiance can be used interchangeably in this FAQ. (But see question #5 for some important considerations about this.)

Wavelengths are given in nanometers (nm). The "origin" is the point of zero red reflectance and zero near-infrared reflectance.

The abbreviation SPOT refers to the Systeme Pour l'Observation de la Terre which has five bands of interest (the bandpasses may not be precisely correct since the document I am looking at lists the "proposed" bands)

SPOT1 covers 430-470 nm
SPOT2 covers 500-590 nm
SPOT3 covers 610-680 nm

SPOT4 covers 790-890 nm
SPOT5 covers 1580-1750 nm

The abbreviation AVHRR refers to the Advanced Very High Resolution Radiometer which has two bands of interest:

AVHRR1 covers 550-700 nm
AVHRR2 covers 700-1000 nm

The abbreviation TM refers to the Landsat Thematic Mapper which has six bands of interest:

TM1 covers 450-520 nm
TM2 covers 520-600 nm
TM3 covers 630-690 nm
TM4 covers 760-900 nm
TM5 covers 1550-1750 nm
TM7 covers 2080-2350 nm

The abbreviation MSS refers to the Landsat MultiSpectral Scanner.
MSS bands are referred to by the old system:

MSS4 covers 500-600 nm
MSS5 covers 600-700 nm
MSS6 covers 700-800 nm
MSS7 covers 800-1100 nm

NIR is used to indicate a band covering all or part of the near-infrared portion of the spectrum (800-1100 nm or a subset of these wavelengths).

Examples: MSS7, TM4, AVHRR2

R is used to indicate a band covering all or part of the portion of the visible spectrum perceived as red by the human eye (600-700 nm). Examples MSS5, TM3, AVHRR1

Questions:

GENERAL

1) What are the important spectral characteristics of vegetation that I should know about?
2) I have some remote sensing data, what bands will show vegetation best?
   2a) TM data
   2b) MSS data
3) I want to use band ratioing to eliminate albedo effects and shadows. What band ratios are best?
   3a) TM data
   3b) MSS data
4) Why is vegetation usually shown in red by remote sensing people?
5) What is the difference between radiance and reflectance?

VEGETATION INDEX

6) What the &*(^ is a vegetation index?
7) What are the basic assumptions made by the vegetation indices?
8) What is the soil line and how do I find it?

BASIC INDICES

9) What is RVI?
10) What is NDVI?
11) What is IPVI?
12) What is DVI?

GENERAL

1) What are the important spectral characteristics of vegetation that I should know about?

A: The cells in plant leaves are very effective scatterers of light because of the high contrast in the index of refraction between the water-rich cell contents and the intercellular air spaces.
Vegetation is very dark in the visible (400-700 nm) because of the high absorption of pigments which occur in leaves (chlorophyll, protochlorophyll, xanthophyll, etc.). There is a slight increase in reflectivity around 550 nm (visible green) because the pigments are least absorptive there. In the spectral range 700-1300 nm plants are very bright because this is a spectral no-man's land between the electronic transitions which provide absorption in the visible and molecular vibrations which absorb in longer wavelengths. There is no strong absorption in this spectral range, but the plant scatters strongly as mentioned above.

From 1300 nm to about 2500 nm vegetation is relatively dark, primarily because of the absorption by leaf water. Cellulose, lignin, and other plant materials also absorb in this spectral range.

SUMMARY: 400-700 nm = dark
700-1300 nm = bright
1300-2500 nm = dark (but brighter than 400-700 nm)

2) I have some remote sensing data, what bands will show vegetation best?

A: Basically a band covering part of the region from 700-1300 nm if you want the vegetation to be bright. (Using a band covering part of 400-700 nm would make vegetation dark, but this isn't the way we generally do things.)

2A) For TM data, either TM4 or TM5

2B) For MSS data, either MSS6 or MSS7 (MSS7 is usually better since it avoids the transition near 700 nm).

3) I want to use band ratioing to eliminate albedo effects and shadows. What band ratios are best?

A: If you want the vegetation to turn out bright (which is usually the most sensible approach) ratio a band covering parts of the range 700-1300 nm with a band covering either 400-700 nm or 1300-2500 nm.

Ratioing a near-infrared band to a visible band is the traditional approach. Usually a visible band covering 650 nm is preferred since this is near the darkest part of the vegetation spectrum usually covered by remote sensing instruments. Basically you want a band where vegetation is bright on the top of the ratio, and a band where vegetation is dark on the bottom.

