- Skye eGuides -
theory into practice

N° 3
Vegetation Indices

www.skyeinstruments.com

CONTENTS

1 INTRODUCTION

The series of Skye eGuides on Remote Sensing have been written to help researchers choose which of the Skye Instruments range of sensors and systems could add valuable data and information to their monitoring projects, and also how to get the best results from the instruments.

This eGuide Notes introduces Vegetation Indices and how measurements of Spectral Reflectance can be used to calculate these Indices to indicate the presence, growth and health status of plants, forests, crops and vegetation on the Earth’s surface, both from space and at ground level.

The Skye Instruments Spectral Reflectance sensors and Vegetation Indices systems are also described, with their many applications.

Example templates for calculating Vegetation Indices from measurements taken with Skye sensors are available on our website using the link below. Please scroll down the page to the NDVI, VI & PRI section.

Example Templates

2 VEGETATION INDICES

As described in the Skye eGuide No 2 on Spectral Reflectance, ratios of reflected wavebands of light and radiation can offer a variety of information on green vegetation, including its presence, biomass, rate of growth, ground area covered and health status. Different types or species of plants can also be identified, such as trees, grasses, crops etc.

The reflected light ratio calculations are often referred to as Vegetation Indices (or VIs), and sometimes just simply as a Greenness Index.

Most VIs are calculated from the ratios of Near Infra Red (NIR) and Visible (VIS) light that is reflected from the area under study. The Red band of the Visible spectrum is the most commonly used.

There are also Indices using other spectral bands to monitor different surfaces, such as minerals, rocks, oceans and surface water, snow and ice etc. This eGuide will concentrate mainly on the Vegetation Indices.

The applications for VIs are many, including:

- Precision Agriculture for better management of crops, horticulture and floriculture
- Climate Change studies
- Carbon Balance of Ecosystems
- Plant productivity and photosynthesis rate
- Phenology
- Monitoring Land Use Changes
- Ground Truthing of Earth Observational Satellite data

Reflected light measurements for VI calculations can be made at individual leaf level, whole plant, entire crop or ecosystem and even continent wide, depending on the technique employed.

The most widely used VI is the Normalised Differential Vegetation Index or NDVI. This is fully described in the following chapters, along with RVI, PRI, EVI, EVI2, WBI, MSAVI2, fPAR and LAI.

3 MEASUREMENTS FOR VI CALCULATIONS

Components of Vegetation Indices include Spectral Reflectance measurements. At ground level or during airborne measurements these are made using simultaneous Irradiance (Incident) and Radiance (reflected) readings.

Spectral Reflectance is calculated from the ratio of radiance to irradiance. By measuring these two parameters simultaneously, errors caused by changes in total solar irradiance levels are minimised.

Reflectance =Radiance / Irradiance

In each VI equation in the following chapters, the Spectral Reflectance measurements are denoted by their wavebands, and should always be interpreted as the Radiance / Irradiance of that band.

e.g.

NIR (Near Infra red)	= NIR (radiance) / NIR (irradiance)
RED	= RED (radiance) / RED (irradiance)
VIS (Visible)	= VIS (radiance) / VIS (irradiance)
531 nm	= 531nm (radiance) / 531nm (irradiance)

etc.

4 SIMPLE RATIO VEGETATION INDICES

4.1 RVI

The Simple Ratio Vegetation Index, known as SR or RVI was one of the first ratios of NIR and Red light used, and is the simplest equation:

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

This can also be broadened to:

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

RVI values for bare soil are around 1. Higher values denote higher densities of vegetation, and can be around 30.

4.2 WBI

The Water Band Index or WBI is another example using this simple equation, but uses the 900nm and 970nm bands, or 900nm and 1530nm bands

$$WBI = \frac{970}{900} \quad \text{or} \quad \frac{1530}{900}$$

This index is a reflectance measurement that is sensitive to changes in canopy water status. As the water content of vegetation canopies increases, the strength of the absorption around 970nm or 1530nm increases relative to that of 900nm. Applications include canopy stress analysis, productivity prediction and modelling, fire hazard condition analysis, cropland management, and studies of ecosystem physiology.

