How is environmental change monitored from space?

Cyclical, Abrupt and Gradual Patterns

Learning Objectives

- Introduction to types of change
  - Data considerations for monitoring change
- Cyclical
  - Definition
  - Measuring with Earth observation data
  - Examples
- Abrupt
  - Definition
  - Measuring with Earth observation data
  - Examples
- Gradual
  - Definition
  - Measuring with Earth observation data
  - Examples

Earth is Constantly Changing

- Natural change
- Human caused change
- Change occurs on various scales
  - Time
    - Wildfires burn over days & weeks
    - Climate change occurs over decades & centuries
  - Space
    - Wildfires burn over 0.1 – 10km^2
    - Climate change occurs across the globe

Briksdalsbreen Norway 2003 & 2008 (Source: Wikimedia Commons)


Wildfire Yosemite (Source: Wikimedia Commons)

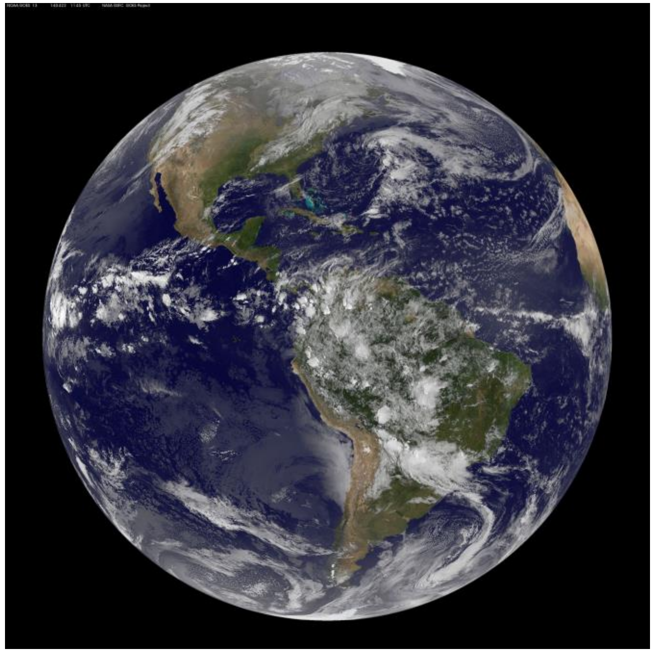
Monitoring Environmental Change

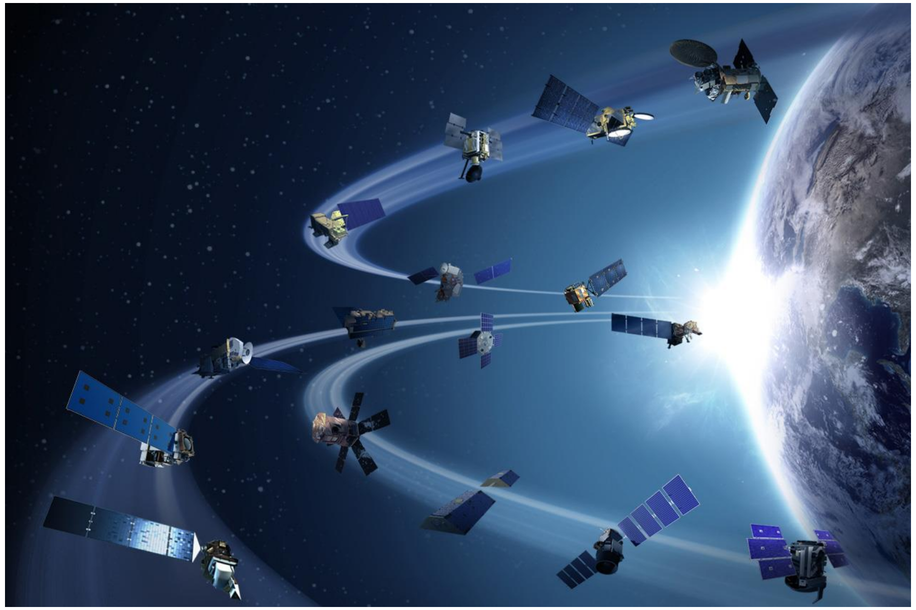
- Valuable for a variety of reasons:
  - Minimize impact on environment
  - Ensure compliance with laws
  - Protect human health
  - Predicting into the future

Adapted from the Fourth National Climate Assessment (2018)

Monitoring Environmental Change from Space

- Based on what we have talked about in class so far:
  - Why would satellite data be advantageous for monitoring environmental change from space?





Data Requirements

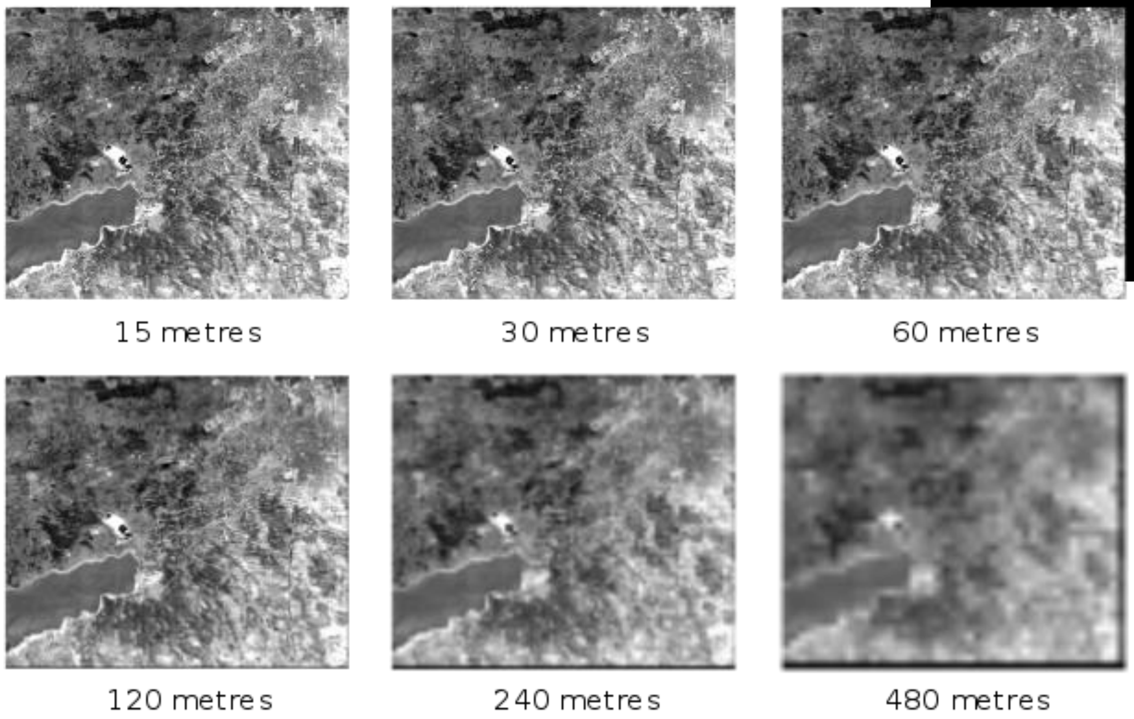
- Data requirements vary with the type of environmental change studied
- Selecting suitable data is crucial in successfully detecting environmental change
- At a minimum you need to know the required:
  - Level of spatial detail
  - Region of the electromagnetic spectrum
  - Frequency of re-visit
  - Temporal dimension

Level of spatial detail

- Smallest ground object that can be resolved in the image
- More detail generally implies less area covered by single image and bigger file size

Examples:

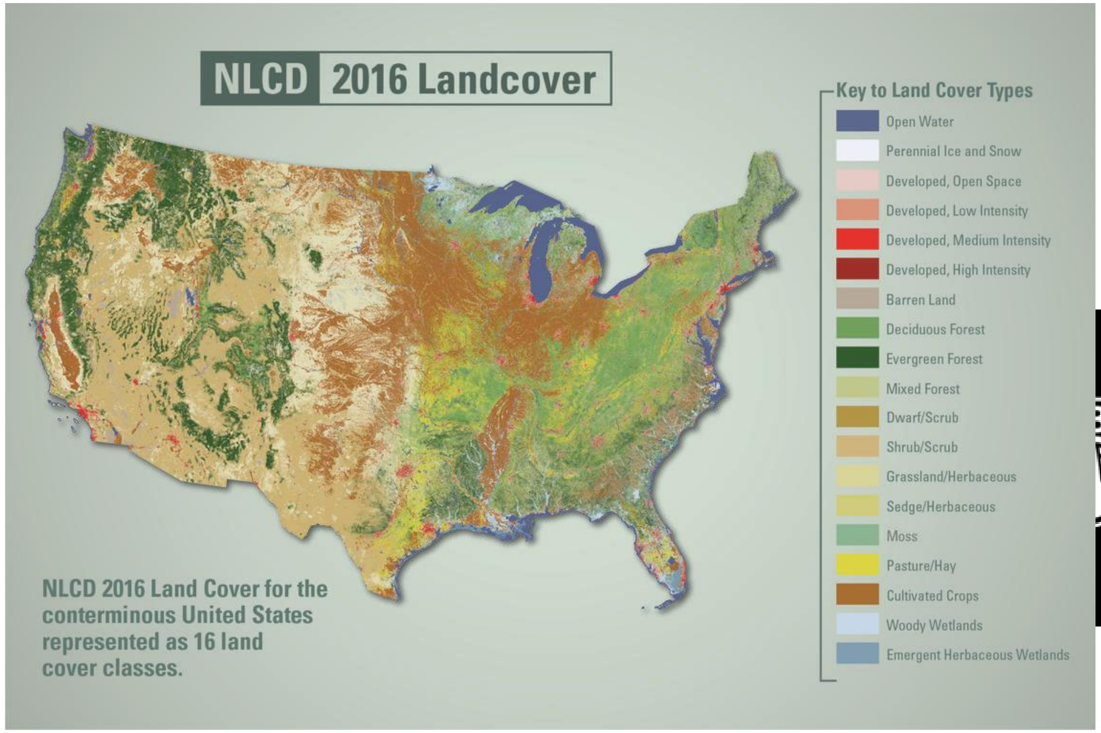
- Moderate resolution (>25m) is suitable to detect amount of forest lost or gained in an area
- Very fine resolution (<1m) is needed to detect changes at single tree level



Decreasing spatial resolution from l715m panchromatic (Source: Wikimedia Commons)

Level of Spatial Detail

- Spatial resolution
- Coarse scale
  - Ice sheets
  - MODIS
- Moderate scale
  - Land cover
  - Landsat
- Fine scale
  - Individual trees
  - <1m

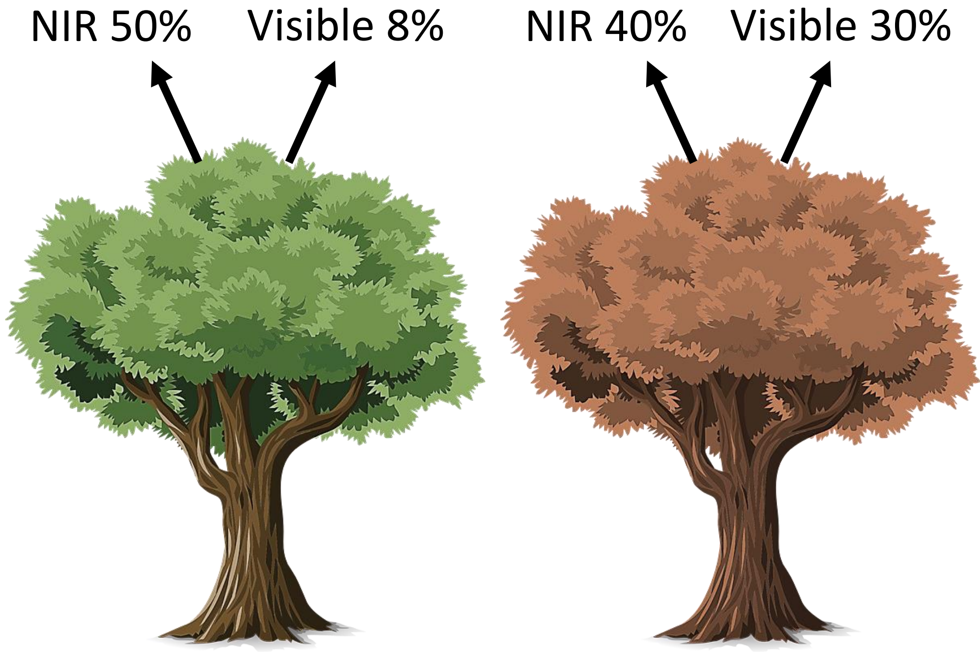


Region of the Electromagnetic Spectrum

- Specific regions of the electromagnetic spectrum where the change occurs
- Satellite sensors have different spectral resolutions

Examples:

