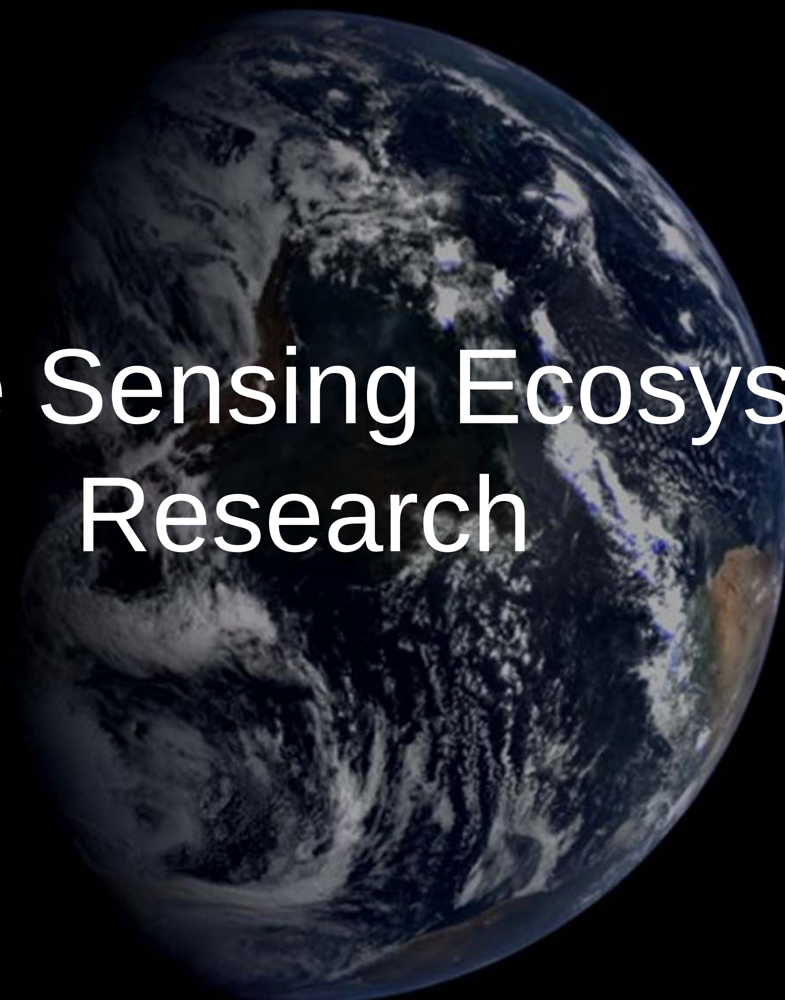
Remote Sensing Ecosystem Research



K. Fred Huemmrich
University of Maryland Baltimore County

What is Remote Sensing?

What is Remote Sensing?

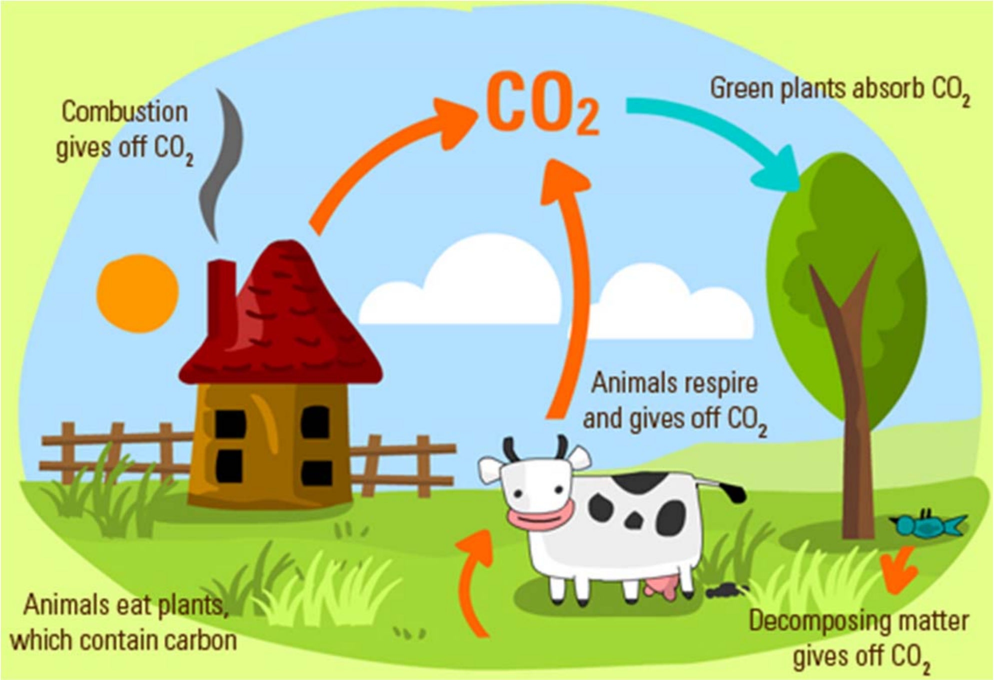
- At its most basic, remote sensing involves observing objects at a distance
- We can get information about an object from energy that has gone through or bounced off of it
- We can use energy from light, sound waves, radio waves, etc. to get this information

Why do I use remote sensing?

Why do I use remote sensing?

- I want to study how ecosystems work and how they respond to a changing environment
- Remote sensing imagery lets me observe large areas, up to the entire planet
- Remote sensing lets me make repeated measurements without disturbing the ecosystem

The Carbon Cycle

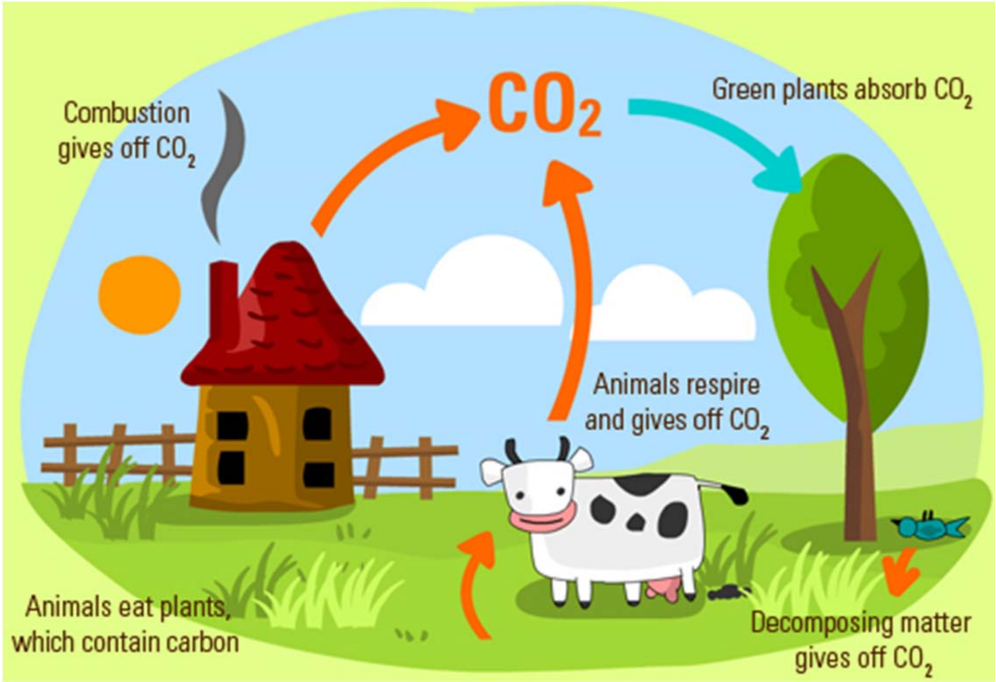


- The CO_2 in the atmosphere is absorbed by green plants (producers) to make food in **photosynthesis**.
- When animals feed on green plants, they give off CO_2 into the atmosphere during **respiration**.
  - <u>Plants respire too!</u>
- CO_2 is also given off when plants and animals die. This occurs when decomposers (bacteria and fungi) break down dead plants and animals (decomposition) and release the carbon compounds stored in them.

http://eschooltoday.com/ecosystems/the-carbon-cycle.html

The Carbon Cycle

- Human activities that burn fossil fuels, like heating homes and running cars, give off carbon into the atmosphere.



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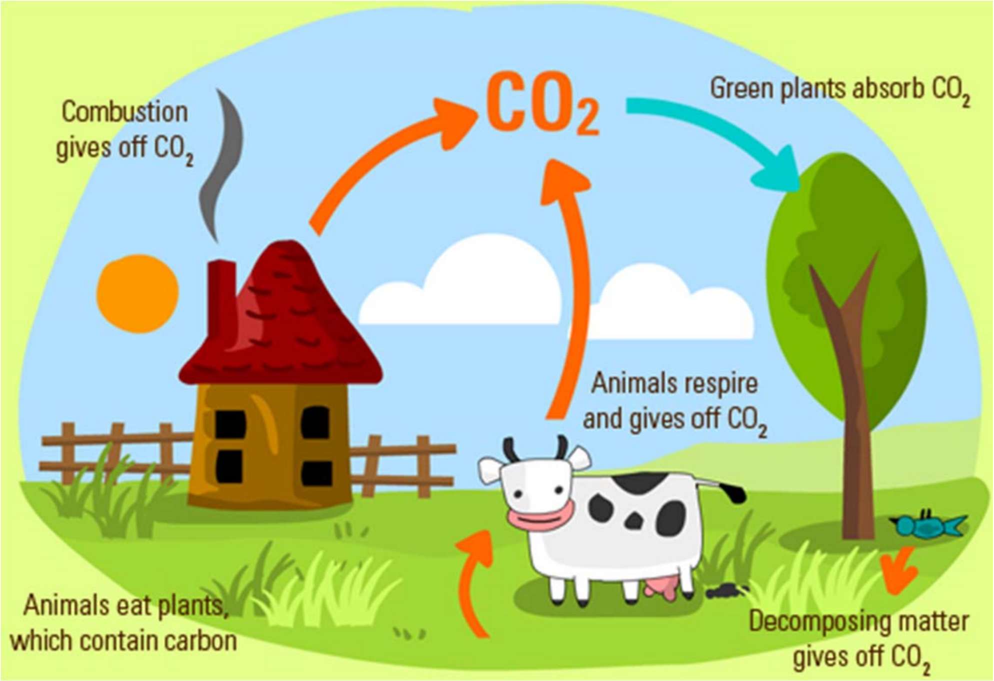
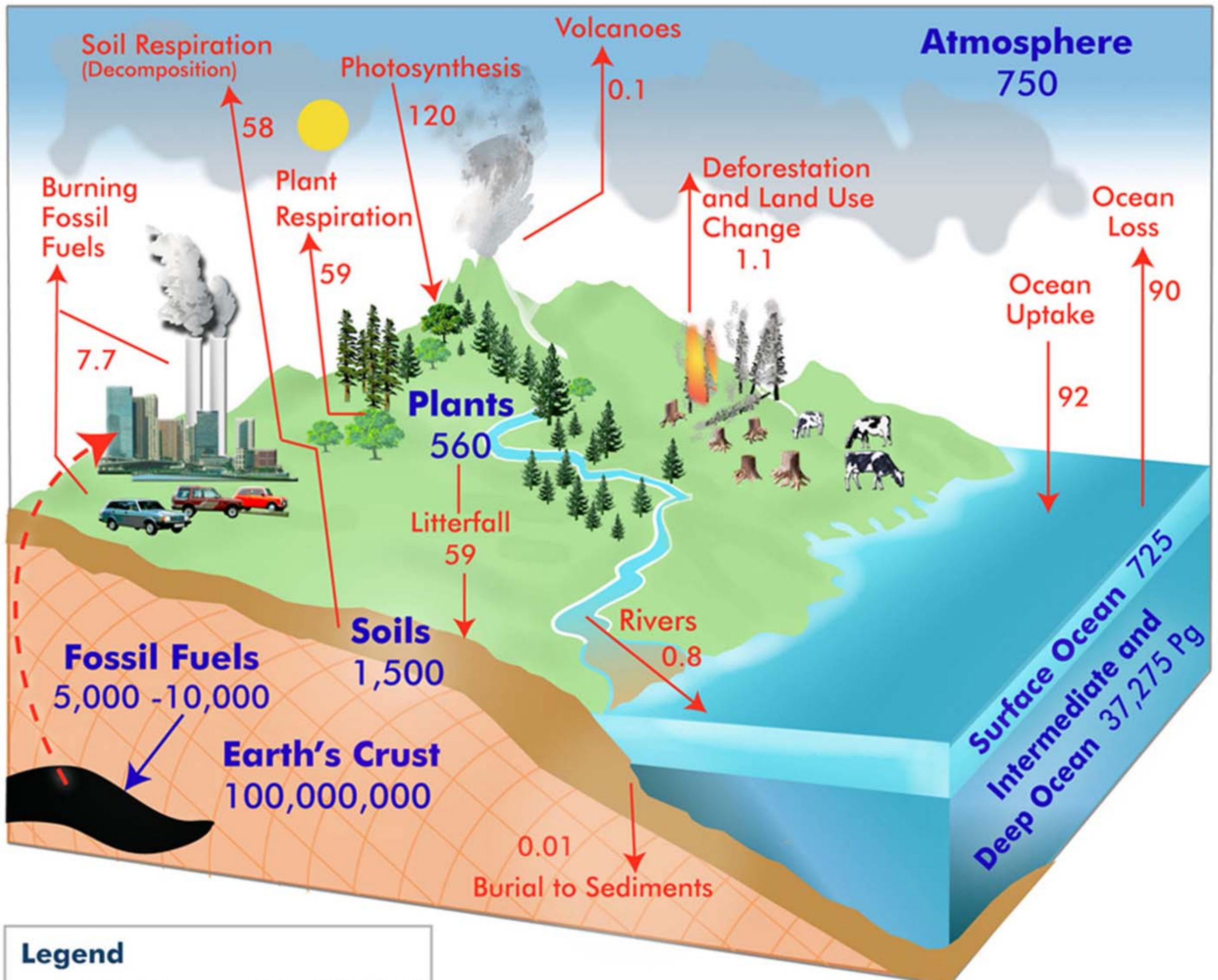


This cycling of carbon is necessary to support life on Earth

The CO_2 that remains in the atmosphere is a greenhouse gas that causes warming and is altering the climate

http://eschooltoday.com/ecosystems/the-carbon-cycle.html

Global Carbon Cycle



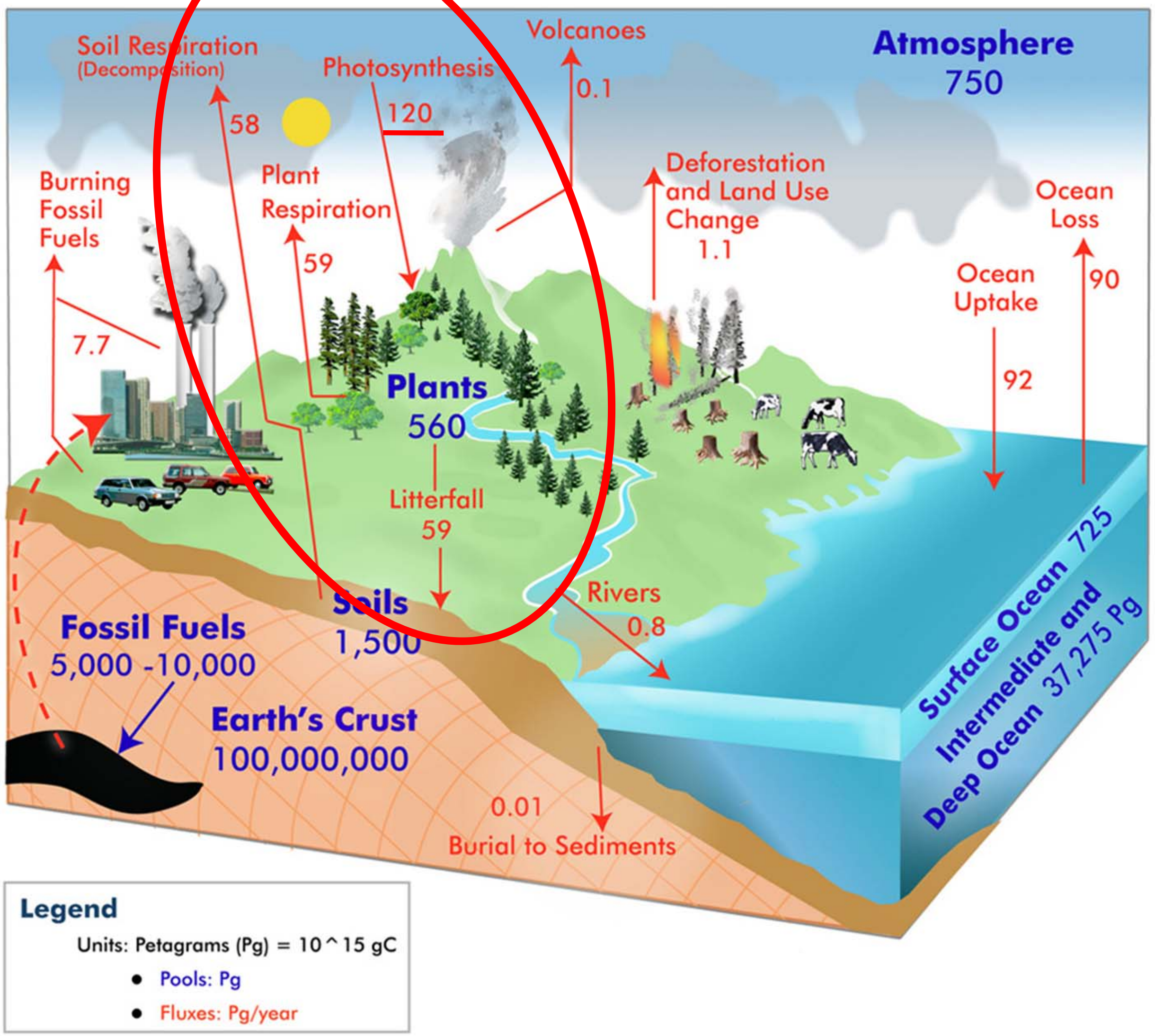
Legend

Units: Petagrams (Pg) = 10^15 gC

- Pools: Pg
- Fluxes: Pg/year

Data Sources: Adapted from Houghton, R.A. Balancing the Global Carbon Budget. Annu. Rev. Earth Planet. Sci. 007.35:313-347, updated emissions values are from the Global Carbon Project: Carbon Budget 2009.

Global Carbon Cycle



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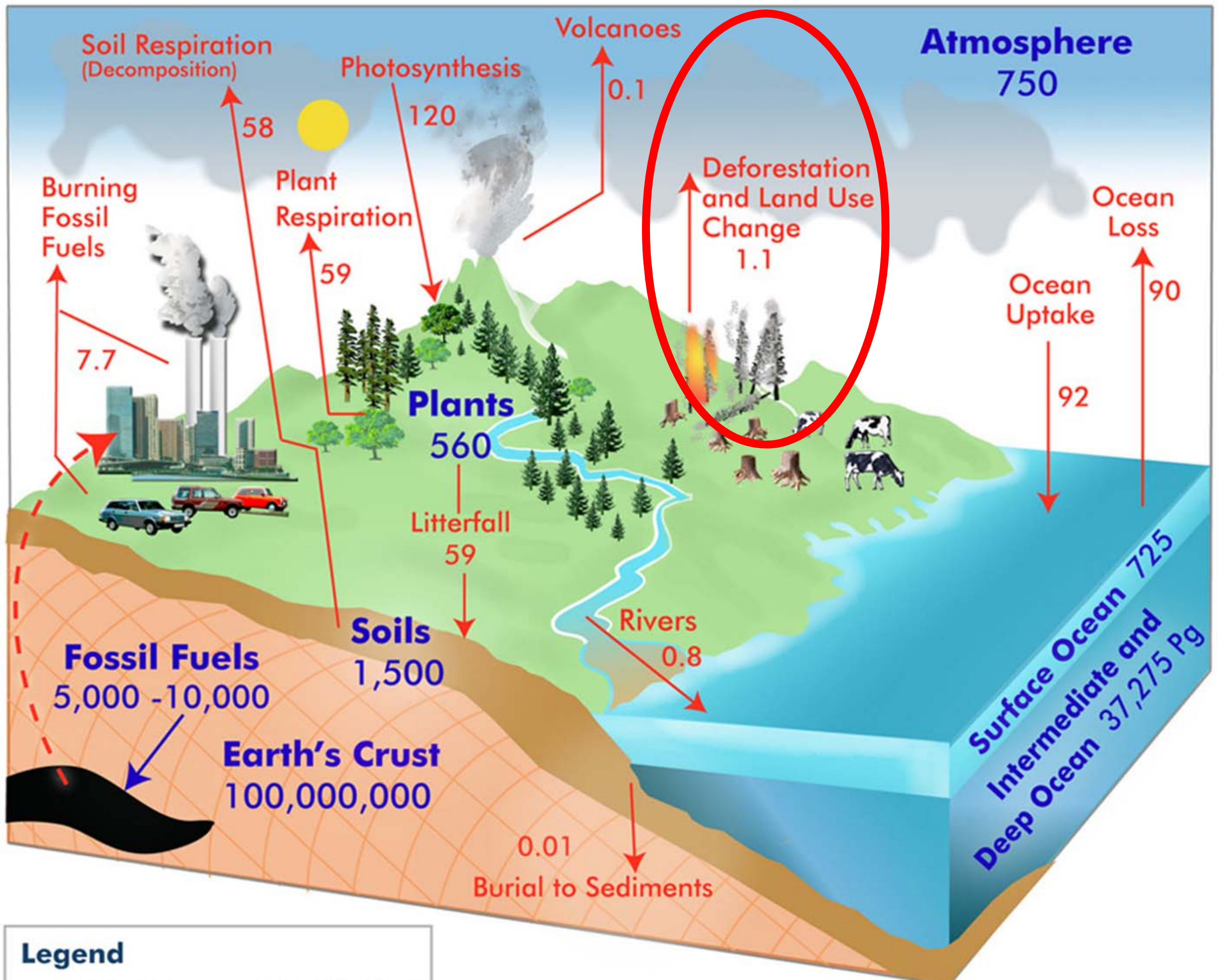
Global Carbon Cycle



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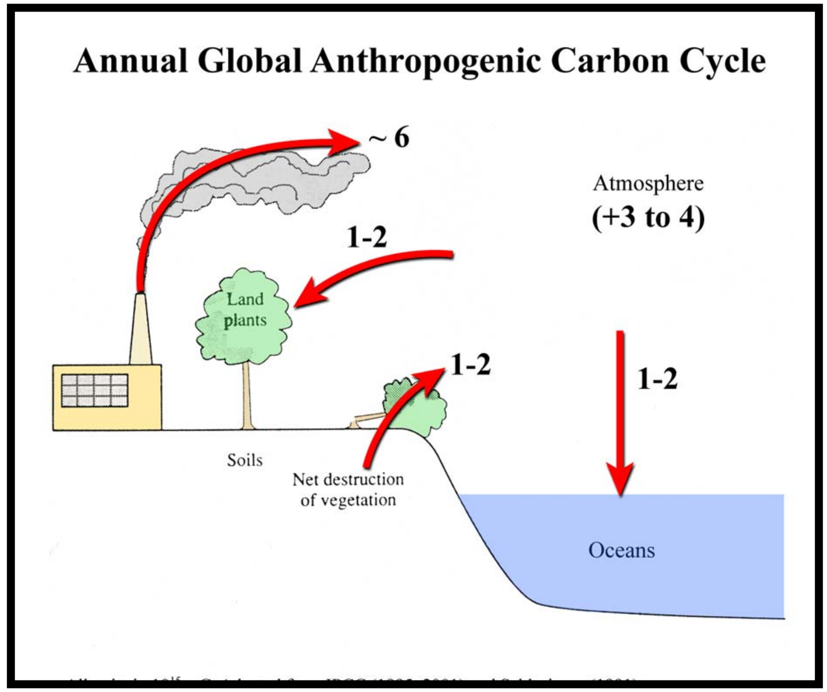
Carbon (C) Sink on Land

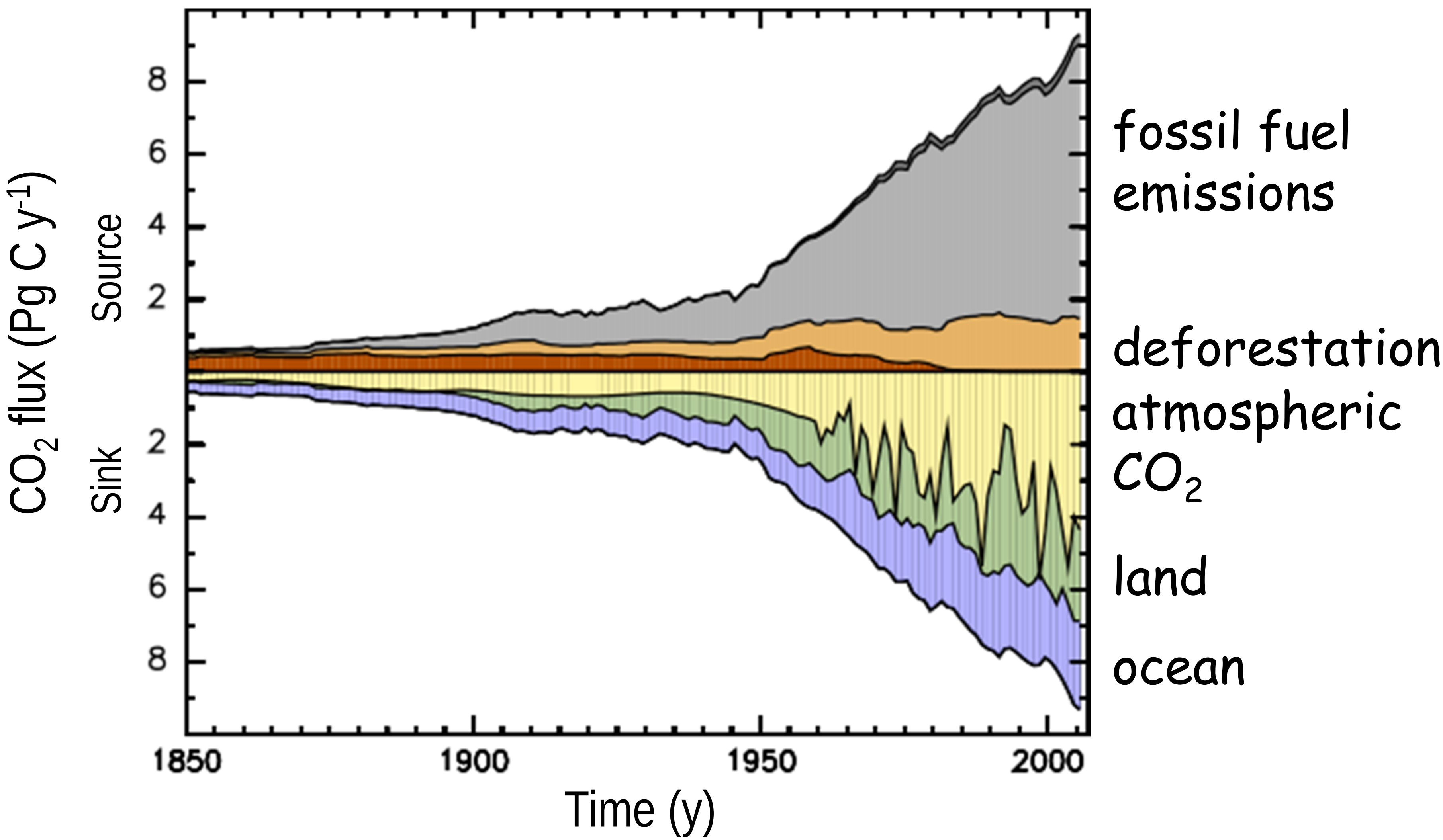
A sink refers to a process that takes carbon out of the atmosphere
A source refers to a process that puts carbon into the atmosphere