The common range of WBI for green vegetation is 0.8 to 1.2.

5 NORMALISED VEGETATION INDICES

The equations of the Normalised Vegetation Indices have additional components to minimise the effects of variable irradiance (illumination) levels, and give a limited value range between –1 and +1.

Two widely used normalised indices, NDVI and PRI, are described here though there are many more which use different wavebands to highlight different ground parameters.

5.1 NDVI

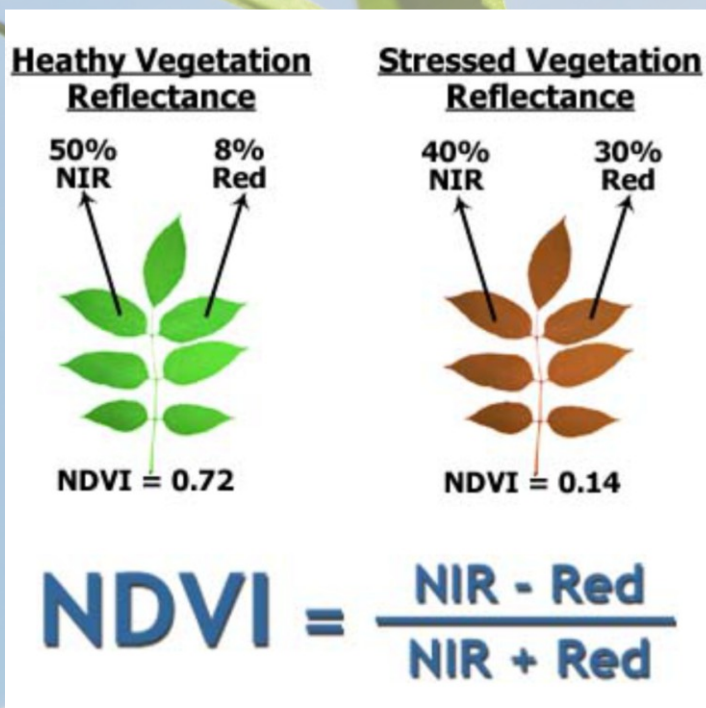
The highly popular Normalised Differential Vegetation Index NDVI is calculated from NIR and Red wavebands as follows:

$$NDVI = \frac{(NIR - Red)}{(NIR + Red)}$$

NDVI values can range between –1 and 1.

Data from vegetated areas yields positive values of NDVI due to high near-infrared and low red or visible reflectance. As the amount of green vegetation increases, NDVI increases in value up to nearly 1, although values above 0.8 are rarely seen.

In contrast, bare soil and rocks generally show similar reflectances in the near-infrared and red or visible, generating positive but lower NDVI values close to 0.
The red or visible reflectance of water, clouds, and snow are larger than their near-infrared reflectance, so areas containing these features produce negative NDVIs.



5.2 PRI

The Photochemical Reflectance Index PRI uses the same normalised equation as NDVI but with reflectances from the 531nm (green) and 570nm (yellow) wavebands.

$$PRI = \frac{(570 - 531)}{(570 + 531)}$$

However, some researchers prefer to use the PRI orientation as

$$PRI = \frac{(531 - 570)}{(531 + 570)}$$

The PRI is sensitive to changes in carotenoid pigments, e.g. xanthophyll pigments, in live vegetation. Carotenoid pigments are indicative of photosynthetic Light Use Efficiency (LUE), or the rate of carbon dioxide uptake by vegetation per unit energy absorbed, i.e. rate of photosynthesis.