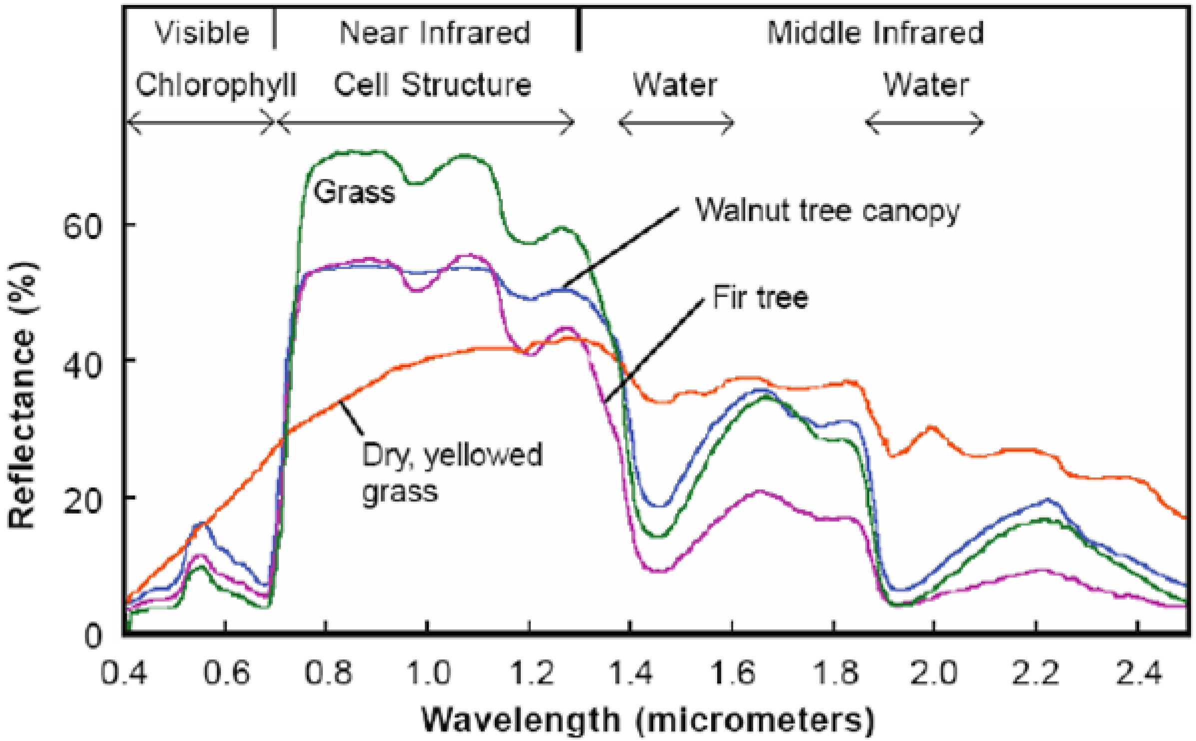
- Broad classes, such as dead or live vegetation, can usually be separated using few, wide bands
- More specific classes, such as different rock types require comparison of many, narrow bands



Changes in reflectance in dead or alive vegetation

Region of the EMS

- Spectral Resolution
- Vegetation health
  - Red
  - NIR
    - NDVI
- Land cover (vegetation, rock, soil, water)
  - More bands needed

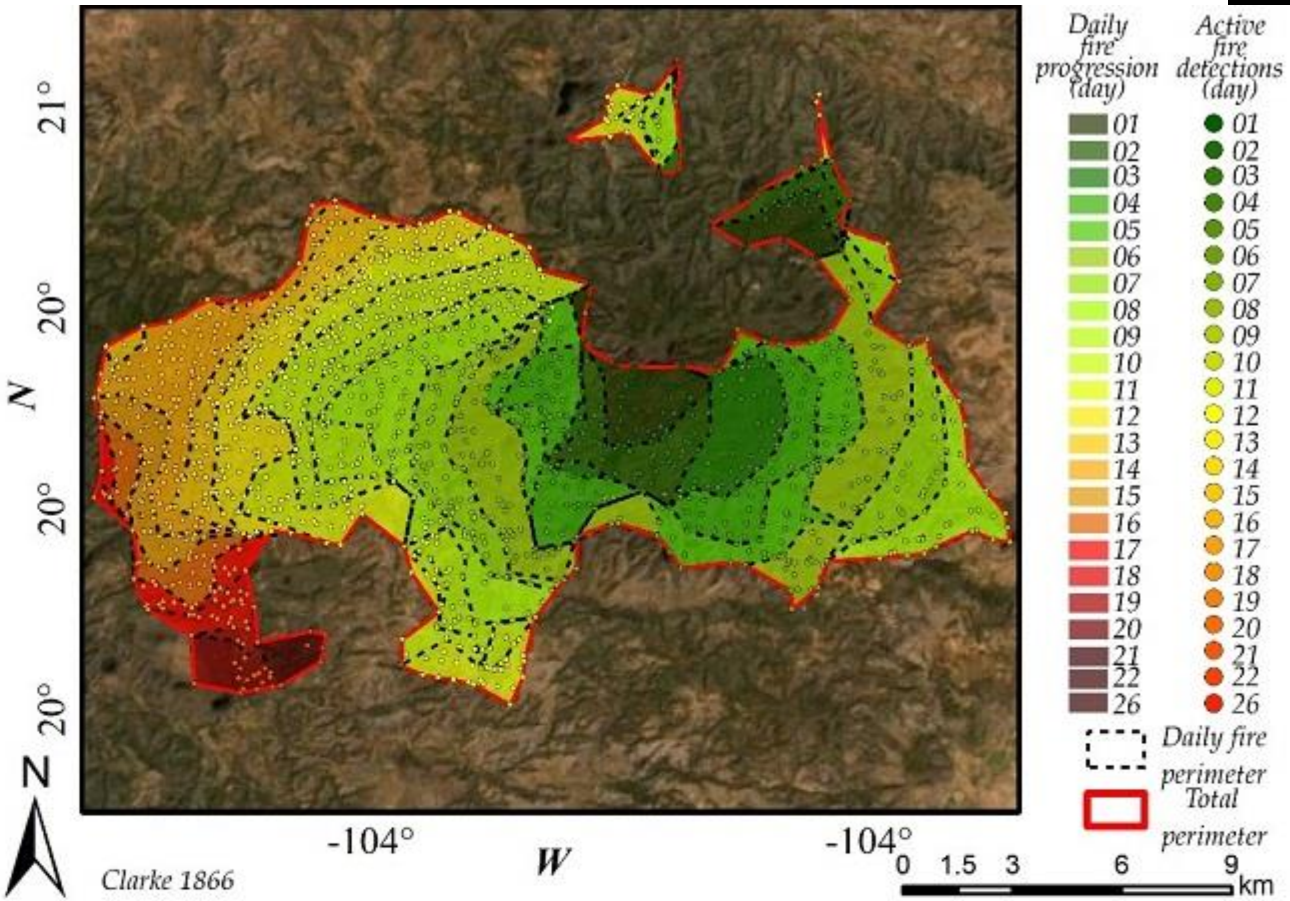


Frequency of re-visit

How *often* do you need to see an area to characterize the change?

Examples:

- Logging/cut blocks
  - 16-day re-visit sufficient
  - Landsat
- Fire progression
  - Daily (or finer)



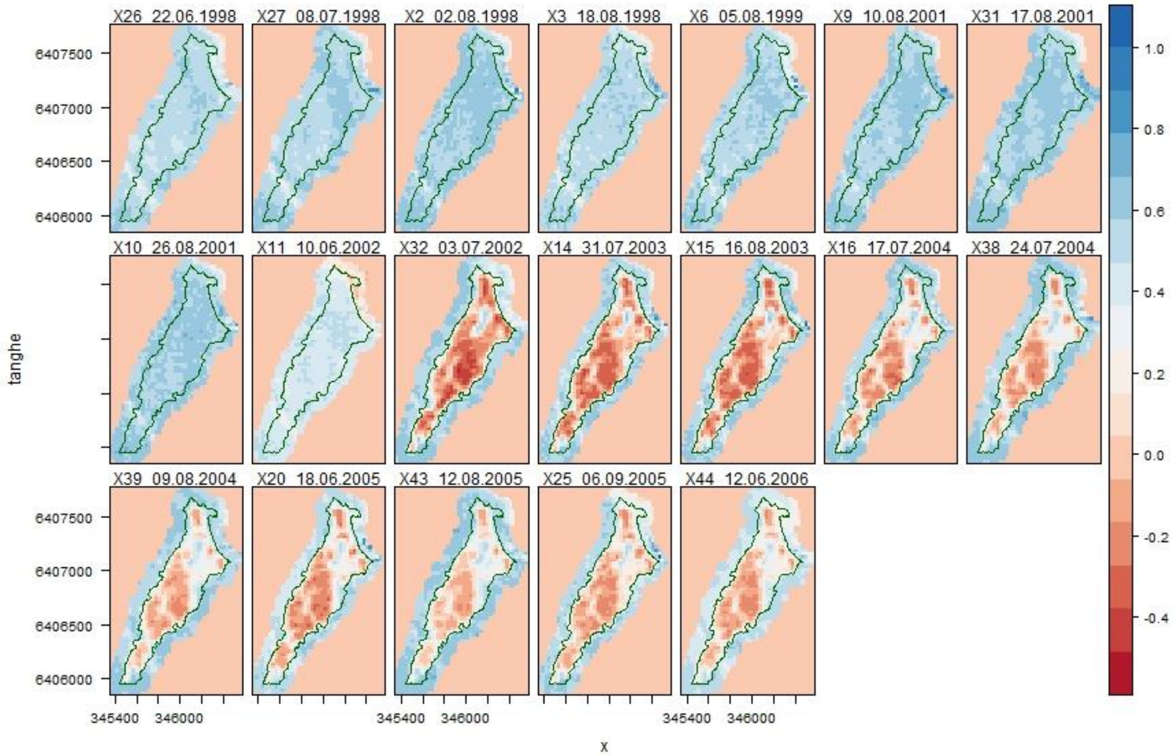
Temporal Dimension

How *long* do you need to collect data to be able to characterize the change?

Varies with the scope of study:

Examples:

- Changes in climate are slow, require long term information (>10 years)
- Area burned after a fire event is a fast change, require short term information (a week or two)



Sudden changes after a fire event in the NIR and SWIR regions of the spectrum
@ Ignacio San-Miguel

- Aerial imagery is available for the last ~100 years, while satellite only for the last ~50 years

Data Requirements

- As we talk about different kinds of change, and specific examples
  - Consider the data requirements necessary to detect those changes
- What level of spatial detail is required?
  - i.e. spatial resolution
- What region of the EMS is required?
  - i.e. spectral resolution
- What frequency of re-visit is required?
  - i.e. temporal resolution
- What temporal dimension is required?
  - i.e. how long do we need to be collecting data for

Three Types of Change from Remote Sensing

Cyclical

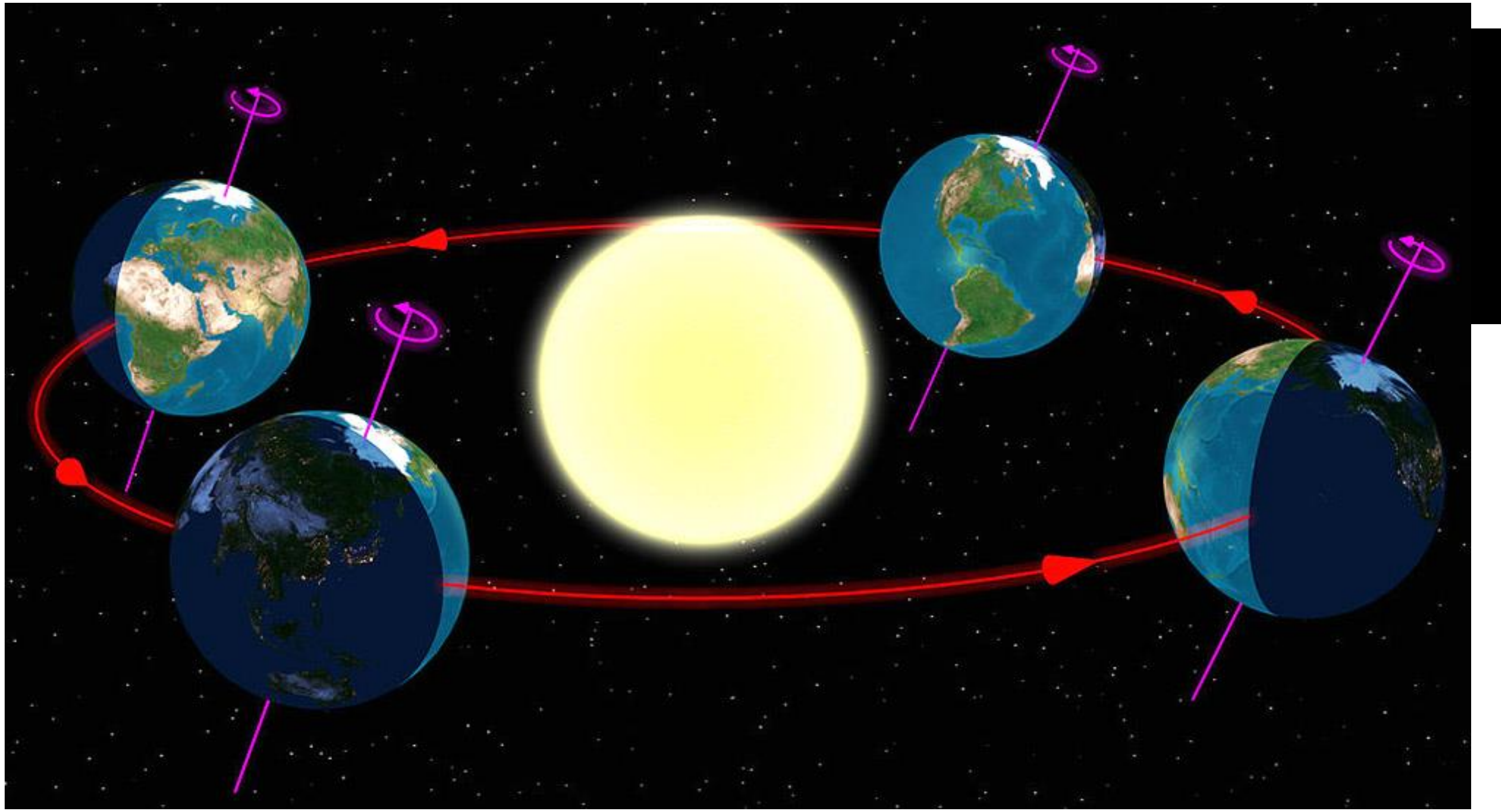
Abrupt

Gradual

Season Cycles

A few examples:

- Temperature
- Day length
- Snow cover
- The greening and browning of deciduous vegetation
- Animal migration
- Animal hibernation
- Canadians going to Florida each winter!
- Our hobbies
    - Ski in the winter
    - Hike and bike in the summer



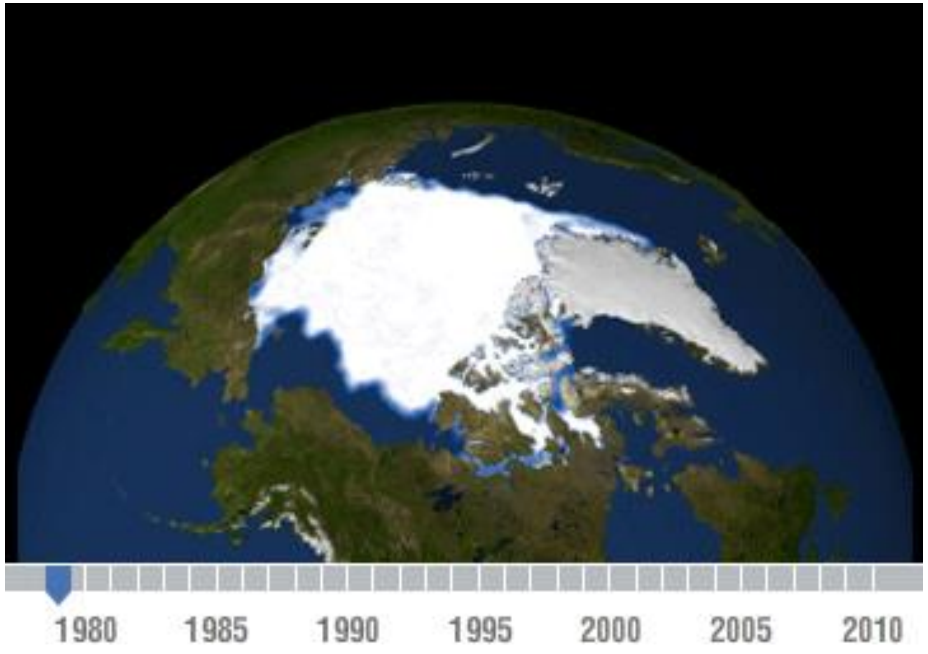
The Equinox (Source: paukrus)

Cyclical Patterns

What is a cyclical pattern?