1. There is a C sink on land that absorbs a significant amount of the fossil fuel C that is emitted to the atmosphere (about 15 to 30%).
2. This sink provides a valuable environmental service
3. This sink varies over the landscape and over time. We want to be able to understand and monitor that variability globally



Global Carbon Budget (1850-2006)

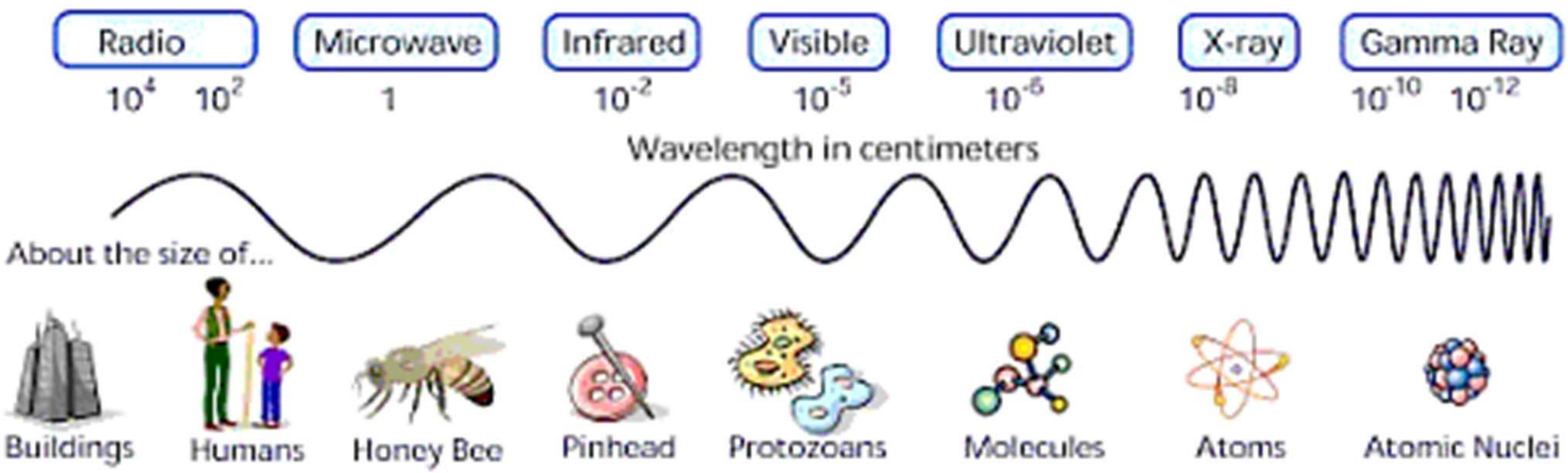
By budget we mean keeping track of carbon dioxide entering and leaving the atmosphere



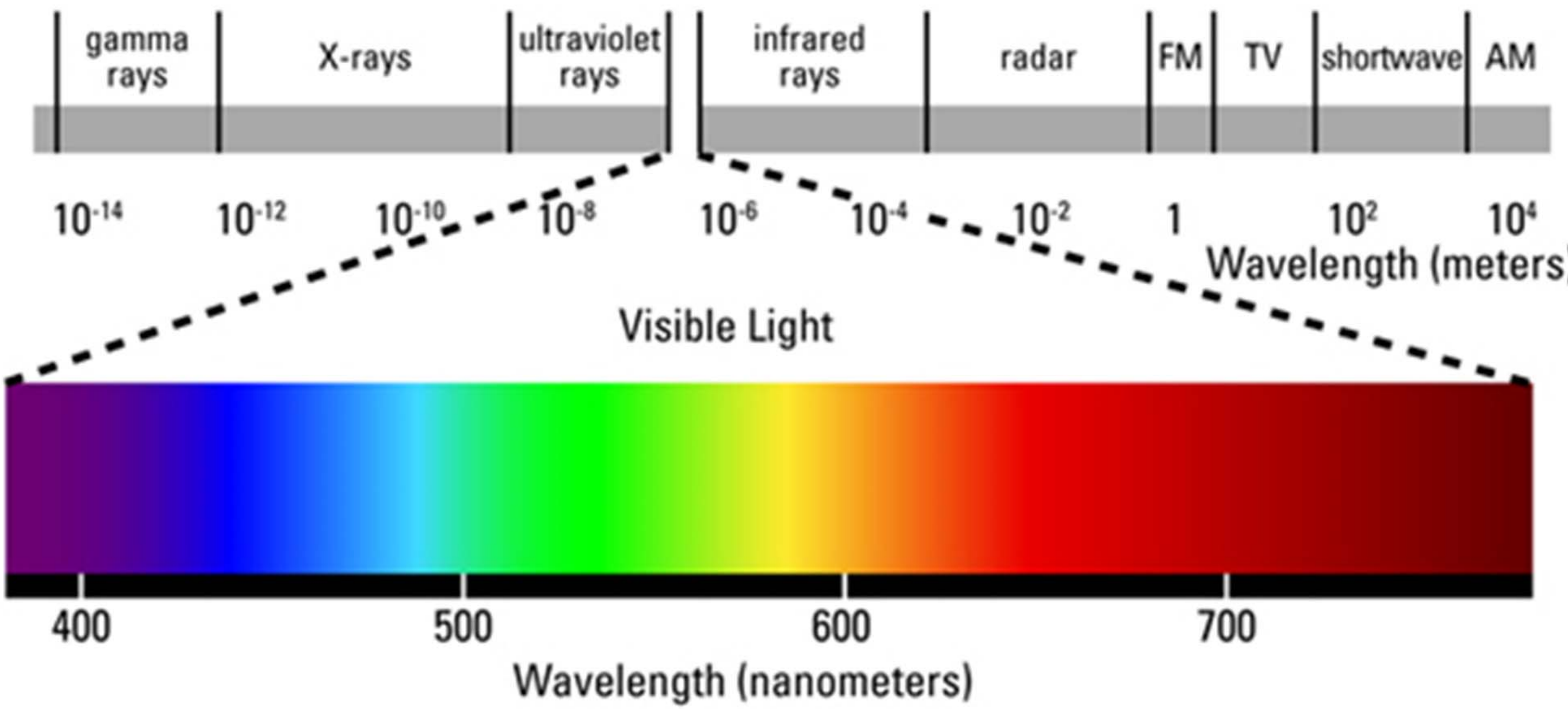
Le Quéré, unpublished; Canadell et al. 2007, PNAS

In my work I use information from electromagnetic radiation from the sun that is reflected from the surface of the Earth

The *whole* electromagnetic (EM) spectrum consists of the longest wavelengths (radio), shortest ones (gamma rays), and everything in between.

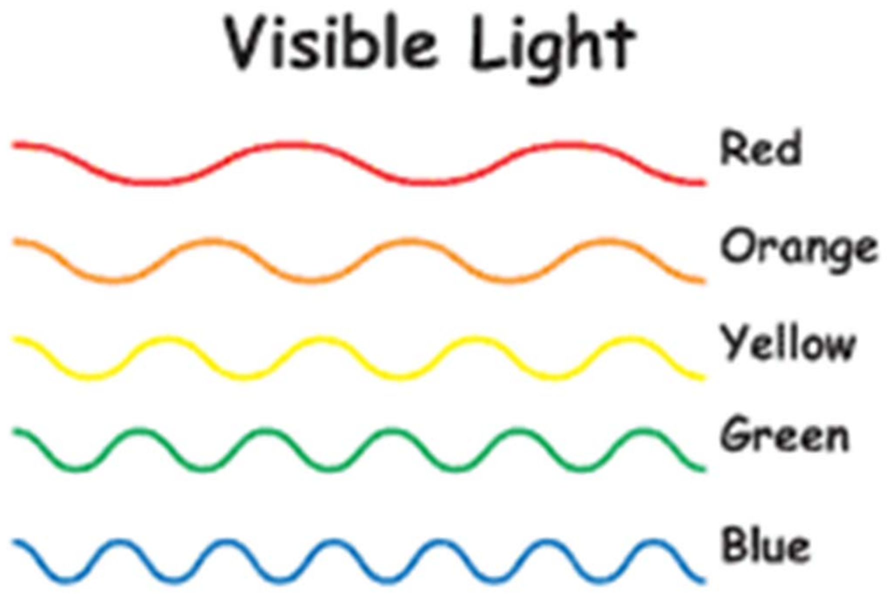


Visible light, the light we see with our eyes alone, is a *very small part* of the whole spectrum of radiant energy in the universe.



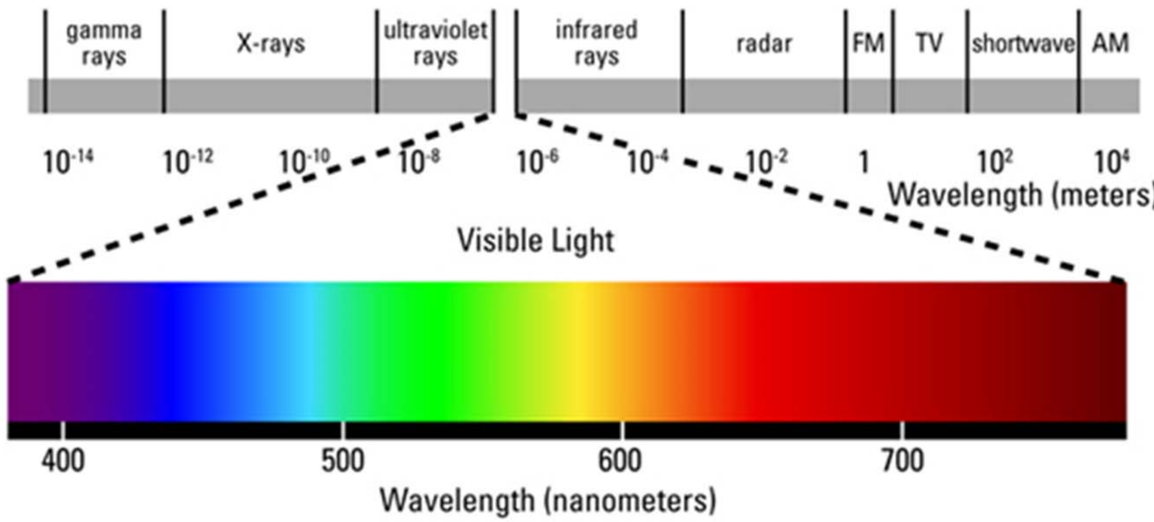
Colors have different wavelengths!

We see colors as different *because* they have different wavelengths.



Red has the *longest* wavelengths of visible light, and blue/purple has the *shortest* wavelengths of visible light.

Wavelengths we see as green are about 525-550 nanometers (nm) in length. Wavelengths we see as red are 630-700 nm in length.



A nanometer is 1 billionth of a meter = 1 / 1,000,000,000

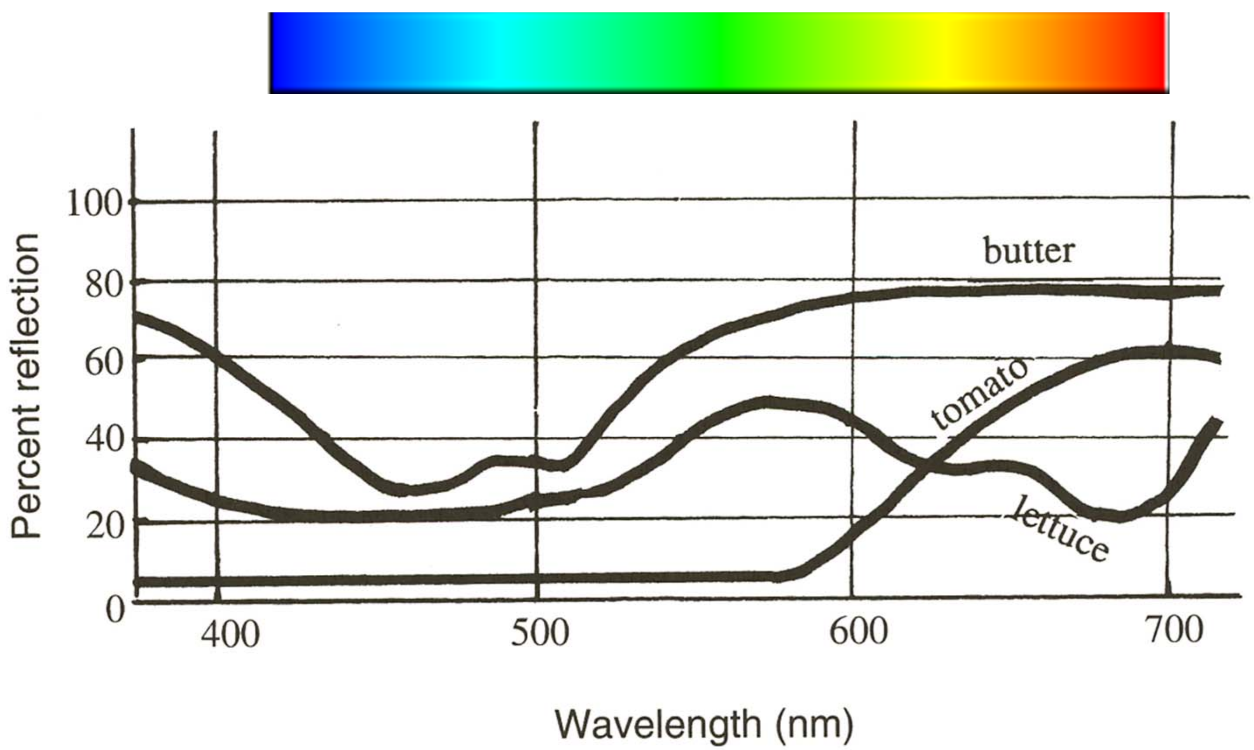
(smaller than the size of a protozoa)

The red petals of this poppy flower reflect strongly at wave-lengths of 700 nm.

Photo: Jeannette Allen

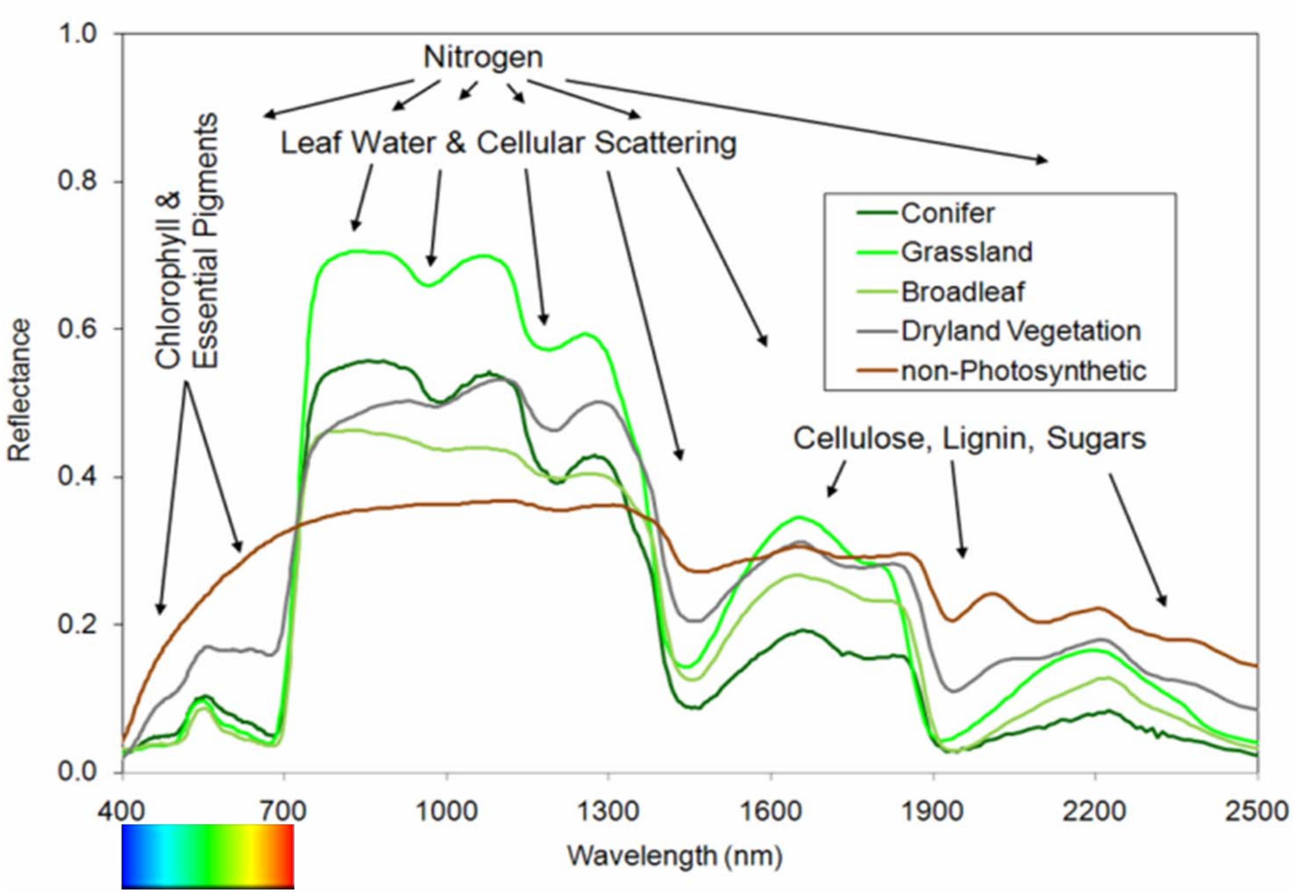
Every kind of surface has its own *spectral signature,* somewhat like a fingerprint.

Butter reflects weakly in blue and strongly in yellow to red.
Tomato reflects weakly in blue and strongly in red.



Reflectance Spectra of Vegetation

- The factors that control reflectance vary with wavelength
- They include: amount of leaf nitrogen, amount of leaf water content, amount of chlorophyll, overall amount of green leaves, etc.
- These are all factors that can affect plant productivity
- So, there is a physical link between reflectance and the condition of the plants



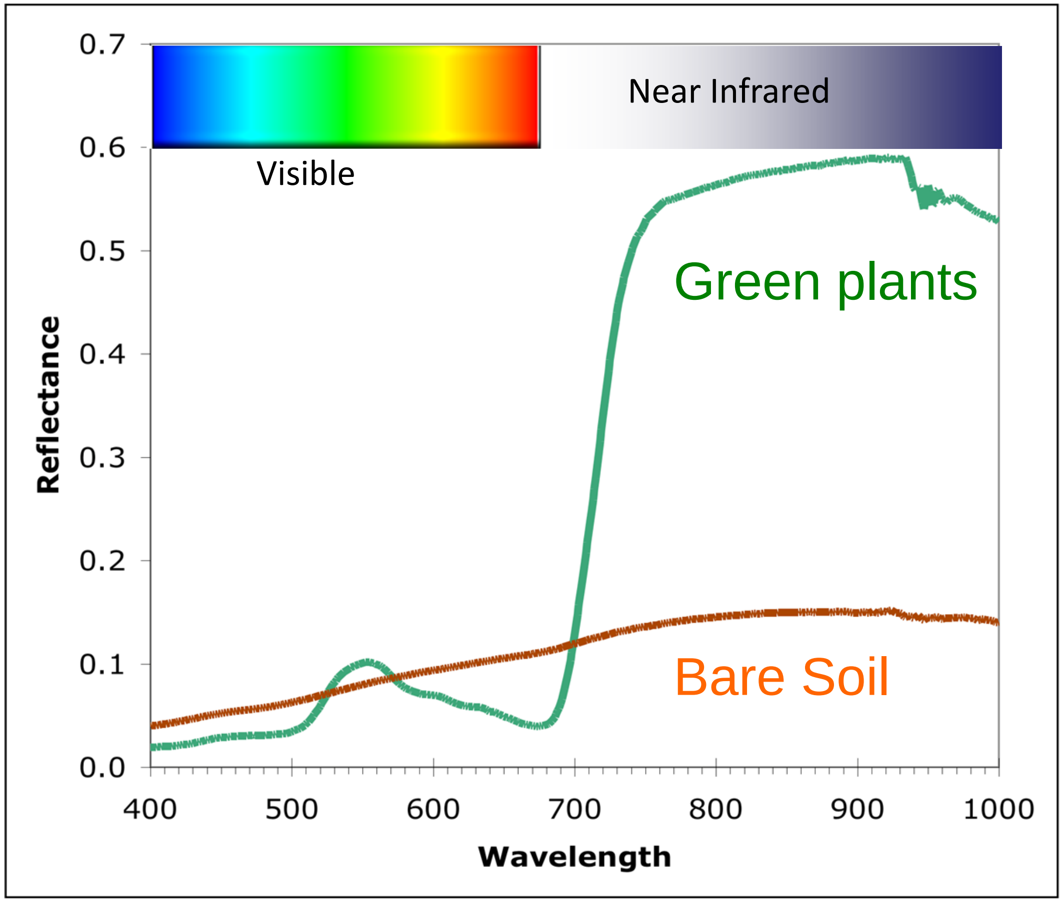
Reflectance Spectra of Vegetation

Reflectance in the visible part of the spectrum is mainly determined by plant pigments like chlorophyll

- Chlorophyll absorbs strongly in the blue and red, that's why plants look green

In the near infrared (the infrared wavelengths just beyond what we can see) plants absorb little radiation and so are very reflective

- This makes green leaves look very different than just about anything else on the Earth.



Reflectance Spectra of Vegetation

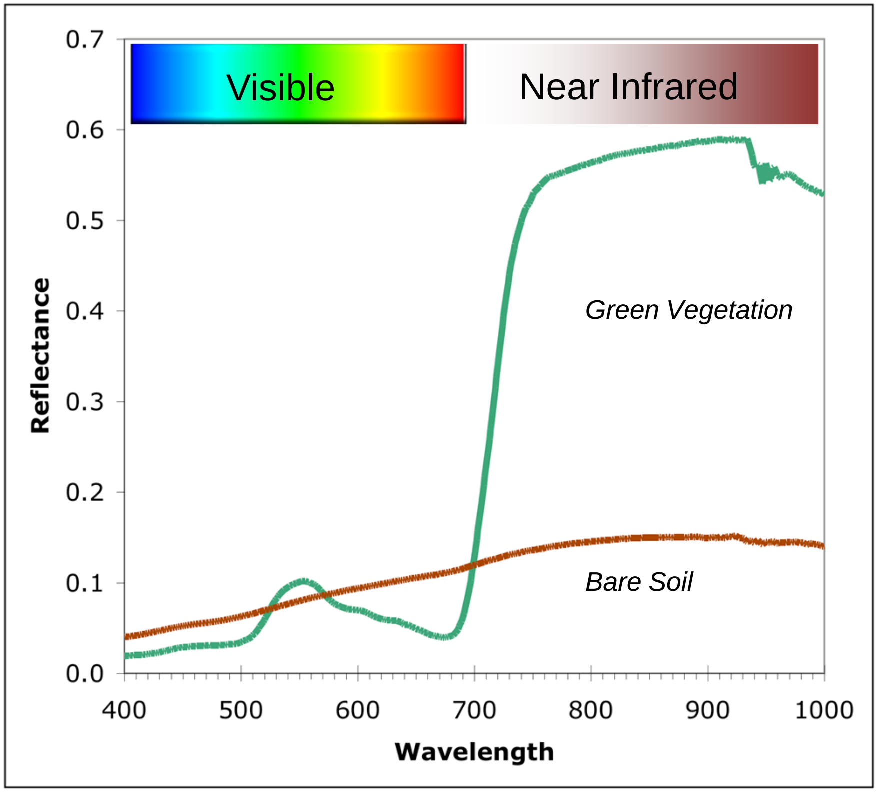
Visible

Near Infrared

Normalized Difference Vegetation Index

The Normalized Difference Vegetation Index (NDVI) has long been used to detect the amount of green (photosynthetically active) vegetation

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



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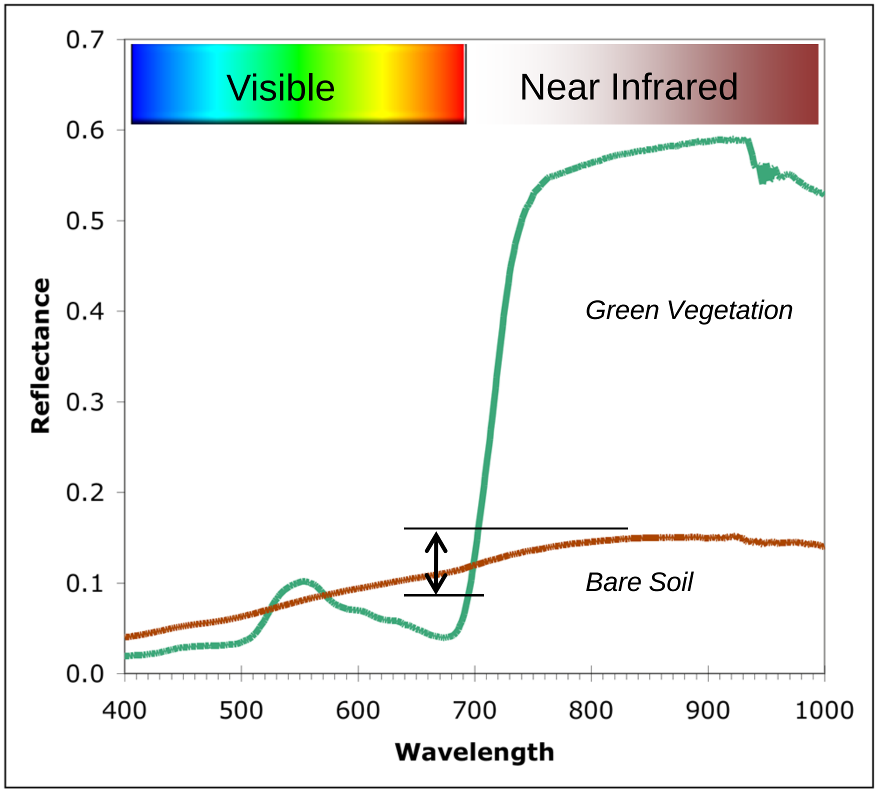
No Green Leaves:
Small difference between red and near infrared reflectance