The xanthophyll pigment absorbs energy at 531nm, while the 570 nm band is a reference point. When more light falls on a plant than can be used in photosynthesis, to prevent damage to the plant the excess energy is absorbed by the xanthophyll. This pigment has a cyclic change of state that absorbs and dissipates excess energy to protect the plant as needed.

PRI is used in studies of vegetation productivity and stress. PRI measurements can be used to assess general ecosystem health using field measurements and satellite remote sensing data.

Applications include vegetation health in evergreen shrublands, forests, and agricultural crops prior to senescence.

PRI values range from –1 to 1. Healthy vegetation is usually within the range –0.2 to + 0.2.

6 OPTIMISED VEGETATION INDICES

The popular NDVI calculation is not suitable for every ecosystem, nor for every stage of plant growth. For example NDVI tends to saturate in dense vegetation and is sensitive to underlying soil colour.

Other indices have been derived to optimise and enhance different ecosystem characteristics, some popular ones are described in this chapter, but again there are many more available.

6.1 EVI

The Enhanced Vegetation Index, EVI, was developed as an alternative vegetation index to address some of the limitations of the NDVI. The EVI was specifically developed to:

- be more sensitive to changes in areas having high biomass
- reduce the influence of atmospheric conditions on vegetation index values
- correct for canopy background signals

EVI tends to be more sensitive to plant canopy differences like leaf area index LAI, canopy structure, plant phenology and stress than does NDVI, which generally responds just to the amount of chlorophyll present.

However the two VIs complement each other in global vegetation studies and improve upon the detection of vegetation changes and extraction of canopy biophysical parameters.

$$EVI = G \times \frac{(NIR - RED)}{(NIR + C1 \times RED - C2 \times BLUE + L)}$$

where :
G is the Gain Factor
NIR/RED/BLUE are reflectance measurements in those bands
L is the soil adjustment factor
C1 , C2 are the coefficients of the aerosol resistance term, which uses the blue band to correct for aerosol influences in the red band.

6.1.1 MODIS EVI

MODIS EVI uses the equation above, using the following coefficients:

NIR is MODIS Band 2 841-876 nm
RED is MODIS Band 1 620-670 nm
BLUE is MODIS Band 3 459-479 nm

L ... .= 1
C1 .. ..= 6
C2 .. ..= 7.5
G (gain factor)..=2.5

So the equation becomes:

$$EVI = 2.5 \times \frac{(NIR - RED)}{(NIR + 6 \times RED - 7.5 \times BLUE + 1)}$$

MODIS values range from –1 to 1. Healthy vegetation is usually within the range 0.2 to 0.8.

6.1.2 EVI2

An alternative 2 band EVI equation was developed to calculate this VI from historical data where there was no blue band measurements available , e.g. AVHRR satellite data. It is also reported that the blue band can be problematic, and its Signal to Noise ratio (S/N) quite poor. This is mainly due to the nature of the reflected energy in this part of the spectrum over land, which is extremely low.

EVI2 is calculated using just the NIR and Red bands, as follows:

$$EVI2 = \frac{2.5 * (NIR - RED)}{(NIR + 2.4 * RED + 1)}$$

In many studies EVI2 has shown a good correlation with MODIS EVI.

Ref.: Jiang, Z., Huete, A. R., Didan, K. & Miura T. (2008).
Development of a two-band Enhanced Vegetation Index without a blue band,
Remote Sensing of Environment, 112(10), 3833-3845.
http://measures.arizona.edu/documents/dataviewer/EVI2_Paper_Huete.pdf

6.2 MSAVI

MSAVI (or MSAVI2) is a modification of the SAVI index. It uses NIR and Red bands in its calculation and compensates for exposed soil areas. It is best used where vegetation cover is less than 40%.

SAVI is an indice that was developed to take into account the soil background. When the NDVI calculation is made, unless the vegetation is 100% cover, the calculation will incorporate changes in soil moisture and the NDVI value is not totally correct.