Although vegetation is more highly reflective in green than in red, early work showed that near-infrared-red combinations were preferable to green-red combinations (Tucker, 1979).

3A) TM: The traditional ratio is TM4/TM3. TM5/TM7 is also good, but many clays will also be fairly bright with this combination. I see no immediate reason why TM5/TM3 or TM4/TM7 wouldn't work, but they usually aren't used.

3B) MSS: The traditional ratio is MSS7/MSS5 and MSS6/MSS5 is also used.

4) Why is vegetation usually shown in red by remote sensing people?

A: This is one of the apparently silly things done in remote sensing. There are three reasons for it: The first (and rather pointless) reason is TRADITION. People in remote sensing have been doing this a long time and virtually everyone who has spent much time working with remote sensing will Instinctively interpret red splotches as vegetation. Bob Crippen (not the astronaut) at JPL said that he spent some time trying to break this tradition by showing vegetation in green, but he was ultimately beaten into submission. (Consider it this way: you are a remote sensing professional, you usually give talks to remote sensing professionals. They expect vegetation in red so you don't have to add an explanation that "vegetation is shown as green." This simplifies your life.)

The second reason is the fact that the human eye perceives the longest visible wavelengths to be red and the shortest visible wavelengths to be blue. This is an incentive for remote sensing images to be set up so that the shortest wavelength is shown as blue and the longest one is shown as red. Usually a near-infrared band is the longest wavelength being displayed (this is especially true for MSS and aerial color infrared photography). Since vegetation is brightest in the near-infrared, vegetation turns out red. Using red for vegetation in digital data makes the digital data color scheme similar to that for color infrared film. This can make it easier for a person familiar with color infrared film pictures to adjust to the interpretation of digital remote sensing data.

The third (and only sensible) reason is to remind the audience that they are not seeing real colors. If vegetation is shown as green, the audience is more likely to subconsciously think that the image is true color, while if vegetation is red they will immediately realize that the image is false color.

5) What is the difference between radiance and reflectance?

A: Radiance is the variable directly measured by remote sensing instruments. Basically, you can think of radiance as how much light the instrument "sees" from the object being observed. When looking through an atmosphere, some light scattered by the atmosphere will be seen by the instrument and included in the observed radiance of the target. An atmosphere will also absorb light, which will decrease the observed radiance. Radiance has units of watt/steradian/square meter.

Reflectance is the ratio of the amount of light leaving a target to the amount of light striking the target. It has no units. If all of the light leaving the target is intercepted for the measurement of reflectance, the result is called "hemispherical reflectance."

Reflectance (or more specifically hemispherical reflectance) is a property of the material being observed. Radiance, on the other hand, depends on the illumination (both its intensity and direction), the orientation and position of the target and the path of the light through the atmophere. With effort, many of the atmospheric effects and the solar illumination can be compensated for in digital remote sensing data. This yields something which is called "apparent reflectance," and it differs from true reflectance in that shadows and directional effects on reflectance have not been dealt with. Many people refer to this (rather inaccurately) as "reflectance."

For most of the vegetation indices in this FAQ, radiance, reflectance, and apparent reflectance can be used interchangibly. However, since reflectance is a property of the target material itself, you will get the most reliable (and repeatable) vegetation index values using reflectance. Apparent reflectance is adequate in many cases.

VEGETATION INDEX

6) What is a vegetation index?

A: A vegetation index is a number that is generated by some combination of remote sensing bands and may have some relationship to the amount of vegetation in a given image pixel. If that sounds sarcastic or even insulting, it's meant to. Jim Westphal at Caltech pointed out to me one day that vegetation indices seemed to be more numerology than science. This may be an overly harsh assessment, since there is some basis for vegetation indices in terms of the features of the vegetation spectrum discussed above; however, the literature indicates that these vegetation indices are generally based on empirical evidence and not basic biology, chemistry or physics. This should be kept in mind as you use these indices.

7) What are the basic assumptions made by the vegetation indices?

A: The most basic assumption made is assuming that some algebraic combination of remotely-sensed spectral bands can tell you something useful about vegetation. There is fairly good empirical evidence that they can.

A second assumption is the idea that all bare soil in an image will form a line in spectral space. This is related to the concept of the soil line discussed in question number 7. Nearly all of the commonly used vegetation indices are only concerned with red-near-infrared space, so a red-near-infrared line for bare soil is assumed. This line is considered to be the line of zero vegetation.

