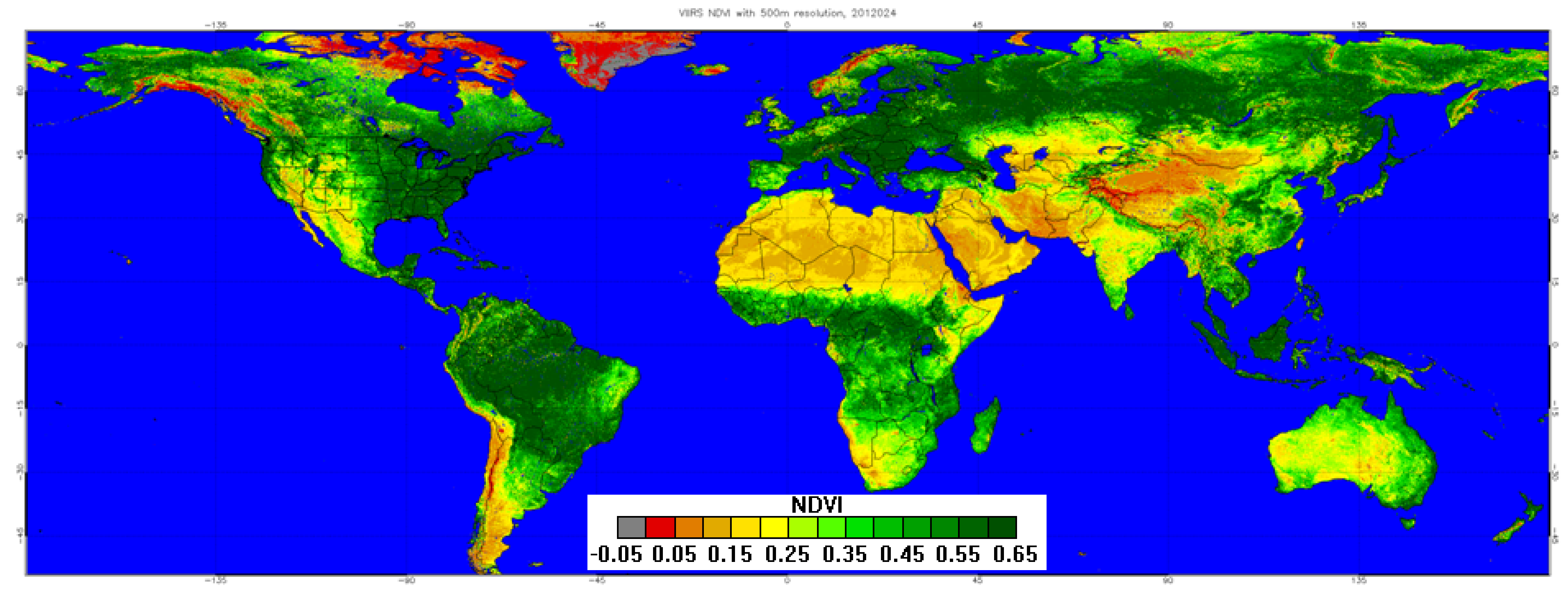
Vegetation indices



From pictures to data

- So far, we have focused on visualization
  - Using false color to see things that are otherwise invisible
- When we derived geospatial data from images, it was through manual interpretation
  - Digitizing land cover polygons
- We will now start to use LandSat images to derive measurements of properties of the land cover
- We will focus in vegetation indices, with a focus on the Normalized Difference Vegetation Index (NDVI)

The information in LandSat layers

- Each layer is an 8 bit grayscale image
  - Single wavelength band
  - Integer numbers from 0 to 255 (**digital numbers**, or DN)
  - Relative scale, no units
- No different from a single channel from an RGB digital photograph
- To use the data for display, and for some types of change detection, this is fine
- To calculate some important quantities (like greenness of vegetation), need to convert DN's to radiance or (better still) reflectance

Radiance and reflectance

- Remote sensing instruments actually measure **radiance**
  - Amount of light the instrument captures
  - Affected by the properties of objects on the ground, but also by intensity and direction of illumination (angle of the sun, amount of atmospheric interference, etc.)
  - Measure of energy, with units watts/steradian/m^2
- We want to know **reflectance**
  - Ratio of light leaving a target to the amount of light striking the target
  - As a ratio, it's unitless
  - This is a property of the objects
- Radiance can be converted to reflectance with some corrections for angle of the sun, etc. based on **metadata** included with the image

Converting DN to radiance

- Radiance was recorded by the satellite, but was converted to a DN for distribution – need to convert back to radiance
- Radiance for a given band (L_λ) is linearly related to DN, and the conversion is:

  $L_\lambda = (gain_\lambda \times DN) + bias_\lambda$

- DN comes from the image, and the gain and bias coefficients are functions of the sensors – they are constants, and are known for each band

Converting radiance (L_λ) to reflectance (R_λ)

- Reflectance can be calculated from radiance by accounting for the sun-earth distance (d), the radiance emitted by the sun for each band ($E_{sun,\lambda}$), and the solar elevation angle (Θ_{SE})