The SAVI calculation uses an 'L' parameter, where 'L' is a soil adjustment factor with values between 0 and 1. L=0 for 100% vegetation cover, and L=1 for 0% vegetation cover. It is common to set L at 0.5.

However, MSAVI was developed to take away the requirement to incorporate an 'L' parameter. When results are compared using SAVI and MSAVI, there is virtually no difference.

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

NIR & RED are reflectance measurements in those bands
L is the soil brightness correction factor

MSAVI uses the following formula to calculate L:

$$L = \frac{1 - 2*s*(NIR - RED) * (NIR - s*RED)}{NIR + RED + L}$$

Where:
s is the slope of the soil / vegetation line from a plot of red versus near infrared brightness values

MSAVI2 was further developed to eliminate the need to find the soil line from a feature-space plot or even explicitly specify the soil brightness correction factor

$$MSAVI2 = \frac{(2*NIR + 1 - \sqrt{((2*NIR+1)^2 - 8*(NIR - RED))})}{2}$$

Similar to the other VIs, MSAVI values range from –1 to 1, where positive values indicate vegetation, near zero is bare soil and negative values indicate ice and snow.

Ref.: Qi J., Chehbouni A., Huete A.R., Kerr Y.H., 1994. Modified Soil Adjusted Vegetation Index (MSAVI). Remote Sens Environ 48:119-126.
http://naldc.nal.usda.gov/download/50306

7 fPAR

The Fraction of Absorbed Photosynthetically Active Radiation, FAPAR, sometimes also noted fAPAR or fPAR. is the fraction of the incoming solar radiation in the Photosynthetically Active Radiation spectral region (400-700 nm) that is absorbed by green vegetation.

fPAR is directly related to the primary productivity of photosynthesis and some remote sensing models use it to estimate the uptake of carbon dioxide by the vegetation in ecosytems.

It can be measured directly using field instruments from irradiance and radiance PAR sensors, or can be calculated from NDVI, or estimated from satellite sensing data.

Using previously calculated NDVI values, fPAR can be obtained using the following equation:

$$fPAR = (1.24 * NDVI) - 0.168$$

Ref: Potential of MODIS ocean bands for estimating CO_2 flux from terrestrial vegetation: A novel approach
A. F. Rahman,[1] V. D. Cordova,[2] J. A. Gamon,[3] H. P. Schmid,[4] and D. A. Sims[1]
GEOPHYSICAL RESEARCH LETTERS, VOL. 31, 2004
http://onlinelibrary.wiley.com/doi/10.1029/2004GL019778/pdf

8 LAI

Leaf area index, LAI, is a dimensionless quantity that characterises plant canopies. It is defined as the one-sided green leaf area per unit ground surface area.

LAI = leaf area / ground area

units m2 / m2

LAI ranges from 0 (bare ground) to over 10 (dense conifer forests)

As LAI quantifies plant canopy structure, it is highly related to a variety of canopy processes, such as water interception, evapotranspiration, photosynthesis, respiration, and leaf litterfall. So LAI is often used in remote sensing to quantify the above ecosystem processes.

The interrelationships between LAI and fPAR are high, and the utility of each is high. Neither LAI or fPAR are critical variables themselves, rather they are both essential intermediate variables used to calculate terrestrial energy, carbon, water cycling processes and biogeo-chemistry of vegetation. The current consensus is that LAI will be used preferentially by ecological and climate modellers who desire a representation of canopy structure in their models. fPAR will be preferentially used by remote sensing scientists to interpret satellite data, and projects interested in simple direct estimates of photosynthetic activity and primary production.

Actual leaf area can be measured directly but is a laborious and often destructive method. LAI can be indirectly estimated in several ways, two methods using light and radiation sensors are described below.