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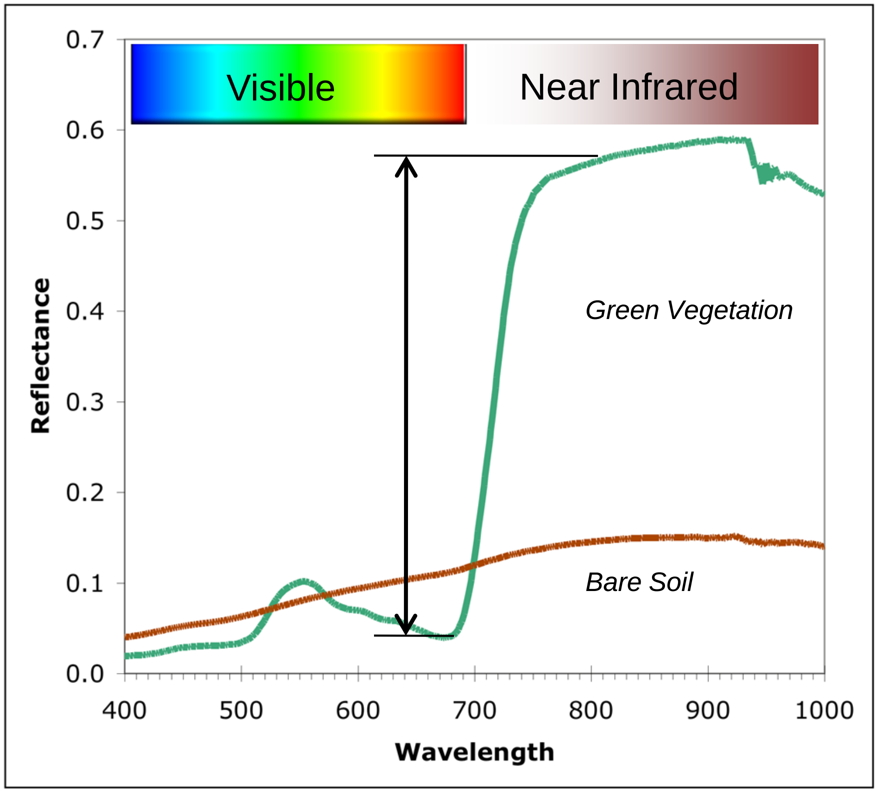
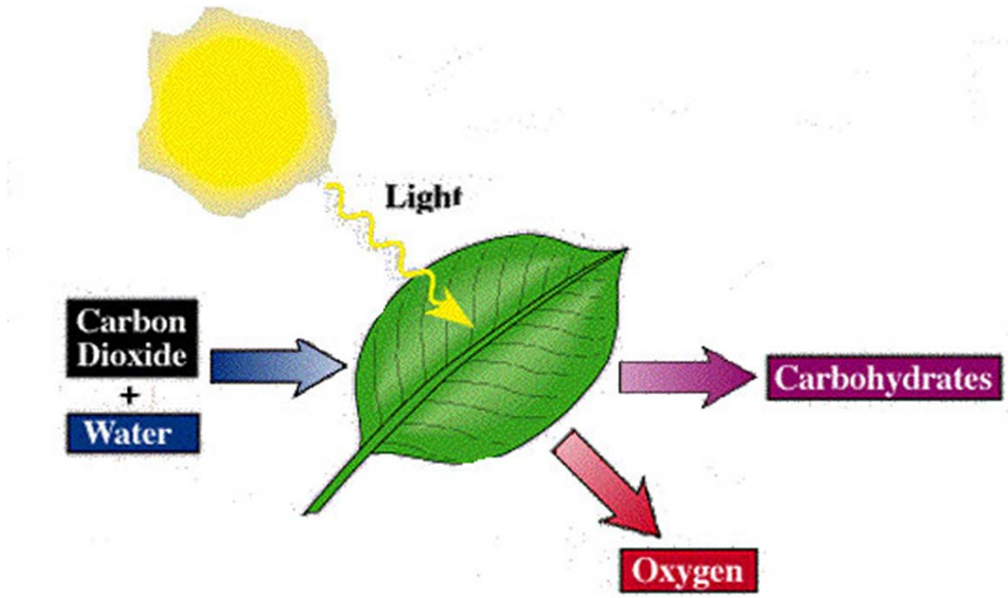
Green Leaves:
Large difference between red and near infrared reflectance



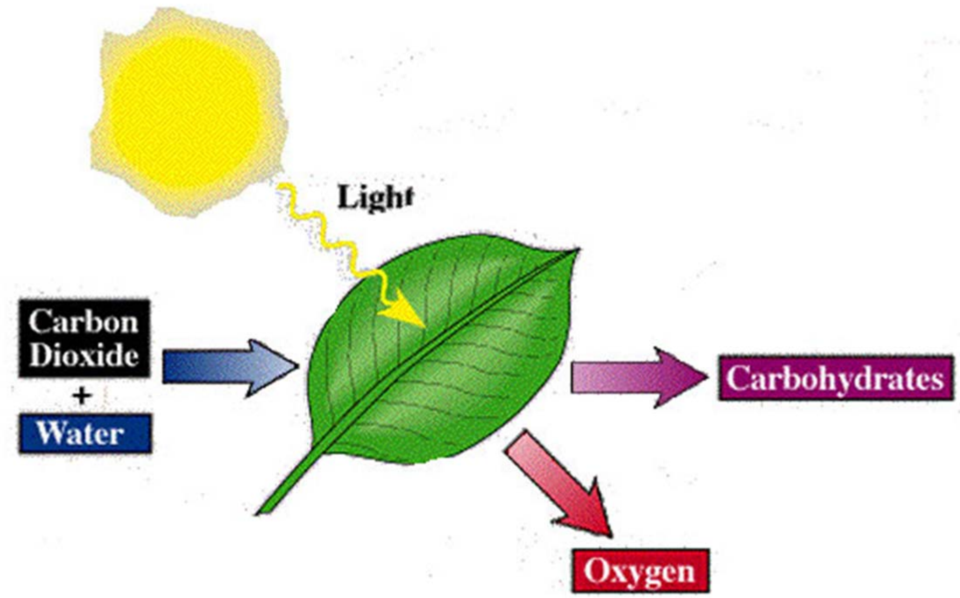
Photosynthesis

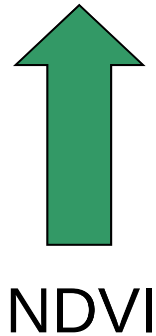


Plants take in CO_2 and water and in the presence of chlorophyll and sunlight make carbohydrates (food) and O_2

Photosynthesis and NDVI

As the amount of illuminated leaves increases
both the amount of photosynthesis and NDVI increases





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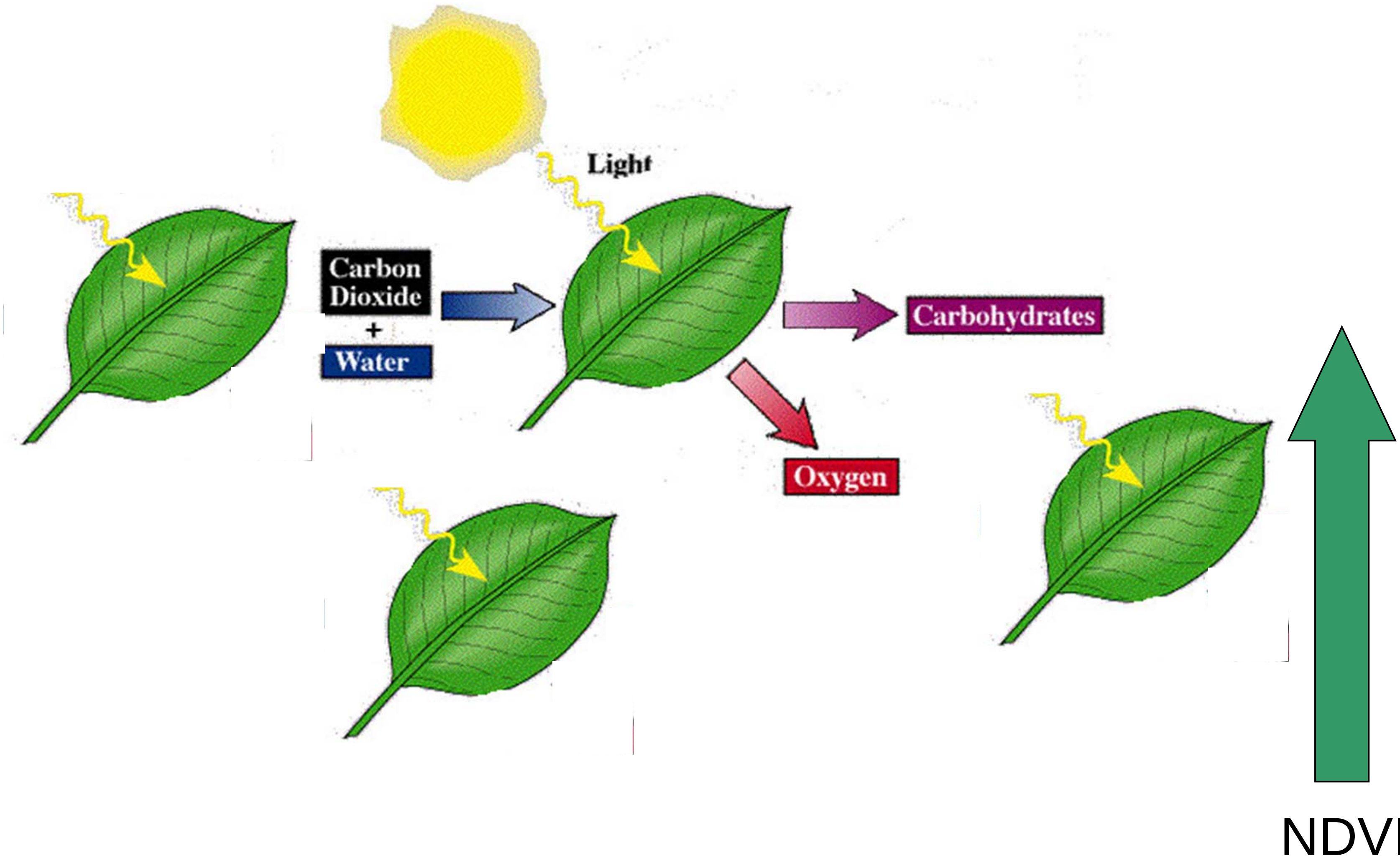

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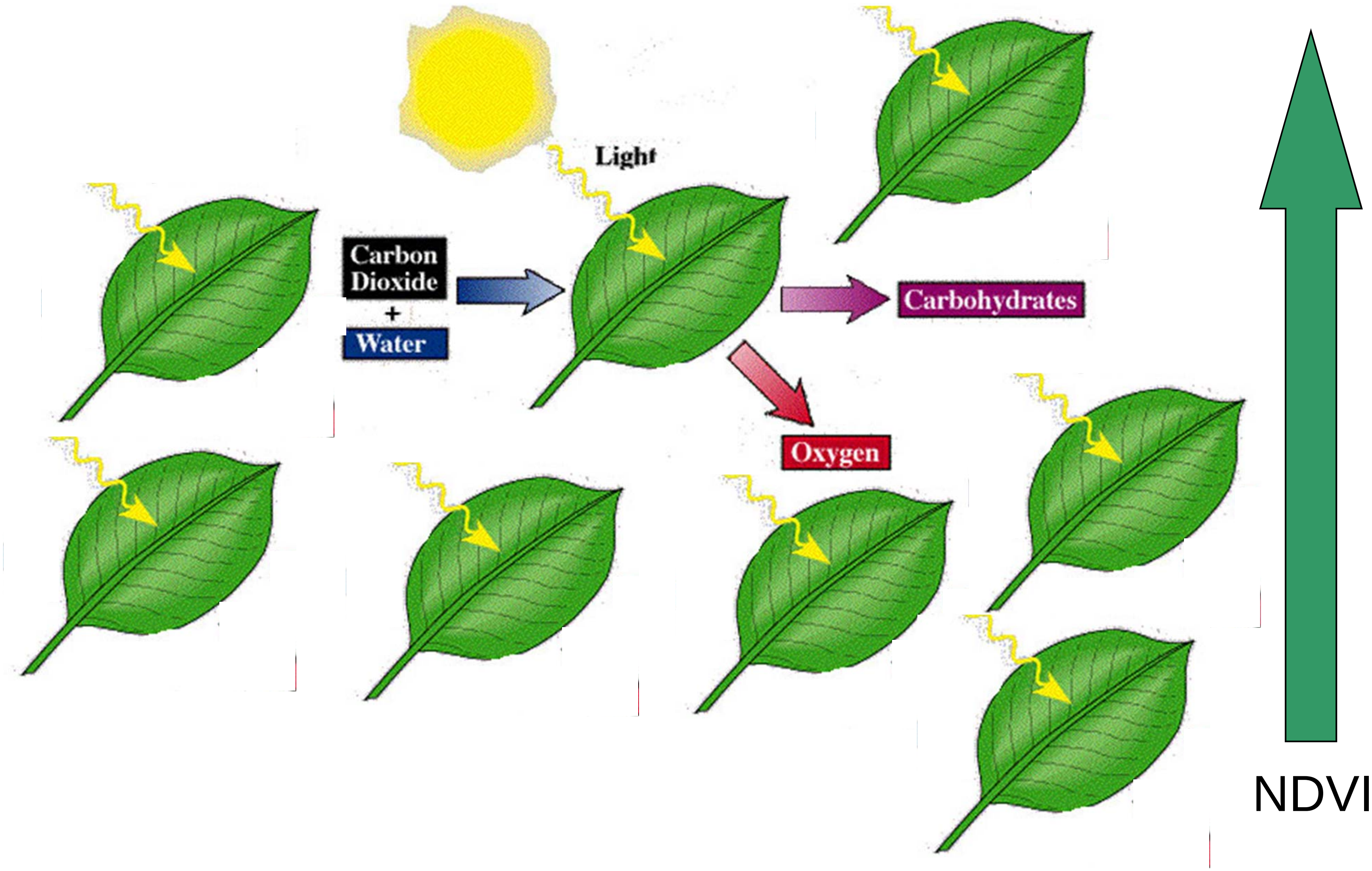
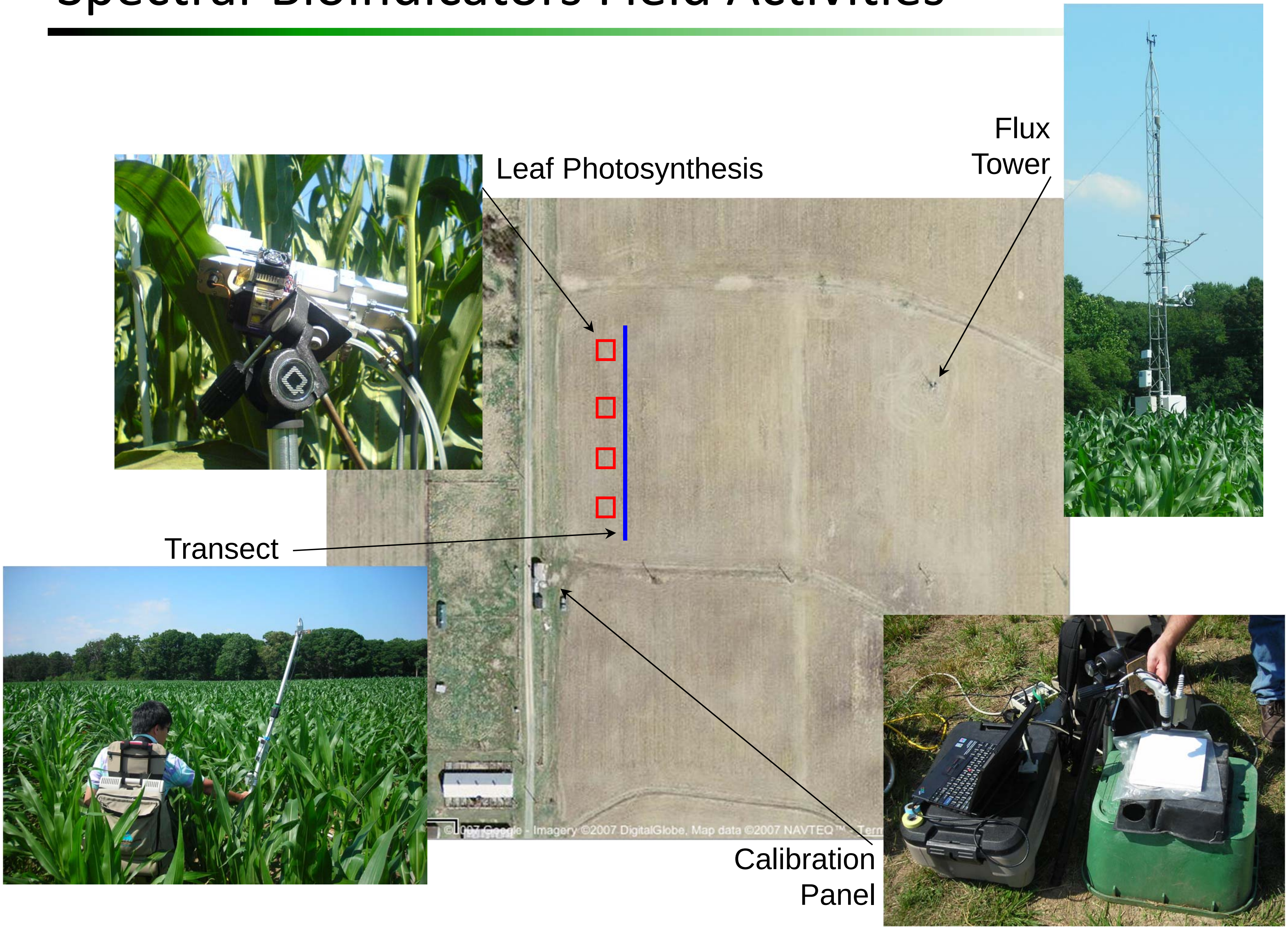
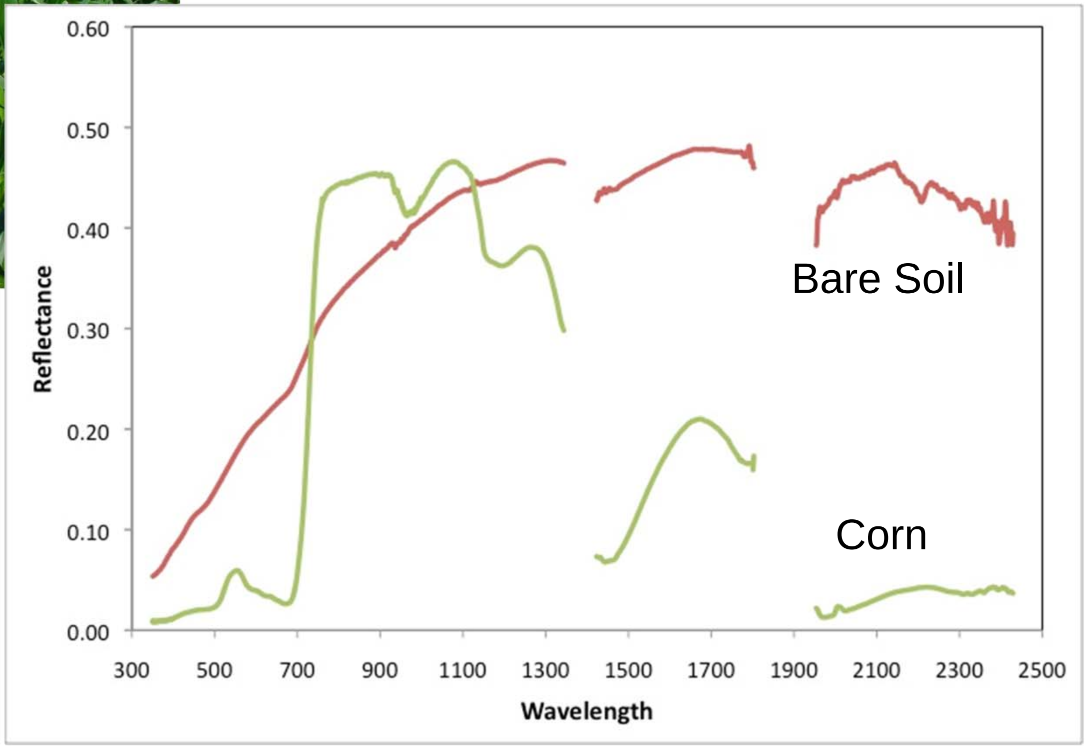
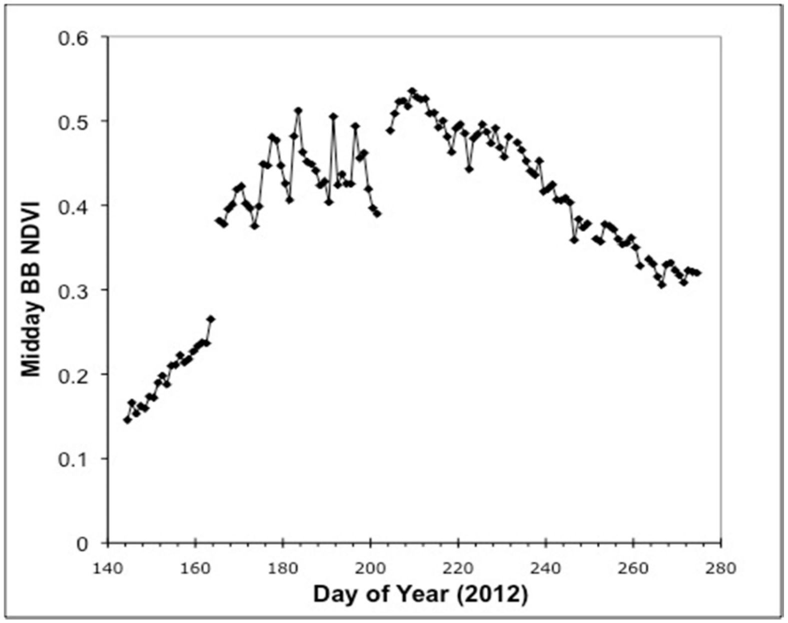


Spectral-Bioindicators Field Activities



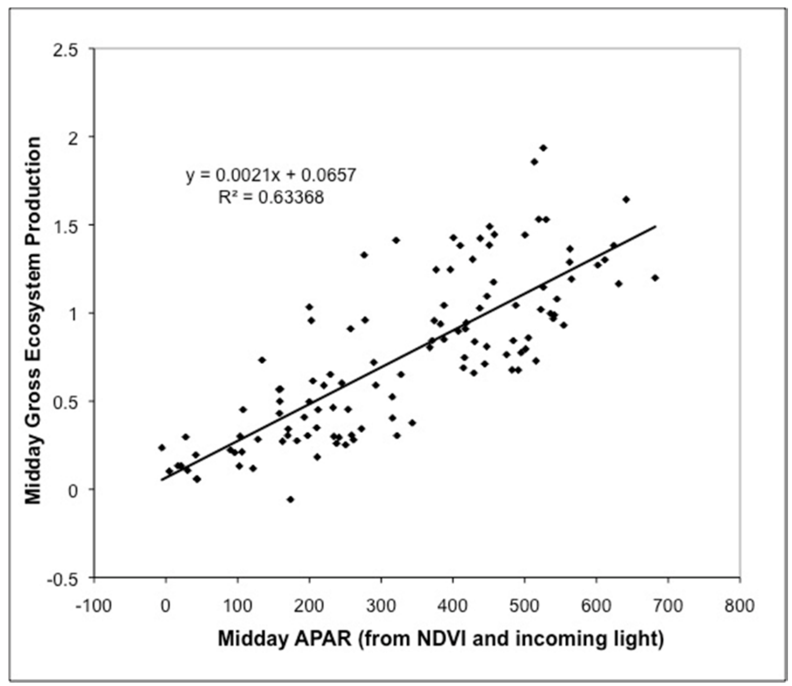
Field measurements with a spectrometer





Can measure seasonal change in NDVI from ground-based instruments

And compare to flux tower measurements of productivity (amount of CO_2 taken up by plants per unit area per second)



Satellite Remote Sensing

The three important characteristics of a satellite sensor are:

- Spectral characteristics – what spectral bands (colors) can the instrument detect and how accurately can it measure them?
- Spatial resolution – how big are the areas on the ground that the instrument can resolve?
- Repeat time – how often can you observe the same place on the ground? Depends on orbit.

