

# **Vegetation Indices**

Enhancing green vegetation  
using mathematical equations  
and transformations

# What is a “vegetation index”?

- Some mathematical combination or transformation of spectral bands that accentuates the spectral properties of green plants so that they appear distinct from other image features.



NDVI Anomaly, Kenya, January 2009

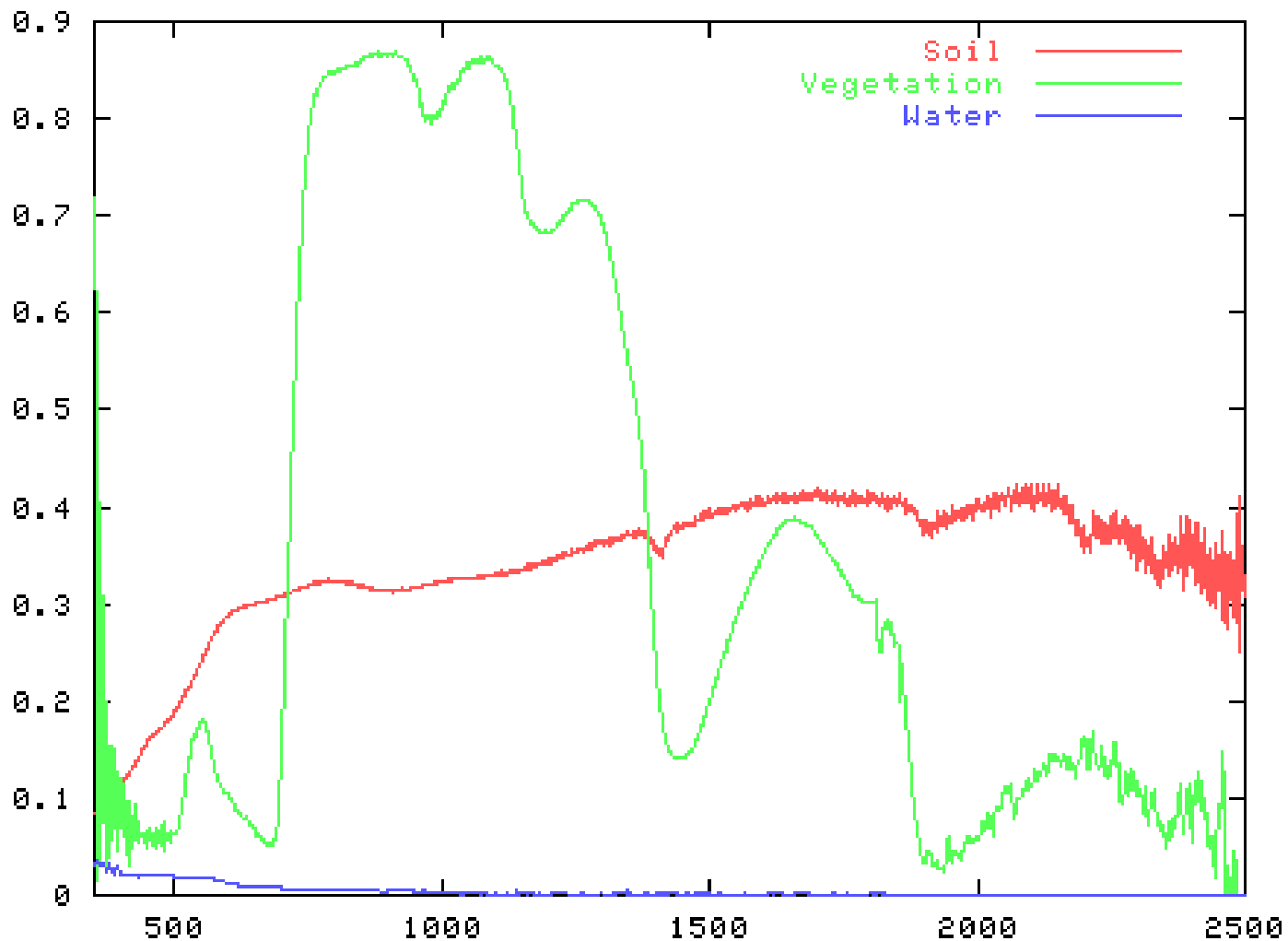
# What Should Vegetation Indices Do??

- Indicate the AMOUNT of vegetation (*e.g.*, %cover, LAI, biomass, *etc.*)
- Distinguish between soil and vegetation
- Reduce atmospheric and topographic effects if possible

# How is Vegetation Spectrally Distinct?

- Reflectance in individual wavelength regions (bands)?
- Shape of spectral curve created by looking at more than one wavelength regions?
- Changes in spectral curves with amount of vegetation?
- Others?

# Vegetation vs. Soil and Water



# Soil Reflectance

- Can be bright in NIR (like vegetation)
  - dry soil especially bright
  - wet soil much darker than dry soil
- Soil can have low red reflectance (like vegetation)
- BUT...the **DIFFERENCE** between NIR reflectance and Red reflectance for soil is much less than for live vegetation! (**shape** of curve)

# Points to Note: Soils

- Soil components that affect spectral reflectance can be grouped into three components:
  1. Colour
  2. Roughness
  3. Water content



# Points to Note: Soils

- Variation in any one soil parameter can give rise to a line on a 2D scattergram.
- For RED-NIR scattergrams, this is termed the “soil line”, and is used as a reference point in most vegetation studies.

# Points to Note: Vegetation Indices

- There are three types of vegetation Index available:
  1. Simple, Intrinsic Indices
  2. Indices which use a soil line
  3. Atmospherically Corrected Indices

# Points to Note: Vegetation Indices

- Within these, there have been four general approaches taken, based on the characteristics of the tasselled-cap.

1. measure the distance between where the pixel plots in the tasselled cap plot from the soil line. (The soil line is used because it is generally easier to find than the 100% vegetation point).

2. assume that the isovegetation lines all intersect at a single point.

3. recognise that lines do not intersect at a single point.

4. assume that the isovegetation lines are non-linear.

- Vegetation indices based on accentuating the DIFFERENCE between red and NIR reflectance in image pixels

# Difference Vegetation Index (DVI)

- Probably the simplest vegetation index
- $DVI = NIR - Red$ 
  - Sensitive to the amount of vegetation
  - Distinguishes between soil and vegetation
  - Does NOT deal with the difference between reflectance and radiance caused by the atmosphere or shadows

# Ratio-based Vegetation Indices

- Simplest ratio-based index is called the Simple Ratio (SR) or Ratio Vegetation Index (RVI)
- $SR = NIR/Red$ 
  - High for vegetation
  - Low for soil, ice, water, *etc.*
  - Indicates amount of vegetation
  - Reduces the effects of atmosphere and topography

# Why Simple Ratios Reduce Atmospheric and Topographic Effects

$$L_{NIR} = E_{NIR} t_{NIR} r_{NIR} / \pi$$

$$L_{Red} = E_{Red} t_{Red} r_{Red} / \pi$$

$$\text{So } L_{NIR} / L_{red} = \left( \frac{E_{NIR} t_{NIR} r_{NIR}}{\pi} \right) / \left( \frac{E_{Red} t_{Red} r_{Red}}{\pi} \right)$$