At this point, there are two divergent lines of thinking about the orientation of lines of equal vegetation (isovegetation lines):

1) All isovegetation lines converge at a single point. The indices that use this assumption are the "ratio-based" indices, which measure the slope of the line between the point of convergence and the red-NIR point of the pixel. Some examples are: NDVI, SAVI, and RVI

2) All isovegetation lines remain parallel to soil line.
These indices are typically called "perpendicular" indices and they measure the perpendicular distance from the soil line to the red-NIR point of the pixel. Examples are: PVI, WDVI, and DVI.

8) What is the soil line and how do I find it?

A) The soil line is a hypothetical line in spectral space that describes the variation in the spectrum of bare soil in the image. The line can be found by locating two or more patches of bare soil in the image having different reflectivities and finding the best fit line in spectral space. Kauth and Thomas (1976) described the famous "triangular, cap shaped region with a tassel" in red-NIR space using MSS data. They found that the point of the cap (which lies at low red reflectance and high NIR reflectance) represented regions of high vegetation and that the flat side of the cap directly opposite the point represented bare soil.

THE SIMPLE WAY OF FINDING THE RED-NIR SOIL LINE:
Make a scatterplot of the red and NIR values for the pixels in the image. I recommend putting red on the x-axis and NIR on the y-axis (the rest of the instructions assume this). There should be a fairly linear boundary along the lower right side of the scatterplot. The straight line that best matches this boundary is your soil line. You can either select the points that describe the boundary and do a least squares fit, or you can simply made a hardcopy and draw in the line that looks like the best fit. (You have to make a lot of judgment calls either way.)

9) What is RVI?

A) RVI is the ratio vegetation index which was first described by Jordan (1969). This is the most widely calculated vegetation index, although you rarely hear of it as a vegetation index. A common practice in remote sensing is the use of band ratios to eliminate various albedo effects. Many people use the ratio of NIR to red as the vegetation component of the scene, and this is in fact the RVI.

SUMMARY: ratio-based index
isovegetation lines converge at origin
soil line has slope of 1 and passes through origin.
range 0 to infinity

CALCULATING RVI:

$$RVI = \frac{NIR}{red}$$

10) What is NDVI?

A) NDVI is the Normalized Difference Vegetation Index which is ascribed to Rouse et al. (1973), but the concept of a normalized difference index was first presented by Kriegler et al. (1969). When people say vegetation index, this is the one that they are usually referring to. This index has the advantage of varying between -1 and 1, while the RVI ranges from 0 to infinity. RVI and NDVI are functionally equivalent and related to each other by the following equation:

$$NDVI = \frac{RVI-1}{RVI+1}$$

SUMMARY: ratio-based index. Isovegetation lines converge at origin
soil line has slope of 1 and passes through origin
range -1 to +1

CALCULATING THE NDVI:

$$NDVI = \frac{NIR - red}{NIR + red}$$

11) What is IPVI?

A) IPVI is the Infrared Percentage Vegetation Index which was first described by Crippen (1990). Crippen found that the subtraction of the red in the numerator was irrelevant, and proposed this index as a way of improving calculation speed. It also is restricted to values between 0 and 1, which eliminates the need for storing a sign for the vegetation index values, and it eliminates the conceptual strangeness of negative values for vegetation indices. IPVI and NDVI are functionally equivalent and related to each other by the following equation:

$$IPVI = \frac{NDVI+1}{2}$$

SUMMARY: ratio-based index
isovegetation lines converge at origin
soil line has a slope of 1 and passes through origin
range 0 to +1

CALCULATING IPVI:

$$IPVI = \frac{NIR}{NIR+red}$$

12) What is DVI?

A) DVI is the Difference Vegetation Index, which is ascribed in some recent papers to Richardson and Everitt (1992), but appears as VI (vegetation index) in Lillesand and Kiefer (1987). Lillesand and Kiefer refer to its common use, so it was certainly introduced earlier, but they do not give a specific reference.

SUMMARY: perpendicular index
isovegetation lines parallel to soil line
soil line has arbitrary slope and passes through origin
range infinite.

CALCULATING DVI:

$$DVI = NIR - red$$

13) What is PVI?

A) PVI is the Perpendicular Vegetation Index which was first described by Richardson and Wiegand (1977). This could be considered a generalization of the DVI which allows for soil lines of different slopes. PVI is quite sensitive to atmospheric variations, (Qi et al., 1994) so comparing PVI values for data taken at different dates is hazardous unless an atmospheric correction is performed on the data.