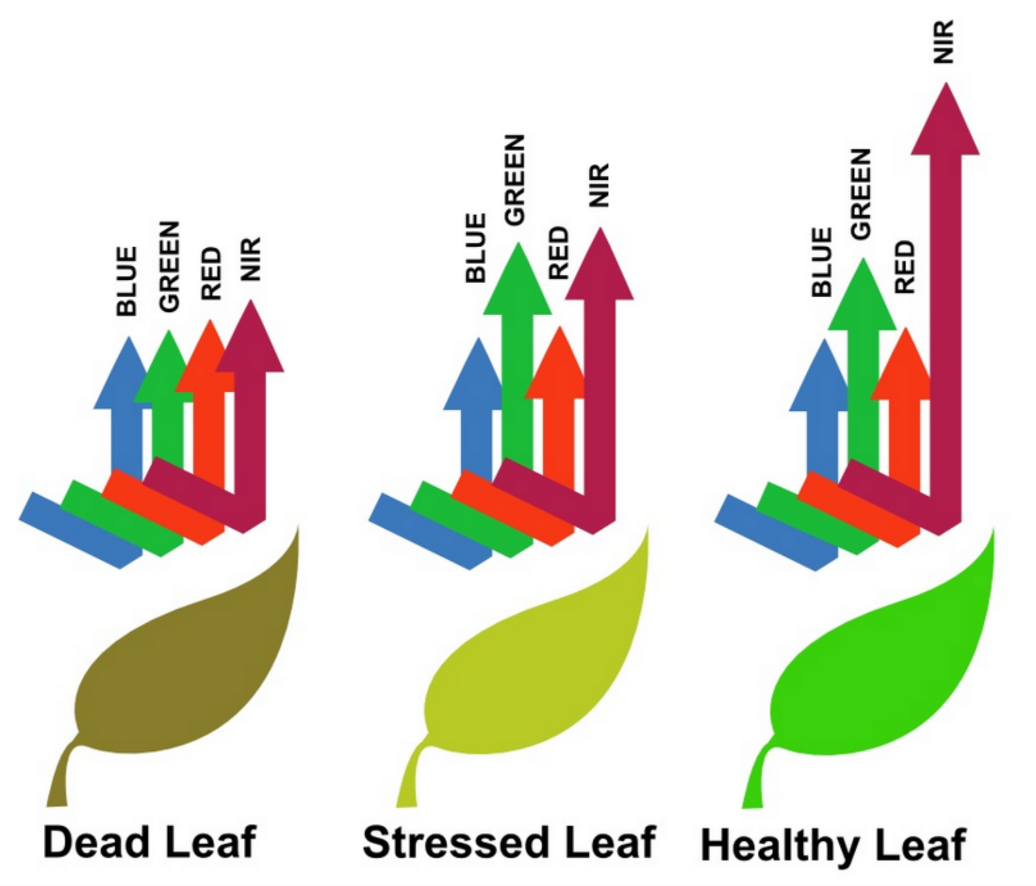
$$R_\lambda = \frac{\pi L_\lambda d^2}{E_{sun,\lambda} \sin(\Theta_{SE})}$$

- The sun-earth distance (in astronomical units) depends on the date of acquisition, and is known
- The radiance emitted by the sun for a wavelength band is known
- The solar elevation angle depends on when and where the image was taken, and is reported in the metadata for the image
- Once calculated, reflectance can be used to calculate a vegetation index, which are relative masures of vegetation photosynthetic activity (i.e. **greenness**)