Largely eliminates irradiance from equation and  
therefore topography

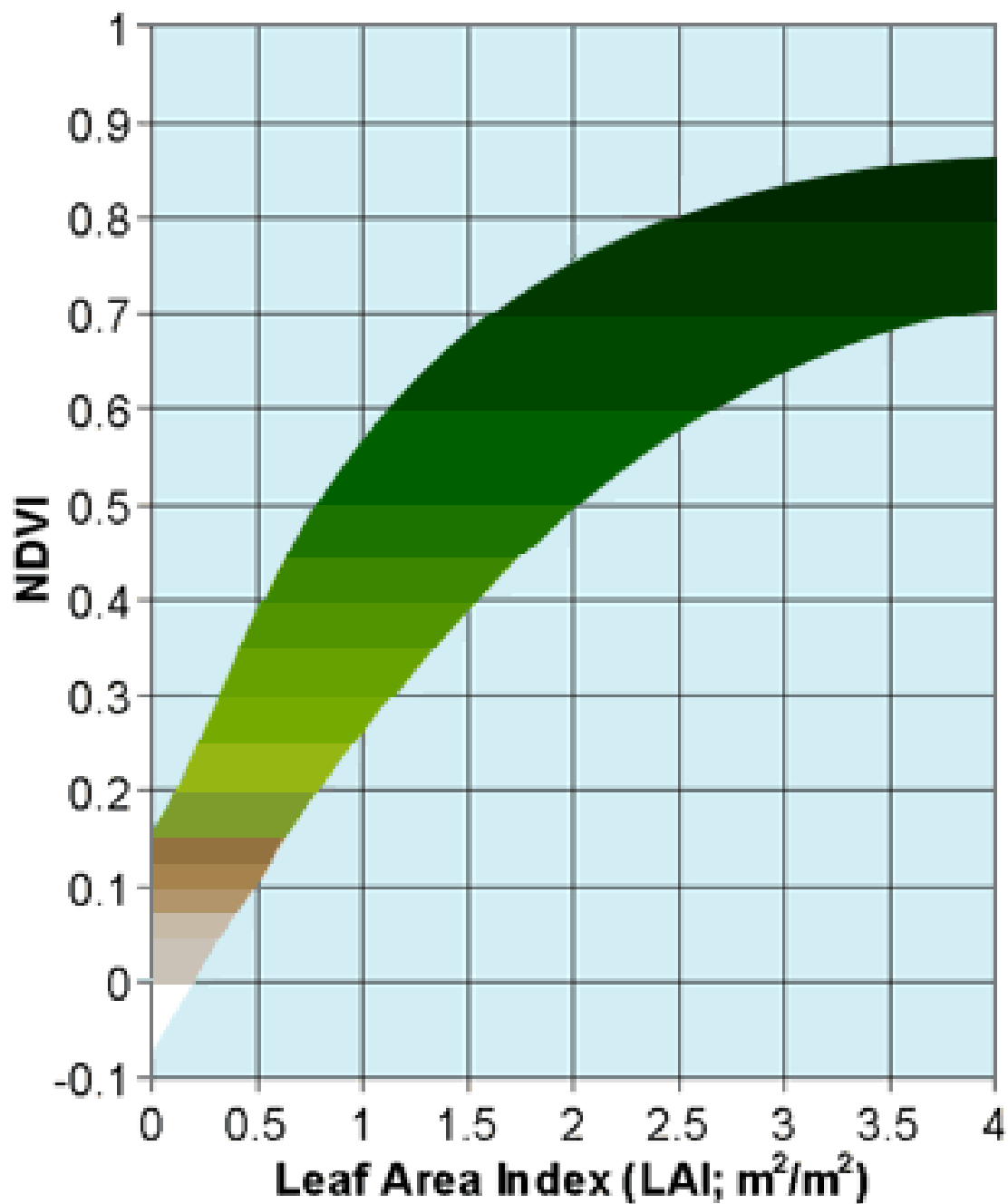
Largely eliminates transmittance and therefore  
atmospheric effects



# Normalized Difference Vegetation Index

- $NDVI = (NIR - Red) / (NIR + Red)$ 
  - Ranges from -1 to 1
  - Never (Rarely?) divide by zero
  - Indicates amount of vegetation, distinguishes veg from soil, minimizes topographic effects, *etc.*
  - A good index!
  - Does not eliminate atmospheric effects!