8.1 LAI from NDVI

LAI can be estimated from NDVI values using this equation:

LAI = a * e (b * NDVI)

Where:
a and b are parameters specific to each vegetation type
default values frequently used are a = 0.0148 and b = 6.192.
e . . . is the exponential function

Ref: Journal of Ecology 2007 95 , 139–150
What is the relationship between changes in canopy leaf area and changes in photosynthetic CO2 flux in arctic ecosystems?
L. E. STREET, G. R. SHAVER, M.WILLIAMS* and M. T. VAN WIJK†
http://www.isaes2011.org.uk/homes/mwilliam/Street2007.pdf

8.2 LAI from PAR Sensors

LAI can be estimated using a pair of PAR Sensors: an Incident PAR sensor above the canopy measuring irradiance falling on the vegetation, plus a Line PAR sensor measuring the averaged level of radiation reaching the ground below the canopy.

$$LAI=-(1/k)\ln(Qb/Qa)$$

where
Qa is an unobstructed PAR reading (PAR irradiance or PARi)
Qb is an average below-canopy PAR reading. (PAR line sensor measurement or PARlq)
k is the extinction coefficient

Ref: Canopy structure measurement by gap fraction analysis using commercial instrumentation
Jon M. Welles and Shabtai Cohen
Journal of Experimental Botany, Vol. 47, No. 302, pp. 1335-1342,1996
http://jxb.oxfordjournals.org/content/47/9/1335.full.pdf

k is often assumed to be close to 0.5, so the equation becomes:

$$LAI = -2 \times \ln(PARlq / PARi)$$

where:
PARlq is an averaged measurement from a line quantum sensor underneath the canopy
PARi is PAR irradiance

9 SKYE PRODUCTS FOR SPECTRAL REFLECTANCE

Skye Instruments have been specialising in Light and Radiation sensors since 1983. All are designed, manufactured and calibrated to the highest standards. Each is supplied with an individual Calibration Certificate traceable to the UK's National Physical Laboratory (NPL).

Sensors are available with Calibrated wavelength responses from 280nm (UV), through VIS and NIR to 2400nm (SWIR). There are thirteen popular models of fixed wavelengths, plus custom models where the wavebands are built and calibrated to the user's individual requirements.

The range includes single channel sensors and 2 and 4 multichannel radiometers. There is a choice of sensor design for Irradiance / Incident light measurements, and Radiance / Reflected light measurements, a pair of which is known as a Spectral Albedometer.

The Spectral Albedometers are used for measuring Spectral Reflectance. Solar Irradiance and Radiance from the observed area are measured simultaneously, minimising errors due to changing light levels throughout the day, making these sensors ideal for long term datalogging.

All Skye Light and Radiation sensors can be supplied as complete systems, with hand held SpectroSense2+ logging meters and GPS mapping, or with DataHog dataloggers for automatic recording. The sensors are also compatible with dataloggers from other manufacturers.

Skye sensors for use in Spectral Reflectance applications are as follows:

fPAR Measurements
fPAR can be recorded in two ways:

a)using the PAR Quantum sensor response in a multichannel spectral albedometer
Incident and Reflected PAR is measured simultaneously, the ratio of which calculates the fraction of PAR absorbed by the area under measurement
b)using NDVI sensors and the calculation fPAR = 1.24 * NDVI - 0.168
This calculation is available as standard in the Skye SpectroSense2+ meter

Information on these sensors can be found here:
PAR Quantum Sensor
NDVI Sensors

NDVI Measurements
NDVI sensors include 2 wavebands, in the Red and NIR wavelength regions.
A 2 channel spectral albedometer (which consists of a pair of Irradiance and Radiance

Information on these sensors can be found here:
[NDVI Sensors]
[SKR 1860 Sensors]

PRI Measurements
PRI sensors include 2 wavebands, in the 531nm and 570nm wavelength regions.
A 2 channel spectral albedometer (which consists of a pair of Irradiance and Radiance radiometers) is used to measure incident and reflected light simultaneously.
Individual measurements from all 4 channels are recorded separately, and the PRI calculation is available as standard in the Skye SpectroSense2+ meter