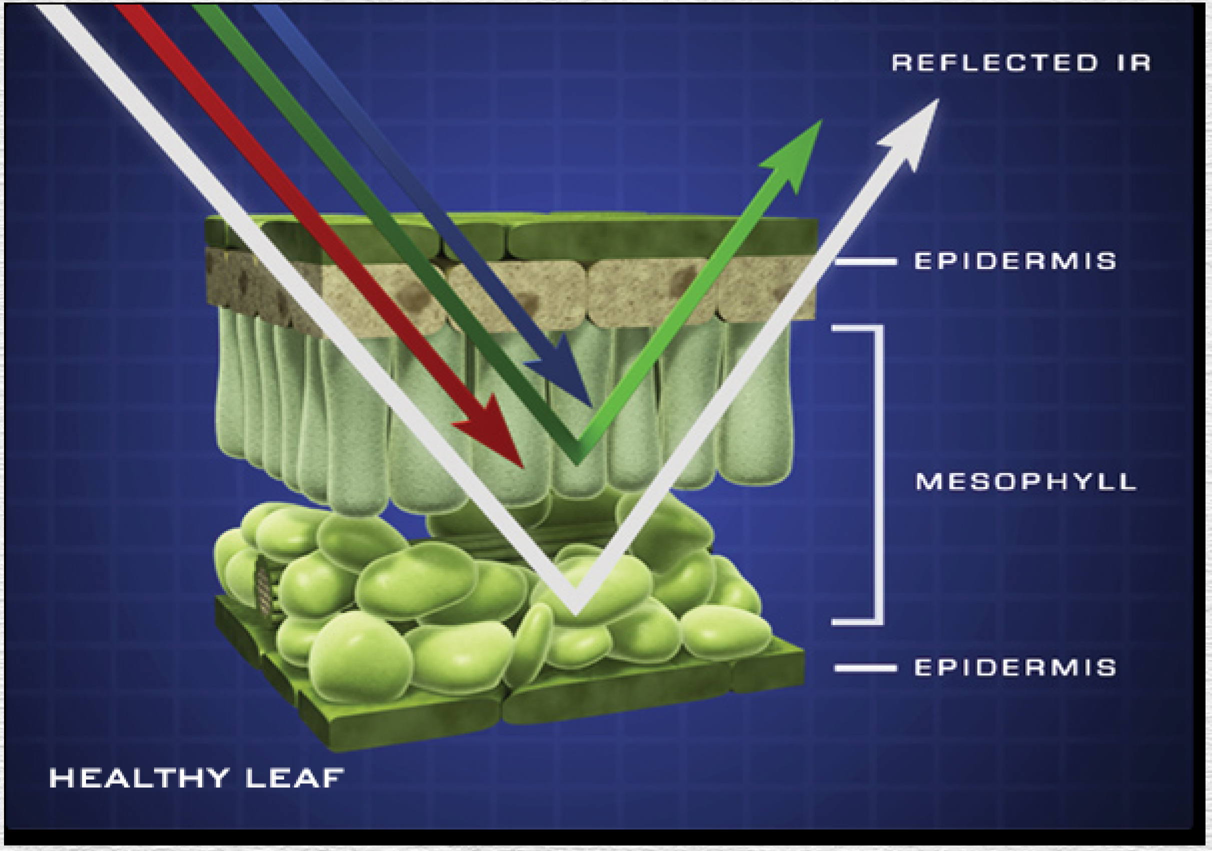
Greenness: the principle

- Band reflectance is different for leaves in different conditions
- We can use differences in reflectance between bands to get a relative measure of photosynthetic activity

Band 3
Band 4



Healthy vegetation



Healthy leaf: chlorophyll absorbs blue and red light for photosynthesis, reflects visible green

Spongy mesophyll reflects near IR

Greenness ≠ green light reflectance

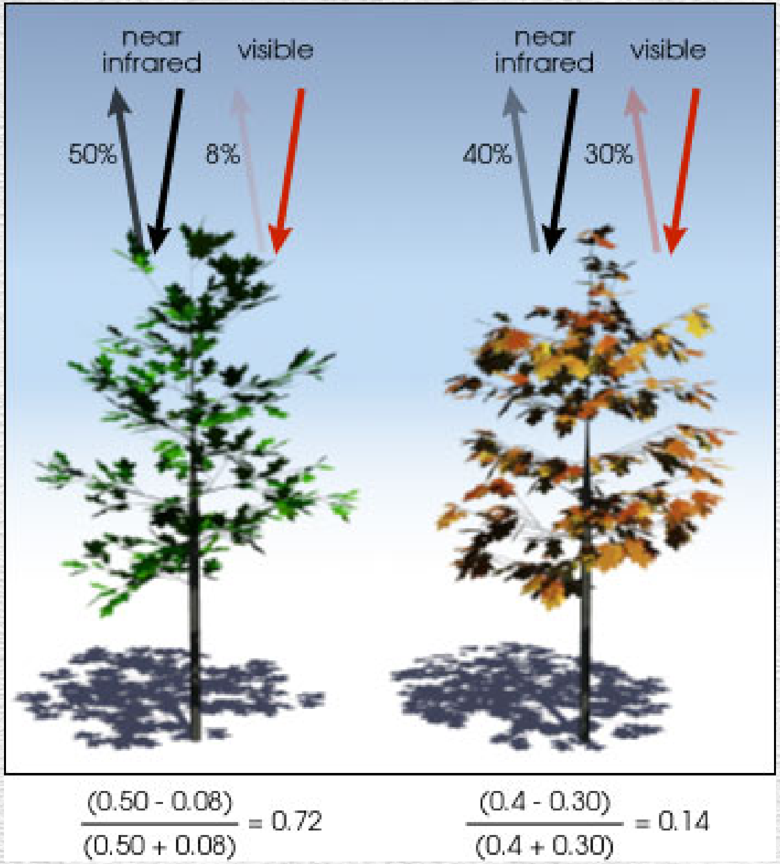
- Greenness of vegetation = health, photosynthetic activity
- We don’t use the green visible band for this – why?
- Greenness is based on reflectance of near infrared radiation, compared with red visible light → the Normalized Difference Vegetation Index (NDVI)

NDVI

- The formula is:

$$NDVI = \frac{\mathrm{NIR} - \mathrm{Red}}{\mathrm{NIR} + \mathrm{Red}}$$

- Can use DN, reflectance, or radiance, but reflectance is best
- NDVI falls between -1 and 1
- Values below 0.1 are typically barren, unvegetated
- Values between 0.2 and 0.3 are typically grass or shrub
- Values between 0.6 and 0.8 are temperate or tropical rainforest (wet, broad-leaved)