I'm going to give some examples of using satellite data to observe how ecosystems change over time

Landsat

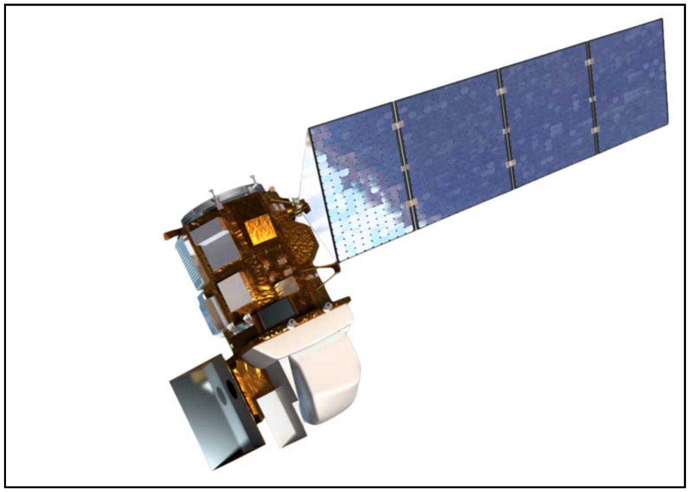
Landsat 1 - On July 23, 1972 the Earth Resources Technology Satellite was launched (renamed Landsat)

Landsat 5 - launched in March 1, 1984, is still functioning, but had problems since November 2011

Landsat 8 - the most recent, was launched on February 11, 2013

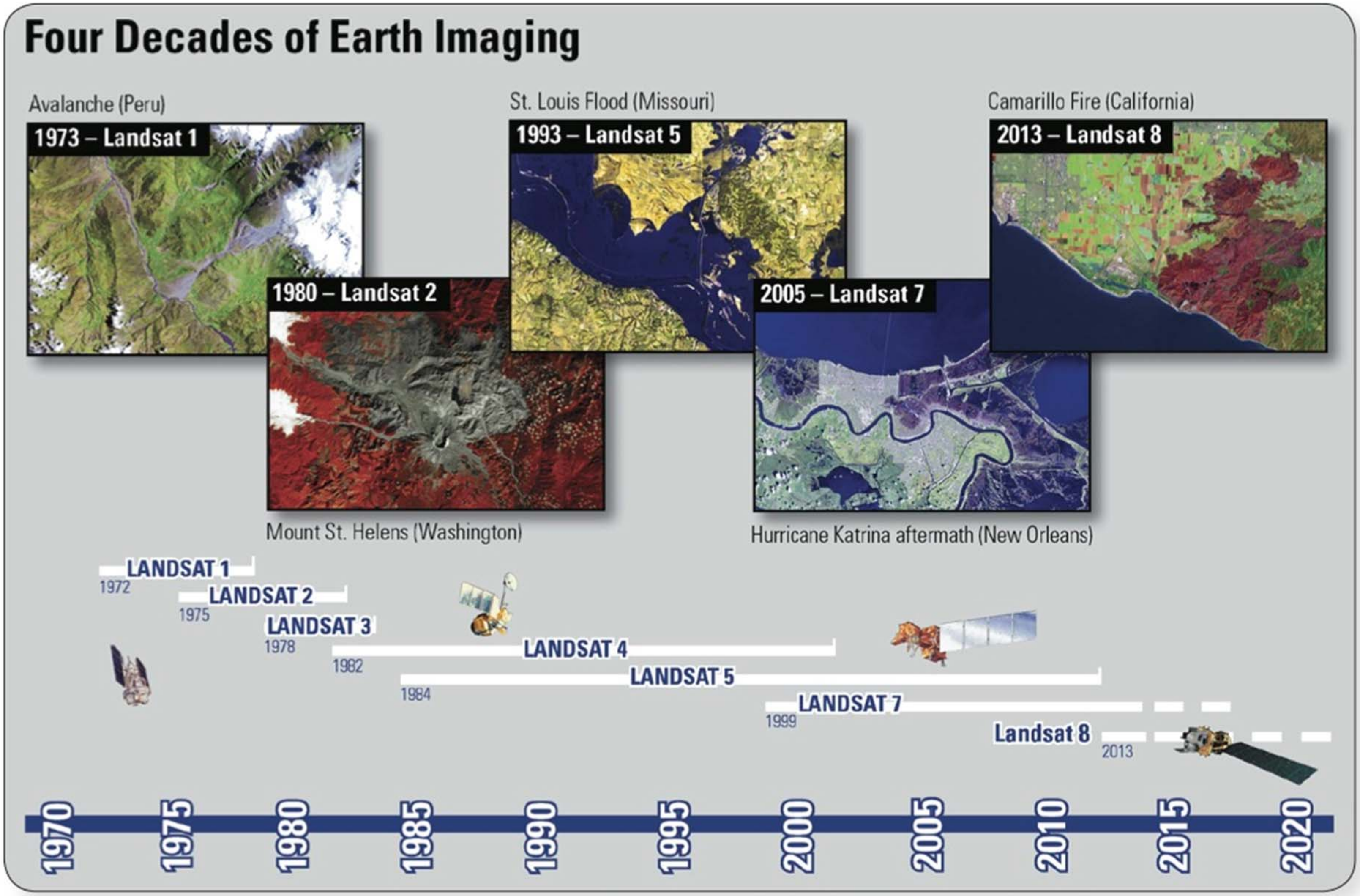
Landsat 1

Landsat 5



Landsat 8

Landsat



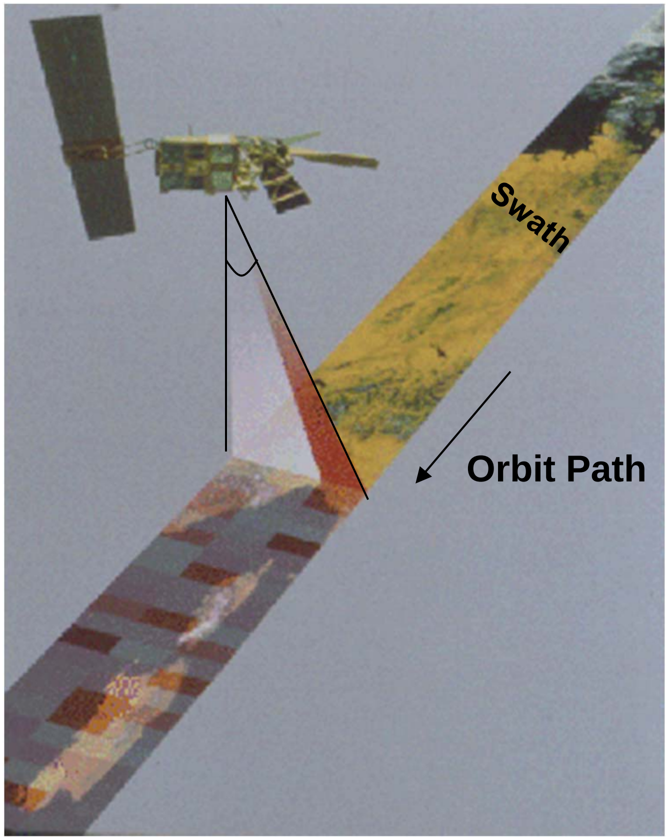
USGS

Landsat

Landsat images along the satellite's ground track in a 185-kilometer-wide (115-mile-wide) swath

Landsat 7 and Landsat 8 orbit the Earth at 705 kilometers (438 miles) altitude.

- making a complete orbit every 99 minutes
- about 14 full orbits each day
- cover every point on Earth once every 16 days
- always passes overhead at about 10:00 AM



Landsat

Landsat Thematic Mapper Spectral Bands

Band 1	**0.45 - 0.52μm (bue)**	**Useful for differentiating/mapping soil, vegetation, water, man-made features**
Band 2	**0.52 - 0.60μm (green)**	**Green reflection of healthy vegetation Assesses plant vigor**
Band 3	**0.63 - 0.69μm (red)**	**Chlorophyll absorption band Important for distinguishing vegetation from soil, man-made features**
Band 4	**0.76 - 0.90μm (near IR)**	**Responsive to plant vigor & biomass Almost complete absorption by water**
Band 5	**1.55 - 1.75μm (mid IR)**	**Plant moisture absorption band Responsive to plant moisture content Useful for plant stress & health analysis**
Band 6	**10.4μm – 12.50μm (far IR, Thermal)**	**Useful for locating hydrothermal and geothermal activities, and measuring surface temperature**
Band 7	**2.08 - 2.35μm (mid IR)**	**Soil moisture absorption band Responsive to soil moisture content Useful for mapping geologic rock formation, soil boundaries, and soil moisture content**

Landsat

Landsat TM and OLI instruments have 30 meter spatial resolution

How big is 30 meters?

Landsat

Landsat TM and OLI instruments have 30 meter spatial resolution

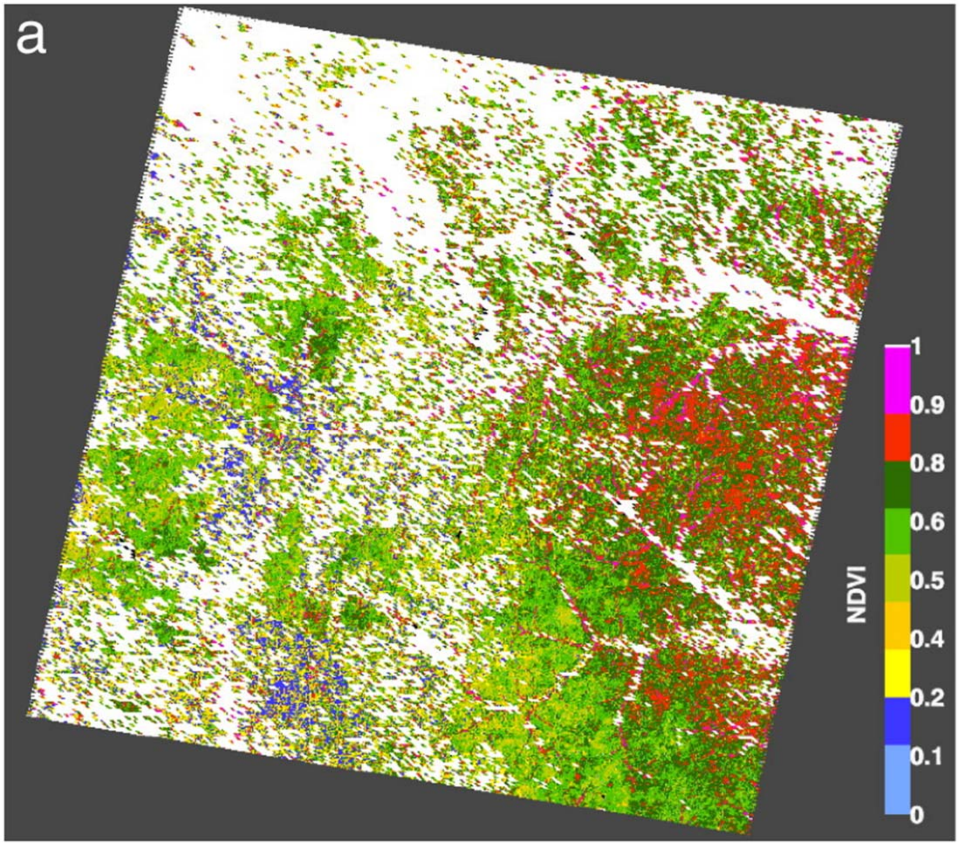
How big is 30 meters?

UMUC courtyard

Landsat NDVI

Landsat-derived NDVI for Kansas Prairie grasslands 23rd July, 2005.
Pixels with higher values of NDVI have more green leaves than those with lower values, and are thus more productive

- Information useful for ranchers, and for understanding the CO_2 uptake by the plants



Ganguly et al. Remote Sensing of Environment 2012

Landsat Ecosystem Disturbance Adaptive Processing System

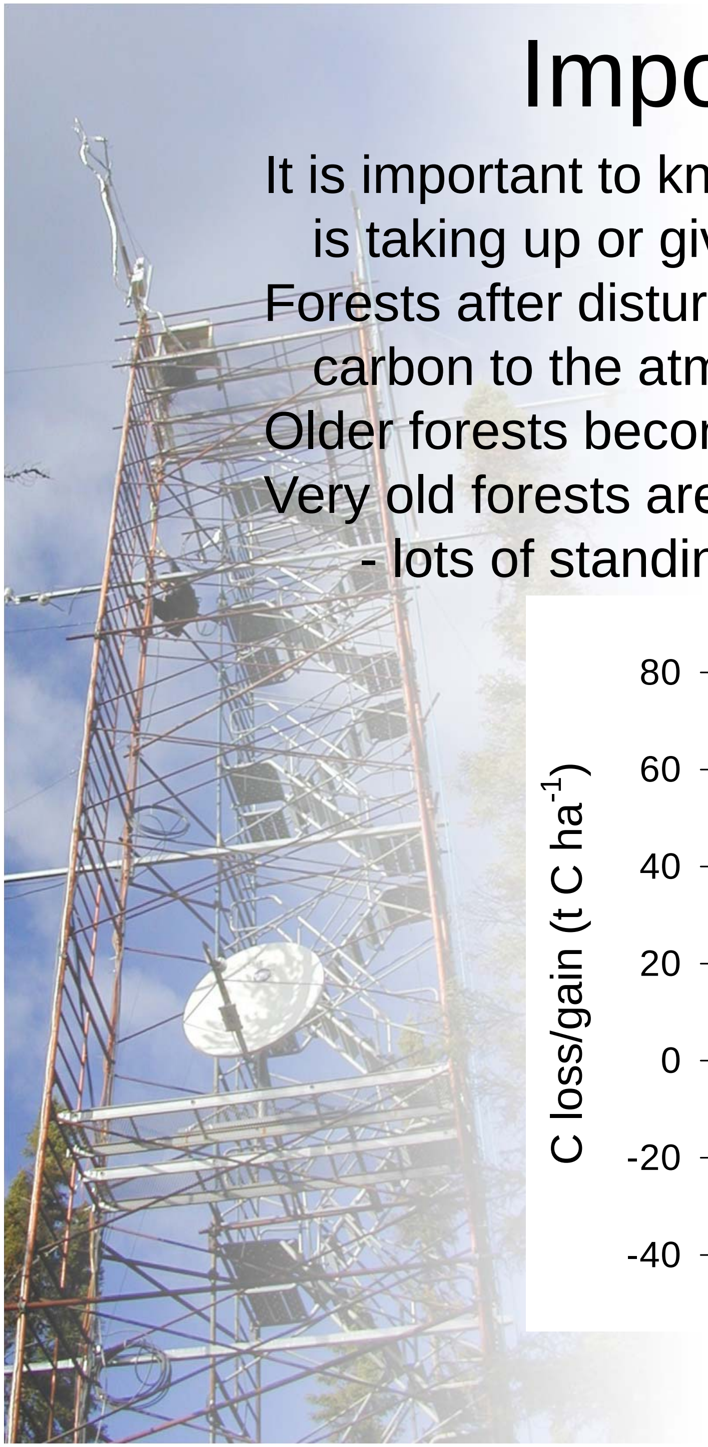
The LEDAPS project processes Landsat data to surface reflectance and uses change-detection techniques to map disturbance, regrowth, and permanent forest conversion across the continent.

Disturbance, such as fires or logging, is an important source of CO_2 from the land into the atmosphere

Landsat-5 image of Eastern Virginia, showing "patchwork" of land-cover types

http://ledaps.nascom.nasa.gov/overview/overview.html

Importance of Forest Age



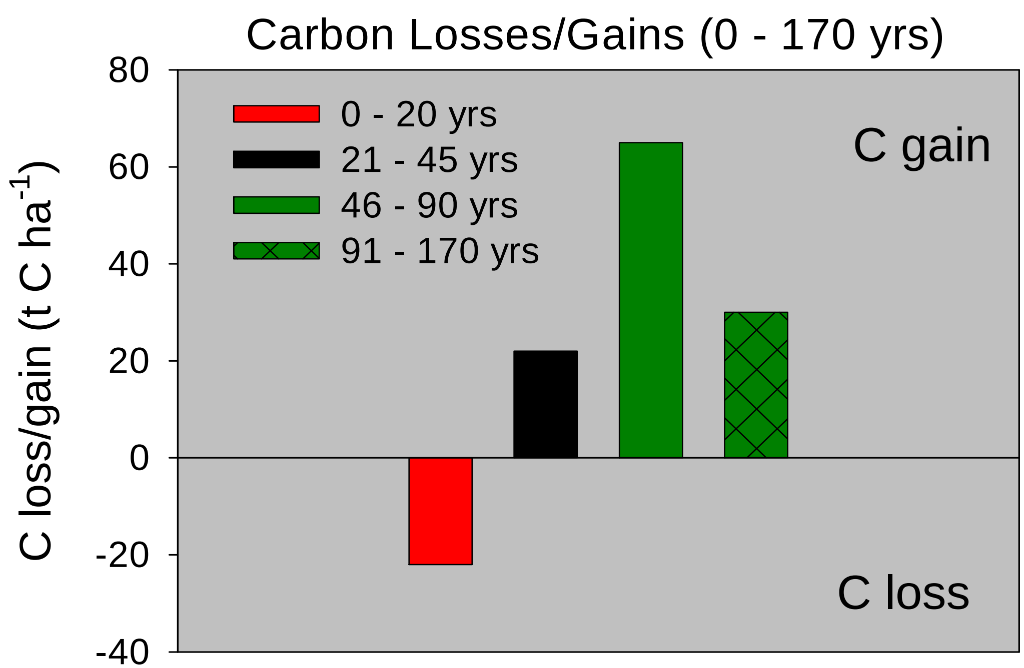
It is important to know the age of a forest to know how much CO_2 it is taking up or giving off to the atmosphere

Forests after disturbance (fire, logging), thus young forests can lose carbon to the atmosphere

Older forests become sinks of carbon (take in more than they lose)

Very old forests are still a sink, but less so

- lots of standing biomass that respires a lot



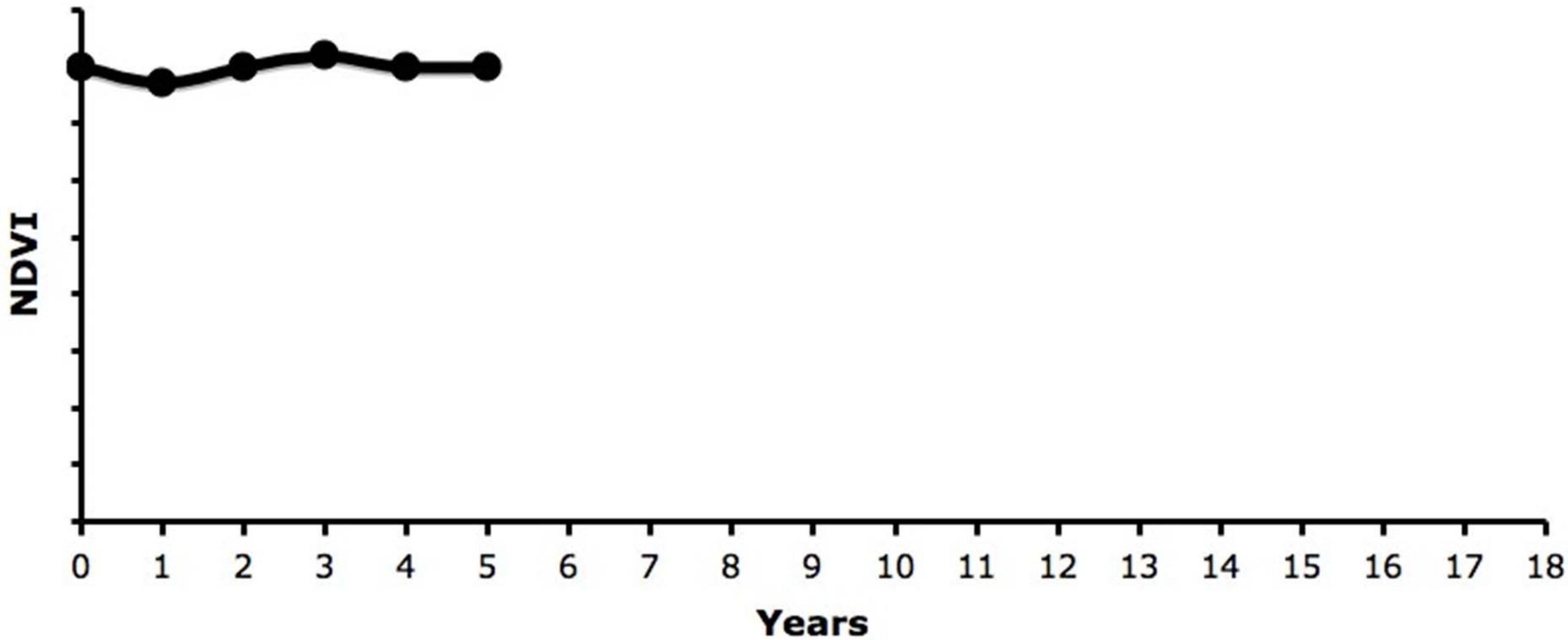
H. Margolis

Detecting Disturbances with Landsat

Unfortunately, NDVI does not directly tell us forest age

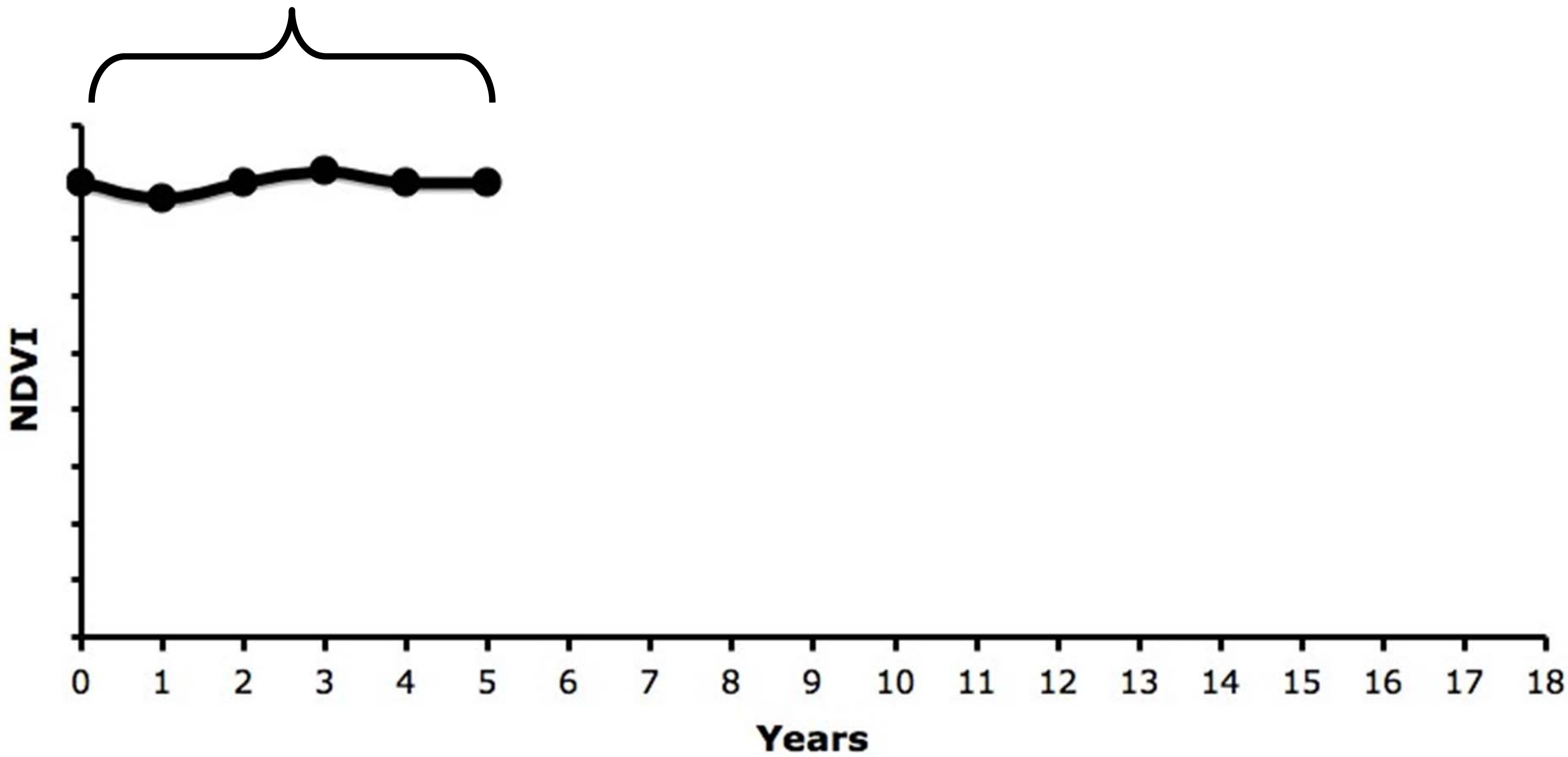
We can determine age by using a time series