- A pattern that repeats over time

- We will focus on:
  - Phenology/vegetation cycles
    - Camera traps
    - MODIS



Seasonal Cycles of Snow and Vegetation

- As temperature warms in the summer:
  - Snow melts
  - Vegetation greens up

- As temperatures cool in the fall:
  - Snow returns
  - Vegetation browns

Source: National Geographic; John Nelson

Vegetation Cycles

Camera time-lapse photography

- Set up a network of cameras
  - Or just one if you are only interested in one spot
- Take one picture each day
  - Results in daily RGB measurements

Time-lapse Camera Data

Attributes

- Single point data
- Very fine spatial scale
- Very high temporal resolution
  - All weather data
- VIS (RGB) data

Applications

- Understanding understory phenology
- Validating satellite data
- Analyzing fine scale vegetation phenology
  - In space & time

Vegetation Cycles

- Camera time-lapse photography

Vegetation Cycles

How can we make meaningful measurements from a time-lapse of photos?

- We can use what we know about spectral signatures!

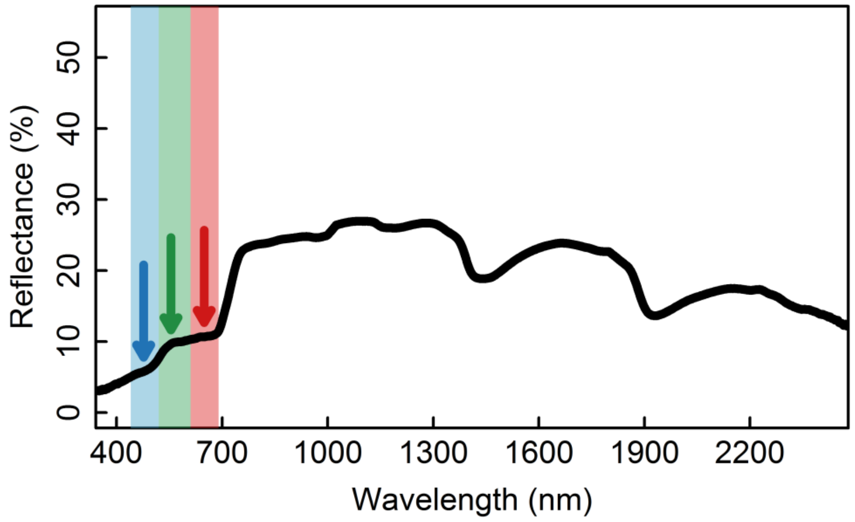


Photo credit: Douglas Bolton, UBC

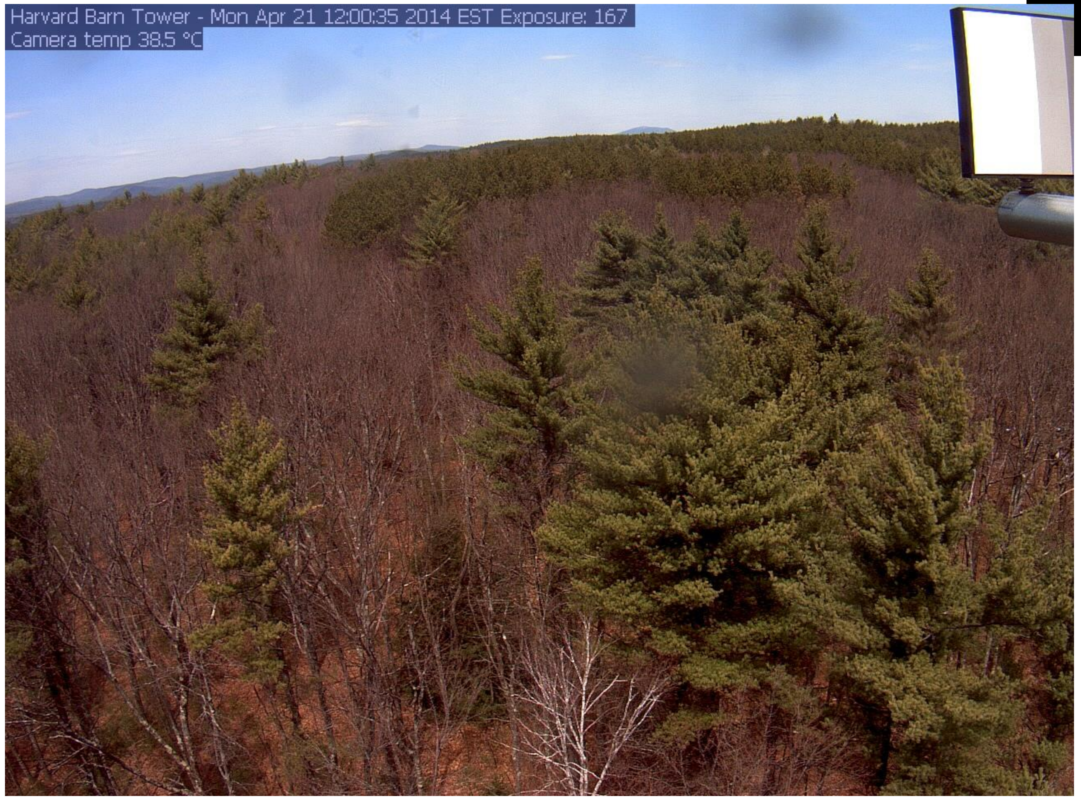
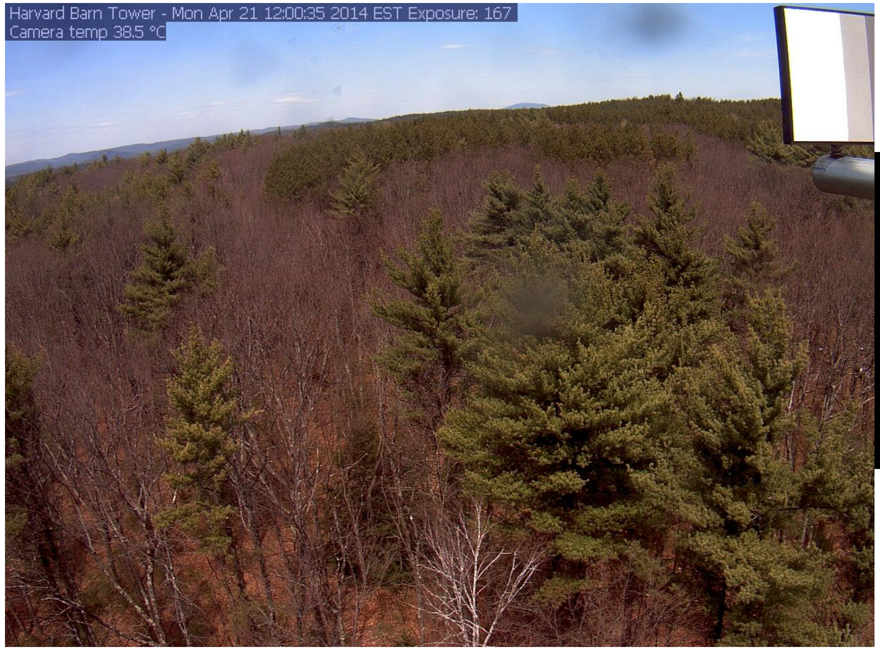
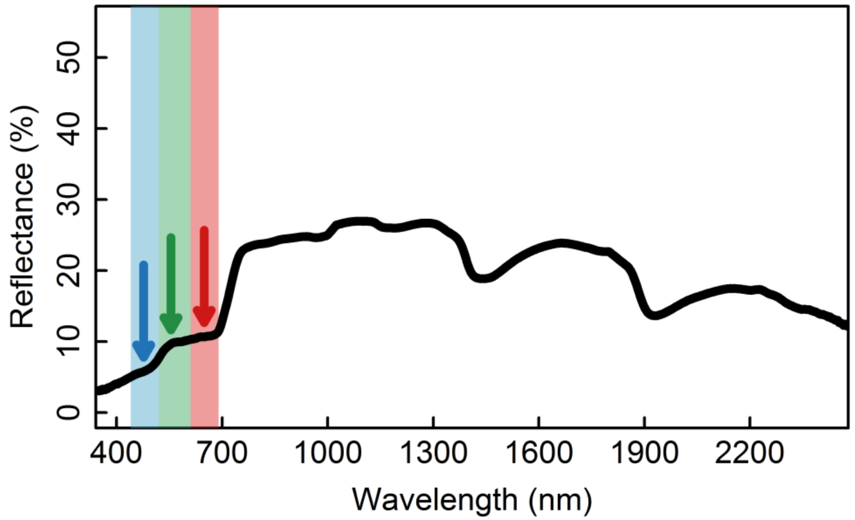


Photo credit: PhenoCam, http://phenocam.sr.unh.edu/

Quick Note About Cameras

- Cameras function like any other remote sensing instrument
  - They have a defined spatial resolution
    - Pixel size
  - And use 3 bands
    - Red
    - Green
    - Blue
  - Additive colour system
    - Equal peak brightness of RGB = white





Vegetation Cycles

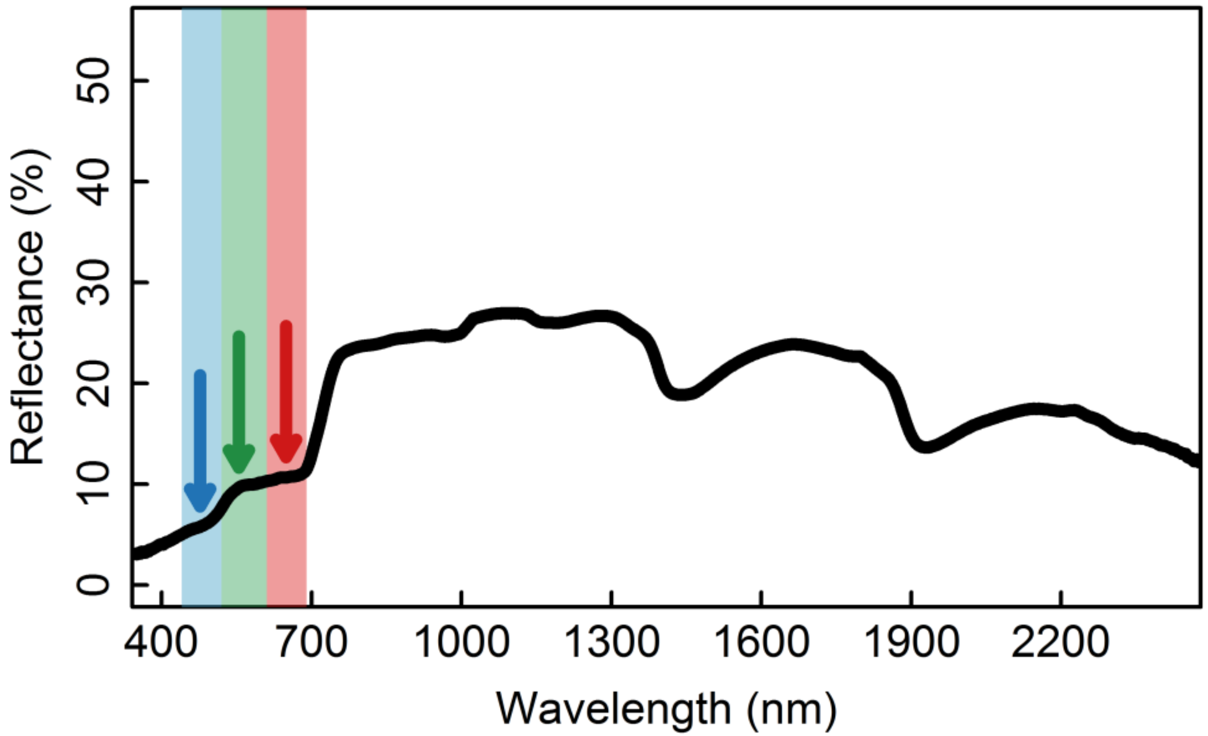
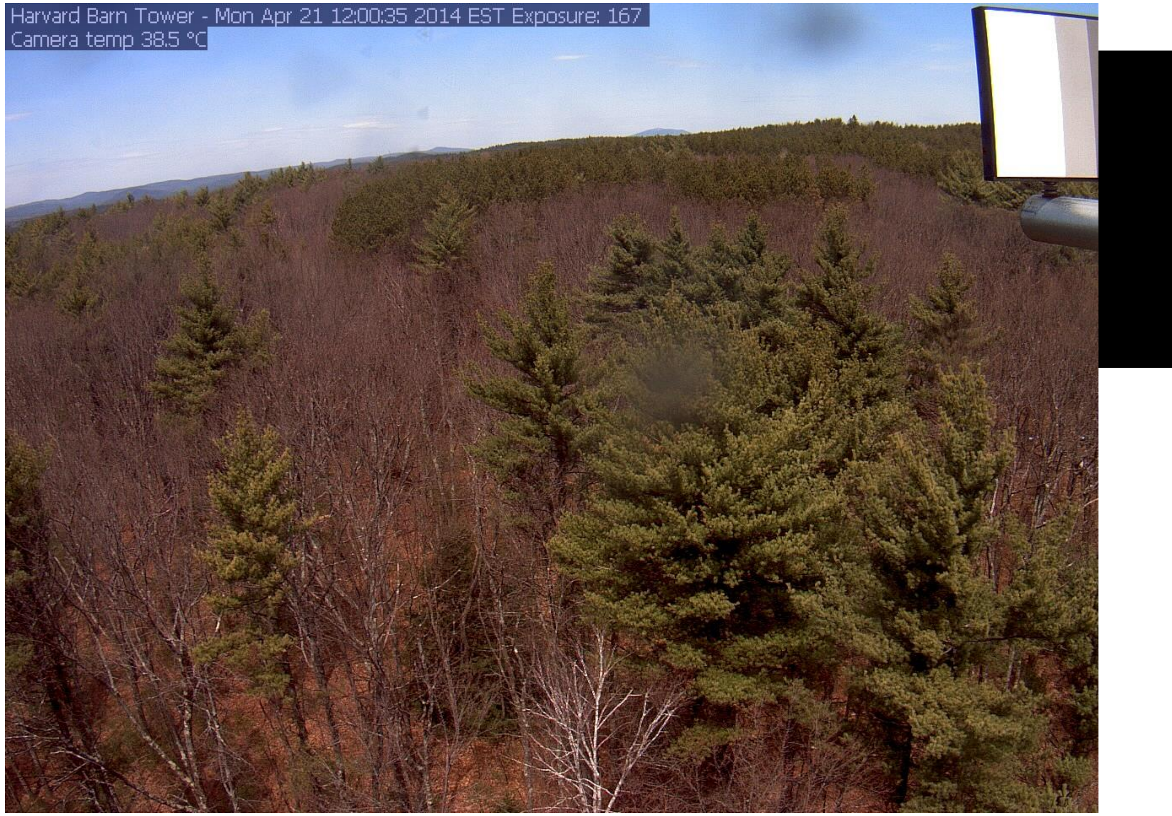