November NDVI for a small piece of your map

NDVI is a single number

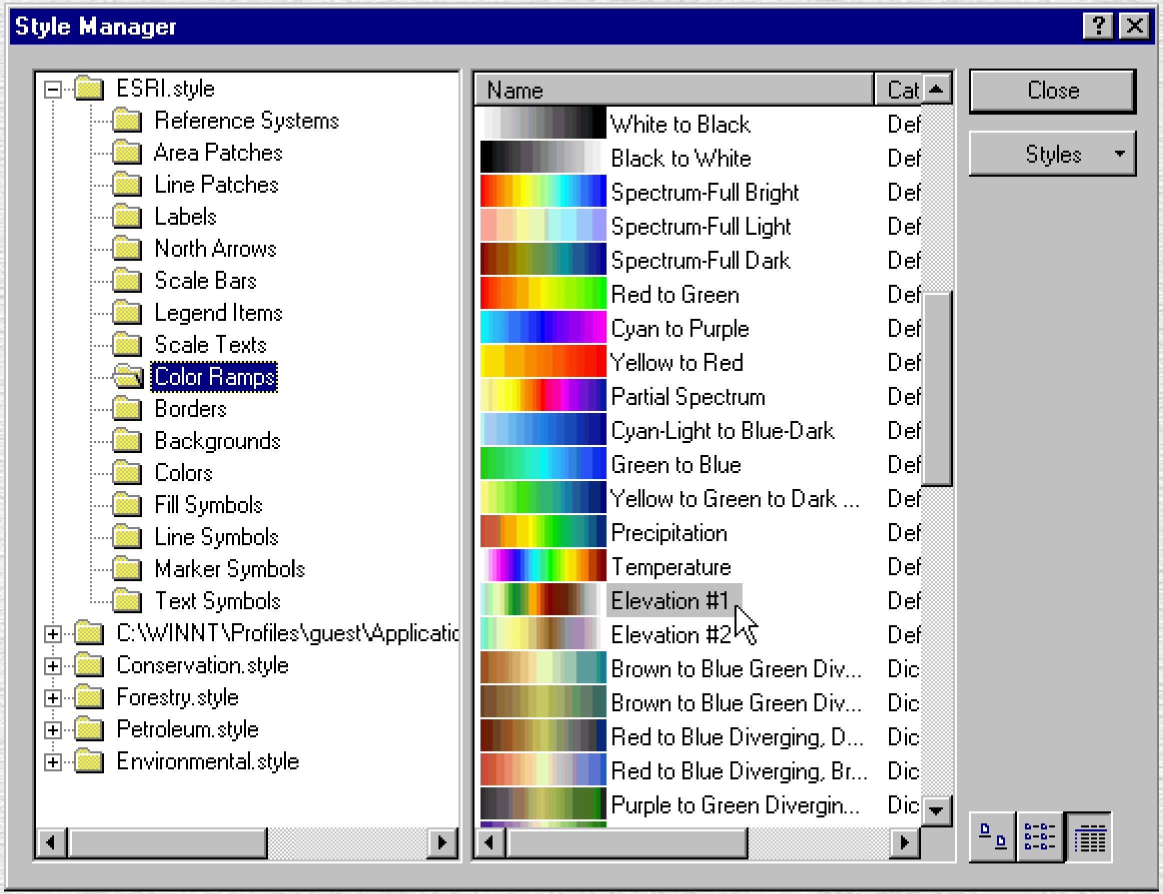
To display it, would need to scale NDVI to a number between 0 and 255 (DN)

One layer with numbers from 0 to 255 is a grayscale image, so how do we get color?
Assign a color ramp

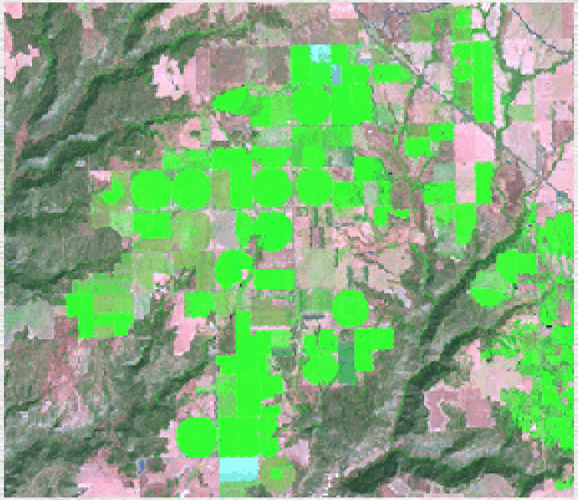
Green assigned to high NDVI
Yellow assigned to moderate to low NDVI
Transitions from deep green to light yellow between the maximum and minimum values in the image

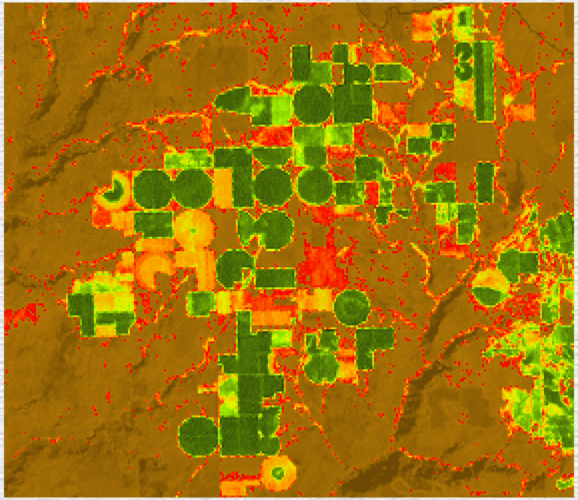
Color ramps

- Color ramps give smooth transitions between colors
- The left side of the ramp is assigned to low values, the right side to high values of NDVI
- So, even though NDVI is a single value, we can use color as a convenient illustration of greenness