SUMMARY: perpendicular index
isovegetation lines are parallel to soil line
soil line has arbitrary slope and passes through origin
range -1 to +1

CALCULATING PVI:

PVI = [sin(a)*NIR] – [cos(a)*red]

where a = the angle between the soil line and the NIR axis.

14) What is WDVI?

A) WDVI is the Weighted Difference Vegetation Index which was introduced by Clevers (1988). This has a relationship to PVI similar to the relationship IPVI has to NDVI. WDVI is a athematically simpler version of PVI, but it has an unrestricted range. Like PVI, WDVI is very sensitive to atmospheric variations (Qi et al., 1994).

SUMMARY: perpendicular index
isovegetation lines parallel to soil line
soil line has arbitrary slope and passes through origin
range infinite

CALCULATING WDVI:

WDVI = NIR-g*red

Where g is the slope of the soil line.

INDICES TO MINIMIZE SOIL NOISE

15) What is Soil Noise?

A) Not all soils are alike. Different soils have different reflectance spectra. As discussed above, all of the vegetation indices assume that there is a soil line, where there is a single slope in red-NIR space. However, it is often the case that there are soils with different red-NIR slopes in a single image. Also, if the assumption about the isovegetation lines (parallel or intercepting at the origin) is not exactly right, changes in soil moisture (which move along isovegetation lines) will give incorrect answers for the vegetation index. The problem of soil noise is most acute when vegetation cover is low.

The following group of indices attempt to reduce soil noise by altering the behavior of the isovegetation lines. All of them are ratio-based, and the way that they attempt to reduce soil noise is by shifting the place where the isovegetation lines meet.

WARNING: These indices reduce soil noise at the cost of decreasing the dynamic range of the index. These indices are slightly less sensitive to changes in vegetation cover than NDVI (but more sensitive than PVI) at low levels of vegetation cover. These indices are also more sensitive to atmospheric variations than NDVI (but less so than PVI). (See Qi et al. (1994) for comparisons.)

16) What is SAVI?

A) SAVI is the Soil Adjusted Vegetation Index which was introduced by Huete (1988). This index attempts to be a hybrid between the ratio-based indices and the perpendicular indices. The reasoning behind this index acknowledges that the isovegetation lines are not parallel, and that they do not all converge at a single point. The initial construction of this index was based on measurements of cotton and range grass canopies with dark and light soil backgrounds, and the adjustment factor L was found by trial and error until a factor that gave equal vegetation index results for the dark and light soils was found. The result is a ratio-based index where the point of convergence is not the origin. The convergence point ends up being in the quadrant of negative NIR and red values, which causes the isovegetation lines to be more parallel in the region of positive NIR and red values than is the case for RVI, NDVI, and IPVI.

Huete (1988) does present a theoretical basis for this index based on simple radiative transfer, so SAVI probably has one of the better theoretical backgrounds of the vegetation indices. However, the theoretical development gives a significantly different correction factor for a leaf area index of 1 (0.5) than resulted from the empirical development for the same leaf area index (0.75). The correction factor was found to vary between 0 for very high densities to 1 for very low densities. The standard value typically used in most applications is 0.5 which is for intermediate vegetation densities.

SUMMARY: ratio-based index
isovegetation lines converge in negative red, negative NIR quadrant
soil line has slope of 1 and passes through origin.
range -1 to +1

CALCULATING SAVI:

$$SAVI = \frac{NIR - red}{NIR + red + L}(1+L)$$

where L is a correction factor which ranges from 0 for very high vegetation cover to 1 for very low vegetation cover. The most typically used value is 0.5 which is for intermediate vegetation cover.

16a) Why is there a (1+L) term in SAVI?

A) This multiplicative term is present in SAVI (and MSAVI) to cause the range of the vegetation index to be from -1 to +1. This is done so that both vegetation indices reduce to NDVI when the adjustment factor L goes to zero.

17) What is TSAVI?

A) TSAVI is the Transformed Soil Adjusted Vegetation Index which was developed by Baret et al. (1989) and Baret and Guyot (1991). This index assumes that the soil line has arbitrary slope and intercept, and it makes use of these values to adjust the vegetation index. This would be a nice way of escaping the arbitrariness of the L in SAVI if an additional adjustment parameter had not been included in the index. The parameter "X" was "adjusted so as to minimize the soil background effect," but I have not yet been able to come up with an a priory, non-arbitrary way of finding the parameter. The value reported in the papers is 0.08. The convergence point of the isovegetation lines lies between the origin and the usually-used SAVI convergence point (for L = 0.5)

SUMMARY: Ratio-based index
isovegetation lines converge in negative red, negative NIR quadrant
soil line has arbitrary slope and intercept.
range -1 to +1

CALCULATING TSAVI:

$$TSAVI = \frac{s(NIR - s*red - a)}{(a*NIR + red - a*s + X*(1+s*s))}$$

where a is the soil line intercept, s is the soil line slope, and
x is an adjustment factor which is set to minimize soil noise (0.08 in original papers).