Photo credit: Douglas Bolton, UBC



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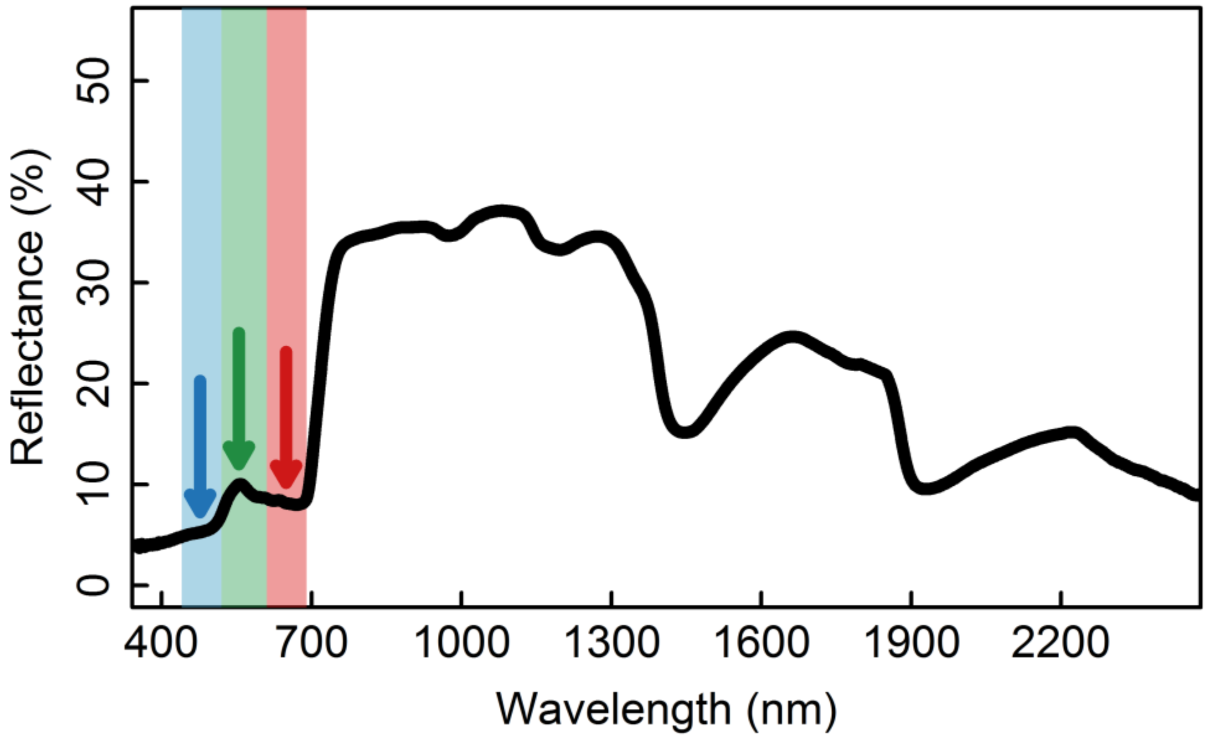
Before leaves come out, the landscape appears brown

Vegetation Cycles



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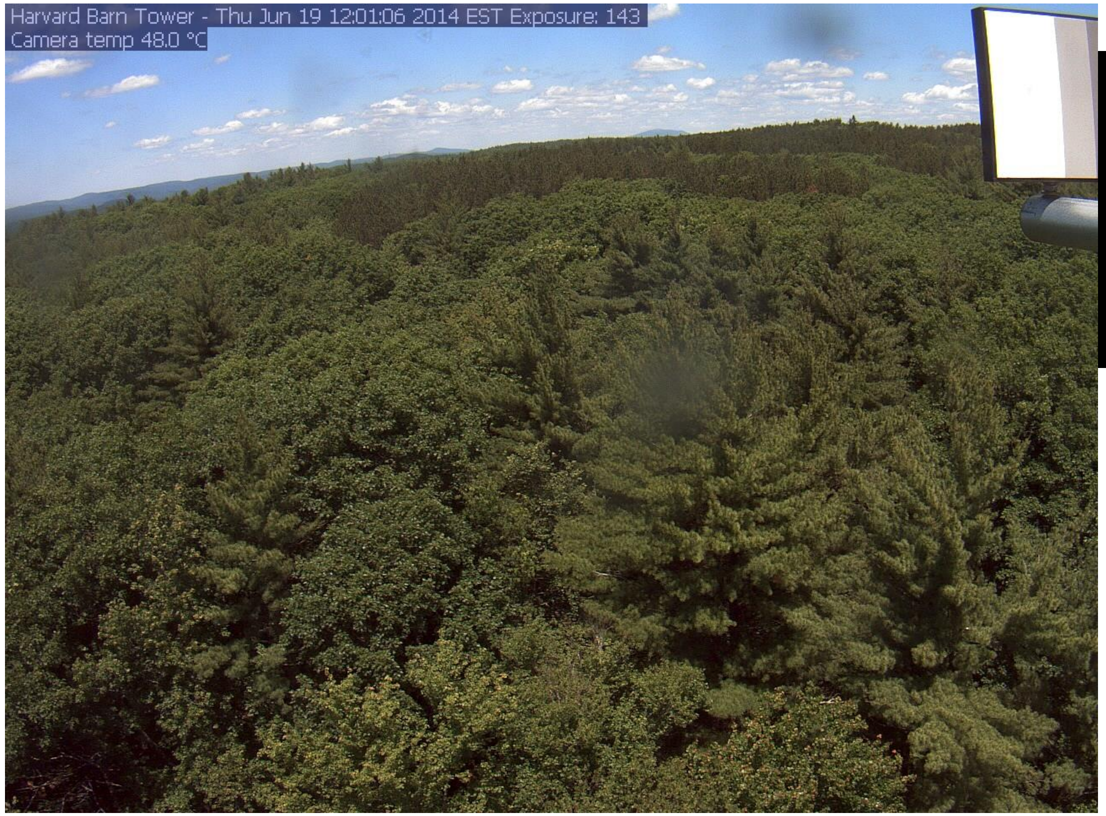

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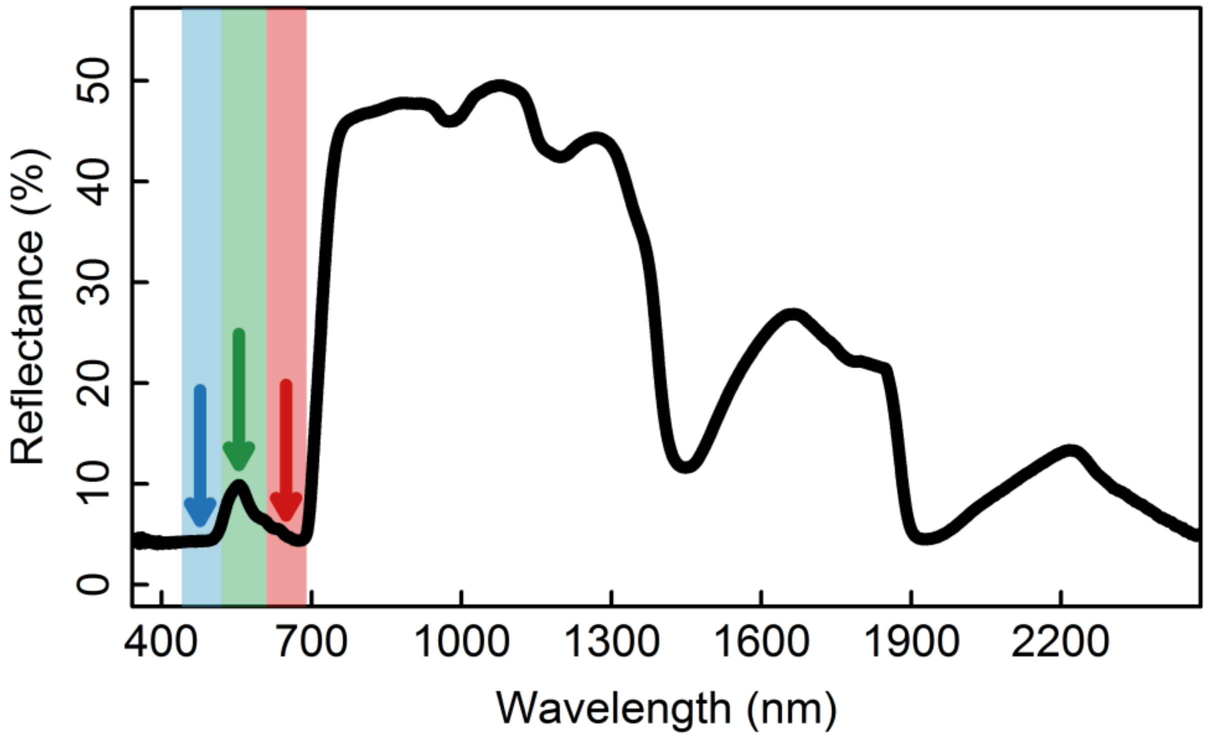
As leaves emerge plants absorb blue and red light, making them green in color

Vegetation Cycles



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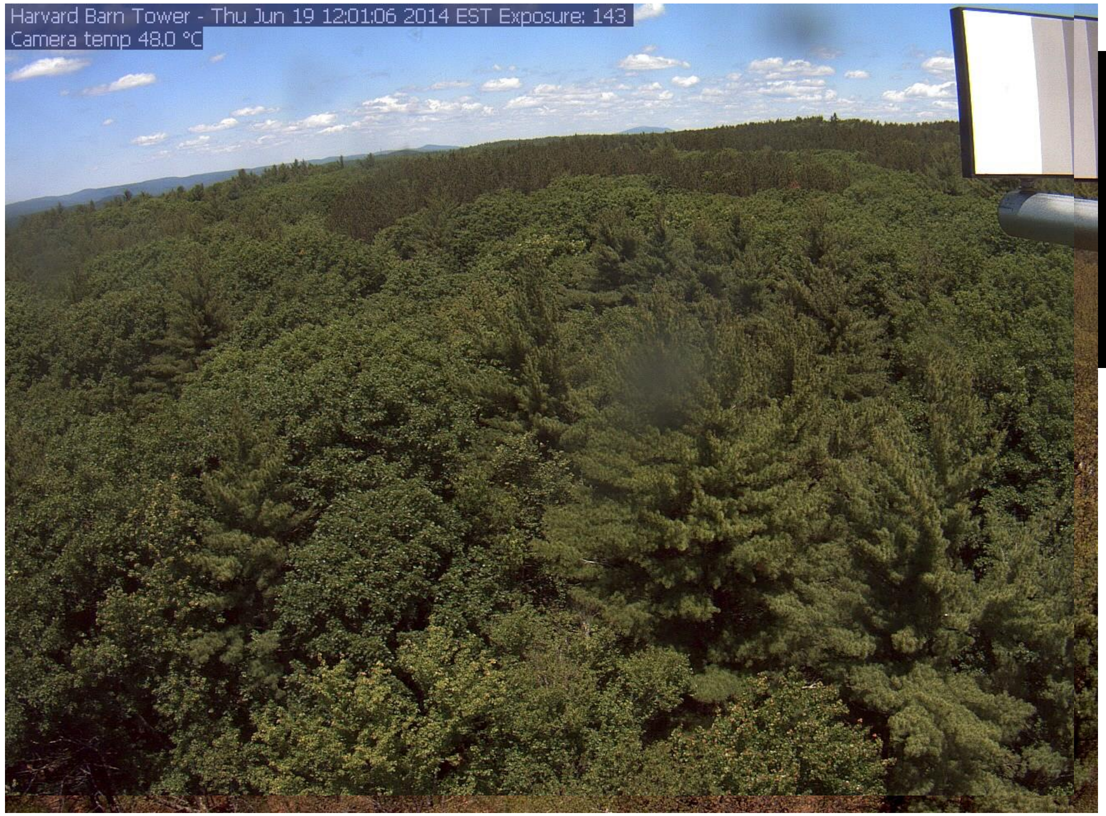