Conceptual diagram of time series of mid-summer observations of a forest

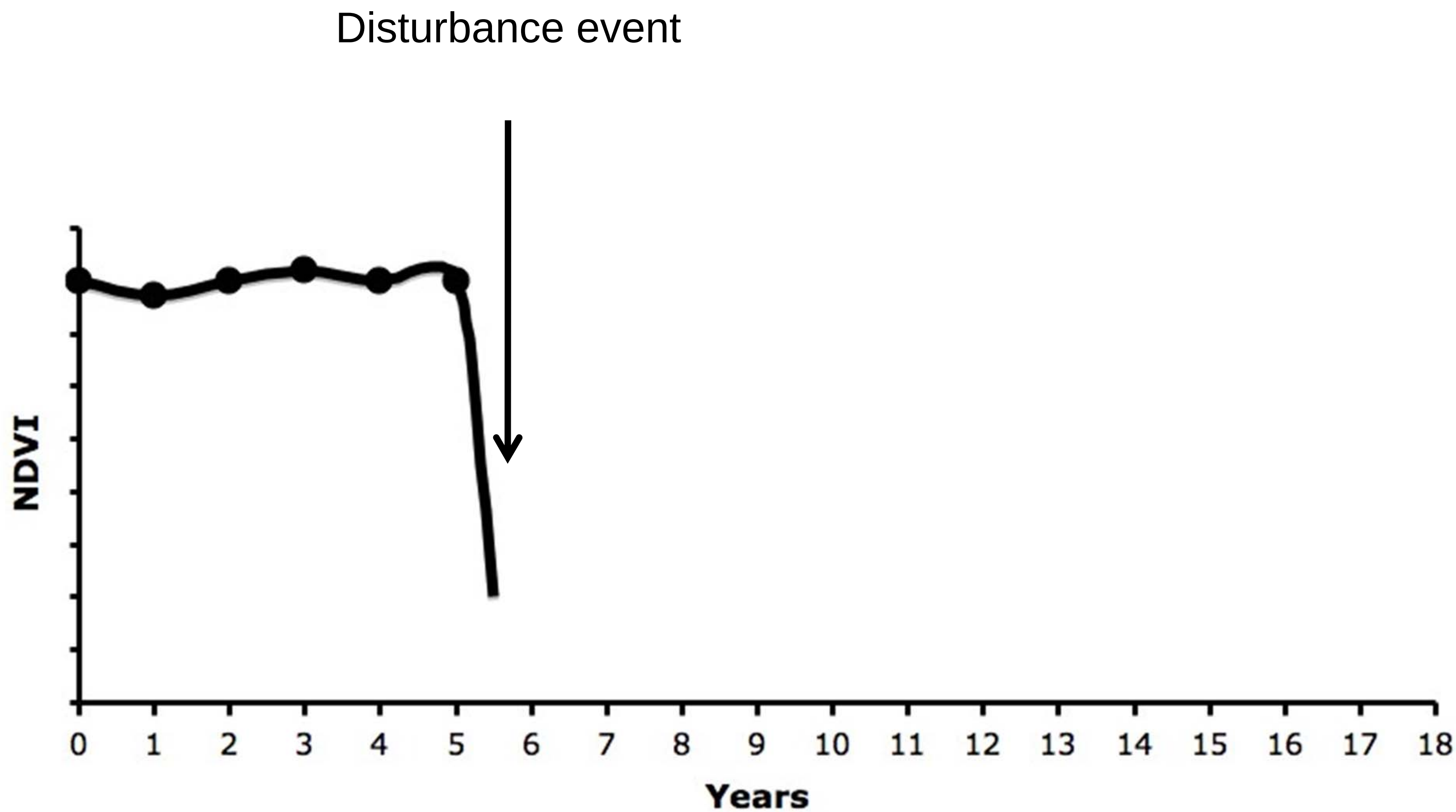


Detecting Disturbances with Landsat

Original (undisturbed) forest

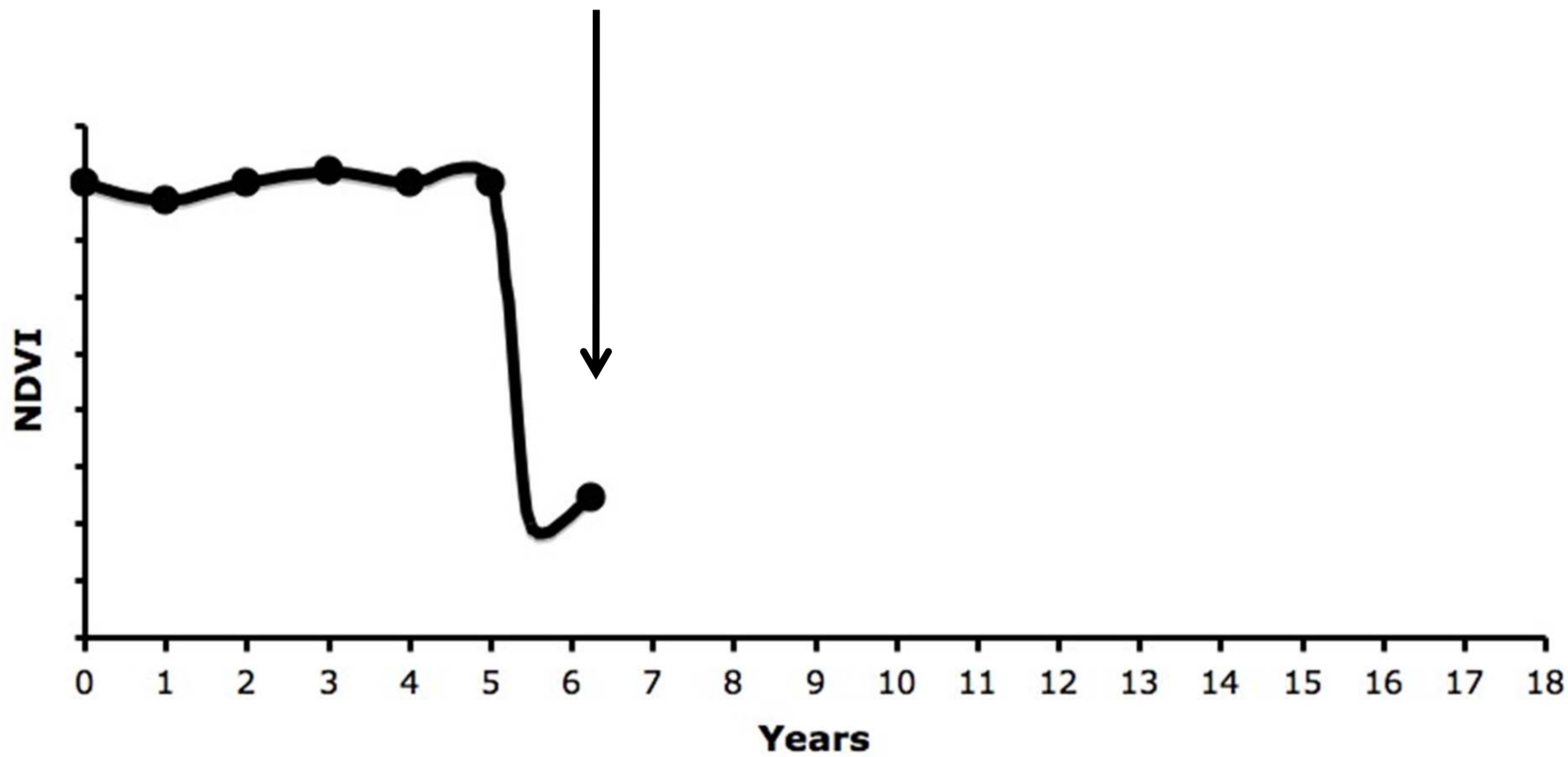


Detecting Disturbances with Landsat

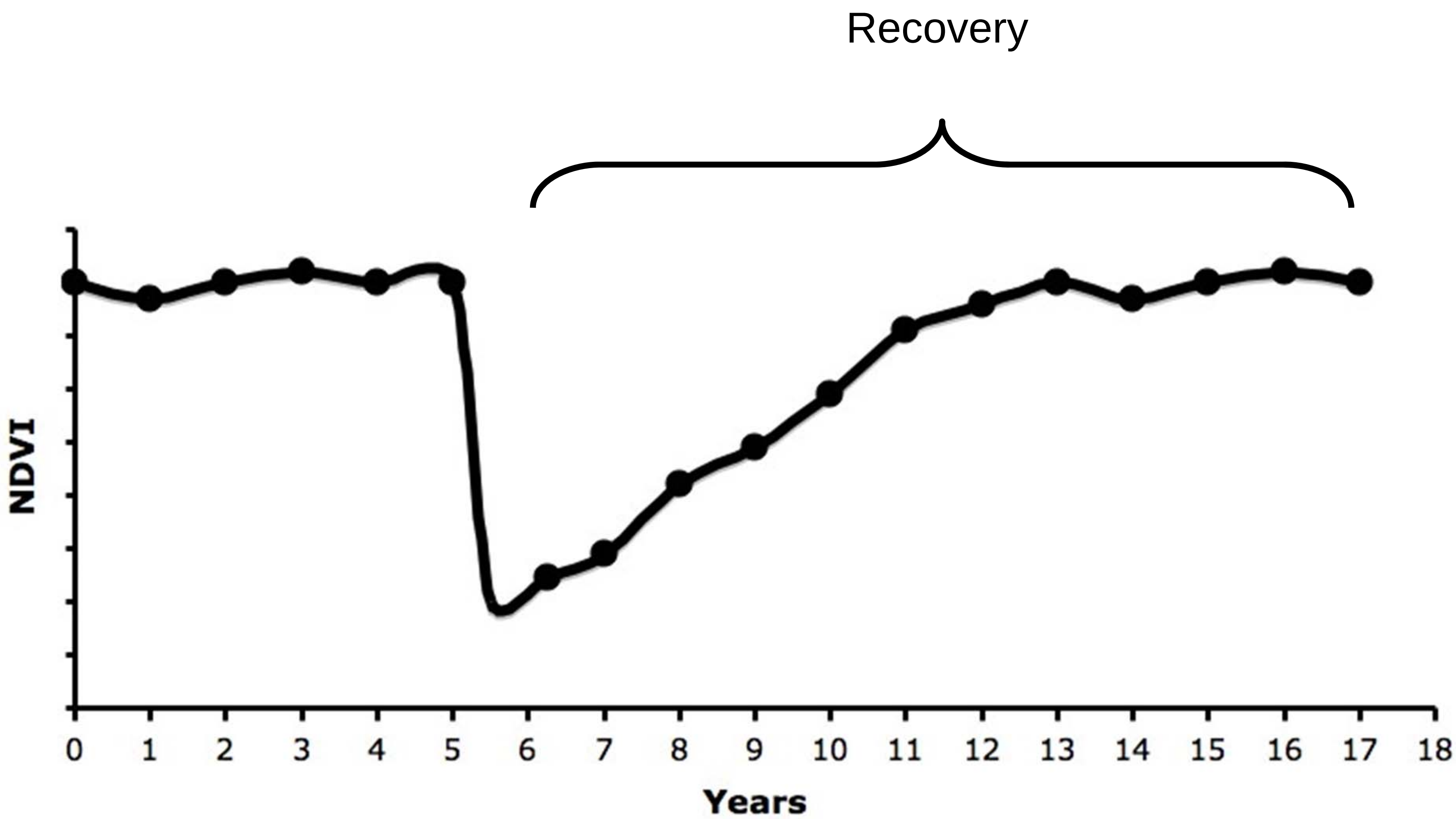


Detecting Disturbances with Landsat

First observation after disturbance

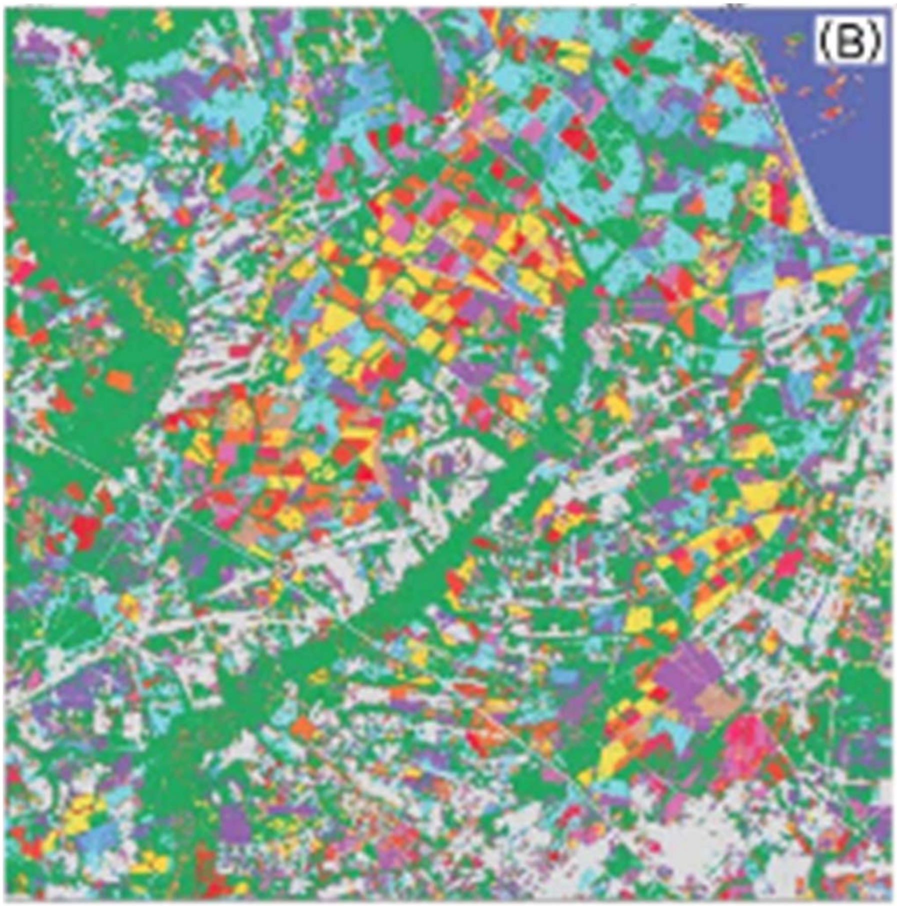


Detecting Disturbances with Landsat



North American Forest Dynamics (NAFD) Study

Looks at multiple years of Landsat images
- colors on image indicate different years of disturbances
- shows the high levels of disturbance that can occur in landscapes
- important for understanding amount of CO_2 released from landscape
- all of the colored pixels are forests, but different ages have different productivities



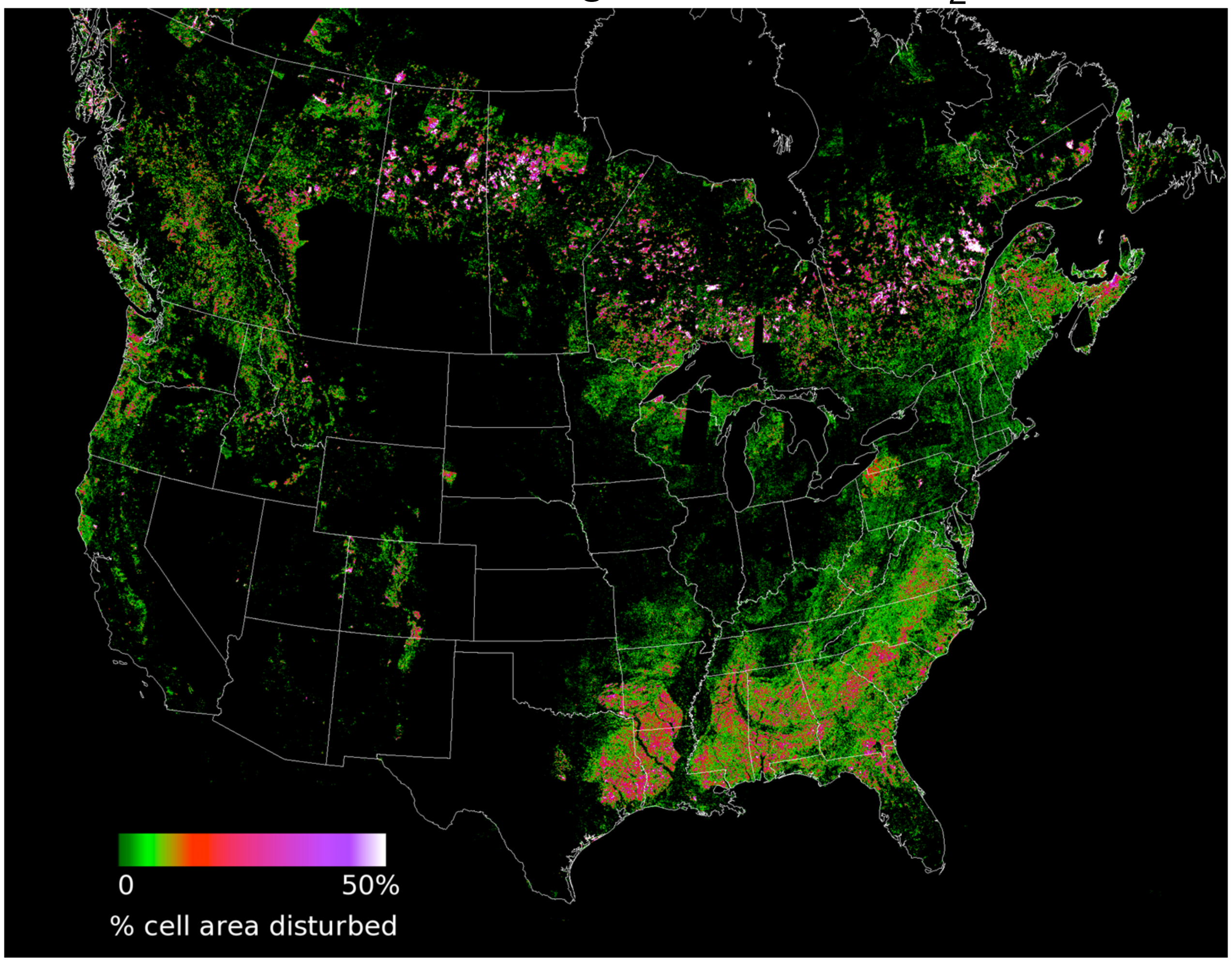
Goward et al.

North American Forest Disturbance from Landsat

Amount of disturbed area over a 10 year period

- significant fraction of forests are disturbed

Critical information for determining how much CO_2 forests are absorbing



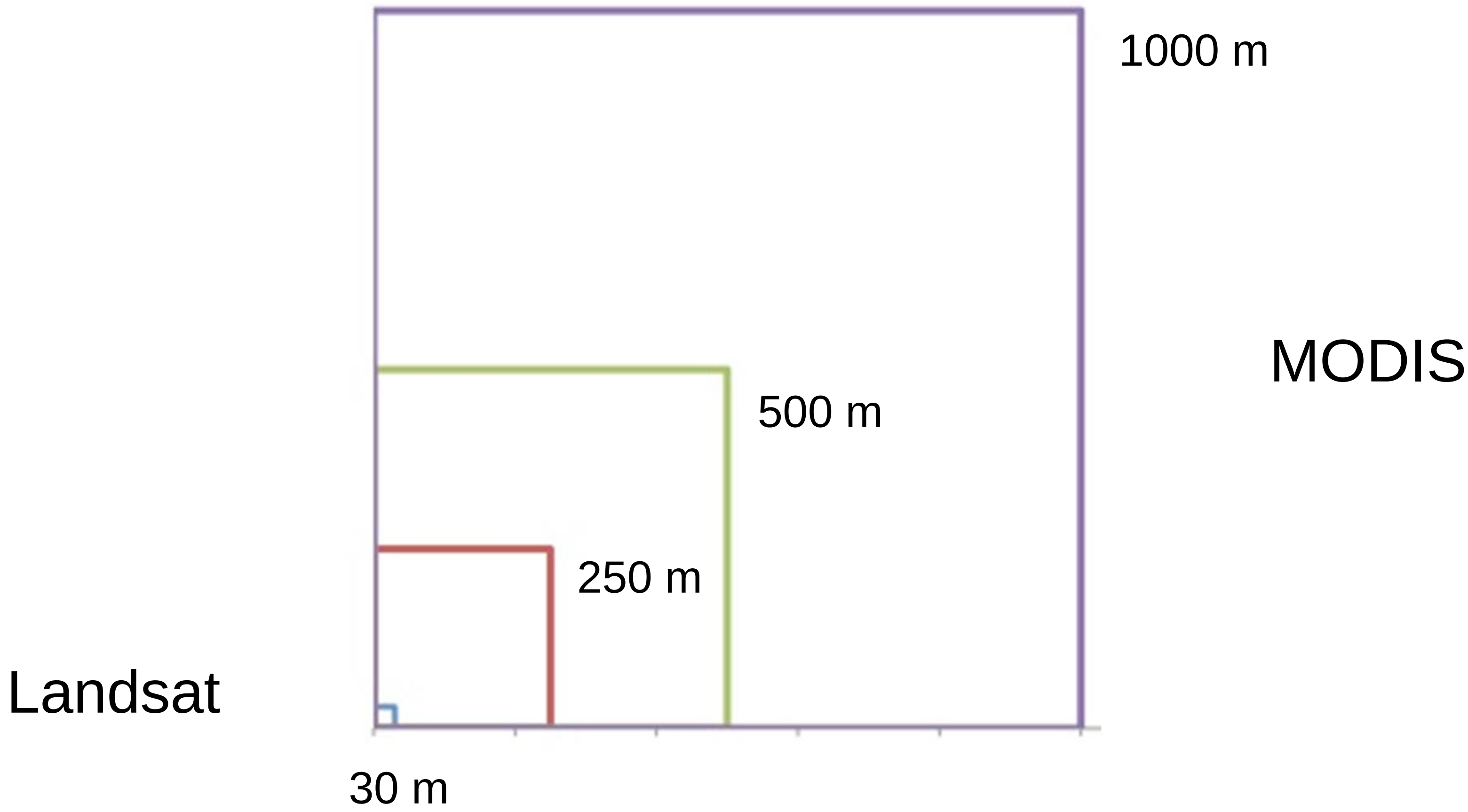
Masek et al.

Moderate Resolution Satellite Data

Moderate resolution missions provide data with much bigger pixels than Landsat, but much more frequent observations

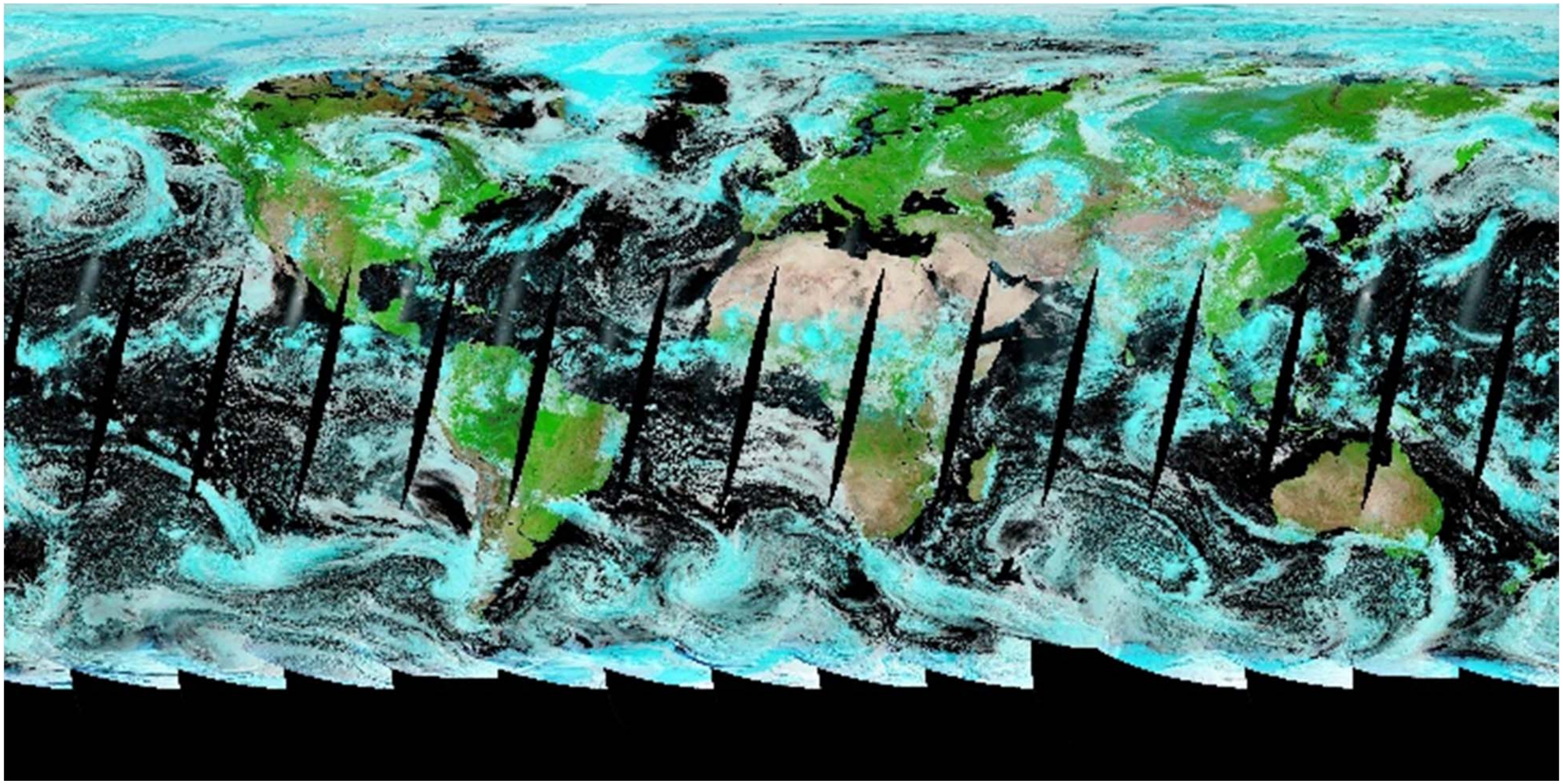
- Started with the Advanced Very High Resolution Radiometer (AVHRR)
  - Since 1981 the NOAA Polar Orbiting Environmental Satellites (POES) have carried a series of AVHRR instruments
  - Not intended for vegetation studies AVHRR can provide global NDVI values for over 30 years
- The MODIS instrument flying on the Terra and Aqua satellites provides frequent global coverage since 2000
  - MODIS pixels are 250, 500, and 1000 m
  - Provides similar spectral bands as Landsat

Pixel Sizes (Spatial resolution)



Global Coverage

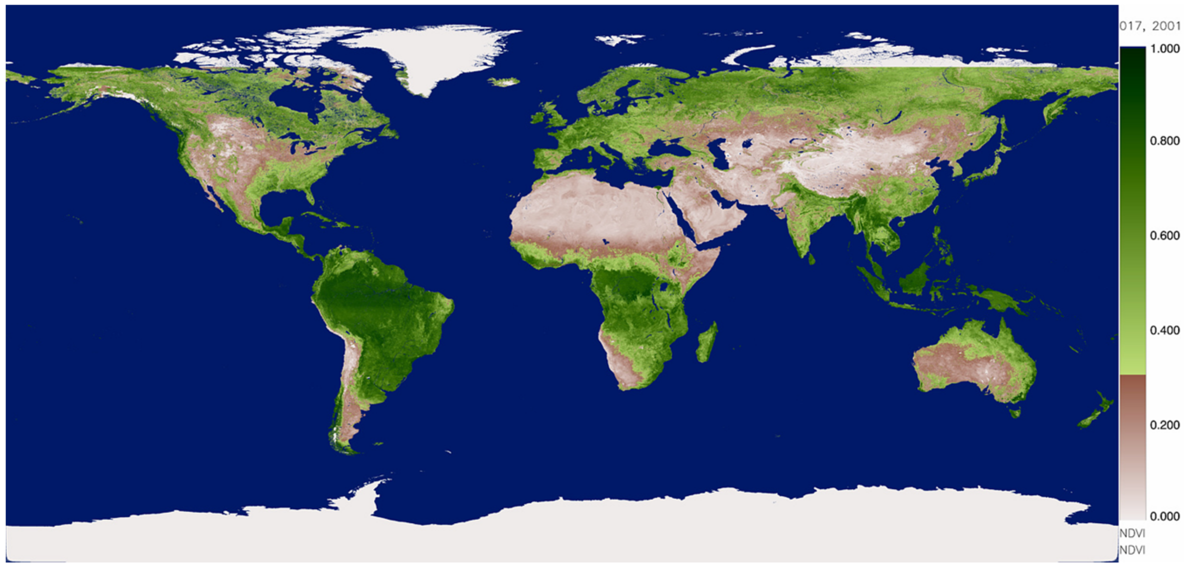
The wide swath of MODIS provides almost global coverage in a single day



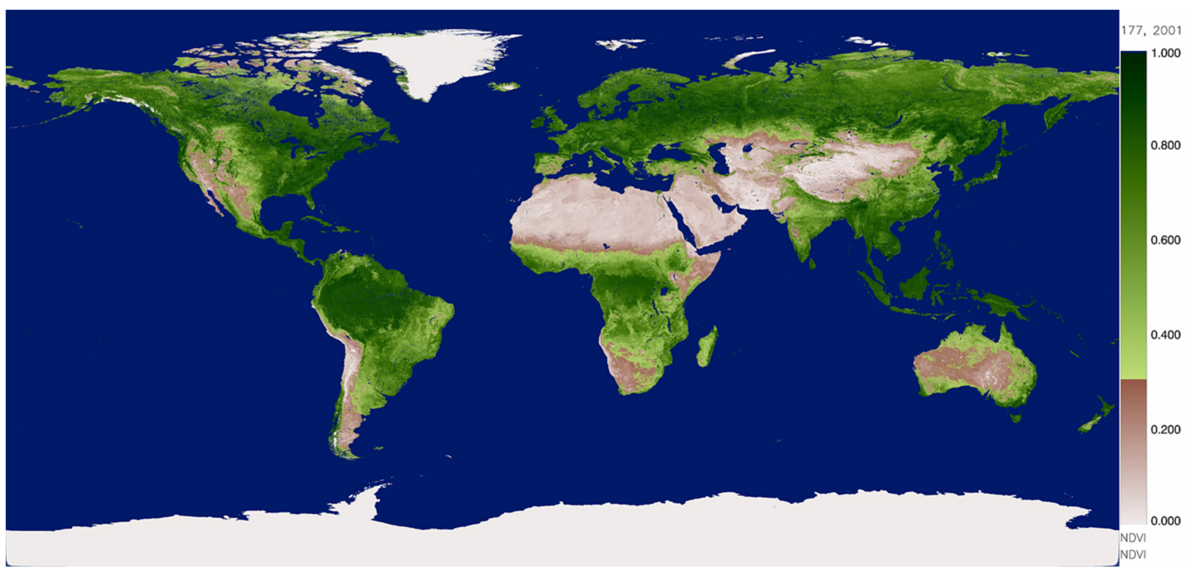
Global NDVI Maps

Multiple days of data are merged together to produce cloud-free data
- 8-day groupings are used for MODIS