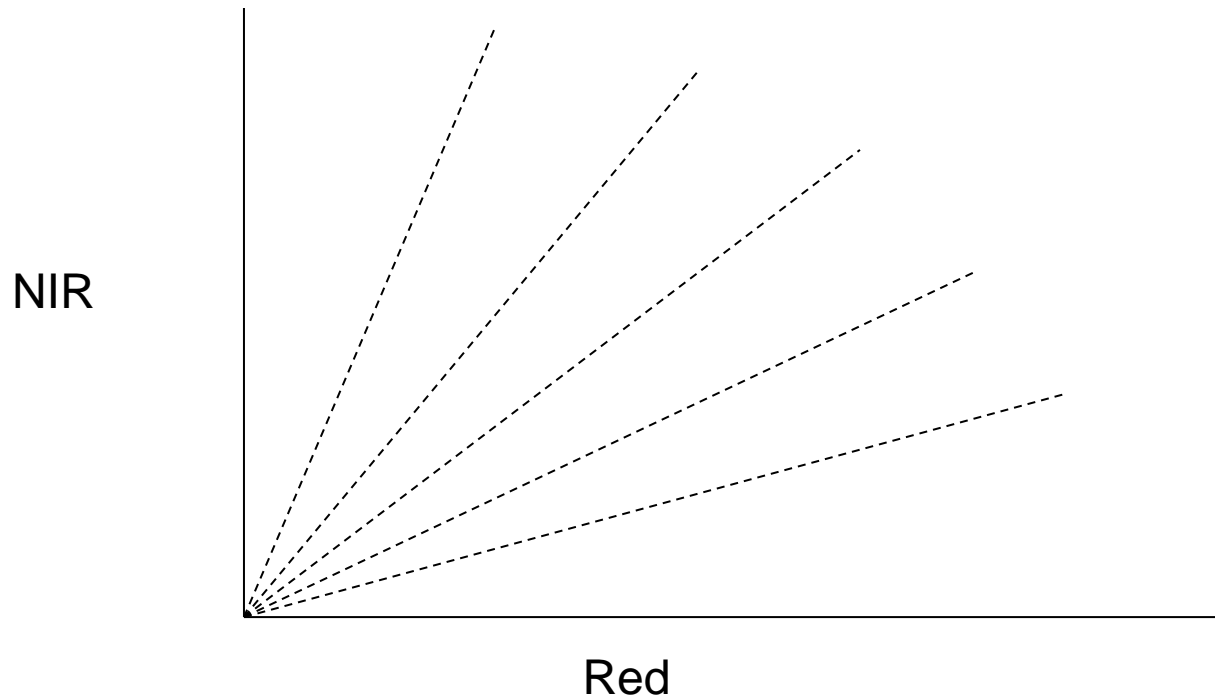
**NDVI vs LAI**



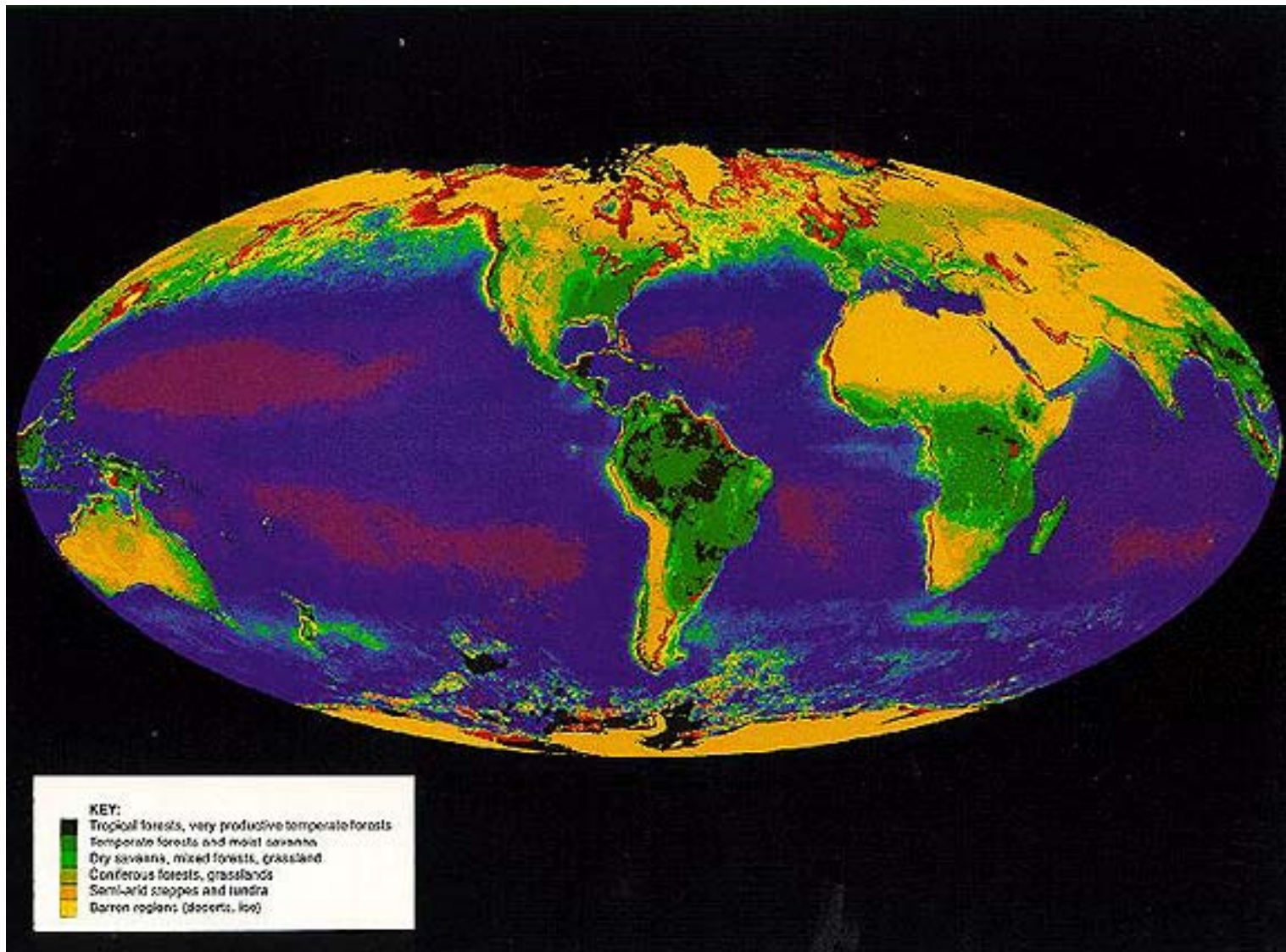
# Choosing an Algebraic Index

- Most difference indices fall short in terms of dealing with atmospheric and topographic effects
- Most ratio-based indices are functionally equivalent (work about the same)
- Some ratio-based indices are computationally “cleaner”
- NDVI is often the index of choice and generally performs pretty well, but you must be aware of potential issues

- Both RVI and NDVI basically measure the slope of the line between the origin of red-NIR space and the red-NIR value of the image pixel.