Photo credit: PhenoCam, http://phenocam.sr.unh.edu/

As plants mature during summer: Plants absorb lots of blue and red light, making them very green

Vegetation Cycles

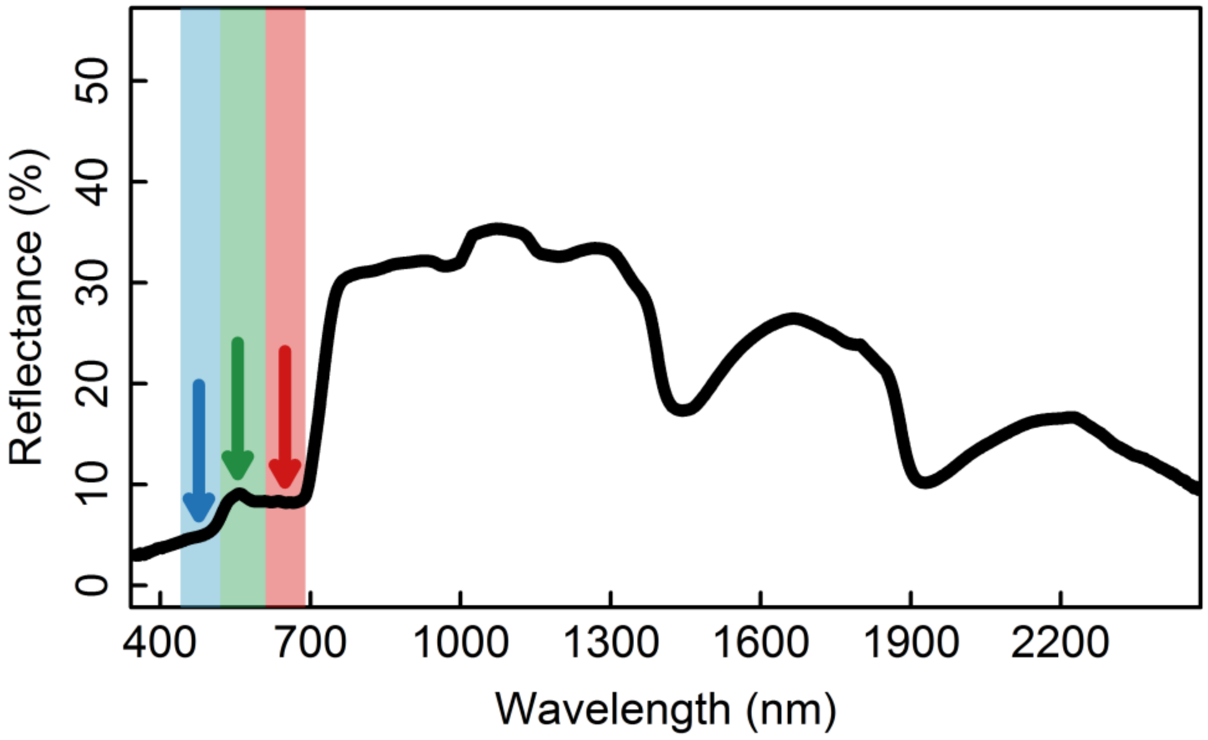

Photo credit: Douglas Bolton, UBC

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As the summer ends, leaves begin to die: Greenness decreases

Vegetation Cycles

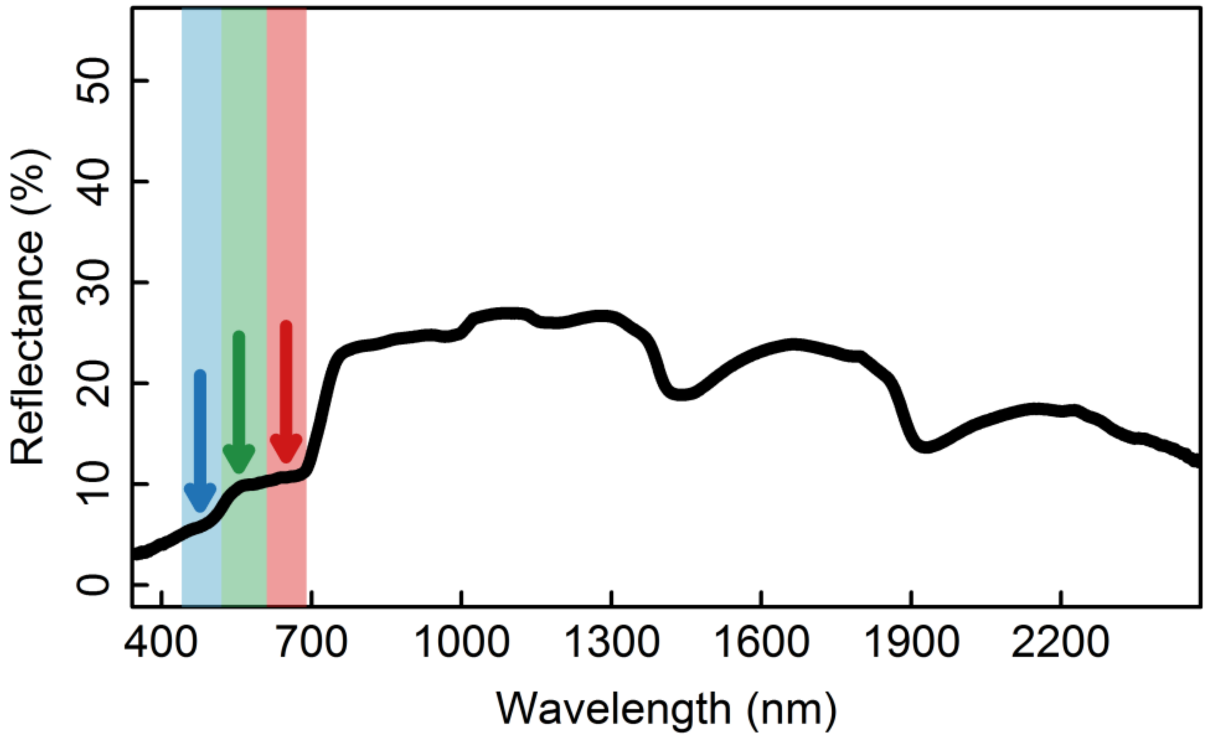


Photo credit: Douglas Bolton, UBC

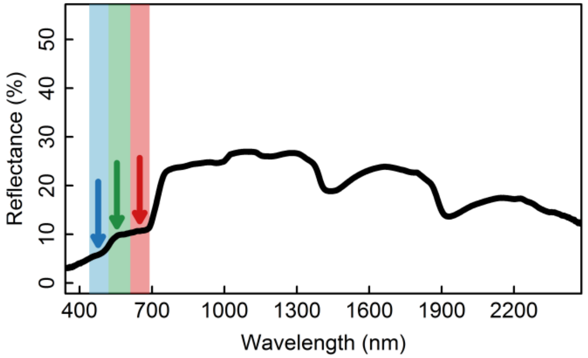
Photo credit: PhenoCam, http://phenocam.sr.unh.edu/

By winter, leaves have fallen, and the landscape returns to a brown color

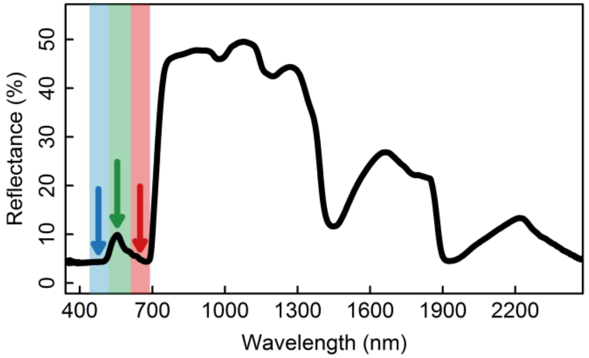
Vegetation Cycles

We can derive RGB based phenology metrics (camera trap version of NDVI):

$$2G_{RBi} = 2*Green – (Blue + Red)$$



Brown vegetation = Low $2G_{RBi}$



Green vegetation = High $2G_{RBi}$

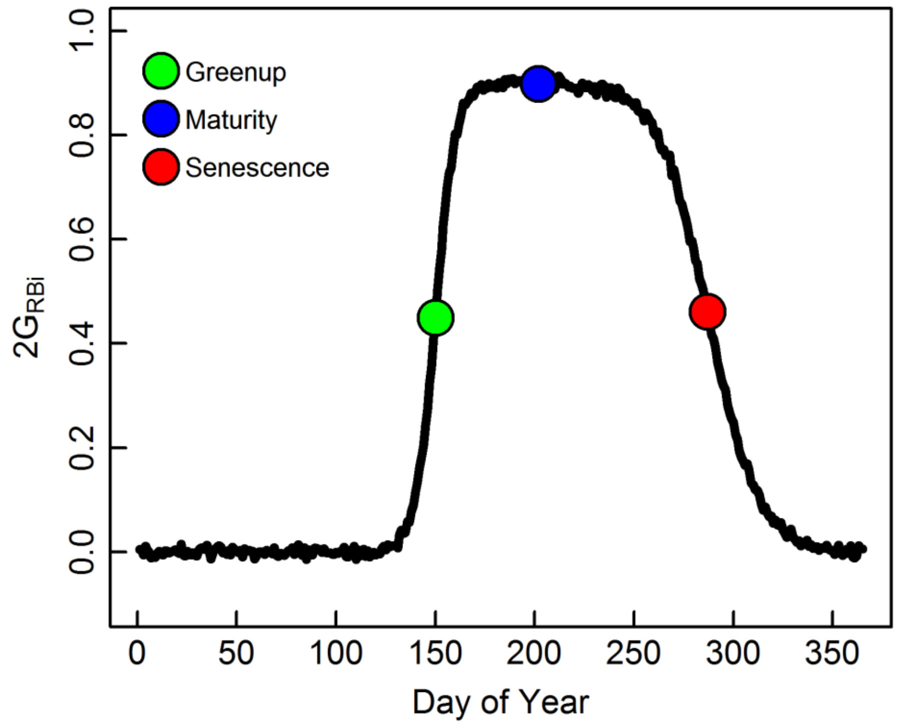
Photo credit: PhenoCam, http://phenocam.sr.unh.edu/

Photo credit: Douglas Bolton, UBC

Vegetation Cycles

- Plot $2G_{RBi}$ for every day of the year
  - From this curve, we can identify key phenology events

- Greenup: When the leaves emerge
- Maturity: When 2GRBi is maximum
- Senescence: When leaves change color and die



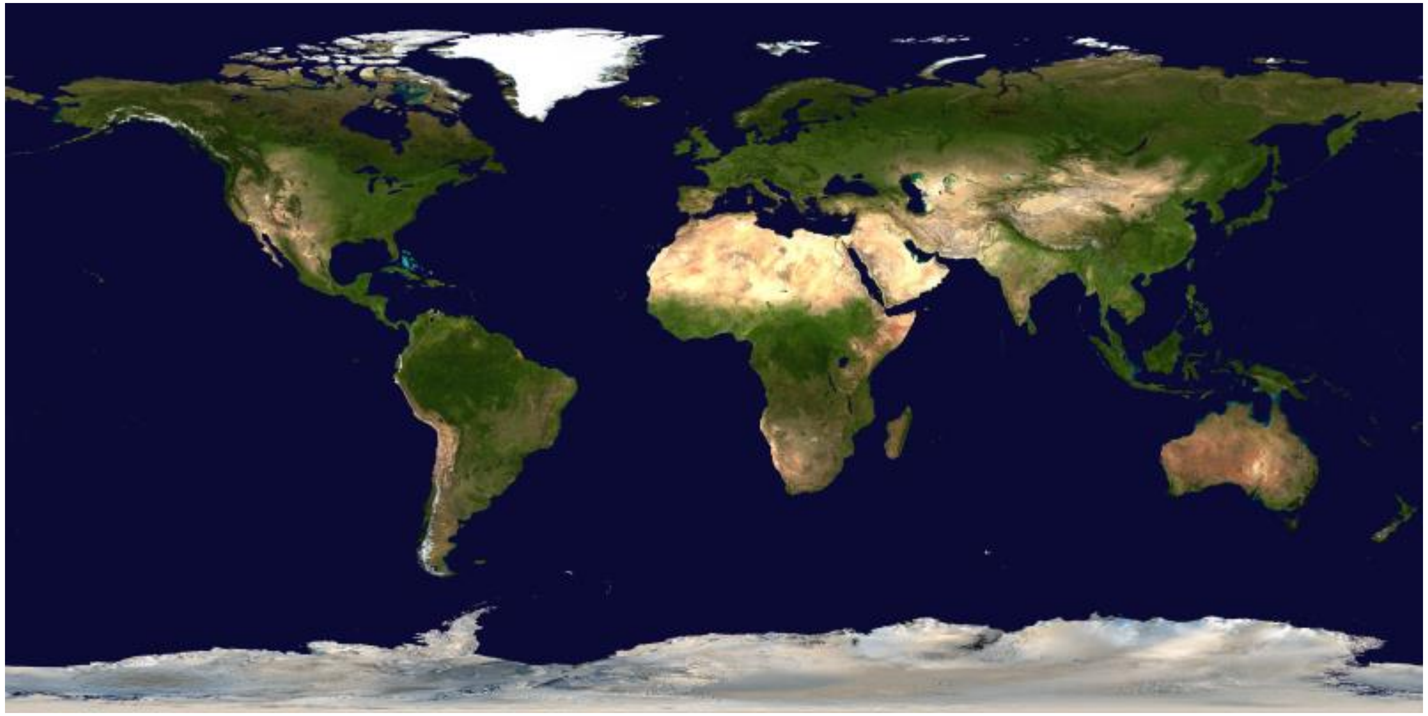
Vegetation Cycles

Time-lapse camera give us a detailed look at vegetation for a few select areas

But what if we want to look at vegetation cycles over large regions?

Or the whole planet?