January 17, 2001

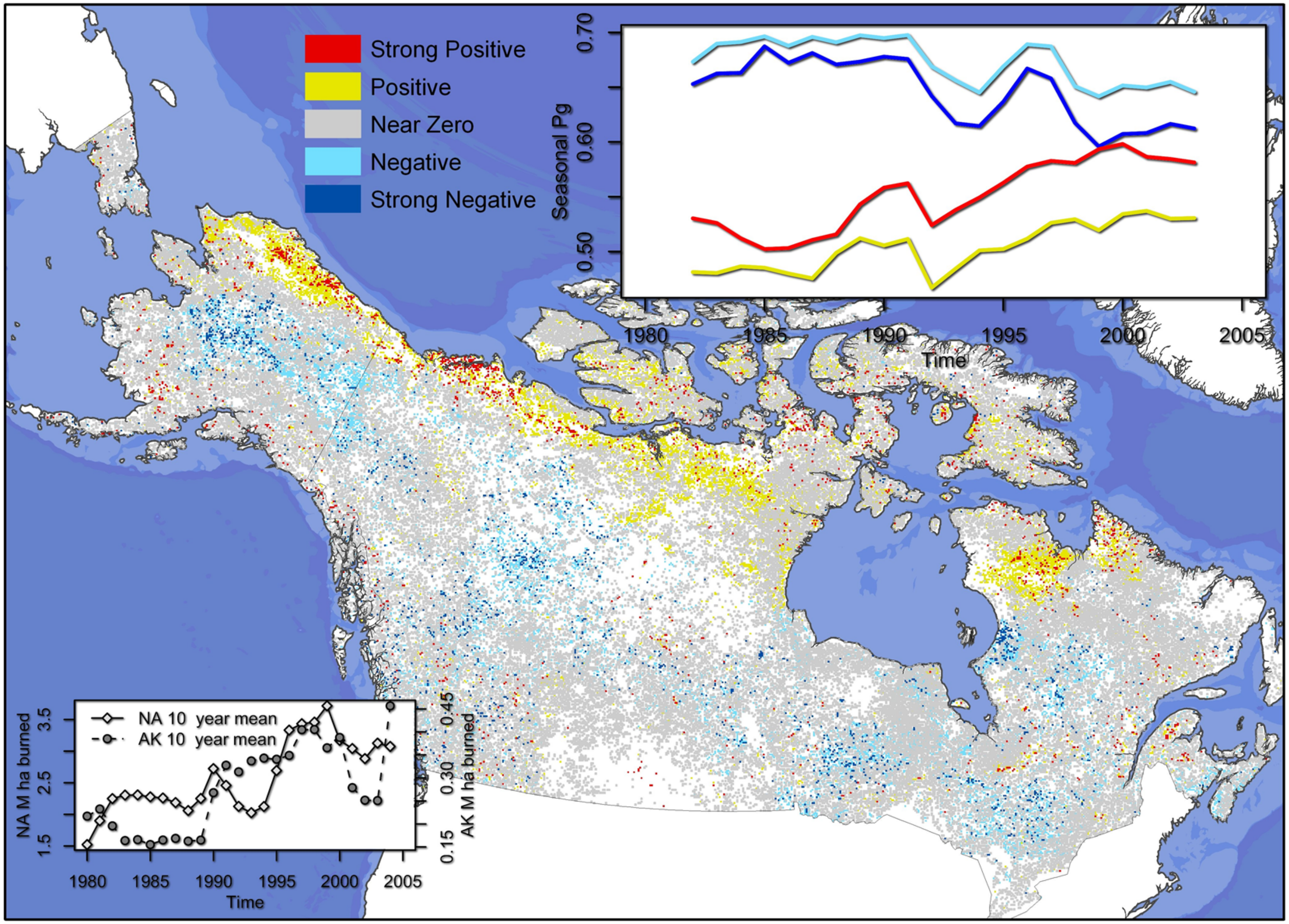


June 26, 2001



Trends in NDVI from satellites over 20 year period

We can use AVHRR satellite data to observe climate caused ecosystem change
- Warm colors indicate areas that are getting greener (NDVI increases)
- Cool colors indicate areas where plants may be stressed (NDVI decreases)

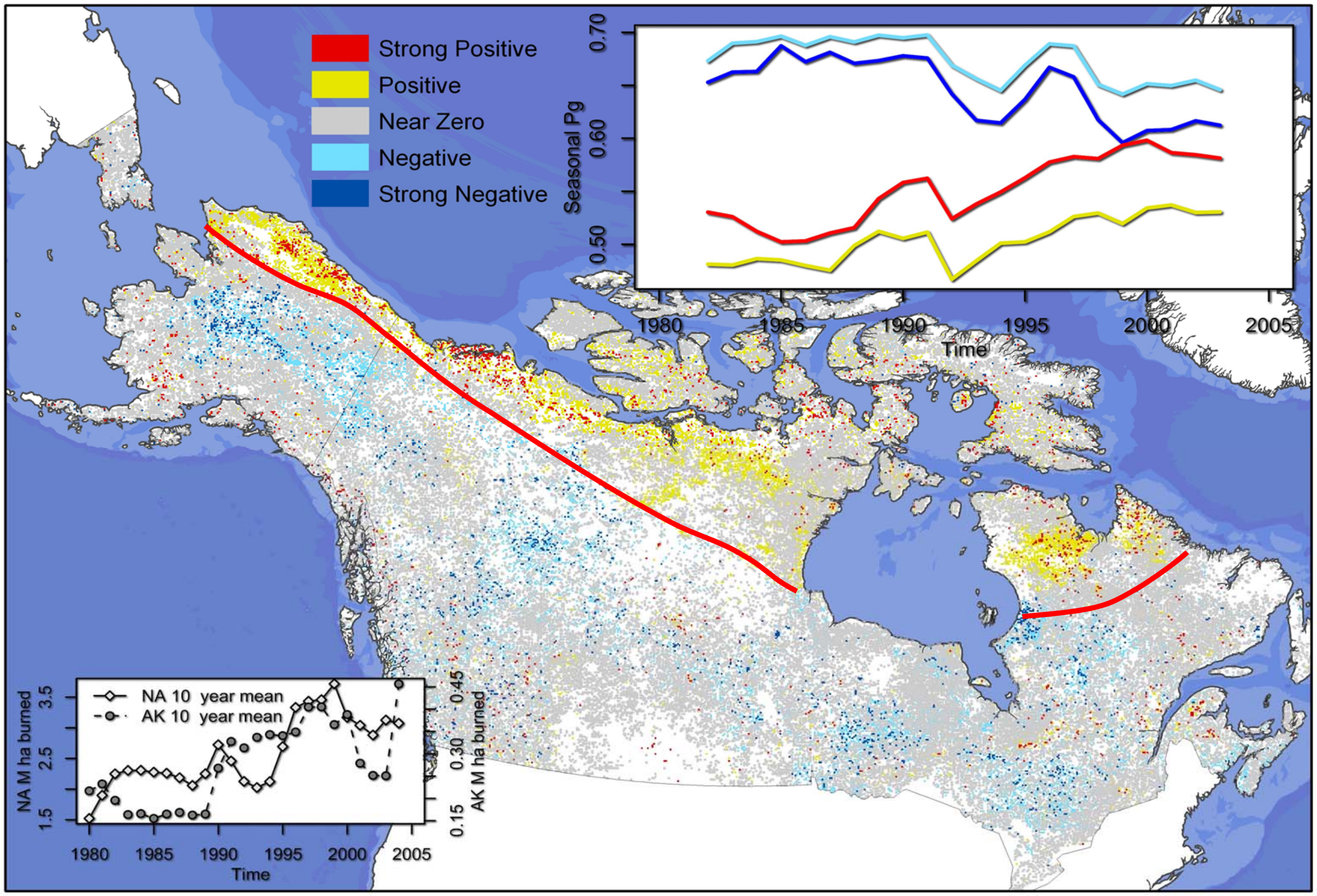


Goetz et al. 2005

Trends in NDVI from satellites over 20 year period

Red line represents the approximate location of treeline (the boundary between the boreal forest and tundra biomes)

- Greening is occurring in the middle of the tundra biome and browning in the middle of the boreal forest biome
- Changes are not observed along the boundary as expected



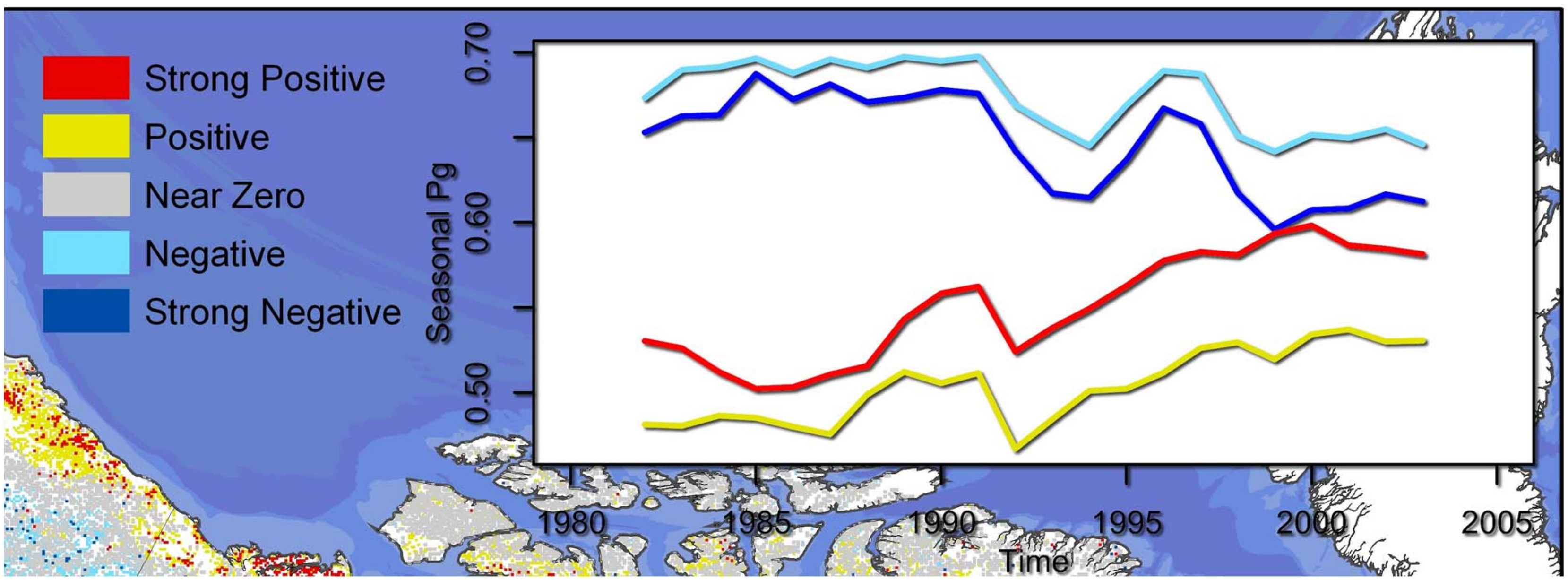
Goetz et al. 2005

Trends in NDVI from satellites over 20 year period

Graph shows trends in vegetation over time

Drop in NDVI in mid-1990s due to eruption of Mount Pinatubo

- dumped huge amounts of aerosols into upper atmosphere
- less light came through the atmosphere and it got cooler
- had an observable effect on plant growth
- artificially repeating this process has been suggested as a way to mitigate greenhouse warming (called geoengineering)



Goetz et al. 2005

Observing Seasonal Changes in Vegetation

All of the data we have looked at so far have used multiple years of observations but always collected in mid-summer near the peak of greenness

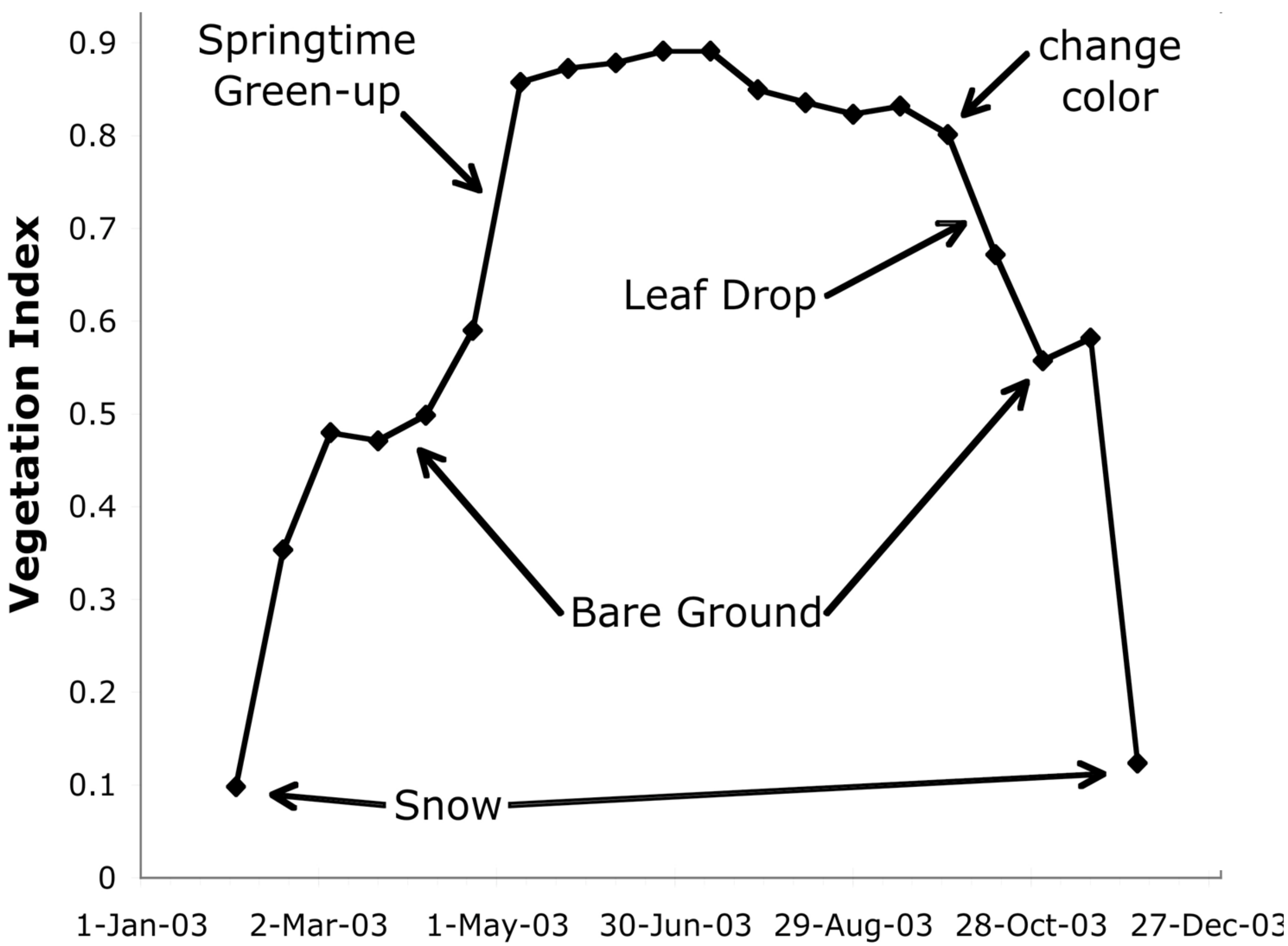
We can examine seasonal changes in vegetation growth using the frequent observations from AVHRR and MODIS

Phenology is the study of periodic plant and animal life cycle events and how these are influenced by seasonal and interannual variations in climate

- Phenology can refer to things like the timing of flowers opening or arrival of migrating birds
- We can think about satellite phenology based on seasonal changes in NDVI

Observing Seasonal Changes in Vegetation

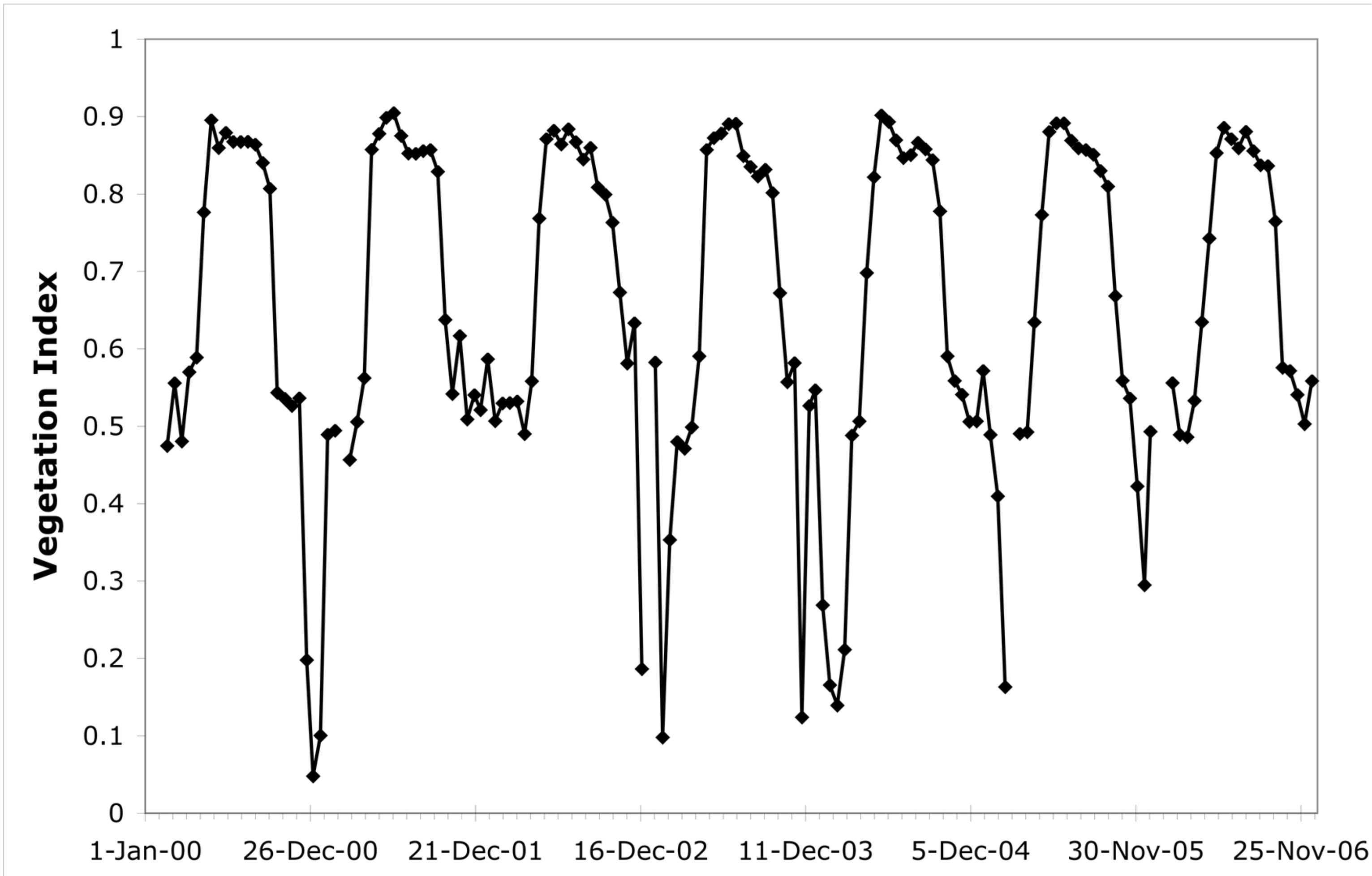
Typical seasonal pattern of NDVI for a deciduous forest



Observing Seasonal Changes in Vegetation

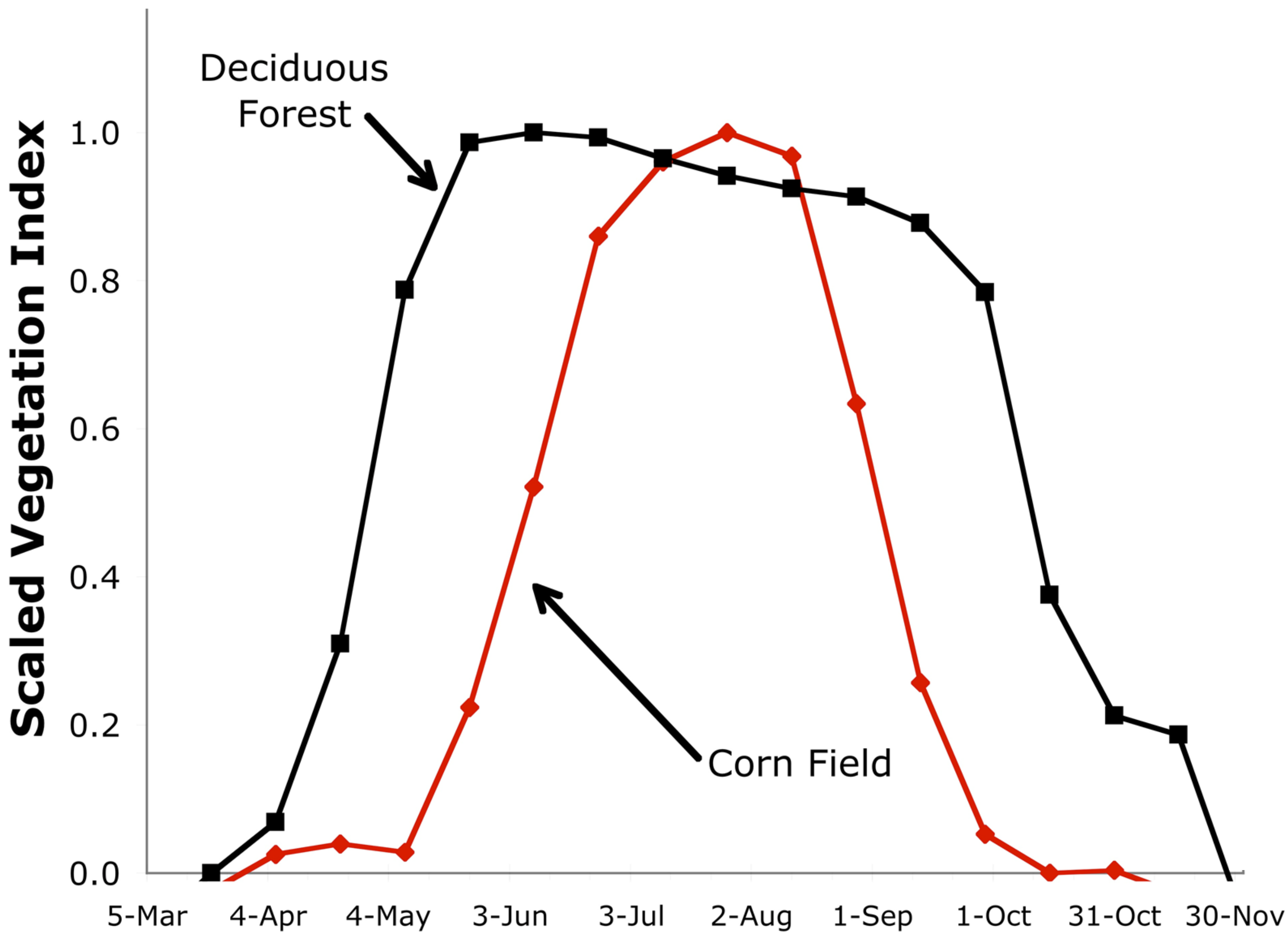
We can use the satellite data to observe year to year changes in seasonal patterns

Affected by weather and climate



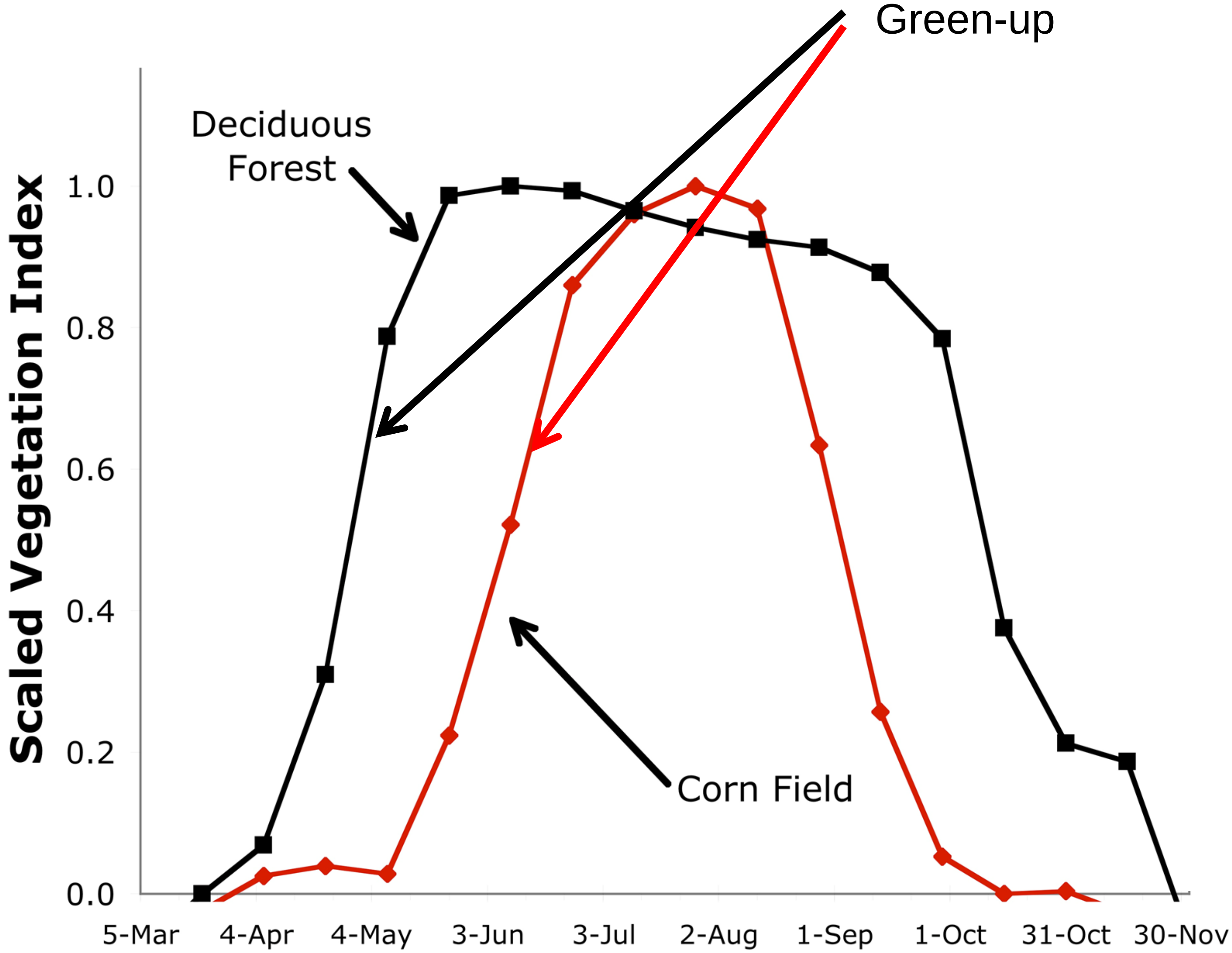
Observing Seasonal Changes in Vegetation

Seasonal patterns differ for different types of vegetation
- Deciduous forest and corn field