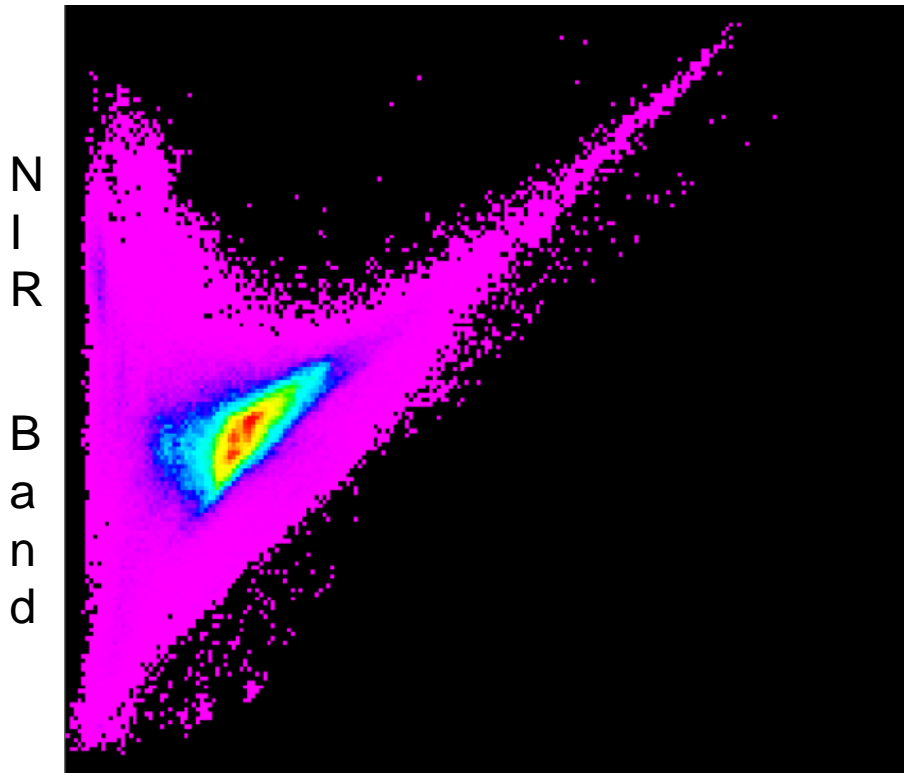
# NDVI



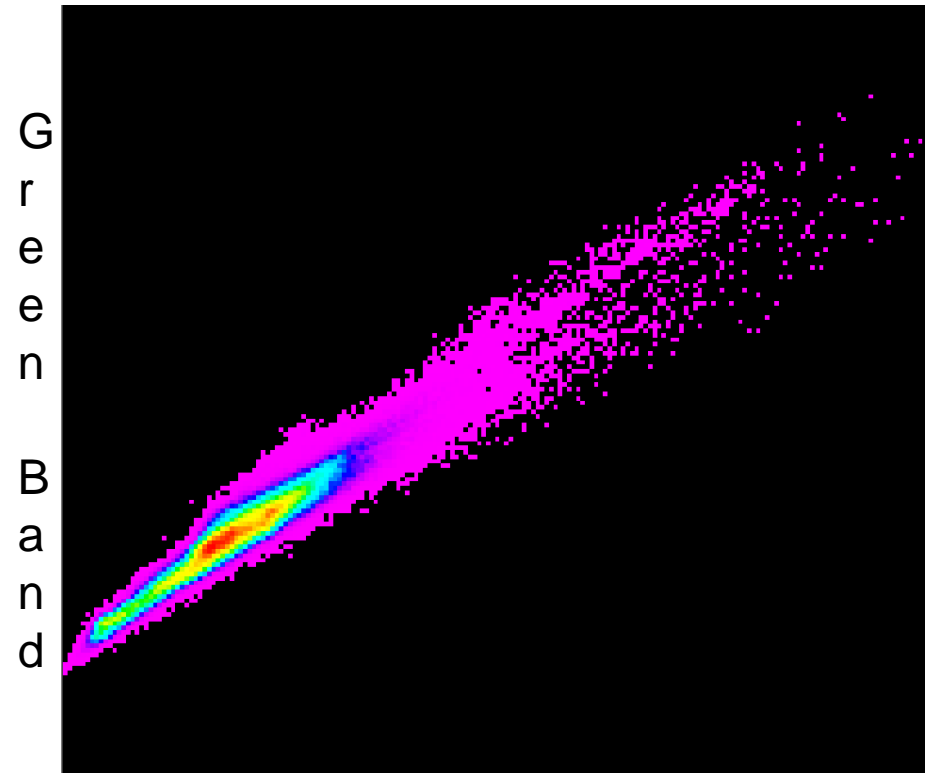
# Feature Space Transformations

- Also called “band space”
- Difficult to visualize because feature space is  $n$ -dimensional (where  $n$  is the number of bands)
- Can mathematically manipulate feature space to find areas that contain lots of spectral information
- Examples are Principal Components Analysis (PCA), Kauth’s Tasseled Cap, Perpendicular Vegetation Index (PVI), and many more

# What is a feature space??



Red Band



Blue Band

# Why is feature space useful?

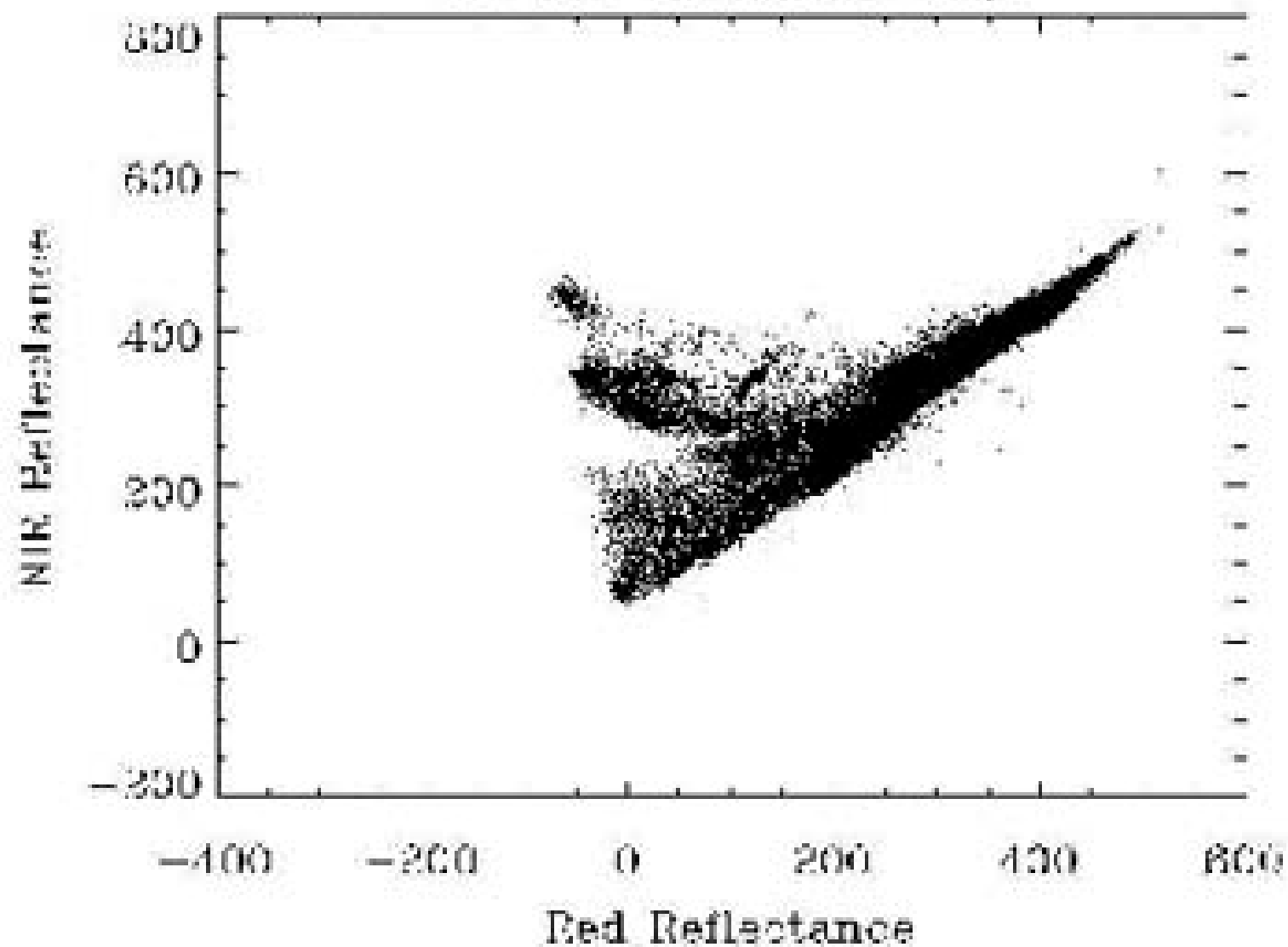
- A way to visualize pixel data – a different way to see information
- Can transform or analyze a feature space mathematically to isolate groups of pixels that may be related



# Creating Feature Space Graphs

- Each axis represents DNs from one satellite band; Multiple axes = multiple bands
- Can plot each pixel in the feature space from an image using its DNs
- Can do “automatically” in most image processing software (e.g., Erdas)
- Can also use statistical and other software tools to do this.