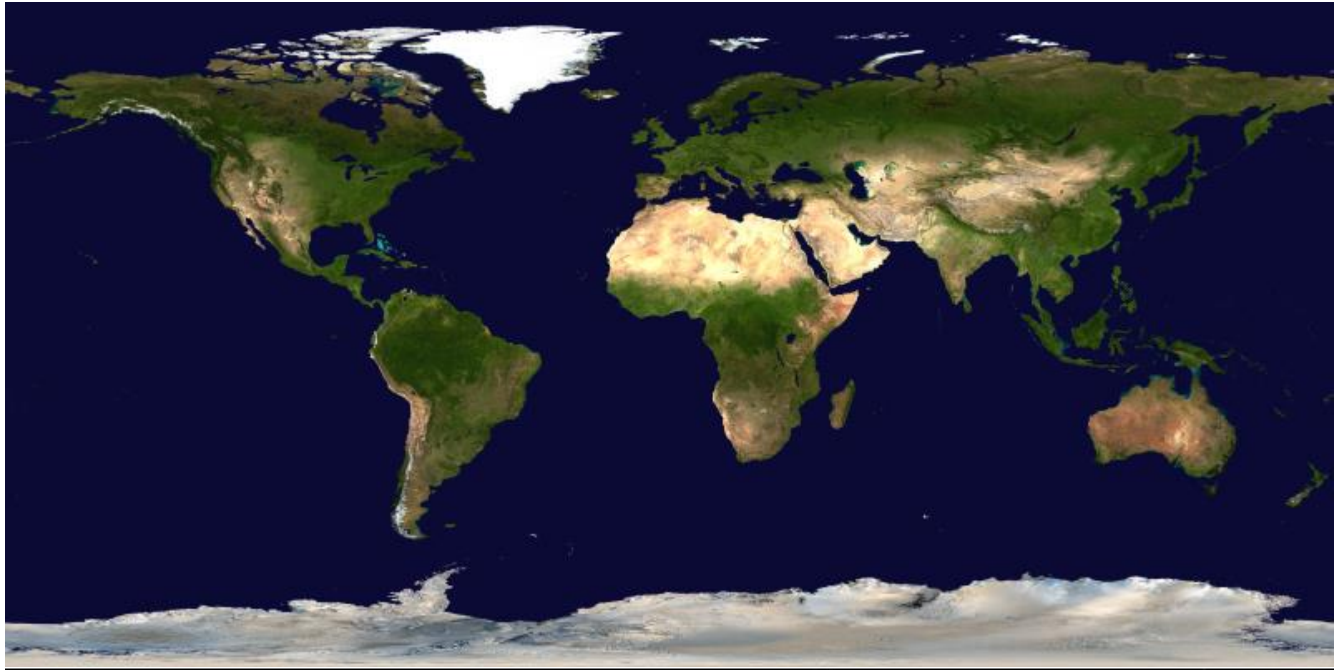
MODIS Data



Vegetation Cycles

- We can use MODIS data for this
  - Daily satellite images
  - 250-1000m resolution

- Allows us to observe how vegetation changes through the year across the entire planet



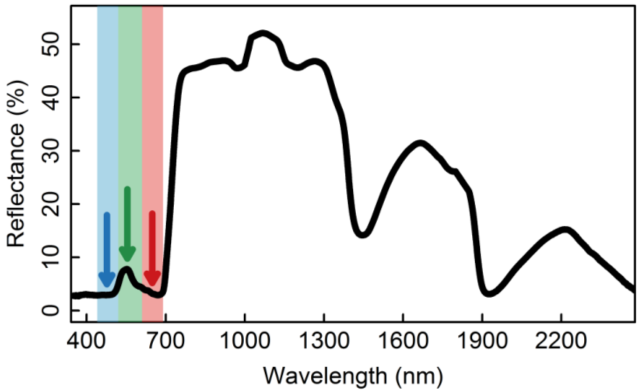
Artist's rendering of NASA's Aqua Satellite Orbiting Earth (Source: Flickr; AIRS)

Vegetation Cycles

- Let's look at the same area again
- This time, we are looking down from space with MODIS data
  - This whole area would fall into a few MODIS pixels!

Photo credit: PhenoCam, http://phenocam.sr.unh.edu/

For the time-lapse cameras, we compared green light to red and blue light



For MODIS data, we compare red light to near infrared (NIR) light. A much stronger signal!

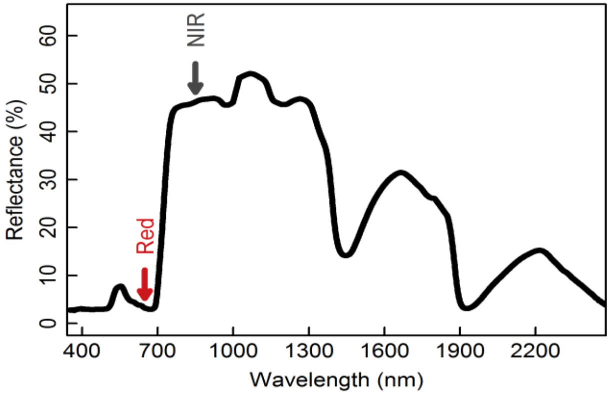
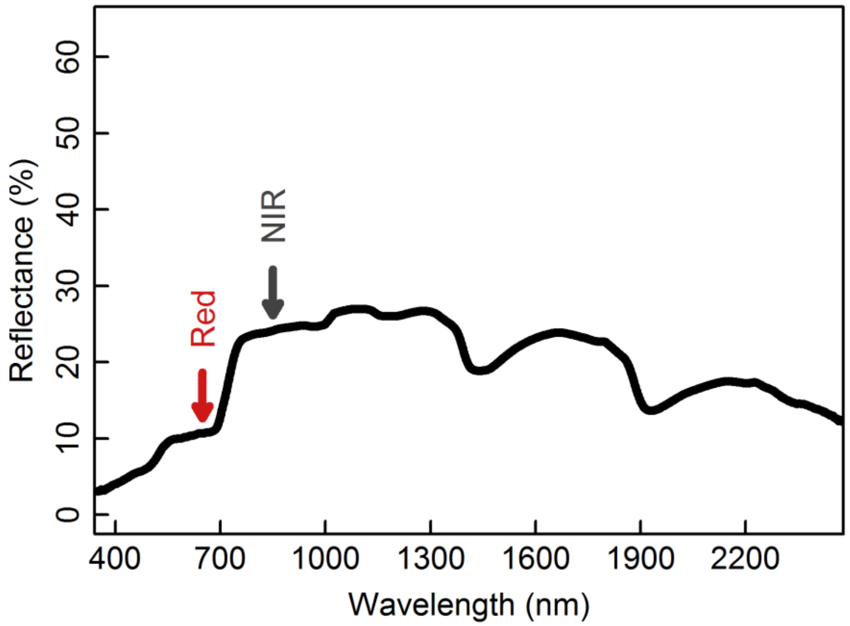


Photo credit: Douglas Bolton, UBC

Vegetation Cycles

- Compare red reflectance to NIR reflectance through the growing season
- As plants greenup, notice how the difference between red and NIR increases



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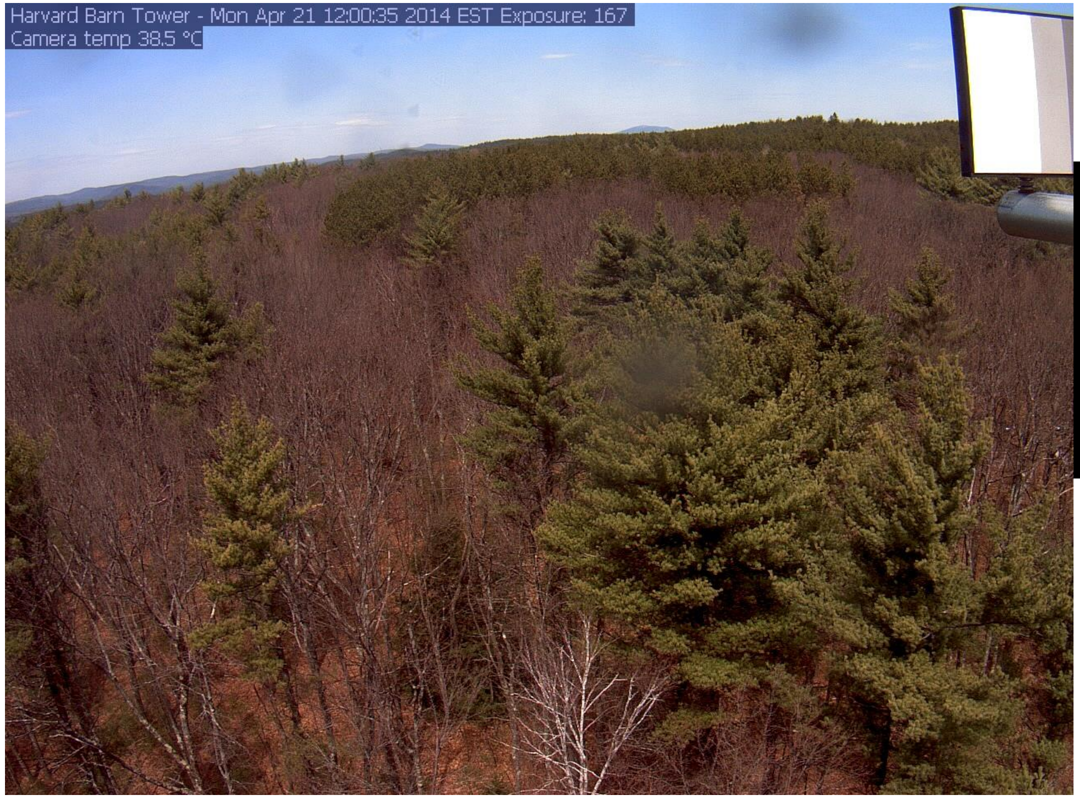
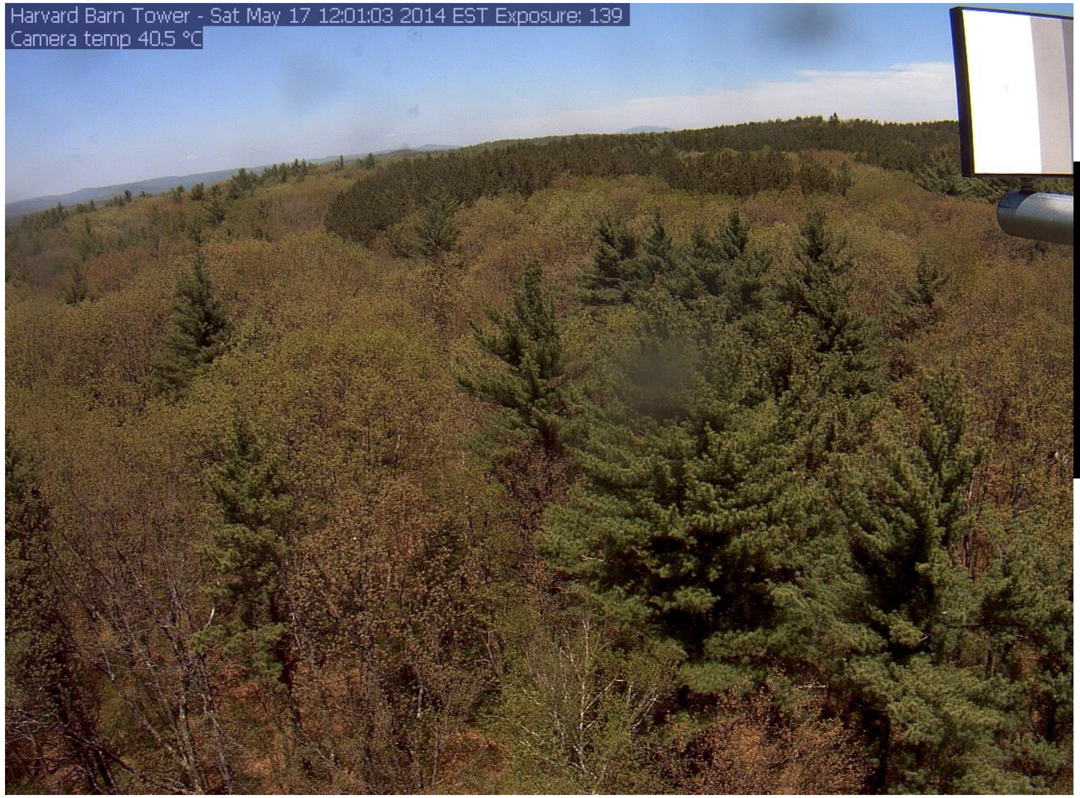


Photo credit: PhenoCam, http://phenocam.sr.unh.edu/

Before trees greenup, red and NIR light is similar

Vegetation Cycles

- Compare red reflectance to NIR reflectance through the growing season
- As plants greenup, notice how the difference between red and NIR increases