Landsat 7,4,3 vs. NDVI





NDVI is better at distinguishing actively growing plants vs. dormant or slowly growing plants

Vegetation indices are pixel-level

- Manual interpretation involved seeing features in an image
  - Recognizing objects, or using texture to discern the cover type
  - Both are done by looking at lots of pixels
- Vegetation indices are calculated for *each individual pixel*
- Two pixels with the same reflectances on band 4 and band 3 will get the same NDVI, even if one is bare ground in an opening between trees, and the other is a vacant lot behind the Best Buy

Other vegetation indices

- NDVI is one of the oldest, and is still widely used
- Others are also used that either fix problems with NDVI, or give additional information:
  - EVI = the Enhanced Vegetation Index
  - Kauth-Thomas (Tasseled Cap) index

EVI

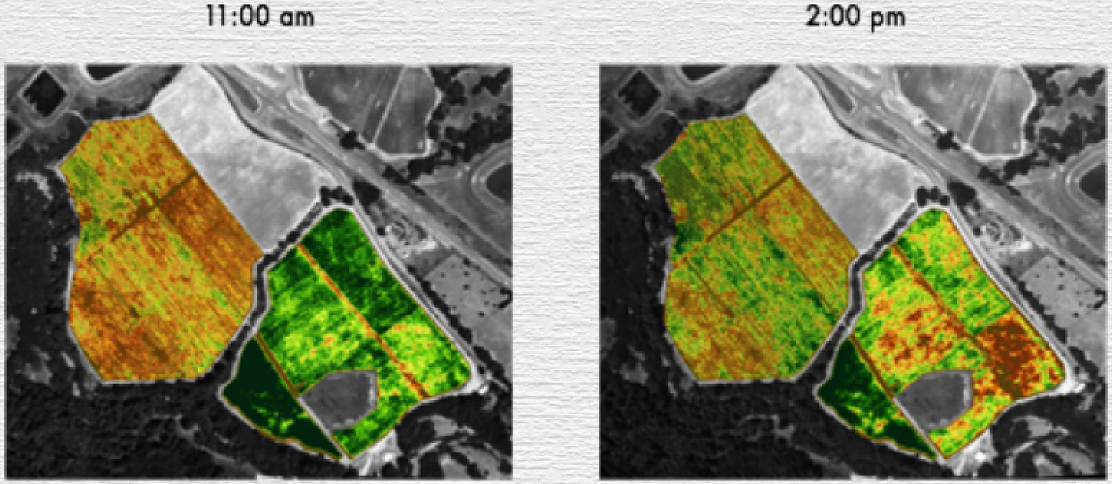
- Designed to work better in areas with high biomass
- Also less affected by atmospheric influences than NDVI (better when applied to DN’s or radiance than NDVI is)
- NDVI is most responsive to chlorophyll in the vegetation
- EVI more responsive to leaf area index, canopy structure, and other aspects of vegetation

$$EVI = \frac{G \times (\mathrm{NIR} - \mathrm{Red})}{\mathrm{NIR} + \mathrm{C1} \times \mathrm{Red} - \mathrm{C2} \times \mathrm{Blue} + L}$$

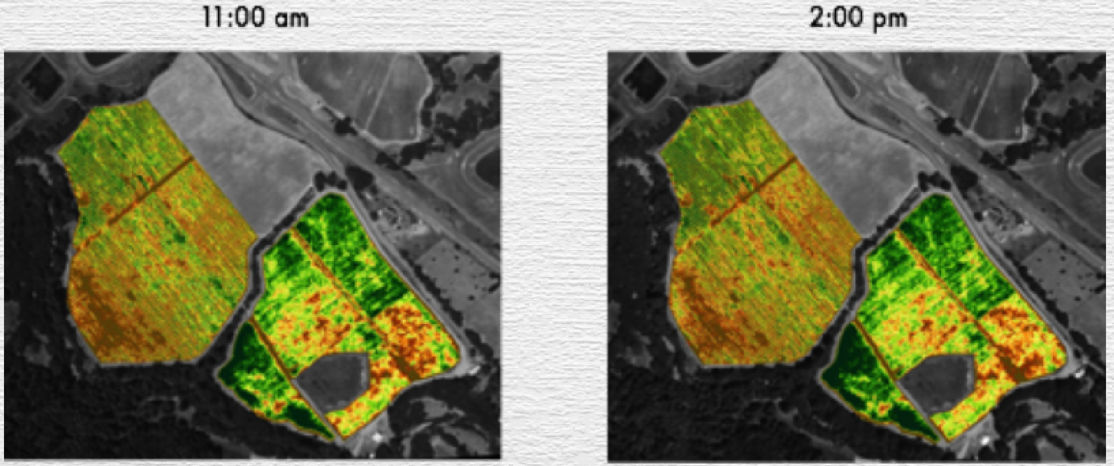
- G, C1, C2, and L are constants, selected to adjust for atmospheric effects
- Also a unitless index