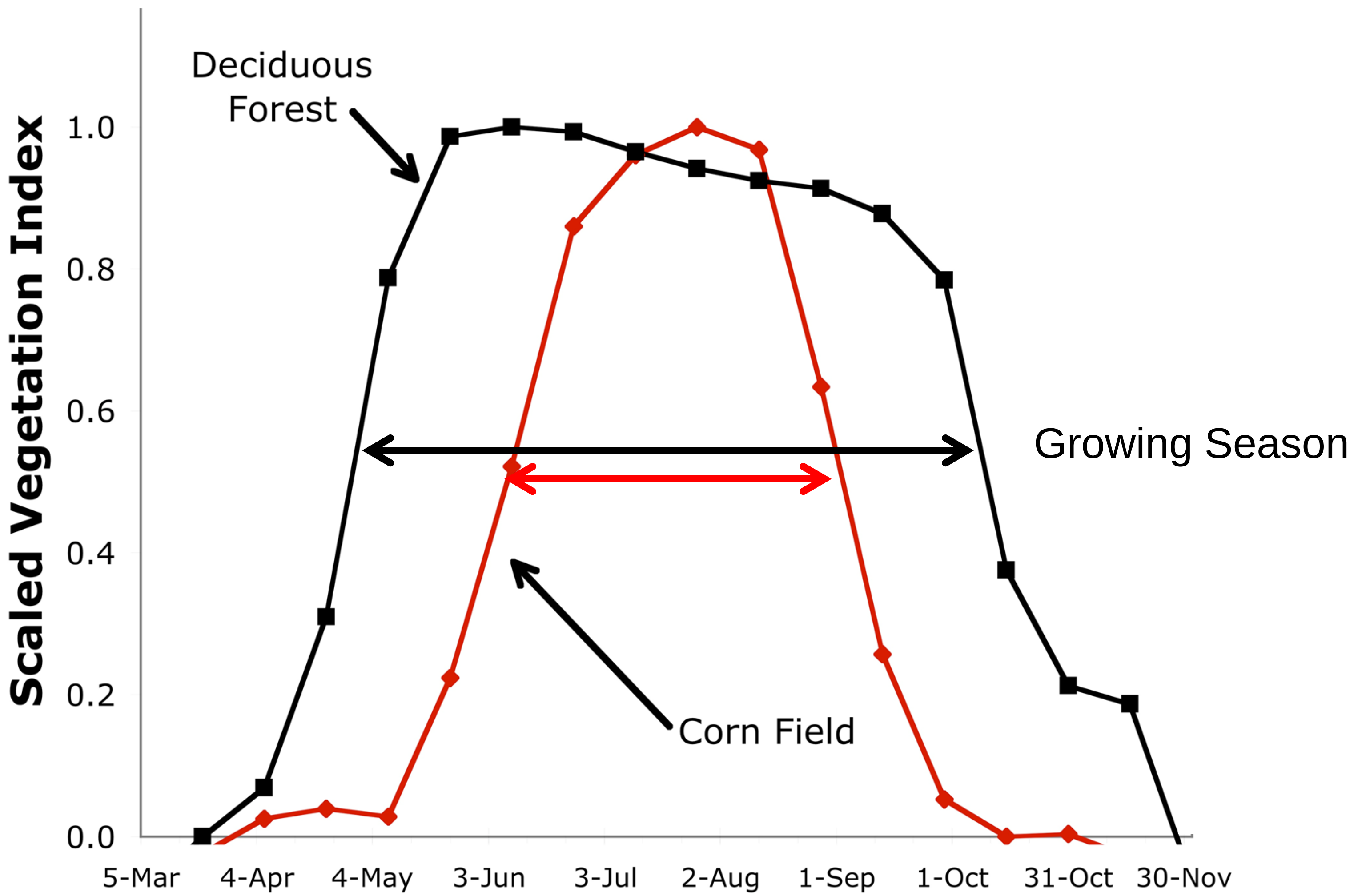
Observing Seasonal Changes in Vegetation

Seasonal patterns differ for different types of vegetation
- Deciduous forest and corn field



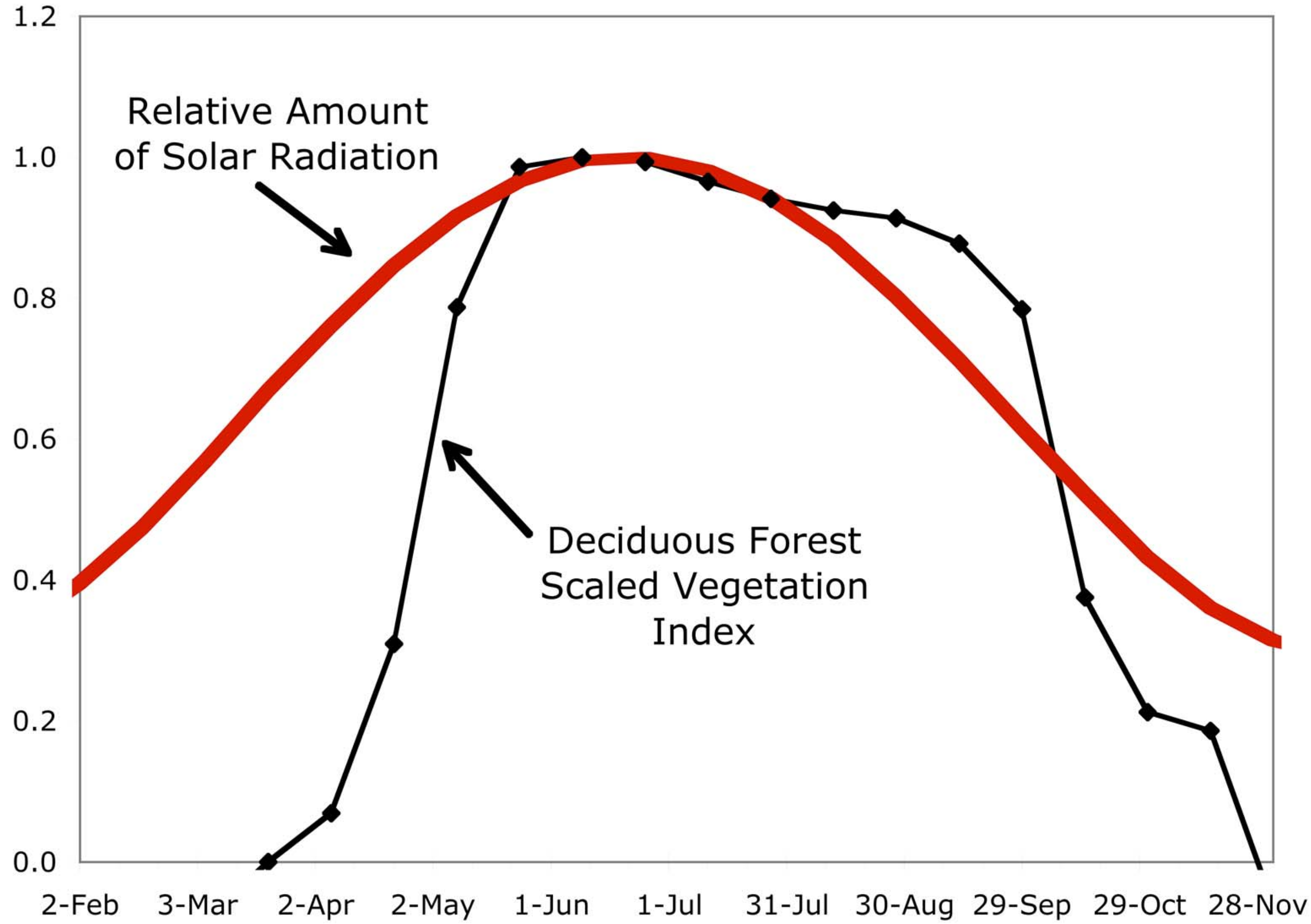
Observing Seasonal Changes in Vegetation

Seasonal patterns differ for different types of vegetation
- Deciduous forest and corn field



Observing Seasonal Changes in Vegetation

Combining information from NDVI and incoming light from the sun provides an estimate of unstressed ecosystem productivity

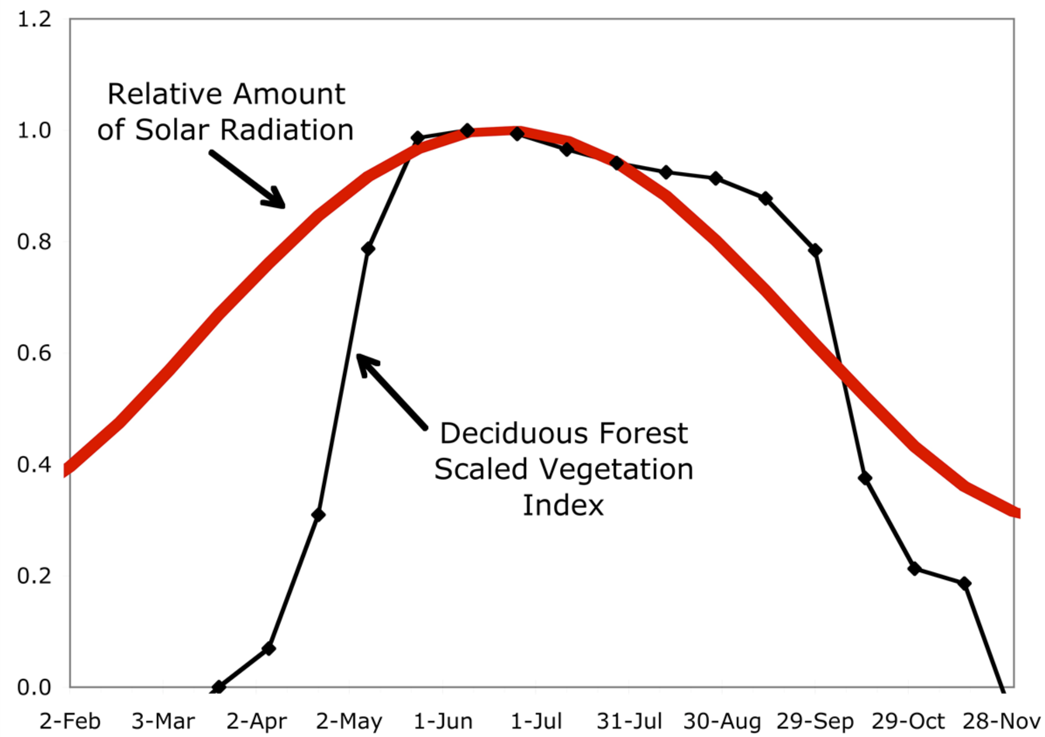


Observing Seasonal Changes in Vegetation

The seasonal change in NDVI does not directly follow the amount of available sunlight.

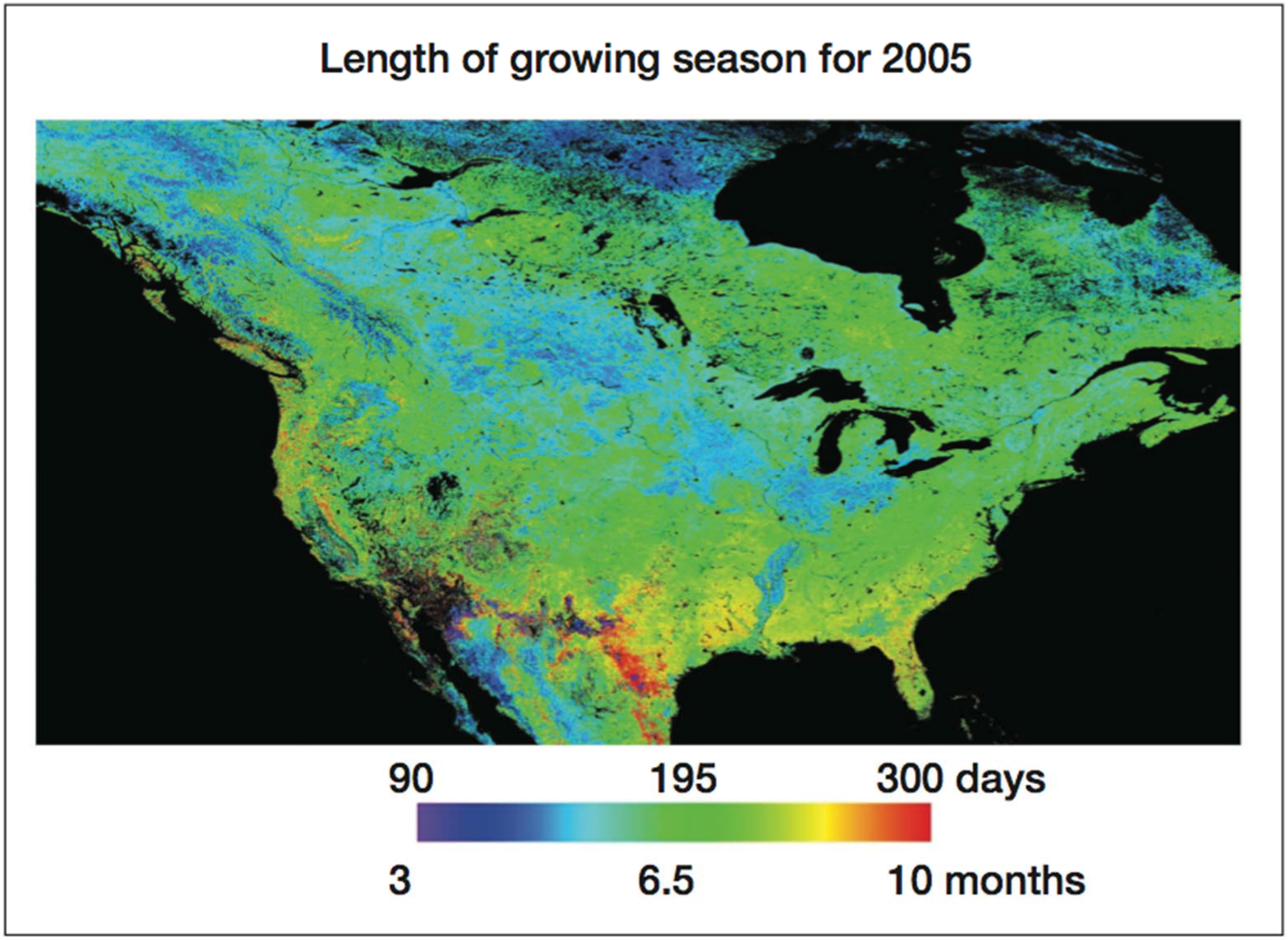
- In the spring, the sun has to warm the environment enough so that the trees can grow new leaves, so springtime green-up comes after the springtime rise of solar energy.
- In the autumn the trees drop their leaves at about the time that the solar energy drops to half its summertime maximum.

- There just isn't enough energy available from the sun to make photosynthesis worthwhile to the trees at that time of year, so the trees drop their leaves and prepare for winter.



Observing Seasonal Changes in Vegetation

We can map phenology parameters over large areas
Important for understanding ecosystem productivity and response to climate change



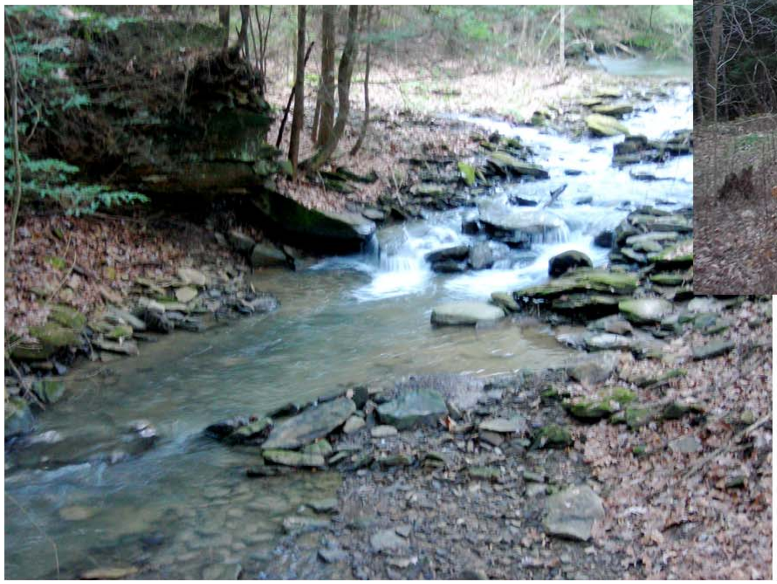
Morisette et al.

Observing Seasonal Changes in Vegetation

An example of using MODIS satellite data to look at effects of climate change on one particular place

Todd Sanctuary in Sarver, Pennsylvania

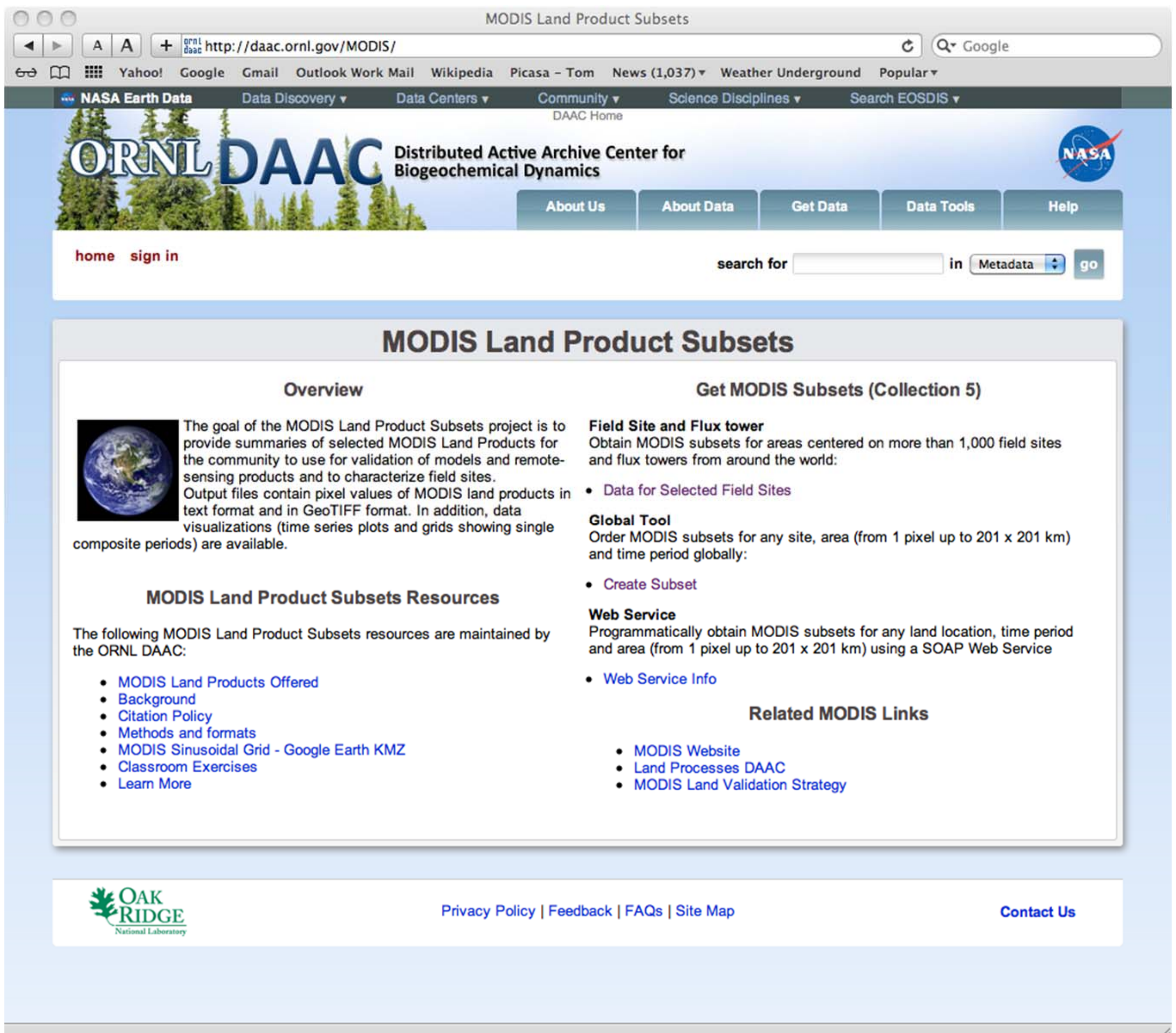
- Owned by the Audubon Society of Western Pennsylvania
- Deciduous forest

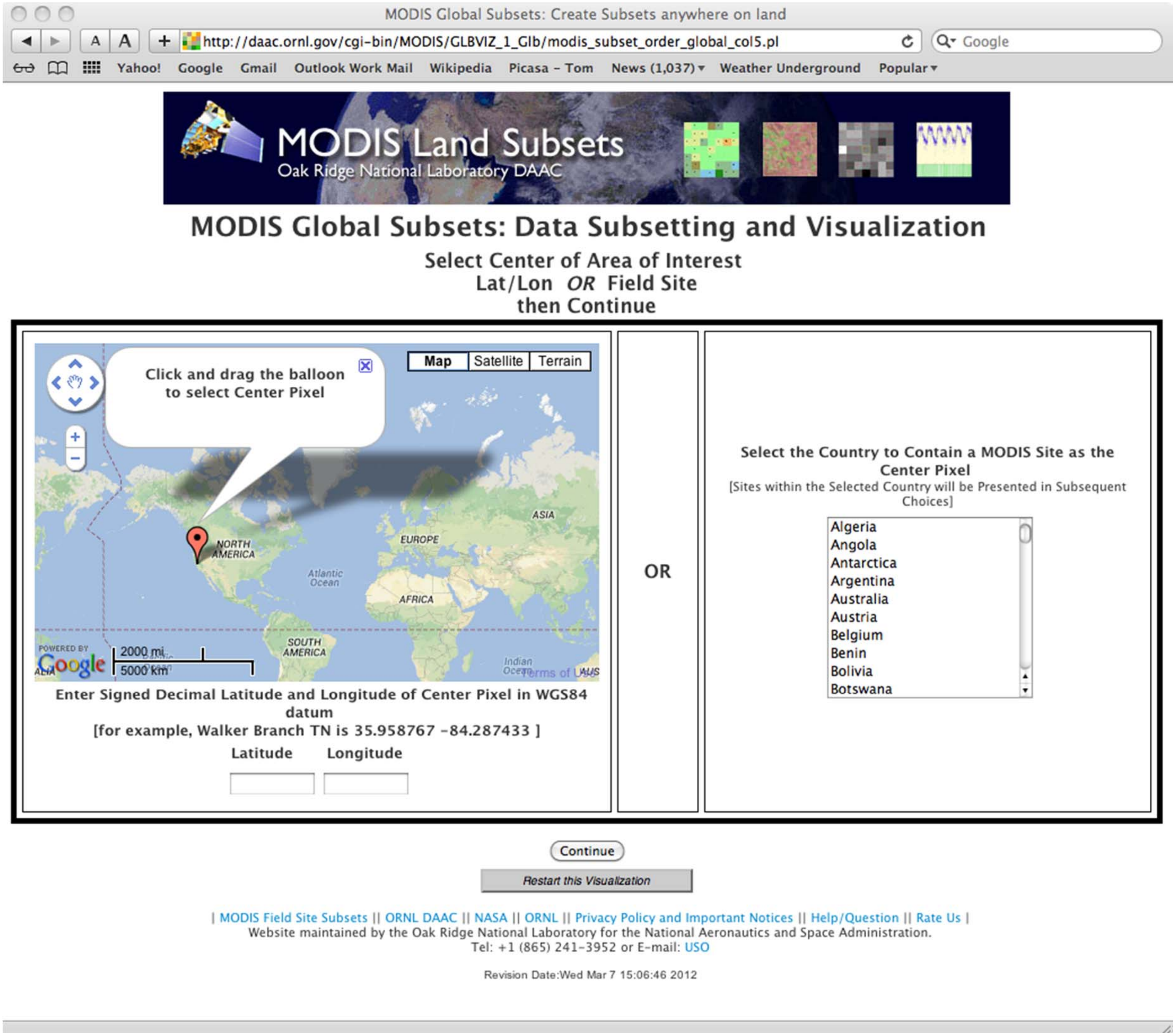


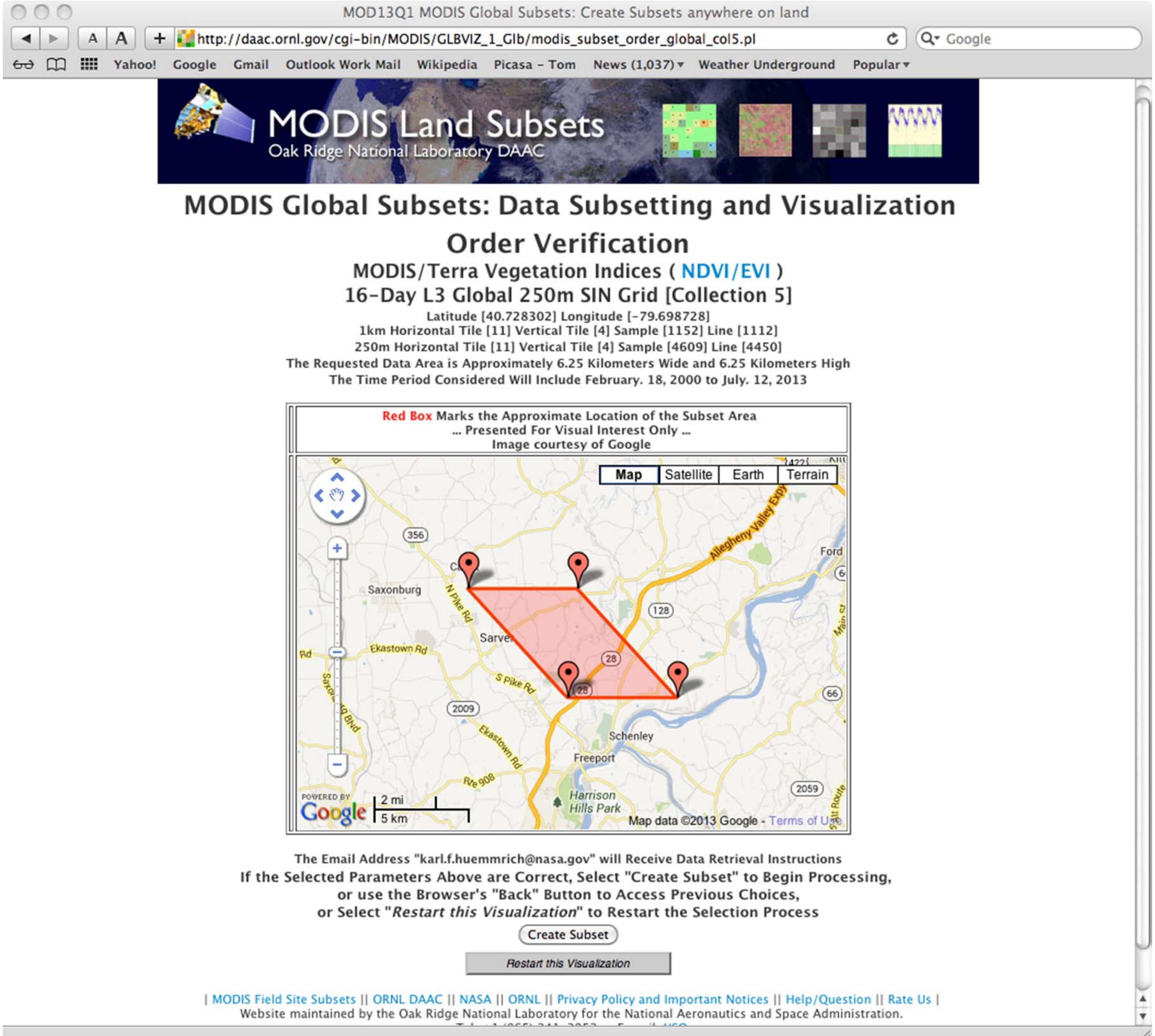
You can download MODIS data for any particular site in the world for free from http://daac.ornl.gov/MODIS