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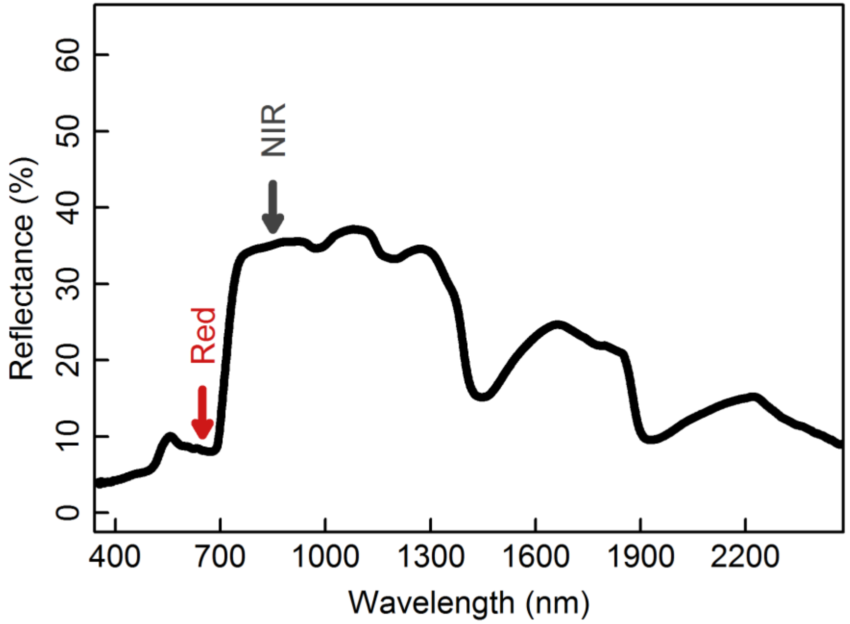
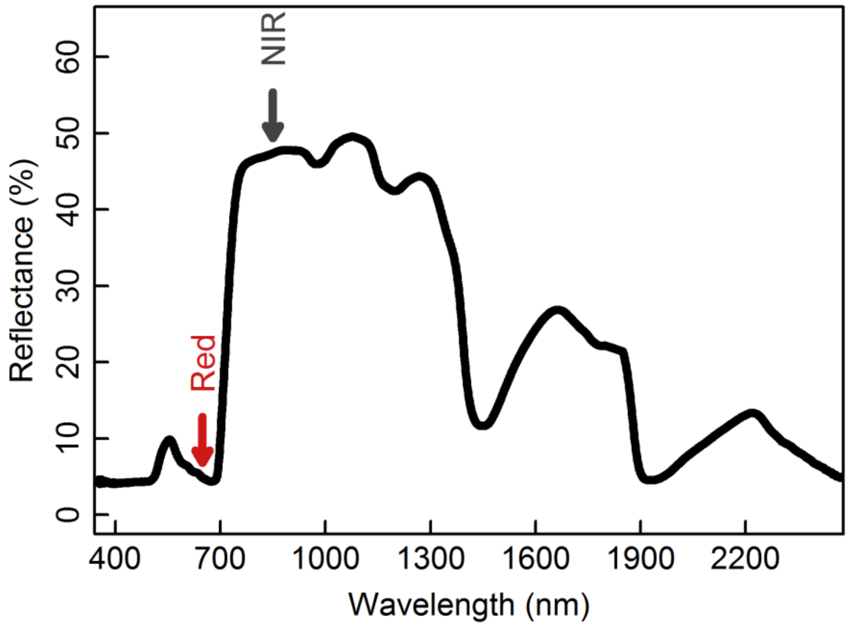


Photo credit: Douglas Bolton, UBC

As trees put on leaves, red light decreases and NIR increases

Vegetation Cycles

- Compare red reflectance to NIR reflectance through the growing season
- As plants greenup, notice how the difference between red and NIR increases



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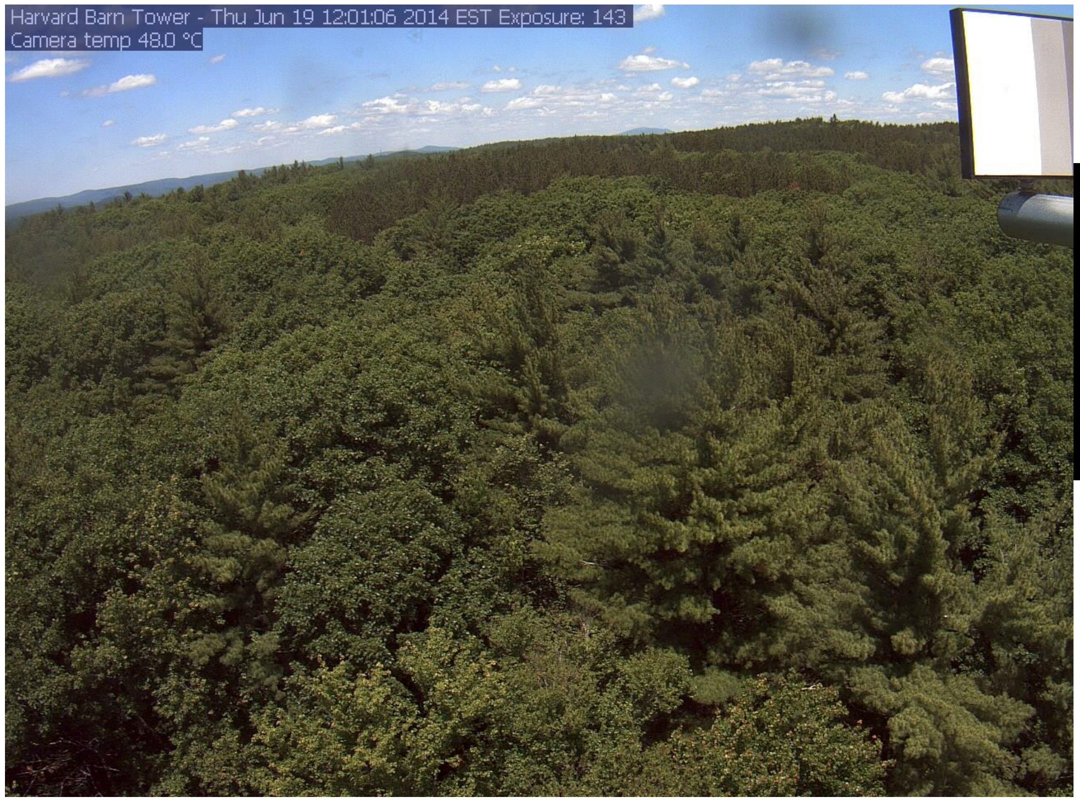


Photo credit: PhenoCam, http://phenocam.sr.unh.edu/

As trees mature, the difference between red and NIR is highest

Vegetation Cycles

- Compare red reflectance to NIR reflectance through the growing season
- As plants greenup, notice how the difference between red and NIR increases

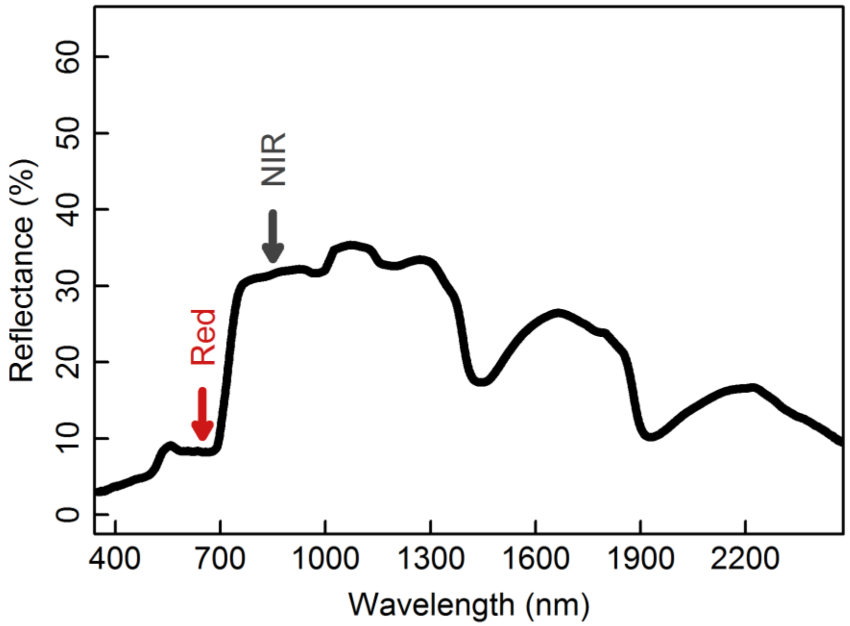


Photo credit: Douglas Bolton, UBC

Photo credit: PhenoCam, http://phenocam.sr.unh.edu/

As leaves die, red reflectance increases and NIR decreases

Vegetation Cycles

- Compare red reflectance to NIR reflectance through the growing season
- As plants greenup, notice how the difference between red and NIR increases

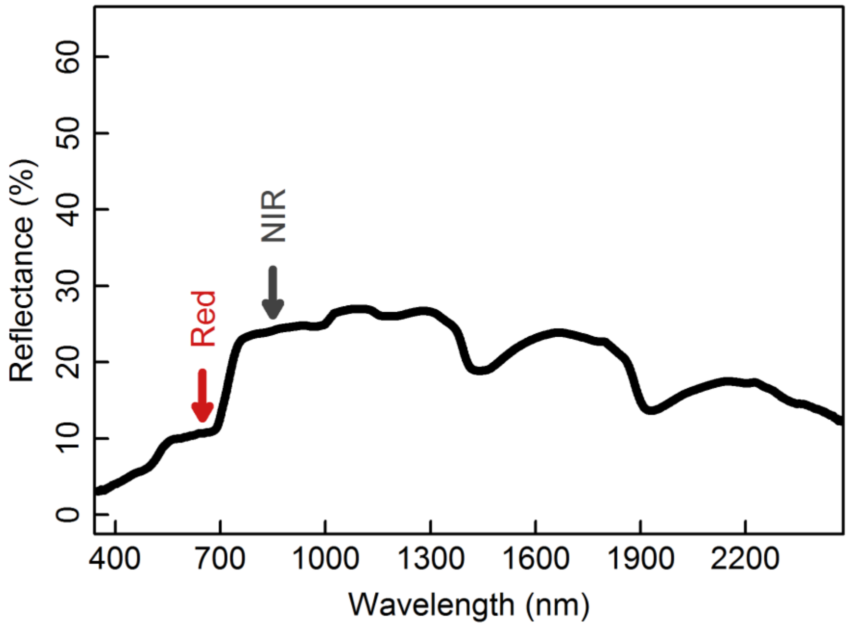


Photo credit: Douglas Bolton, UBC

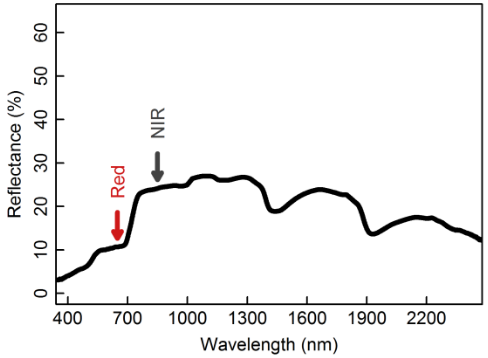
Photo credit: PhenoCam, http://phenocam.sr.unh.edu/

Once leaves fall, the difference between red and NIR is small again

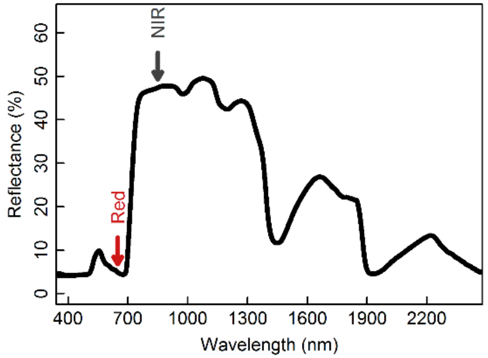
Vegetation Cycles

Calculate a measure of greenness from MODIS images through the year:

$$NDVI = (NIR - Red) / (NIR + Red)$$



Brown vegetation = Low NDVI



Green vegetation = High NDVI

Photo credit: PhenoCam, http://phenocam.sr.unh.edu/ Photo credit: Douglas Bolton, UBC

Vegetation Cycles

Similar to the cameras:

- We can plot NDVI through the year for each MODIS pixel
- And identify key phenology events
  - Greenup, maturity, senescence

- We can calculate the growing season as the length of time between greenup and senescence

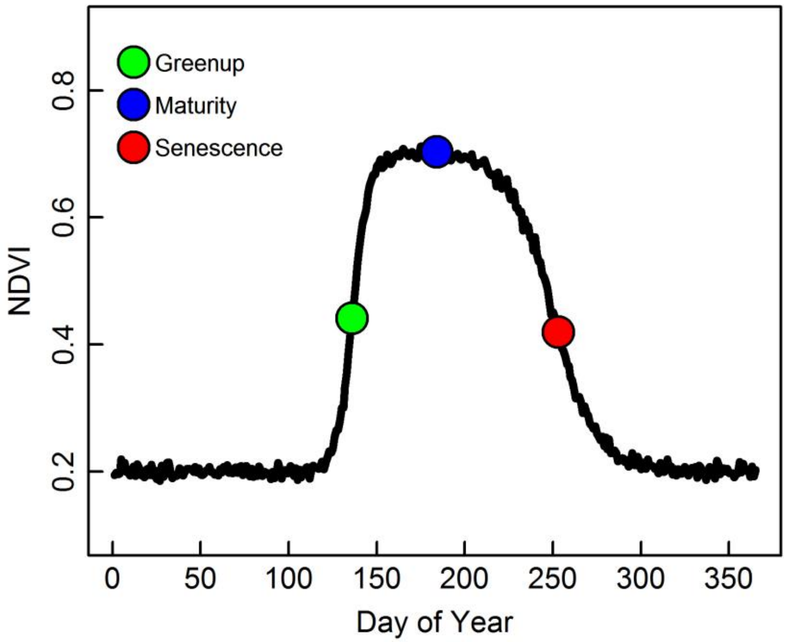
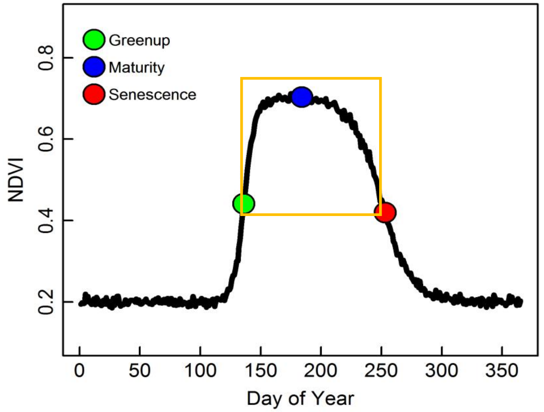


Photo credit: Douglas Bolton, UBC

Vegetation Cycles

- Map of the growing season length
- Growing seasons get shorter as you move further north
- Also shorter in mountainous areas