AV NIR Tasseled Cap

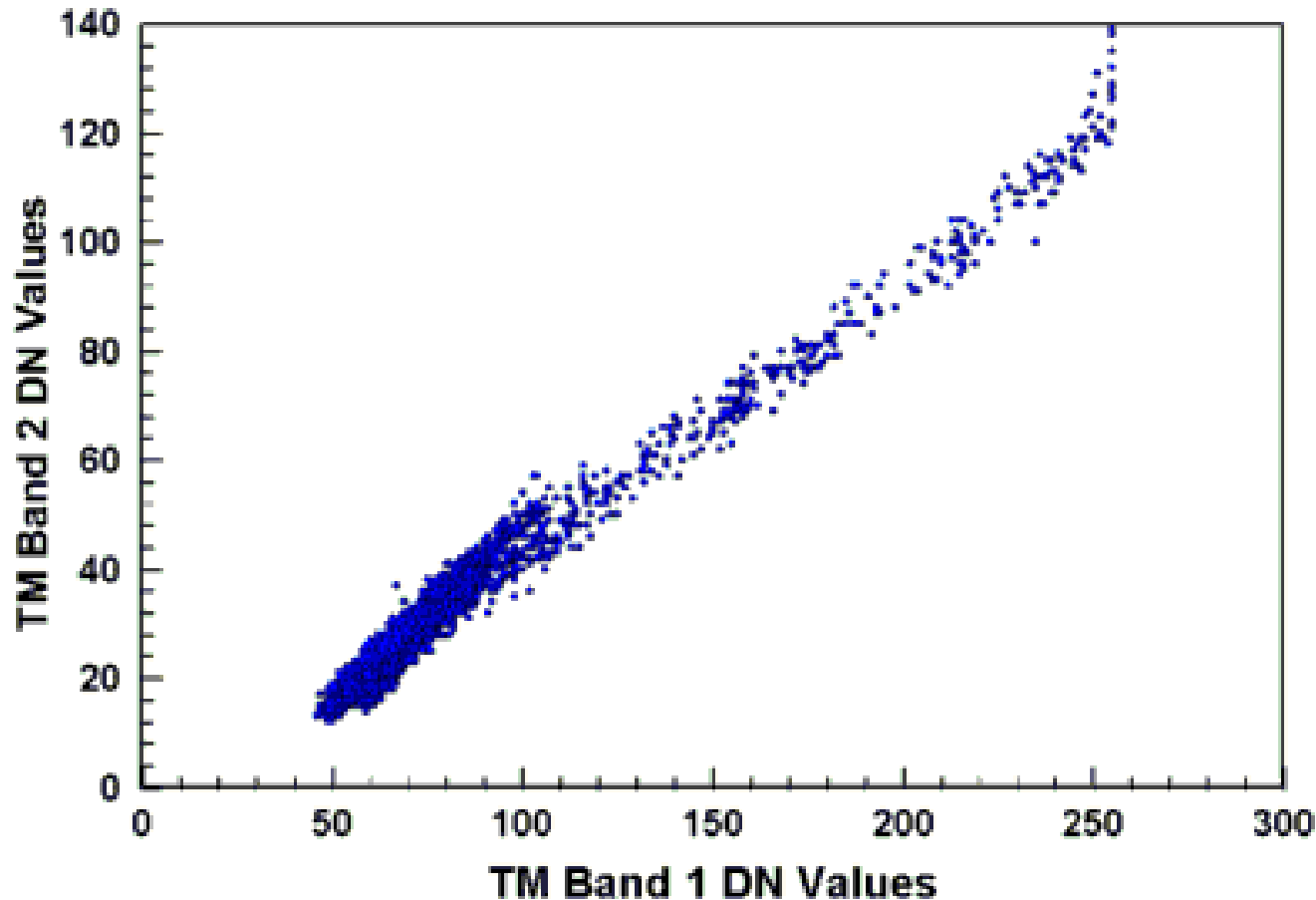


# Principal Components Analysis (PCA)

- Transforms the original satellite bands into new “bands” that isolate important parts of the data (e.g., vegetation).
- Principal component axes (PCs) must be perpendicular to one another
- First 3 PCs usually contain the most useful info
- Other PCs sometimes useful for highlighting some features
- PC2 is usually a good vegetation index