Data comes as text files, no need for image processing

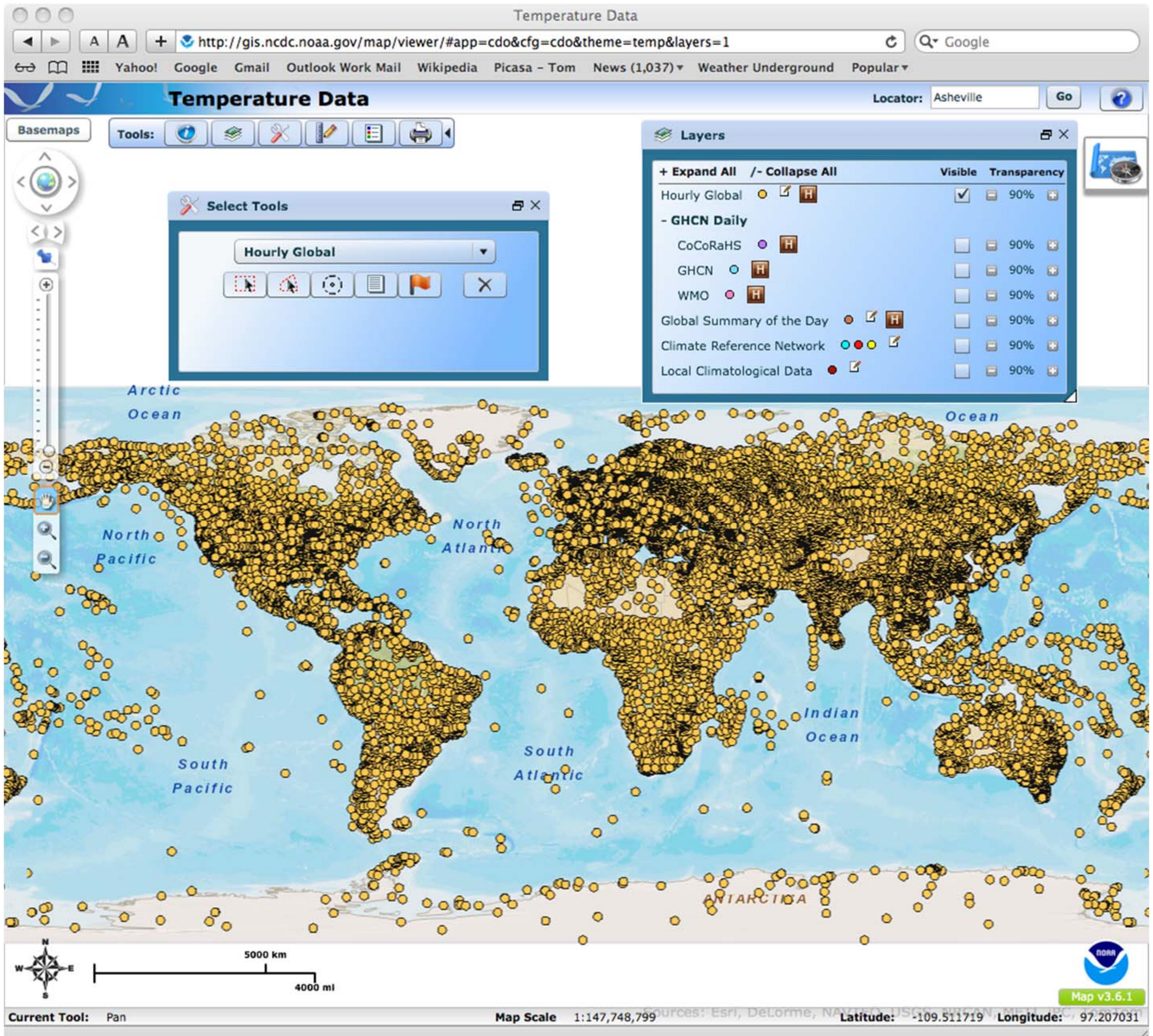
- You can work with it in a spreadsheet
- Best way to do time series




MODIS Global Subsets: Create Subsets anywhere on land
http://daac.ornl.gov/cgi-bin/MODIS/GLBVIZ_1_Glb/modis_subset_order_global_col5.pl
Google
Yahoo! Google Gmail Outlook Work Mail Wikipedia Picasa - Tom News (1,037) Weather Underground Popular
MODIS Land Subsets
Oak Ridge National Laboratory DAAC
MODIS Global Subsets: Data Subsetting and Visualization
Select Center of Area of Interest
Lat/Lon OR Field Site
then Continue
Map Satellite Terrain
Click and drag the balloon
to select Center Pixel
ASIA
NORTH AMERICA
EUROPE
Atlantic Ocean
AFRICA
SOUTH AMERICA
Indian Ocean
2000 mi
5000 km
POWERED BY Google
Terms of Use
Enter Signed Decimal Latitude and Longitude of Center Pixel in WGS84 datum
[for example, Walker Branch TN is 35.958767 -84.287433]
Latitude Longitude
OR
Select the Country to Contain a MODIS Site as the Center Pixel
[Sites within the Selected Country will be Presented in Subsequent Choices]
Algeria
Angola
Antarctica
Argentina
Australia
Austria
Belgium
Benin
Bolivia
Botswana
Continue
Restart this Visualization
| MODIS Field Site Subsets || ORNL DAAC || NASA || ORNL || Privacy Policy and Important Notices || Help/Question || Rate Us |
Website maintained by the Oak Ridge National Laboratory for the National Aeronautics and Space Administration.
Tel: +1 (865) 241-3952 or E-mail: USO
Revision Date:Wed Mar 7 15:06:46 2012


MOD13Q1 MODIS Global Subsets: Create Subsets anywhere on land
http://daac.ornl.gov/cgi-bin/MODIS/GLBVIZ_1_Glb/modis_subset_order_global_col5.pl
Yahoo! Google Gmail Outlook Work Mail Wikipedia Picasa - Tom News (1,037) Weather Underground Popular
MODIS Land Subsets
Oak Ridge National Laboratory DAAC
MODIS Global Subsets: Data Subsetting and Visualization
Order Verification
MODIS/Terra Vegetation Indices (NDVI/EVI)
16-Day L3 Global 250m SIN Grid [Collection 5]
Latitude [40.728302] Longitude [-79.698728]
1km Horizontal Tile [11] Vertical Tile [4] Sample [1152] Line [1112]
250m Horizontal Tile [11] Vertical Tile [4] Sample [4609] Line [4450]
The Requested Data Area is Approximately 6.25 Kilometers Wide and 6.25 Kilometers High
The Time Period Considered Will Include February. 18, 2000 to July. 12, 2013
Red Box Marks the Approximate Location of the Subset Area
... Presented For Visual Interest Only ...
Image courtesy of Google
Map Satellite Earth Terrain
Saxonburg
Sarver
Schenley
Freeport
Harrison Hills Park
Allegheny Valley Expy
Ekastown Rd
S Pike Rd
N Pike Rd
2 mi
5 km
Map data ©2013 Google
The Email Address "karl.f.huemmrich@nasa.gov" will Receive Data Retrieval Instructions
If the Selected Parameters Above are Correct, Select "Create Subset" to Begin Processing,
or use the Browser's "Back" Button to Access Previous Choices,
or Select "Restart this Visualization" to Restart the Selection Process
Create Subset
Restart this Visualization
| MODIS Field Site Subsets || ORNL DAAC || NASA || ORNL || Privacy Policy and Important Notices || Help/Question || Rate Us |
Website maintained by the Oak Ridge National Laboratory for the National Aeronautics and Space Administration.

You can also download historic weather data from the NOAA web site
http://www.ncdc.noaa.gov/cdo-web/search
I got data for the nearest weather station to Todd Sanctuary

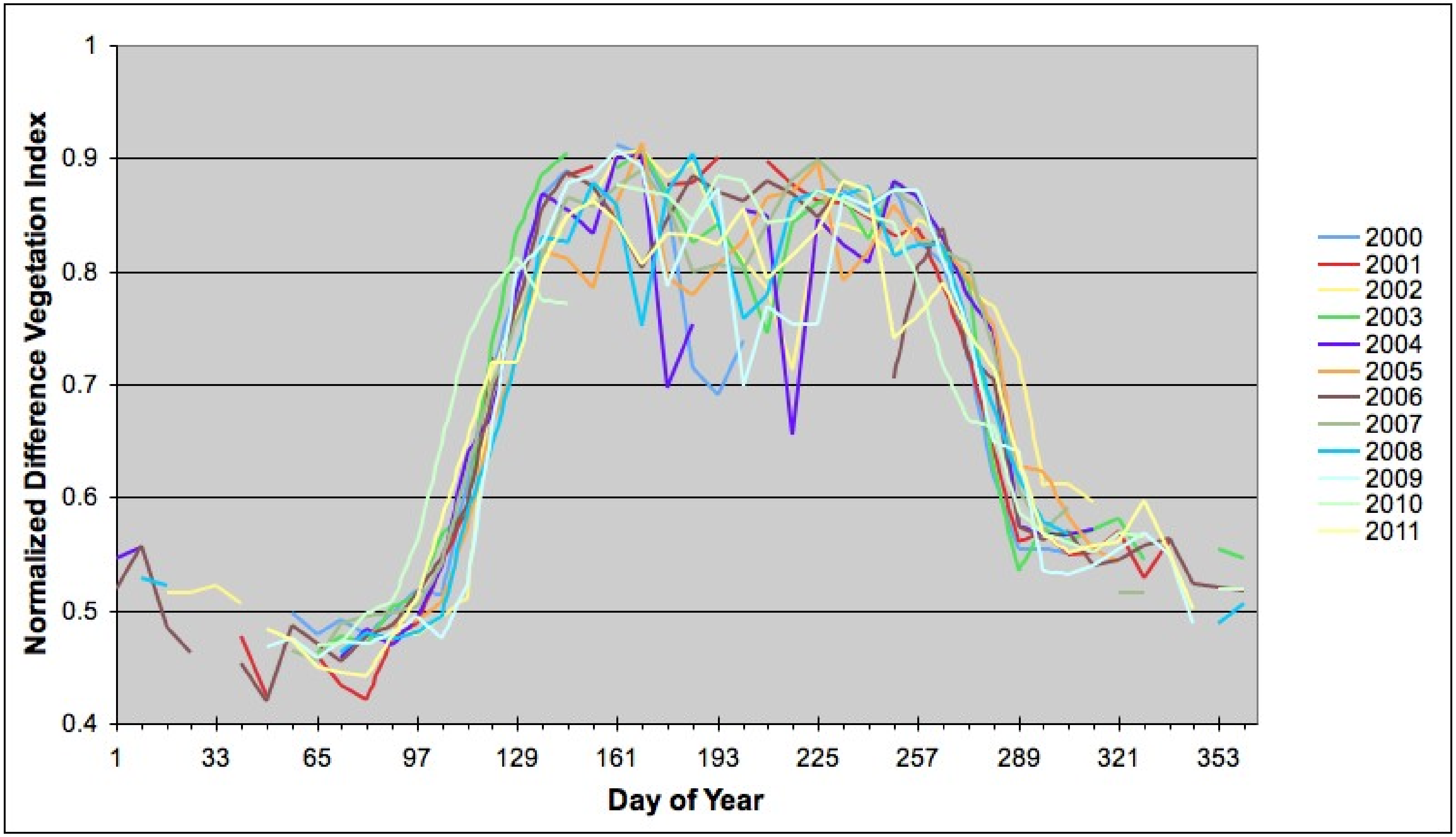


Seasonal changes in MODIS NDVI for Todd Sanctuary

Note variation in springtime green-up

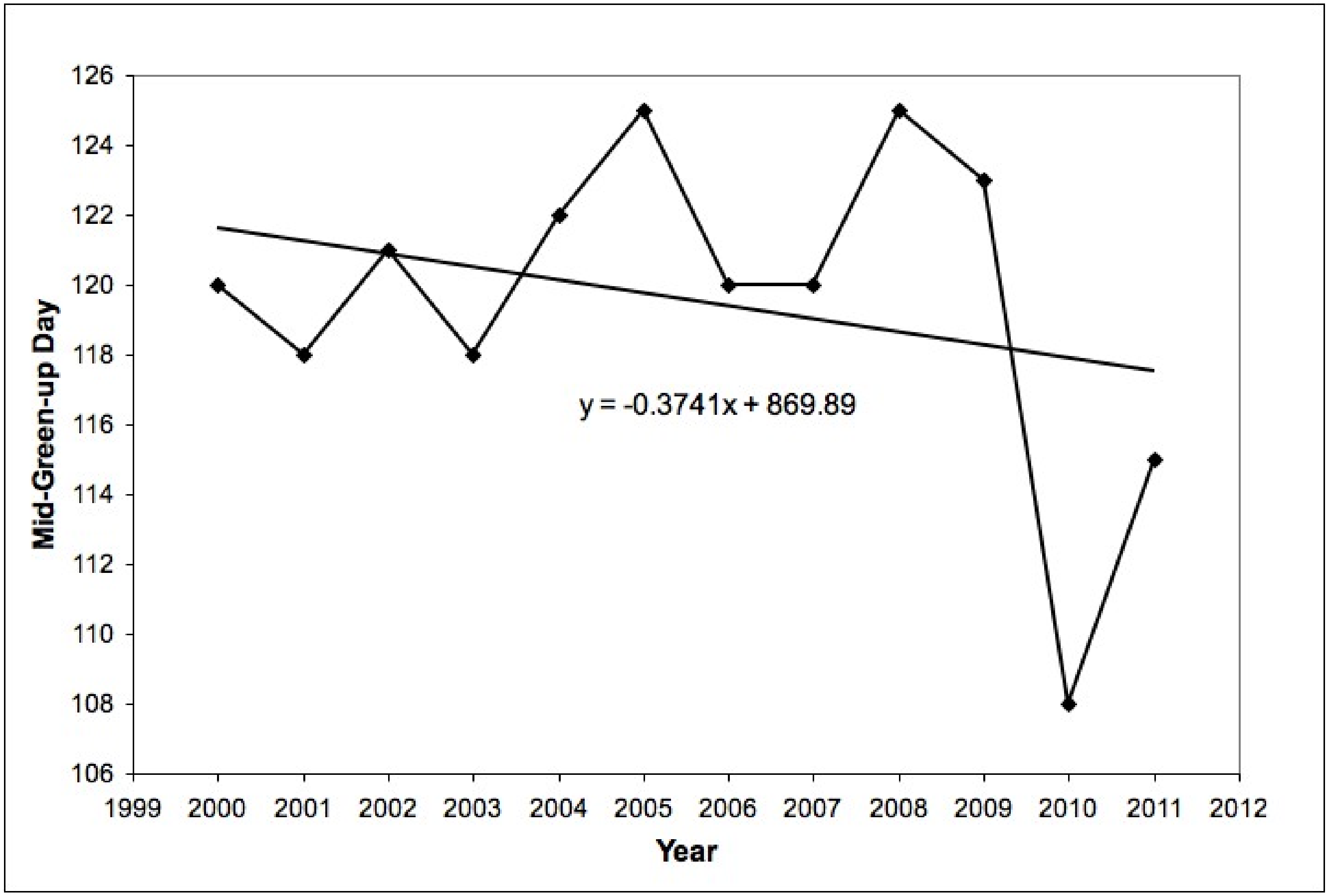
-Mid-summer variability probably due to clouds

Defined date of green-up as day when NDVI was halfway between value for start of green-up and maximum greenness



Seasonal changes in MODIS NDVI for Todd Sanctuary

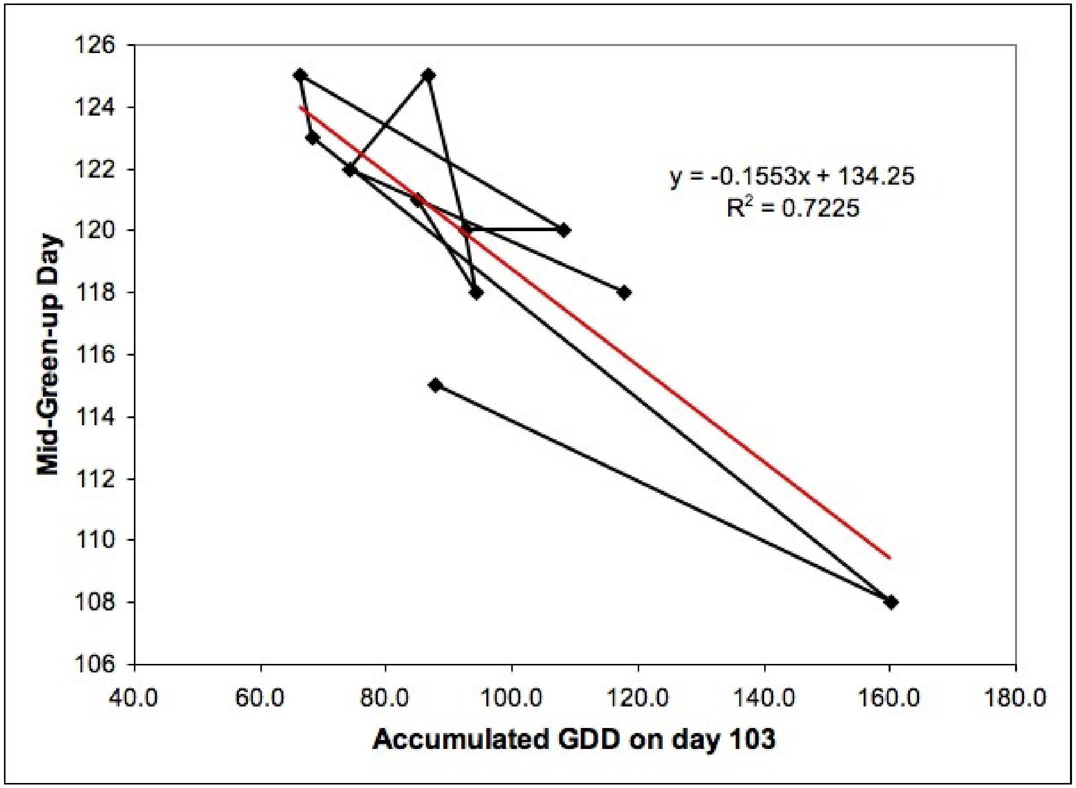
Green-up dates from MODIS NDVI for Todd Sanctuary over MODIS data record



Seasonal changes in MODIS NDVI for Todd Sanctuary

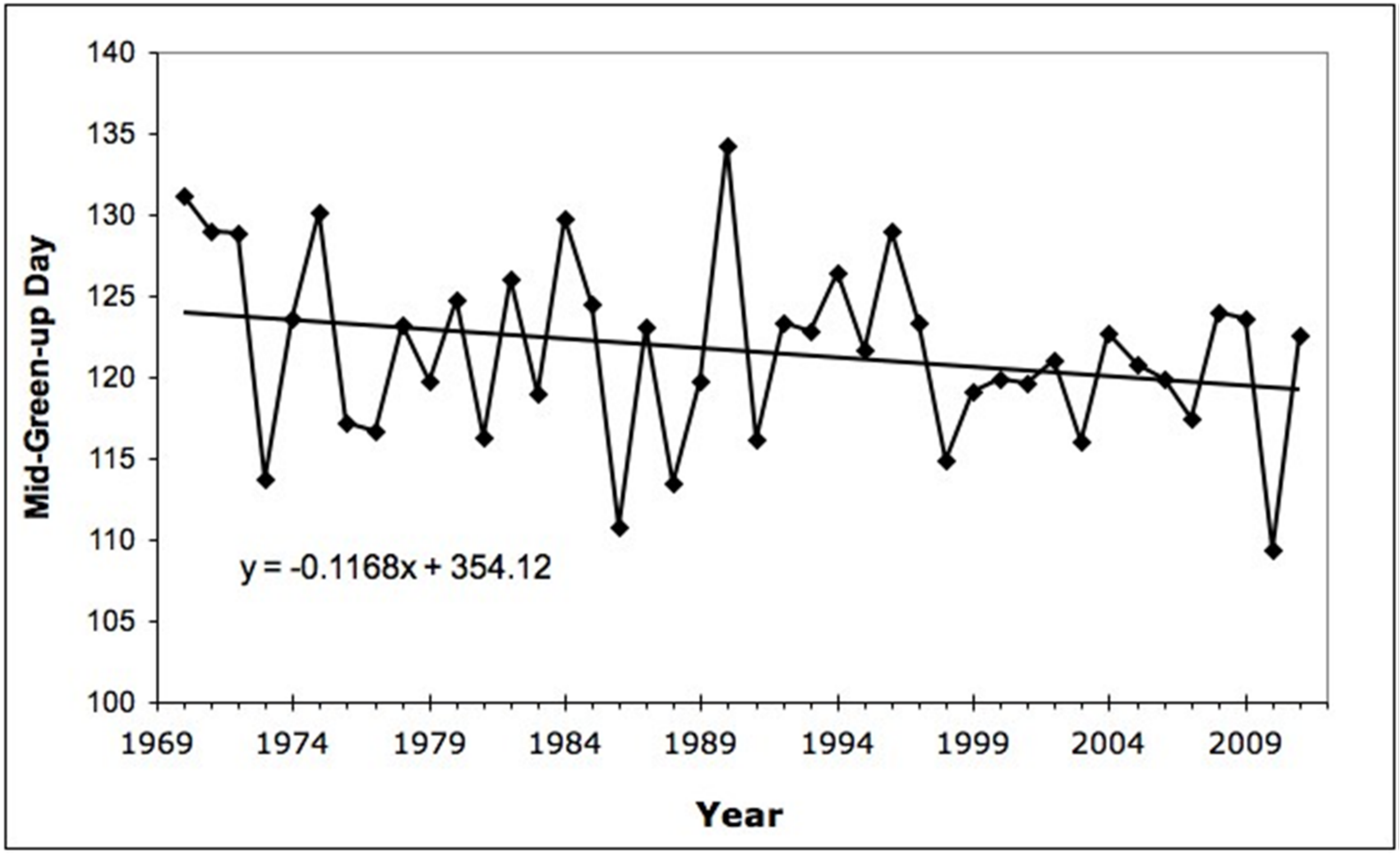
Found a relationship between green-up date and accumulated Growing Degree Days on day 103 for Todd Sanctuary

- Growing Degree Days (GDD) are calculated from the weather data as the sum of the difference in the daily temperature minus an offset, in this case 5° C over multiple days
- The linear regression of accumulated GDD for day 103 describes 72% of the variation in green-up date



Seasonal changes in MODIS NDVI for Todd Sanctuary

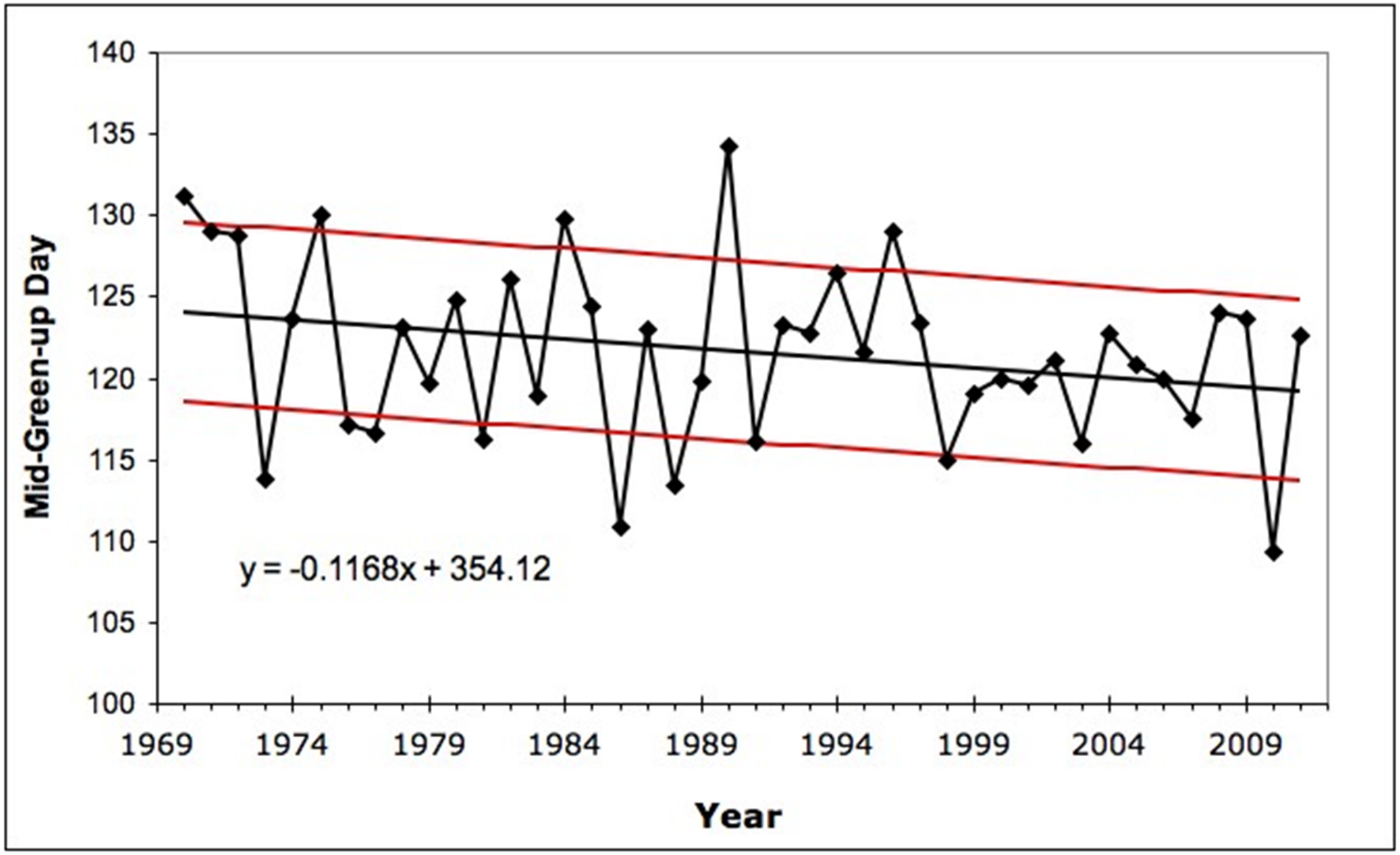
Green-up date calculated using accumulated GDD from the weather data
Can take our analysis back many years before the satellite record began



With this longer time-line we can better detect trends. The trend through over this period has green-up date coming about 0.12 days earlier per year, or green-up date is coming 4.8 days earlier now compared to 1970.

Seasonal changes in MODIS NDVI for Todd Sanctuary

Note there is still a lot of expected variation in green-up dates, but the trend is toward earlier green-up for this site



Conclusions

- Satellites provide important data for understanding ecosystems and their changes
- Landsat can provide detailed spatial descriptions of the landscape
- MODIS can provide good descriptions of change over time
- Landsat and MODIS data are free to use
- Satellite data can help us understand changes happening around us