EVI vs. NDVI

NDVI – big differences in images taken a few hours apart



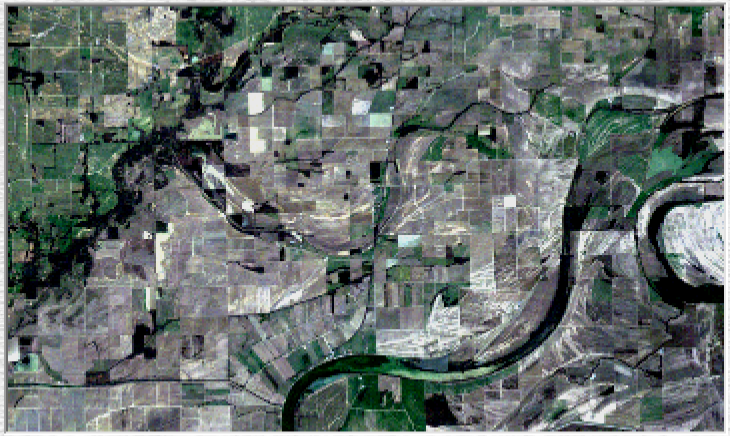
EVI – more stable, consistent results



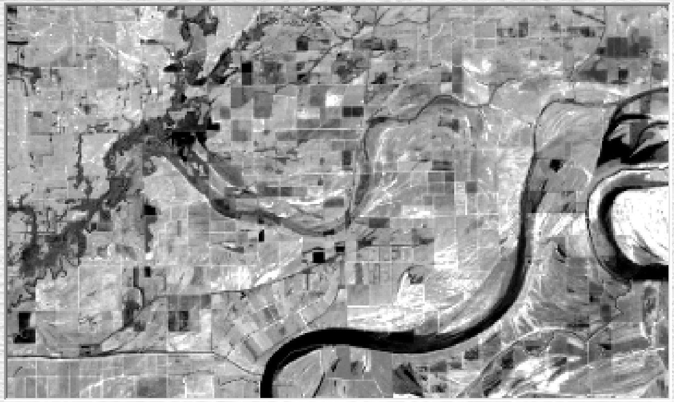
Using reflectance to calculate NDVI helps avoid this problem

Tasseled cap

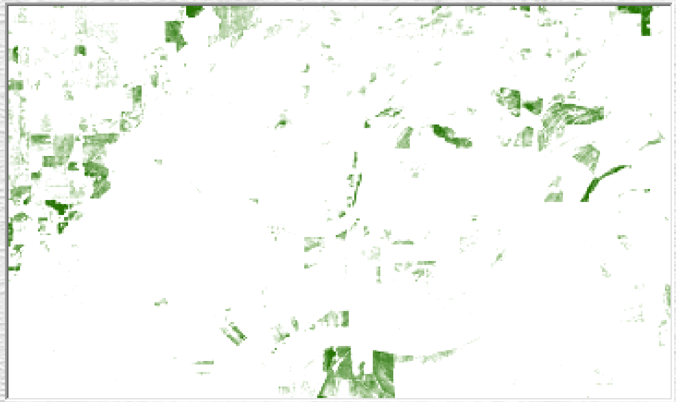
- Reflectance values tend to correlate across the bands
  - First, biggest pattern is positive correlation across all of them = **brightness**
  - Next pattern is the trade-off between near IR and Red = **greenness** (like NDVI or EVI)
  - Last pattern is a trade-off between the first four bands (i.e. visible light and the first near IR band) against the other two IR bands = **wetness**
- Calculated as a linear combination – sums of coefficients multiplied by reflectances across the bands
- The three measures are orthogonal = independent