18) What is MSAVI?

A) MSAVI is the Modified Soil Adjusted Vegetation Index which was developed by Qi et al. (1994). As noted previously, the adjustment factor L for SAVI depends on the level of vegetation cover being observed which leads to the circular problem of needing to know the vegetation cover before calculating the vegetation index which is what gives you the vegetation cover. The basic idea of MSAVI was to provide a variable correction factor L. The correction factor used is based on the product of NDVI and WDVI. This means that the isovegetation lines do not converge to a single point.

SUMMARY: ratio-based index
isovegetation lines cross the soil line at different points
soil line has arbitrary slope and passes through origin
range -1 to +1

CALCULATING MSAVI:

$$MSAVI = \frac{NIR - red}{NIR + red + L}(1+L)$$

Where:
L = 1 - 2*s*NDVI*WDVI
s = the slope of the soil line.

19) What is MSAVI2?

A) MSAVI2 is the second Modified Soil Adjusted Vegetation Index which was developed by Qi et al. (1994) as a recursion of MSAVI. Basically, they use an iterative process and substitute 1-MSAVI(n-1) as the L factor in MSAVI(n). They then inductively solve the iteration where MSAVI(n)=MSAVI(n-1). In the process, the need to precalculate WDVI and NDVI and the need to find the soil line are eliminated.

SUMMARY: ratio-based
isovegetation lines cross the soil line at varying points.
soil line has arbitrary slope and passes through origin
range -1 to +1

CALCULATING MSAVI2:

MSAVI2 = (1/2)*(2(NIR+1)-sqrt[(2*NIR+1)^2 - 8(NIR-red)])

where ^2 signifies the squaring of the value and sqrt() is the square-root operator.

INDICES TO MINIMIZE ATMOSPHERIC NOISE

20) What is Atmospheric Noise?

A) The atmosphere is changing all of the time and all remote sensing instruments have to look through it. The atmosphere both attenuates light passing through it and scatters light from suspended aerosols. The atmosphere can vary strongly across a single scene, especially in areas with high relief. This alters the light seen by the instrument and can cause variations in the calculated values of vegetation indices. This is particularly a problem for comparing vegetation index values for different dates. The following indices try to remedy this problem without the requirement of atmospherically corrected data.

WARNING: These indices achieve their reduced sensitivity to the atmosphere by decreasing the dynamic range. They are generally slightly less sensitive to changes in vegetation cover than NDVI. At low levels they are very sensitive to the soil background. (See Qi et al. (1994) for comparisons.)

NOTE: I seldom work with data without performing an atmospheric correction, so I have made no significant use of any of the indices in this section (T. Ray).

21) What is GEMI?

A) GEMI is the Global Environmental Monitoring Index which was developed by Pinty and Verstraete (1991). They attempt to eliminate the need for a detailed atmospheric correction by constructing a "stock" atmospheric correction for the vegetation index. Pinty and Verstraete (1991) provide no detailed reasoning for this index other than that it meets their requirements of insensitivity to the atmosphere empirically. A paper by Leprieur et al. (1994) claims to find that GEMI is superior to other indices for satellite measurements. However, A. Chehbouni (who happens to be the fourth author of Leprieur et al. (1994)) showed me some examples using real data (the analysis in the paper was based on a model) which strongly contradicted the Leprieur et al. (1994) conclusions. Qi et al. (1994) shows a violent breakdown of GEMI with respect to soil noise at low vegetation covers. I understand that there are several ongoing studies to evaluate GEMI, and I think that the jury is still out.

SUMMARY:

- Non-linear
- Complex vegetation isolines
- Range 0 to +1

CALCULATING GEMI:

$$GEMI = eta*(1-0.25*eta) - \frac{red - 0.125}{1 - red}$$

where :

$$eta = \frac{2*(NIR^2-red^2)+1.5*NIR+0.5*red}{NIR + red + 0.5}$$

22) What are the atmospherically resistant indices?