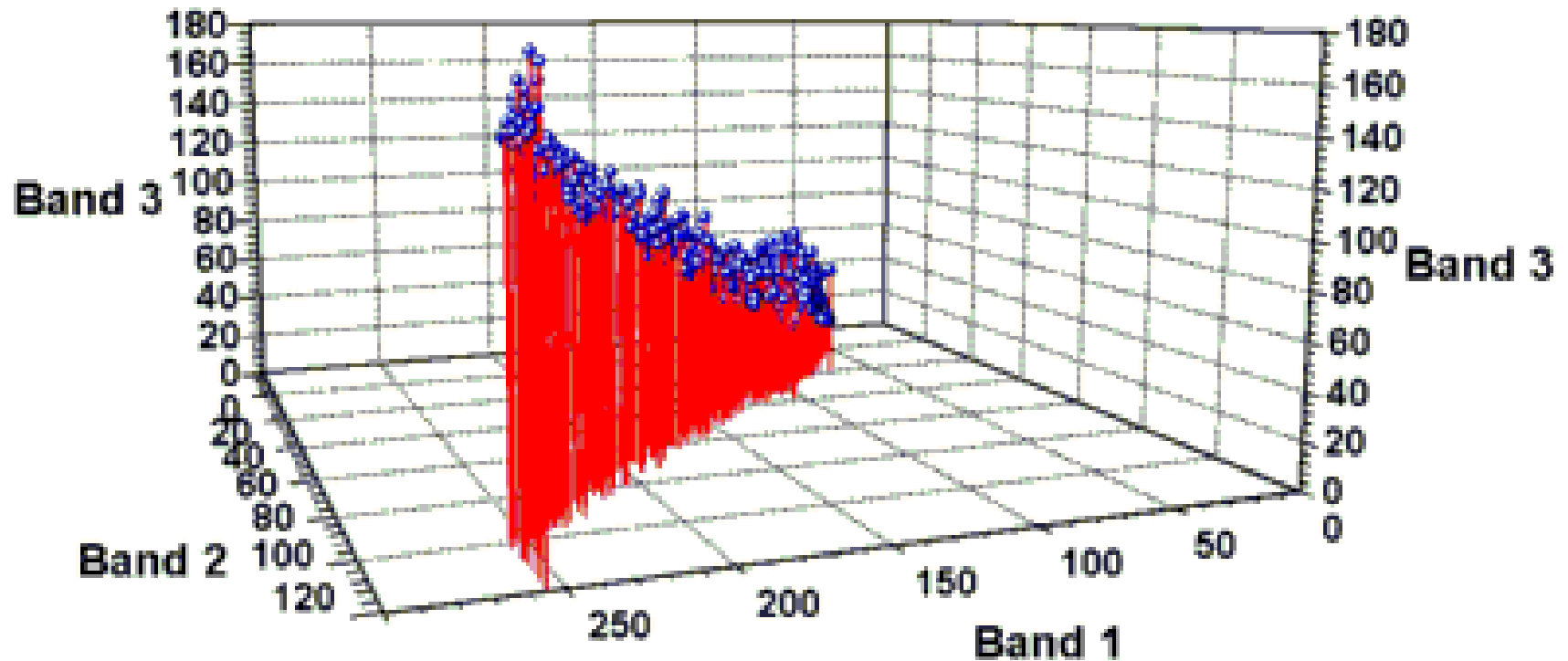
# Principal Components – 2 bands

**Plot Band 1 vs. Band 2  
from TM Scene of Morro Bay**



# Principal Components – 3 bands

**Plot of Bands 1, 2 and 3 of Morro Bay Scene**



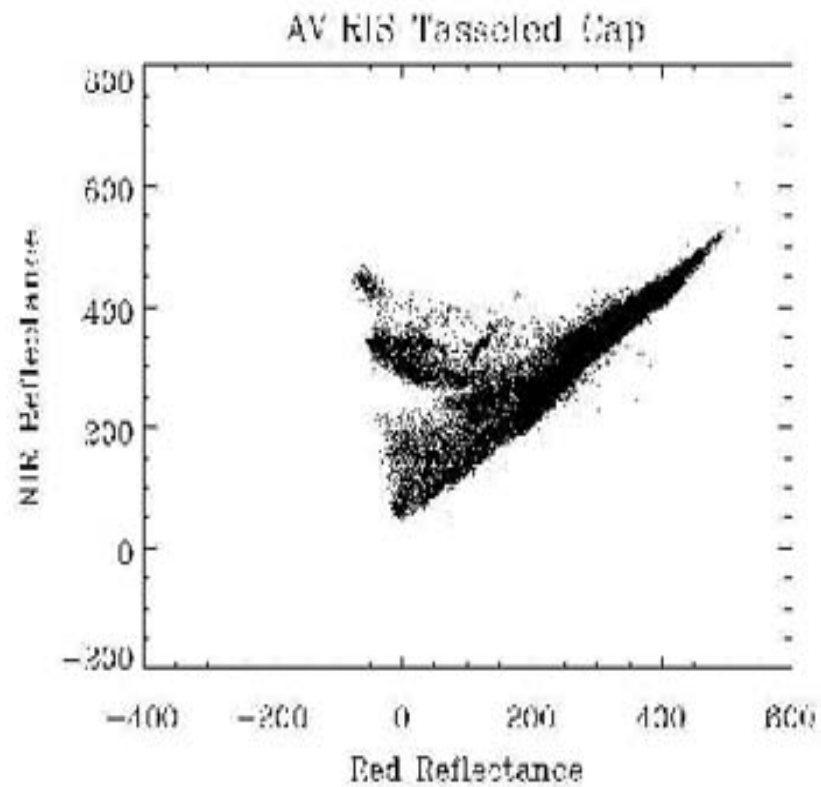
# Kauth's Tasseled Cap

- Like PCA but axes don't have to be perpendicular to each other
- 1<sup>st</sup> axis oriented towards overall scene brightness (brightness)
- 2<sup>nd</sup> axis oriented towards vegetation greenness (greenness)
- 3<sup>rd</sup> and 4<sup>th</sup> axes often called “wetness” and “yellowness” – less useful than first two.

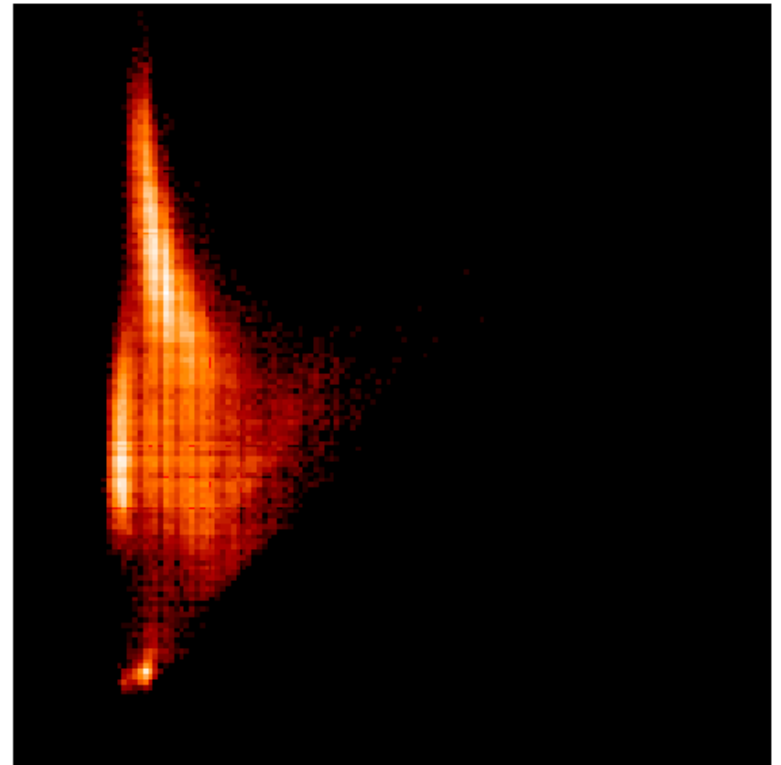
# Tasseled Cap (cont.)

- Fits all the criteria for a good vegetation index
- Almost as widely used as the NDVI
- Excellent index