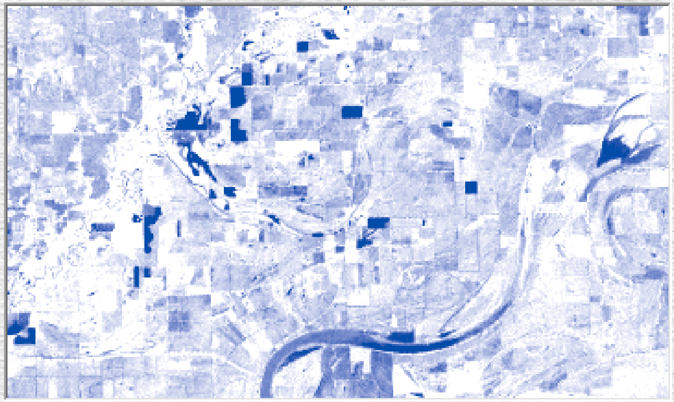
Natural color, 3,2,1 composite



Brightness



Greenness

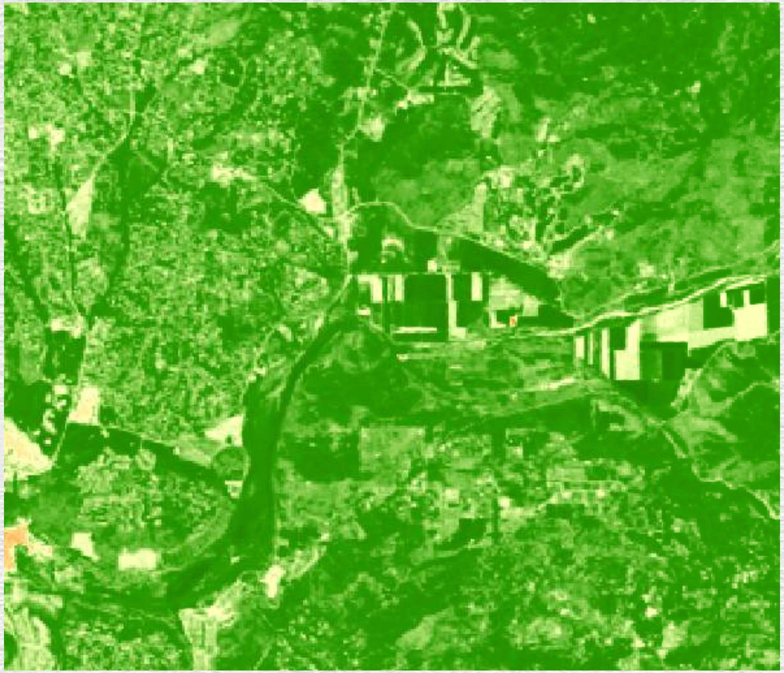


Wetness

Seasonal patterns

- We have seasons in San Diego County! No, really!
  - Rain falls between about Dec – May
  - From June through the following December there may be little or no rainfall
- What would we expect would happen to NDVI in the fall?

Spring vs Fall NDVI



April 2011

November 2011

Which month is greener in general? Exceptions?

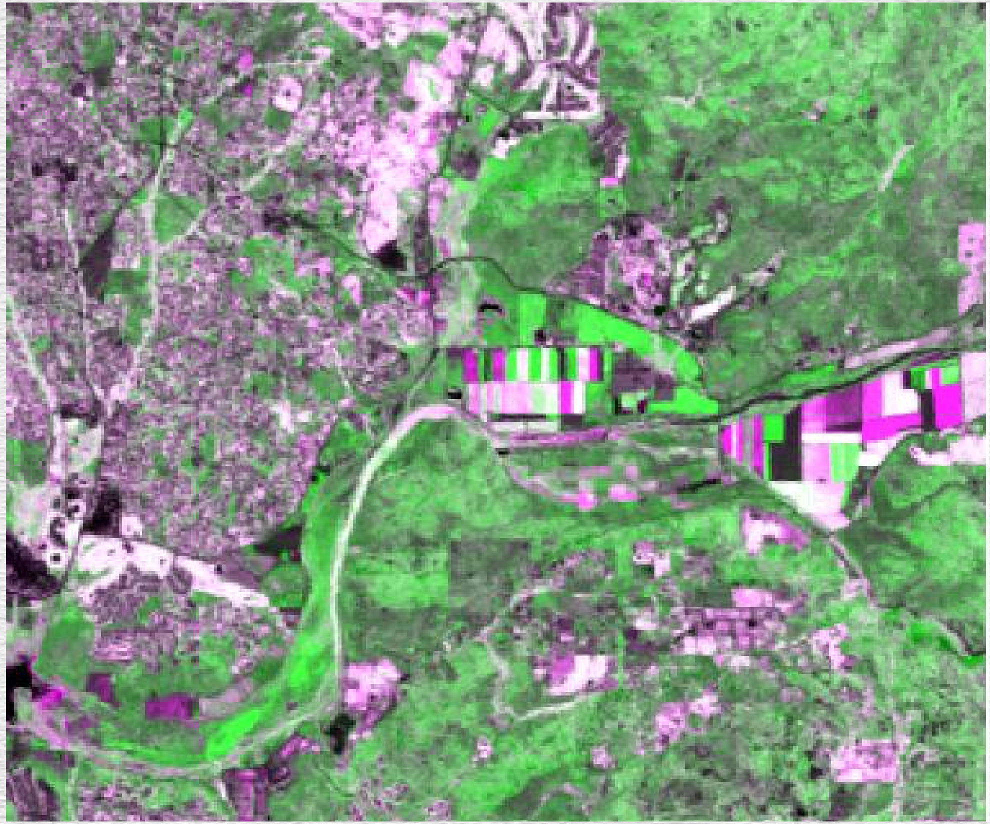
Visualizing differences between two images

- We learned how to assign layers to color channels to make composites
  - True color was the 3,2,1 layers assigned to R,G,B
  - Color infrared was the 4,3,2 assignment
- We can also make a composite image of the two NDVI layers
  - Assign April to green channel
  - Assign November to red and blue
- Color then becomes an indication of differences in NDVI between the seasons
- What will it look like?

April NDVI assigned to green, November NDVI to red and blue

What does black show?

What does white show?



What does purple show?