A) The atmospherically resistant indices are a family of indices with built-in atmospheric corrections. The first of these was ARVI (Atmospherically Resistant Vegetation Index) which was introduced by Kaufman and Tanre (1992). They replaced the red reflectance in NDVI with the term:

$$rb = red - gamma\ (blue - red)$$

with a value of 1.0 for gamma. Kaufman and Tanre (1994) also suggested making the same substitution in SAVI which yields SARVI (Soil adjusted Atmospherically Resistant Vegetation Index). Qi et al. (1994) suggested the same substitution in MSAVI2 which yields ASVI (Atmosphere-Soil-Vegetation Index). Obviously the same substitution can also be made in MSAVI or TSAVI.

Qi et al. (1994) showed that this class of indices were very slightly more sensitive to changes in vegetation cover than GEMI and very slightly less sensitive to the atmosphere and the soil than

GEMI for moderate to high vegetation cover. The atmospheric insensitivity and the insensitivity to soil break down violently for low vegetation cover.
SUMMARY:

ratio-based
isovegetation lines cross as assumed by parent index
soil line as assumed by parent index
range -1 to +1

CALCULATING ARVI:

$$ARVI = \frac{NIR - rb}{NIR + rb}$$

with rb defined as:

$$rb = red - gamma*(red - blue)$$

and gamma usually equal to 1.0

The parent index of ARVI is NDVI. The substitution of rb for red in any of the ratio-based indices gives the atmospherically resistant version of that index.

[**NOTE:** I view these indices for reducing atmospheric noise as late-evolving dinosaurs. The utility of a good atmospheric correction for remotely-sensed data is so high as to make the effort of performing a proper atmospheric correction worthwhile. These end runs around this problem may serve a useful purpose at present while better atmospheric corrections for data collected over land are being developed. However, the move towards atmospheric correction of remote sensing data is underway, and it is almost certainly the wave of the future. - Terrill Ray]

OTHER INDICES

23) What is GVI?

A) GVI stands for **Green Vegetation Index**. There are several GVIs. The basic way these are devised is by using two or more soil points to define a soil line. Then a Gram-Schmidt orthogonalization is performed to find the "greenness" line which passes through the point of 100% (or very high) vegetation cover and is perpendicular to the soil line. The distance of the pixel spectrum in band space from the soil line along the "greenness" axis is the value of the vegetation index. The PVI is the 2-band version of this, Kauth and Thomas (1976) developed a 4-band version for MSS, Crist and Cicone (1984) developed a 6-band version for TM, and Jackson (1983) described how to construct the n-band version.

SUMMARY: perpendicular vegetation index using n bands
isovegetation lines are parallel to soil line.
soil line has arbitrary orientation in n-space
range -1 to +1

CALCULATING GVI:

Default version for MSS

$$GVI = -0.29*MSS4 - 0.56*MSS5 + 0.60*MSS6 + 0.49*MSS7$$

Default version for TM

$$GVI = -0.2848*TM1 - 0.2435*TM2 - .5436*TM3 + 0.7243*TM4 + 0.0840*TM5 - 0.1800*TM7$$

24) Are there vegetation indices using other algebraic functions of the bands?
A) Yes. Rouse et al. (1973, 1974) proposed using the square root of NDVI+0.5, Goetz et al. (1975) proposed log ratios, Wecksung and Breedlove (1977) proposed arctangent ratios, and Tuck (1979) discussed the square root of the NIR/red ratio.

These seem to have been generally abandoned. They make the same assumptions about the isovegetation lines and the soil lines as made by RVI and NDVI, and they have neither the value of common use or of ease of calculation. You will probably never see these, and there is really no good reason to bother with them.

25) Are there vegetation indices that use bands other than the red and NIR bands?
A) Yes. First, the various GVIs make use of more than just the NIR and red bands. In general, the GVI for a given multispectral sensor system uses all of the available bands. Secondly, there have been attempts to develop vegetation indices based on green and red bands as discussed in the next question. Mike Steven at the University of Nottingham has recently informed me of some work on an index using NIR and mid-infrared bands. More on this will be included when I have received a paper from him.

26) Plants are green, why isn't the green chlorophyll feature used directly.
A) There are several reasons for this. First, the reason that plants look so green is not because they are reflecting lots of green light, but because they are absorbing so much of the rest of the visible light. Try looking at an area of bare dry soil and compare that to a grassy field. You will immediately notice that the grassy field is generally darker. It is generally easier to detect things when they are bright against a dark background.