# Tasseled Cap



Near infrared



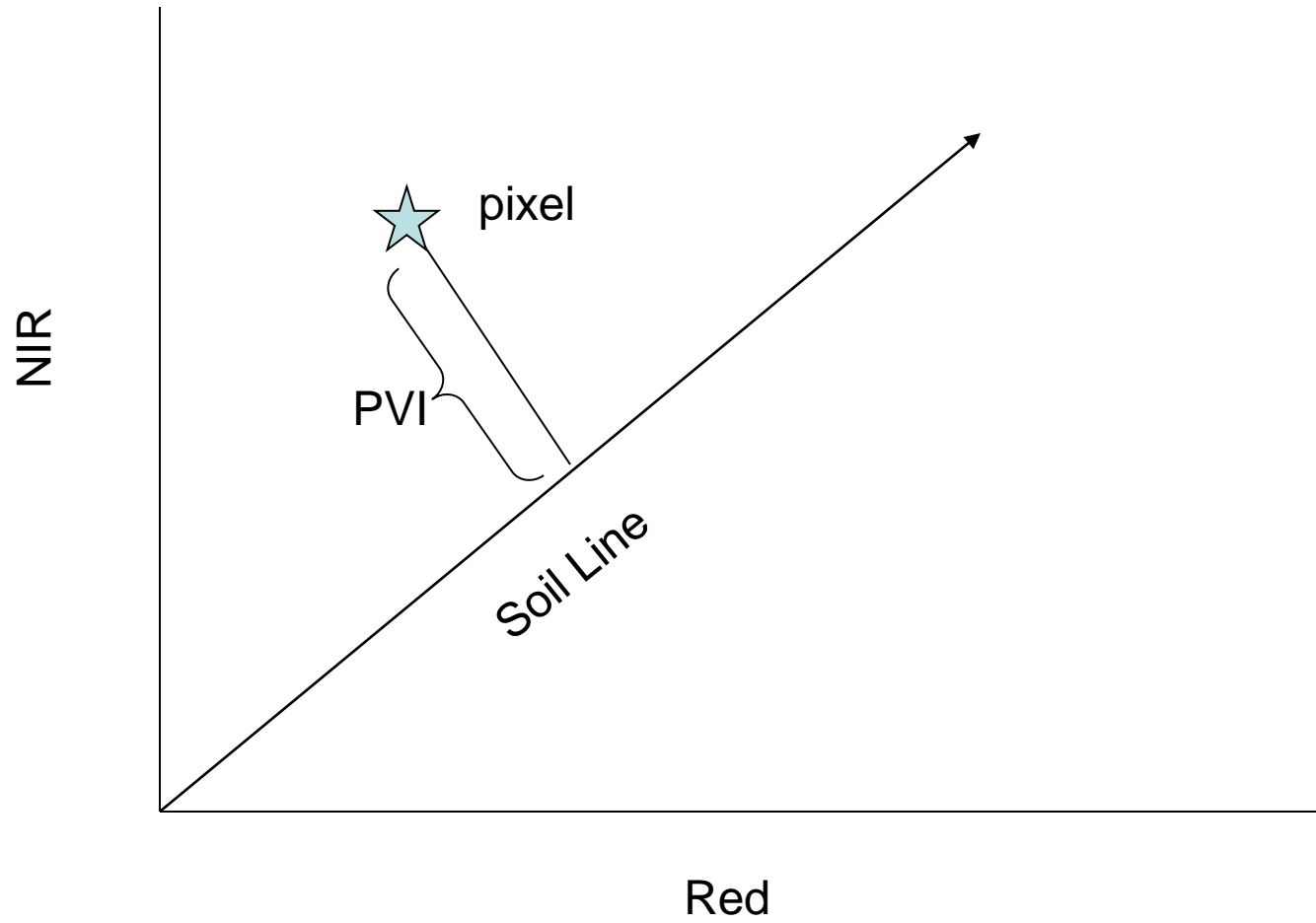
Red

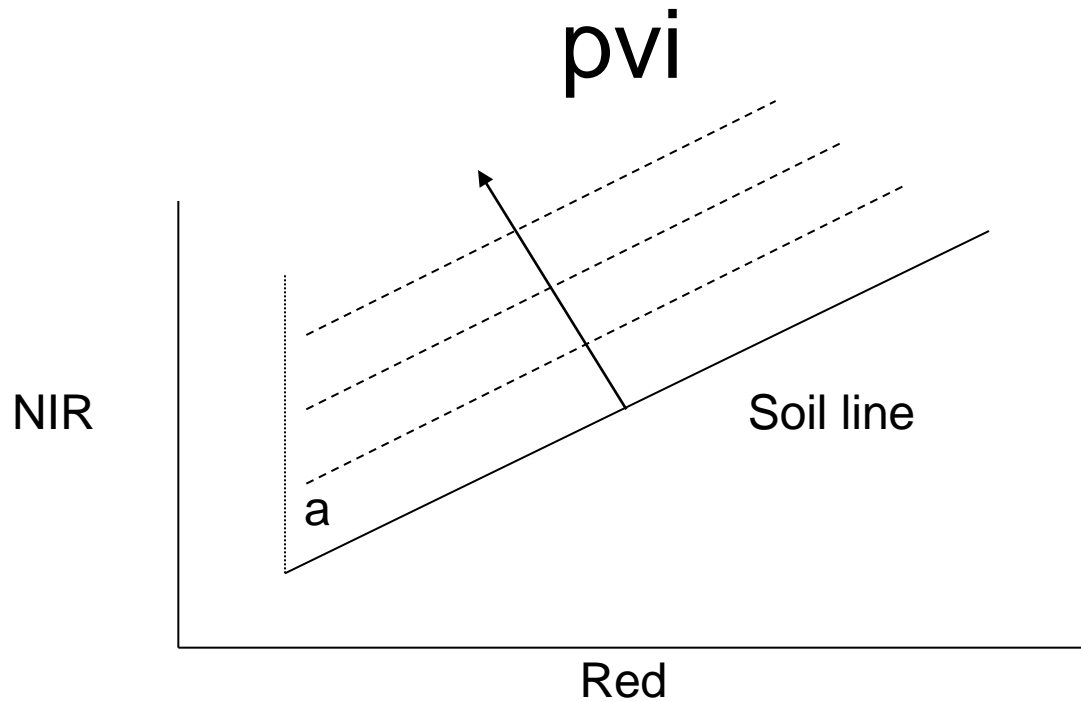


# Perpendicular Vegetation Index (PVI)

- Similar to Tasseled Cap Greenness and 2<sup>nd</sup> Principal Component
- Distance from soil line to pixel plotted in Band 3 – 4 feature space

# PVI





- Perpendicular vegetation index (PVI) of Richardson and Wiegand (1977)

$$PVI_{NIR\ red} = -\sin a (NIR) \cos a (red)$$

- where (NIR) is the near-infrared reflectance, (red) is the red reflectance and (a) is the angle between the soil line and the near-infrared axis.

# IPVI

- Crippen (1990) recognized that the red radiance subtraction in the numerator of NDVI was irrelevant, and he formulated the infrared percentage vegetation index (IPVI):

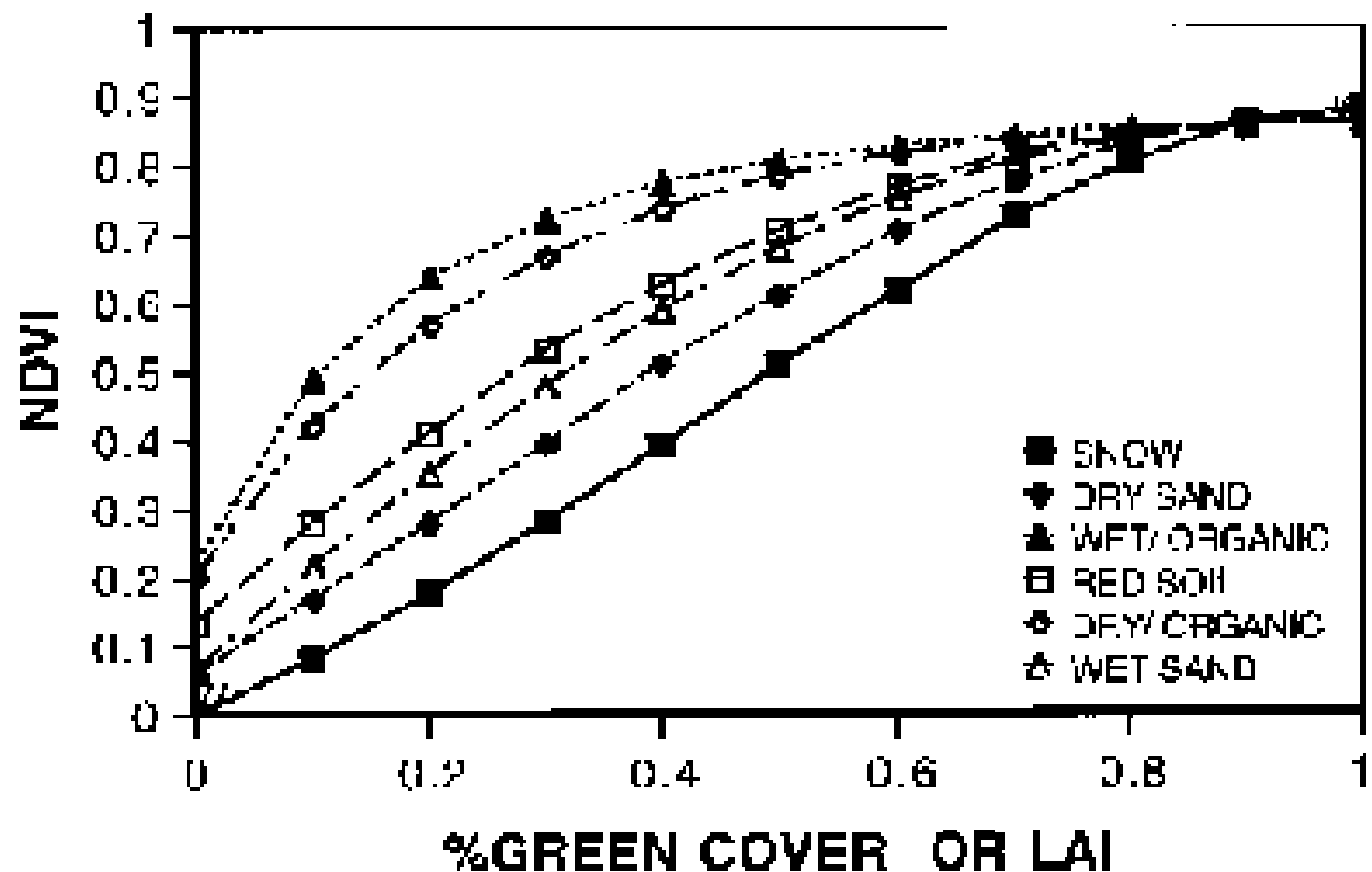
$$\text{IPVI} = \frac{\text{NIR}}{\text{NIR} + \text{RED}} = \frac{1}{2} (\text{NDVI} + 1)$$

- IPVI is functionally equivalent to NDVI and RVI, but it only ranges in value from 0.0-1.0.
- It also eliminates one mathematical operation per image pixel which is important for the rapid processing of large amounts of data.