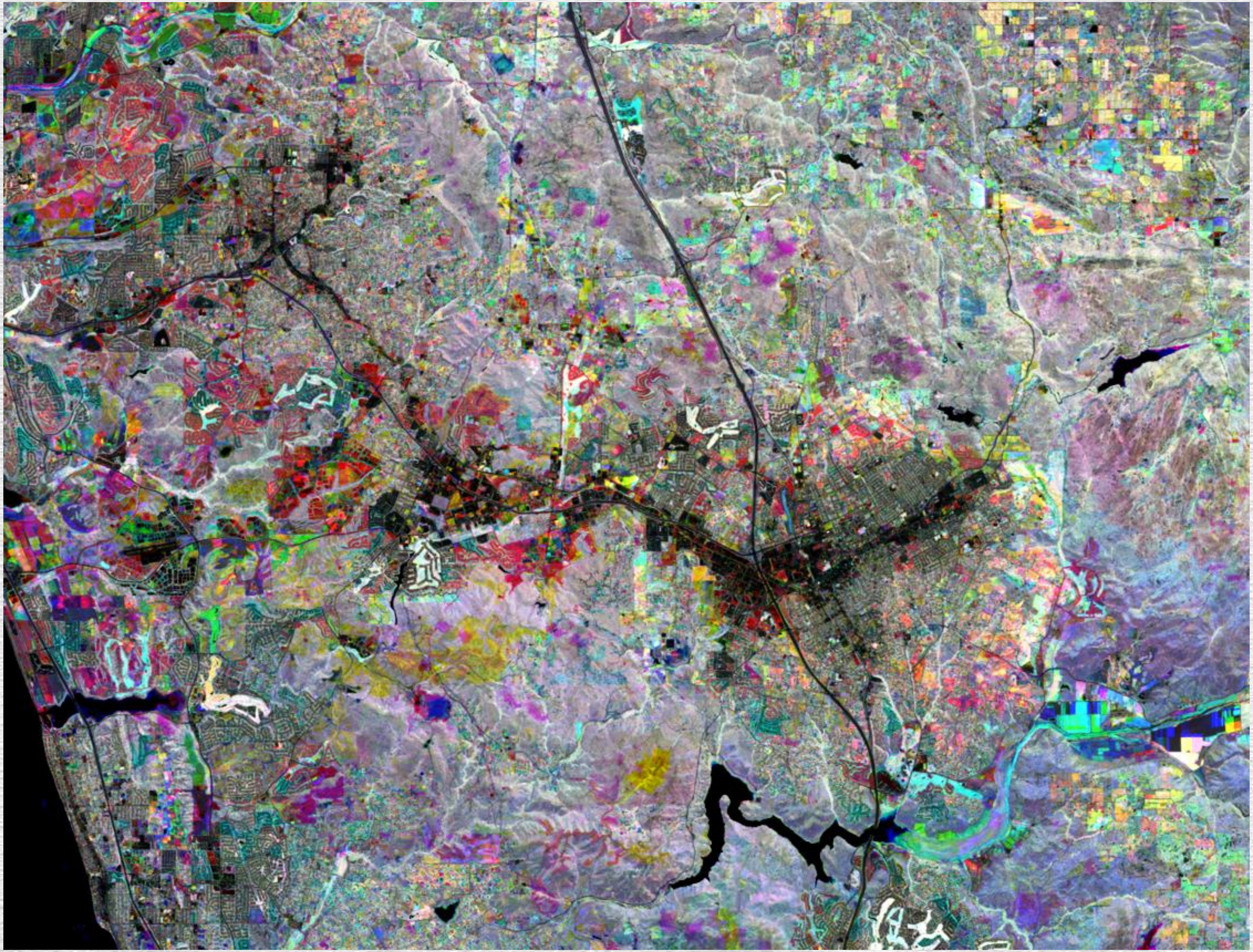
What does green show?

Changes in NDVI over time

- We could calculate NDVI for the same time period in each of three years
- Assign NDVI from each year to a different channel
  - 1984 NDVI to Red
  - 1996 NDVI to Green
  - 2011 NDVI to Blue
- Color would then indicate a pattern of change over years

Patterns of change, and their interpretations

Red (1984)	Green (1996)	Blue (2011)	Color	Land cover change indicated	Likely cause?
High	High	High		No change - green in all three years	Vegetation with consistently high greenness over time
Low	Low	Low		No change - not green in all three years	Consistent lack of vegetation over time
High	High	Low		Vegetated areas became un-vegetated between 1996 and 2011	Development or fire shortly before 2011
High	Low	Low		Vegetated areas became un-vegetated between 1984 and 1996	Development after 1984 (probably not fire, or vegetation would have recovered by 2011).
Low	Low	High		Un-vegetated areas grew vegetation between 1996 and 2011	New park, new agricultural field, new golf course - artificial vegetation
Low	High	Low		Un-vegetated areas grew vegetation between 1984 and 2011, then became un-vegetated in 2011	Possibly fire before 1984, then again before 2011, with recovery in between.
Low	High	High		Un-vegetated areas grew vegetation between 1984 and 1996	Fire recovery, or new artificial vegetation
High	Low	High		Vegetated area became un-vegetated between 1984 and 1996, then became vegetated between 1996 and 2011	Fire just before 1996, or development followed by new artificial vegetation



Red (1984)	Green (1996)	Blue (2011)	Color
High	High	High	
Low	Low	Low	
High	High	Low	
High	Low	Low	
Low	Low	High	
Low	High	Low	
Low	High	High	
High	Low	High	

Today’s activity

- You will calculate reflectance, and radiance for a set of images
- You will calculate NDVI for each
- You will visualize seasonal change, and change over time