Second, this was tried early in the history of satellite remote sensing by Kanemasu (1974) and basically abandoned after a study by Tucker (1979) which seemed to demonstrate that the combinations of NIR and red were far superior than combinations of green and red. The idea of using red and green with MSS data was resurrected in recent years by Pickup et al. (1993) who proposed a PVI-like index using MSS bands 4 and 5 which they called PD54 (Perpendicular Distance MSS band 5 MSS band 4). They claimed a tassel cap like pattern in the scatterplot for these two bands, but most of the MSS data I have looked at doesn't show this pattern. A significant point for PD54 was that it detected non-green vegetation (dry grass).

Third, many soils have iron oxide absorption features in the visible wavelengths. As the soil gets obscured by vegetation cover, this feature becomes less apparent. It is likely that a great deal of the variance measured by the green-red indices is due to this instead of the plant chlorophyll feature (which is why PD54 might appear to be sensitive to non-green plant material). This is fine if you know that the iron oxide absorption in the soil is uniform across the image, but if the iron oxide absorption is highly variable, then this will confuse green-red indices.

PROBLEMS

27) How well do these vegetation indices work in areas with low vegetation cover?
A) Generally, very badly. When the vegetation cover is low, the spectrum observed by remote sensing is dominated by the soil. Not all soils have the same spectrum, even when fairly broad bands are being used. Both Huete et al. (1985) and Elvidge and Lyon (1985) showed that the soil background can have a profound impact and vegetation index values with bright backgrounds producing lower vegetation index values than dark backgrounds. Elvidge and Lyon (1985) showed that many background materials (soil, rock, plant litter) vary in their red-NIR slope, and these variations seriously impact measurements of vegetation indices. Then there is the problem of non-linear mixing.

28) What is the "non-linear" mixing?

A) A lot of remote sensing analysis has been based on the concept of the Earth as spots covered by differently-colored paint. When the spots of paint get too small, they appear to blend together to form a new color which is a simple mixture of the old colors. Consider an area covered by 50% small red spots and 50% small green spots. When we look at the surface from far enough away that we can't see the individual dots, we see the surface as yellow. Different proportions of red and green dots will produce different colors, and if we know that the surface is covered by red and green dots we can calculate what the proportions are based on the color we see. The important thing to know is that any light reaching the observer has only hit one of the colored dots. That is linear mixing.

Non-linear mixing occurs when light hits more than one of the colored dots. Imagine a surface with a lot of small, colored bumps which stick out varying distances from the surface. We can now image that light could bounce from one colored bump to another and then to the observer. Now some of the light coming from the green bump bounced off of a red bump first, and this light will have characteristics of both the red and green bumps. There is also light coming directly from the green bump that only bounced from the green bump. If we could see this individual green bump, it would not look as green as it should. Now, when the light from all of the bumps reaches the observer, the light looks different than when the bumps were simple spots even through the proportion of the area covered by each color is unchanged. (We are assuming that there are no shadows.)

A second way for non-linear mixing to happen is if light can pass through one material and then reflect off of another. Imagine a piece of translucent plastic with half of the area covered by randomly placed translucent green spots placed on top of a red surface. Now light can pass through a green spot on the plastic and then reflect off of the red below before returning to the observer. Once again, the interaction of the light with multiple spots along its path changes the character of the light coming from each spot. Once again the color looks different than the linear case, which is just the case when light cannot pass through green spots. The basic point is that non-linear mixing twists the spectra of the materials being observed into different spectra which do not resemble any of the targets. This can magnify the apparent abundance of a material. Consider the piece of translucent plastic with the translucent green dots. If we put it on top of a low-reflectivity surface, very little of the light that passes through the green dots will be reflected back, so all we see is the light directly reflected from the green dots. Now we put a highly reflective surface behind it, and we see a brighter green because we now see both the light directly reflected from the dots and most of the light which has passed through the green dots (which is green) is reflecting back from the highly-reflective background. If we didn't know better, we might think that we just had more green dots instead of a brighter background.

29) Is the variation in the soil the only problem?

A) No. Many of the commonly studied areas with low vegetation cover are arid and semi-arid areas. Many plants which grow in such areas have a variety of adaptations for dealing with the lack of water and high temperatures. (Even plants growing in areas with relatively cool air temperature have problems with heat regulation in dry climates since transpiration is the main way they keep cool.) These adaptations often decrease the amount of visible light absorbed by the plants and/or decrease the amount of sunlight striking the plants (hence the plants do not reflect as much light). These inherent qualities make arid and semi-arid vegetation hard to detect unless it is observed during periods of relatively abundant water when a whole new set of adaptations to maximize plant productivity takes effect.