# Soil Background Effects

## CASE 2 SINGLE LAYER SHRUBS

TRANSMISSIVE LEAVES



**Table 9: Red-NIR Soil Line Parameters for AVIRIS Data Sampled at Different Band-passes**

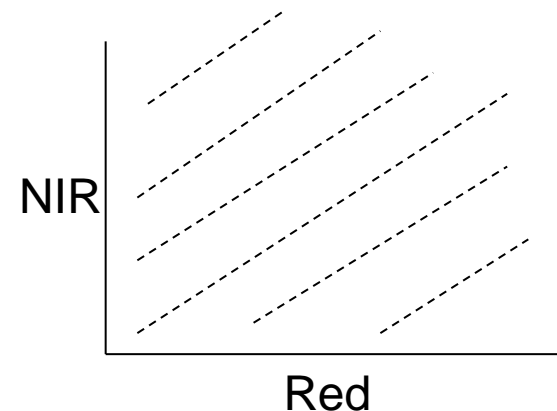
<b>Instrument Simulated</b>	<b>Red Band-pass (μm)</b>	<b>NIR Band-pass (μm)</b>	<b>Slope</b>	<b>Intercept</b>
<b>MSS</b>	<b>0.6-0.7</b>	<b>0.8-1.1</b>	<b>0.9034</b>	<b>52.95</b>
<b>TM</b>	<b>0.63-0.68</b>	<b>0.8-0.9</b>	<b>0.7939</b>	<b>71.39</b>
<b>AVIRIS</b>	<b>0.674</b>	<b>0.755</b>	<b>0.8863</b>	<b>55.00</b>

# Indices get “tuned” to try to reduce these problems.

- *E.g.*, Soil Adjusted Vegetation Index (SAVI)
  - Uses a soil background “fudge factor”

$$SAVI = [(NIR - Red)/(NIR + Red + L)] * (1 + L)$$

L is a soil fudge factor that varies from 0 to 1 depending on the soil. Often set to 1.



# TSAVI

- A further development of this concept is the transformed SAVI (TSAVI) Baret and Guyot, 1991), defined as

$$\text{TSAVI} = a(\text{NIR}-aR-b)/[R=a(\text{NIR}-b) + 0.08(1+a^2)]$$

- Where a and b are, respectively, the slope and intercept of the soil line ( $\text{NIR}_{\text{soil}} = aR_{\text{soil}} + b$ ), and the coefficient value 0.08 has been adjusted to minimise soil effects



# MSAVI

- Qi et al. (1994a) further developed a vegetation index which is basically a version of SAVI where the L-factor is dynamically adjusted using the image data.
- They referred to this index as the Modified Soil Adjusted Vegetation Index or MSAVI. The factor L is given by the following expression:

$$L = 1 - (2 \times \text{slope} \times \text{NDVI} \times \text{WDVI})$$

- where WDVI is the Weighted Difference Vegetation of Clevers (1988) which is functionally equivalent to PVI and calculated as follows

$$\text{WDVI} = \text{NIR} - (\text{slope} \times \text{RED})$$

- Qi et al. (1994a) also created an iterated version of this vegetation which is called MSAVI2:

$$\text{MSAVI2} = 1/2 * ((2 * (\text{NIR} + 1)) - (((2 * \text{NIR}) + 1)^2 - 8(\text{NIR} - \text{red}))^{1/2}).$$

# Atmospherically Corrected Indices

$$ARVI = (NIR - RB) / (NIR + RB)$$

- Where RB is a combination of the reflectances in the Blue (B) and Red (R) channels:

$$RB = R - \gamma (B - R)$$

- And  $\gamma$  depends on the aerosol type (a good value is  $\gamma = 1$  when the aerosol model is not available)
- The authors emphasise the fact that this concept can be applied to other indices. SAVI can be changed to SARVI by changing R to RB.

# Atmospherically Corrected Indices

- Pinty and Verstraete, (1992) proposed a new index to account for soil and atmospheric effects simultaneously.
- This is a non-linear index called GEMI:

$$\text{GEMI} = n(1-0.25n) - (R-0.125)/(1-R)$$

Where  $n =$

$$[2(\text{NIR}^2 - R^2) + 1.5\text{NIR} + 0.5R] / (\text{NIR} + R + 0.5)$$

- This index is seemingly transparent to the atmosphere, and represents plant information at least as well as NDVI – but is complicated, and difficult to use and interpret.

# Which One to Use ?

- In a simulation study, Rondaux et al., (1996) found that an optimised SAVI (OSAVI), where the value of  $X$  was tuned to 0.16 easily out-performed all other indices for application to agricultural surfaces.
- They found that a locally tuned SAVI (MSAVI) was more appropriate for all other applications.
- However, in Niger, Leprieur et al (1996) found GEMI to be less sensitive to the atmosphere – however, they found it incapable of dealing with variations in soil reflectance.
- They suggest that the use of MSAVI with an accurate atmospheric correction is essential or perhaps using a combination of GEMI and MSAVI.

# Overall

- One important difficulty which has been encountered in using the vegetation indices which attempt to minimize the effect of a changing soil background is an increase in the sensitivity to variations in the atmosphere (Leprieur et al., 1994; Qi et al., 1994b).
- There have been several approaches in the development of vegetation indices which are less sensitive to the atmosphere, such as the Atmospherically Resistant Vegetation Index (ARVI) of Kaufman and Tanré (1992) and the Global Environmental Monitoring Index (GEMI) of Pinty and Verstraete (1991).

# Overall contd.

- Chehbouni has data demonstrating that GEMI is highly sensitive to soil noise.
- Qi et al. (1994b) demonstrated that soil noise caused GEMI to violently break down at low vegetation covers, and that all of the vegetation indices designed to minimize the effect of the atmosphere have increased sensitivity to the soil, which makes these indices completely unsuitable for arid regions.

# Creating Your Own Spectral Indices

- Can create custom indices to highlight anything that makes spectra unique
- Can use temporal data just like you use spectral data
- Can build indices for any material, not just vegetation

# Vegetation Index Summary

- Vegetation Indices should highlight the amount of vegetation, the difference between vegetation and soil, and they should reduce atmospheric effects
- Soil background effects should be minimized if possible
- Indices can be customized for particular applications