Information on these sensors can be found here:
[PRI]
[SKR 1860 Sensors]

Other Wavelengths and Vegetation Indices
Skye custom sensors can be matched to the wavebands of a particular satellite for Ground Truth measurements. Multichannel spectral albedometers can be fitted with up to 4 different wavebands, allowing several VIs to be calculated using one pair of sensors. For example:
a) A 2 channel albedometer with Red and NIR wavebands can calculate:
NDVI, RVI, fPAR, EVI2, MSAVI2 and LAI
b) A 2 channel albedometer with 531nm and 570nm wavebands can calculate PRI
c) A 4 channel albedometer with Red, NIR, 531nm and 570nm wavebands can calculate:
NDVI, PRI, RVI, fPAR, EVI2, MSAVI2 and LAI
d) A 2 channel albedometer with 900nm and 970nm wavebands can calculate WBI
e) A 4 channel albedometer with MODIS Blue, Red, NIR, and PAR wavebands can calculate:
NDVI, RVI, fPAR, MODIS EVI, EVI2, MSAVI2 and LAI

Information on these sensors can be found here:
[SKR 1860 Sensors]
[Landbased Systems]

SpectroSense2+ Logging Meter
This Skye meter is an 8 channel display meter, with automatic datalogging and GPS mapping functions. It has a 4 line display for easy viewing of data from a pair of multichannel radiometers or albedometers. Sensors can be easily interchanged using the configurable sensor library.
The following Vegetation Indices can be displayed live on screen:
NDVI, PRI, fPAR, RVI, WBI, EVI, EVI2, MSAVI2, LAI from PAR sensors, LAI from NDVI sensors

Information on these meters can be found here:
SpectroSense2+ meter

DataHog Datalogger

The Skye DataHog is a 16 channel datalogger designed specifically for light and radiation sensors. It is robust and waterproof, and can be linked to a GPRS remote communications module for automatic upload to a web site. Up to 8 wavebands of Irradiance and Radiance measurements can be recorded simultaneously. Multichannel spectral albedometers with wavebands in the SWIR region can also be recorded using the DataHog, allowing calculations of other VIs as well, such as NDSI.
Information on these dataloggers can be found here:
DataHog2
DataHog2 with SD storage
GPRS Option

Published Scientific References
Skye's sensors and systems have been used in Remote Sensing for many years, and the research they have contributed to has been published many times, in a variety of different scientific journals. Please click the link below to view a selection:
Scientific References

7 SKYE INSTRUMENTS LTD

Skye Instruments Ltd has been designing and manufacturing instrumentation for Environmental Monitoring, Plant Growth and Agricultural Research since 1983. The Company started on the Isle of Skye, Scotland and re-located to Wales in 1986.

We have a world-wide reputation for producing high quality instruments which stand up to life in the field, and for having excellent customer relationships. Although we are based in Wales, UK, we have representation in many countries as well as selling direct.

In 2009, Skye became an Employee-Owned Company. Skye has adopted the 'John Lewis' model whereby shares of the company are held in a trust, an Employee Benefit Trust. All employees are equal owners and benefit from profit-sharing.

Quality Policy

The Company recognises that its performance must be of a consistently high standard to secure the satisfaction, confidence and loyalty of its customer base.
It is the Policy of Skye Instruments Limited to satisfy all customers by offering a high standard of personal attention by trained and courteous employees.
It is the Policy of Skye Instruments to develop, produce and market high quality, precision instrumentation for environmental, botanical and laboratory use. The aim is to provide a first class product and service that fully satisfies the initial and continual needs and expectations of all customers.

Environmental Philosophy

Skye are an environmentally aware Company and strive to ensure our business activities have the minimum possible adverse impact on the environment. We are proud of the fact that many of our products will be used to improve the natural environment around the world by increasing the understanding of natural events and minimising damage caused by human activities.

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