30) What if I can't get a good soil line from my data?

A) If you're working in an area with high plant cover, this can be common. This makes it virtually impossible to use the perpendicular indices or things like TSAVI and MSAVI1. However, NDVI is at its best with high plant cover, so it is still available to you. The correction factor L for SAVI should be near 0 for this sort of situation, which makes SAVI equivalent to NDVI. MSAVI2 also need no soil line. If you really want to use an index which requires a soil line, you will need to construct it with field and laboratory spectra, but this is not an easy task, and really not advisable.

31) How low a plant cover is too low for these indices?

A) These are rules of thumb, your mileage may vary:

RVI, NDVI, IPVI = 30%
SAVI, MSAVI1, MSAVI2 = 15%
DVI = 30%
PVI, WDVI, GVI = 15%

The more uniform your soil, the lower you can push this.

FUTURE DIRECTIONS

32) I hear about people using spectral unmixing to look at vegetation, how does this work?

A) See 22 for a thumbnail description of linear mixing. Basically, you assume that the given spectrum is a linear combination of the spectra of materials which appear in the image. You do a least squares fit to find weighting coefficients for each individual material's spectrum which gives the best fit to the original spectrum. The weighting coefficients are considered to be equal to the abundances of the respective materials. For detailed discussions of this see Adams et al. (1989), Smith et al. (1990), Roberts et al. (1994) and Smith et al. (1994). There is also the highly sophisticated convex geometry technique discussed in Boardman (1994).

33) Are there any indices which use high spectral resolution data?

A) Yes. Elvidge and Chen (1994) have developed indices of this kind. They depend on the fact that when you take a derivative of the red edge in the vegetation spectrum you get a bump at about 720 nm. It is known that the red edge in be seen in high spectral resolution data down to about 5% cover (Elvidge and Mouat, 1988; Elvidge et al., 1993). Three indices were developed. The first used the integral of the first derivative of the reflectance spectrum over the range 626-795 nm. The second took the first derivative of the reflectance spectrum, subtracted the value of the derivative at 625 nm and integrated the result over the range 626-795 nm. The third index used the integral of the absolute value of the second derivative of the reflectance spectrum integrated over the range from 626-795 nm. Of these three indices, the first one was found to have greater predictive power than RVI or NDVI, but less predictive power than SAVI or PVI. The index which used the second derivative has greater predictive power than SAVI and PVI.

The index which used the difference between the first derivative and the value of the first derivative at 625 nm had the greatest predictive power.

FINAL QUESTION

34) What vegetation index should I use?

A) NDVI.

Nearly everyone who does much with the remote sensing of vegetation knows NDVI, and its often best to stick to what people know and trust. NDVI is simple. It has the best dynamic range of any of the indices in this FAQ and it has the best sensitivity to changes in vegetation cover. It is moderately sensitive to the soil background and to the atmosphere except at low plant cover.To just take a quick qualitative look at the vegetation cover in an image, you just can't beat NDVI unless you are looking at an area with low plant cover.

PVI is somewhat less common in its use, but it is also widely accepted. It has poor dynamic range and poor sensitivity as well as being very sensitive to the atmosphere. It is relatively easy to use, and finding the soil line is important for using some of the other indices. It sometimes is better than NDVI at low vegetation cover. You really should probably use SAVI if you are looking at low vegetation cover, and if you use a correction factor which is not 0.5 you had better be prepared to cite the Huete (1988) paper and the fact the correction factor is larger than 0.5 for very sparse vegetation. MSAVI is also good, but it has seen very little use.

If you have high spectral resolution data, you should consider the Elvidge and Chen (1994) indices. Remember that many of the indices which correct for the soil background can work poorly if no atmospheric correction has been performed. If you are planning to seriously use vegetation indices for a multitemporal study, you should take a close look at the variability of the soil, and you should do an atmospheric correction. There is some concern about vegetation indices giving different values as you look away from the nadir, but this may not be terribly serious in your application.

SUMMARY: In order of preference for each type of sensor:

TM or MSS (or any broad-band sensor)

1: NDVI (or IPVI)
2: PVI
3: SAVI (top of list for low vegetation)
4: MSAVI2

High Spectral Resolution Data (e.g. AVIRIS)

1: First derivative index with baseline at 625 nm.

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