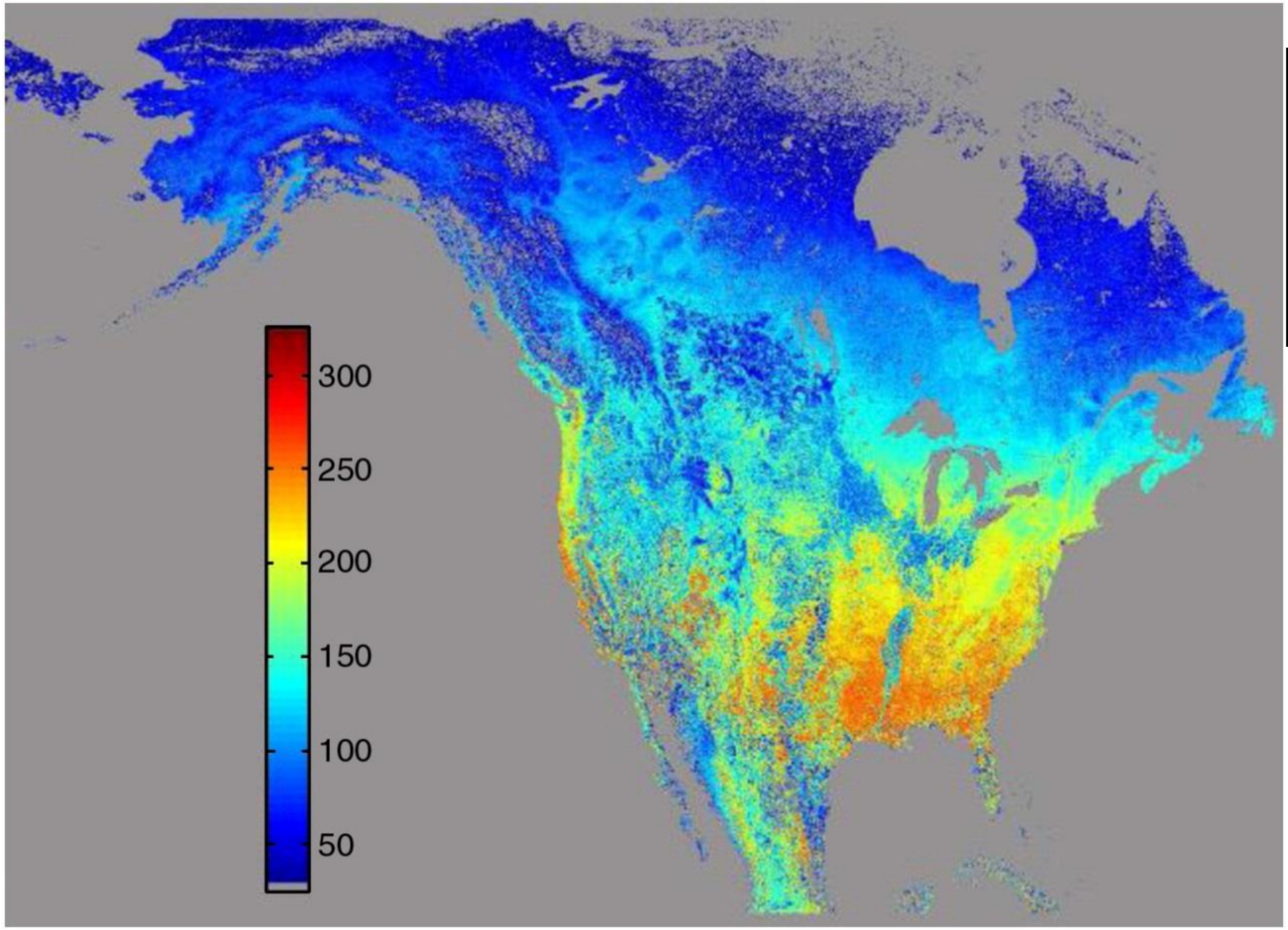


Photo credit: Ganguly et al. 2010

Vegetation Cycles

- With years of MODIS observations, we can see how vegetation cycles look from year to year

- If we monitor this for many years, we could start to see changes in the growing season as the climate warms

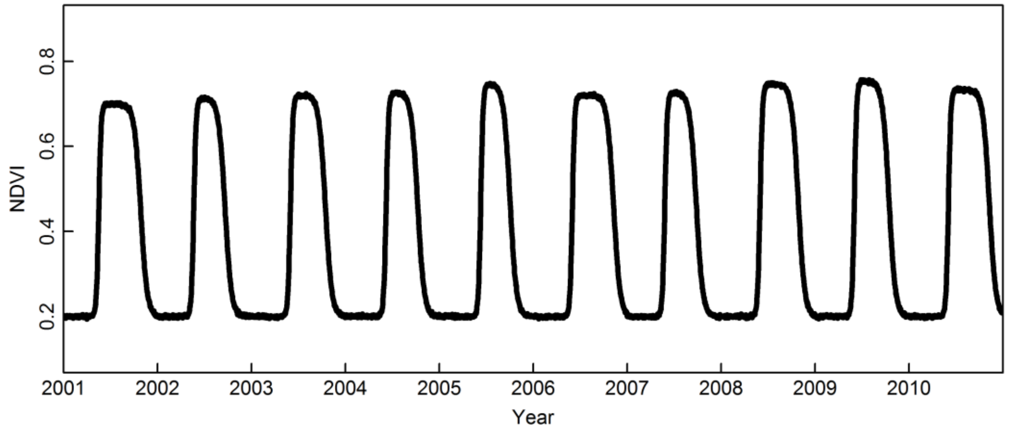


Photo credit: Douglas Bolton, UBC

Review of Measuring Vegetation Cycles

Two approaches covered:

- Camera time-lapse
  - Can get detailed information on vegetation cycles for a few areas of interest
- MODIS data
  - Can get broad-scale information for the whole planet

- In both techniques, we identify changes in the spectral signature of plants
  - Using different spectral bands
    - RGB for cameras
      - $2G_{RBI}$
    - Red & NIR for MODIS
      - NDVI

Thinking Back to Data Requirements…

- What are the data requirements if I want measure phenological changes in my backyard due to this year's drought?

- What are the data requirements if I want to measure global phenological changes due to climate change?

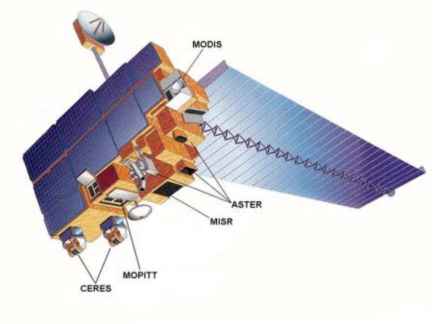
Thinking Back to Data Requirements…

I want to measure phenological changes in my backyard due to this year's drought

- High level of spatial detail
- VIS/NIR ideal
- Daily measurements required
- Only 1 – 2 years of data required

I want to measure global phenological changes due to climate change

- Low level of spatial detail
- VIS/NIR ideal
- Daily measurements required
- Decades of data required at minimum



Three Types of Change from Remote Sensing

Cyclical

Abrupt

Gradual

Abrupt Changes

- An abrupt change is a rapid shift from one state or condition to another
- Example: Forest fire

Before fire

After fire

Photo credit: USFWS

Abrupt Changes

- We will focus on three dominant types of abrupt changes that occur in forests
  - Forest fires
  - Forest harvesting
  - Land Cover/Land Use Change

- Why do we care about monitoring these three types of abrupt changes?

Fire - Forest (Source: Wikimedia Commons)

Timber harvesting in Kielder Forest (Source: Wikimedia Commons)

How does each type of change impact global carbon cycle?

		Type of change	Short term	Long term
Fire - Forest (Source: Wikimedia Commons)		Forest fires	Carbon transferred to atmosphere	Forest regrows, carbon transferred back to forest
Timber harvesting in Kielder Forest (Source: Wikimedia Commons)		Forest harvest	Carbon transferred to forest products (Houses, paper, etc.)	Forest regrows, carbon transferred back to forest
		Land Cover / Land Use Change	Can vary depending on what happens to the logs	Forest does NOT regrow, carbon NOT transferred back to forest

Changes also impact habitat in unique ways

- Fire is a natural part of ecosystems
- Recently burned areas can be important habitat for certain species
  - Moose forage in recently burned areas
  - Grizzly bears may prefer to forage in recently burned areas

- Harvesting can alter ecosystems in unnatural ways
  - Can remove important habitat

- Land conversion from forest to agriculture or development leads to habitat loss

Detecting Abrupt Changes

- Two step process:
  - First, we must detect where abrupt changes have occurred
  - Second, we must identify what type of disturbance it is

Fire - Forest (Source: Wikimedia Commons)

Timber harvesting in Kielder Forest (Source: Wikimedia Commons)

Detecting abrupt changes

- How will we detect abrupt changes?
  - Example using Landsat images

Before fire

After fire

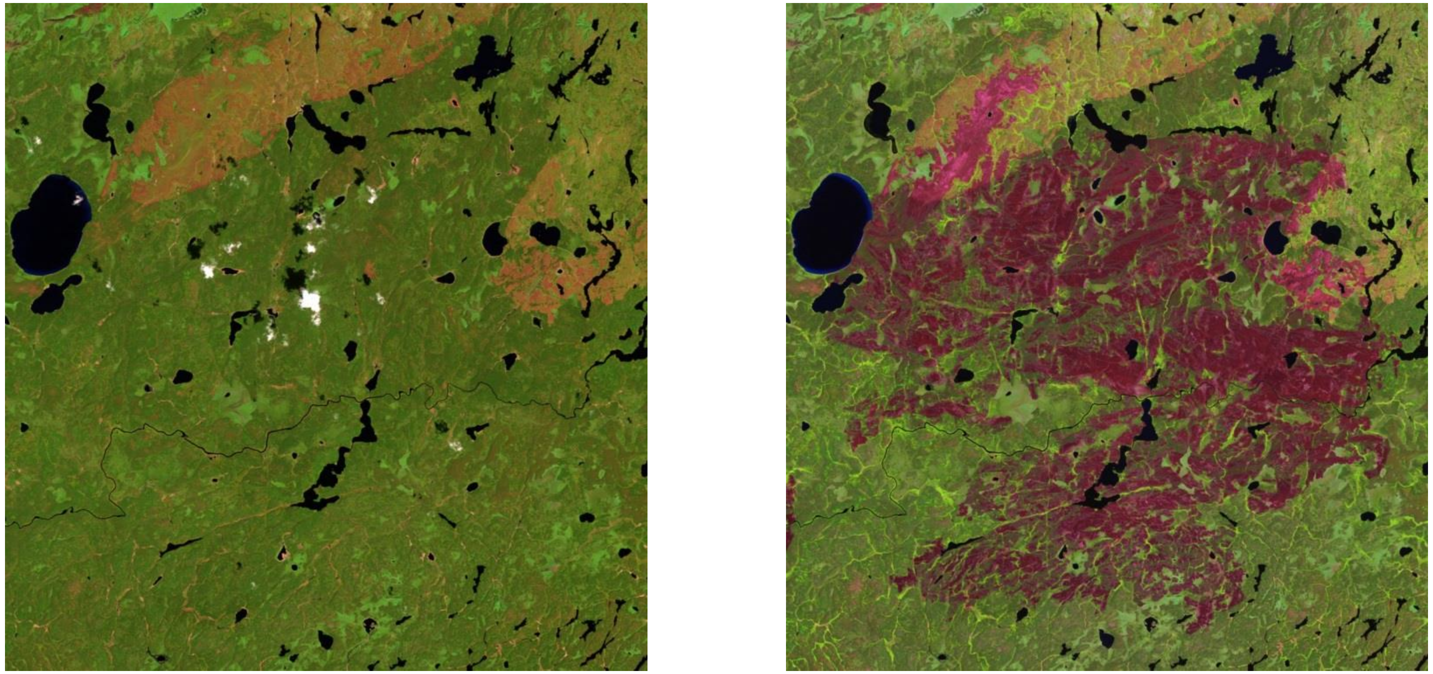
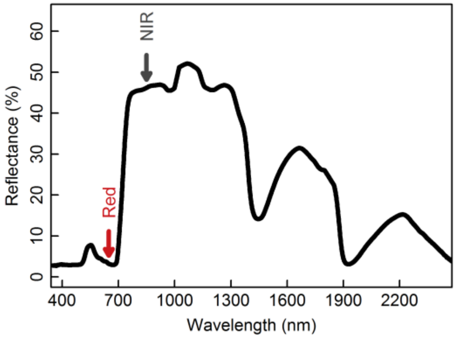


Photo credit: USGS

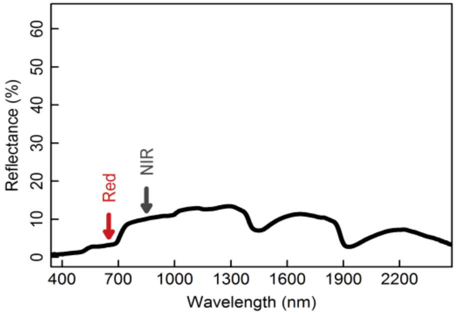
Detecting Abrupt Changes

- How do we detect where abrupt changes have occurred?
  - We look for sharp changes in spectral signatures

Photo credit: USFWS



Before fire: Strong vegetation signal

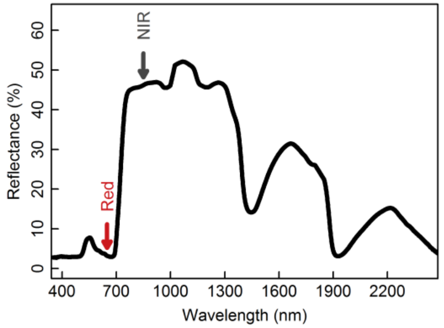


After fire: Live vegetation is removed, weak vegetation signal

Photo credit: Douglas Bolton, UBC

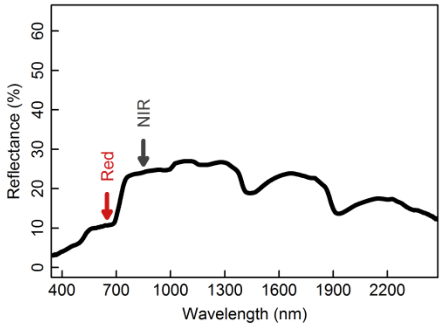
Detecting Abrupt Changes

- It is inefficient to look at entire spectral signatures
- To simplify, we can just focus on a metric like NDVI
  - NDVI = (NIR-Red) / (NIR + Red)



Before fire

Green vegetation = High NDVI



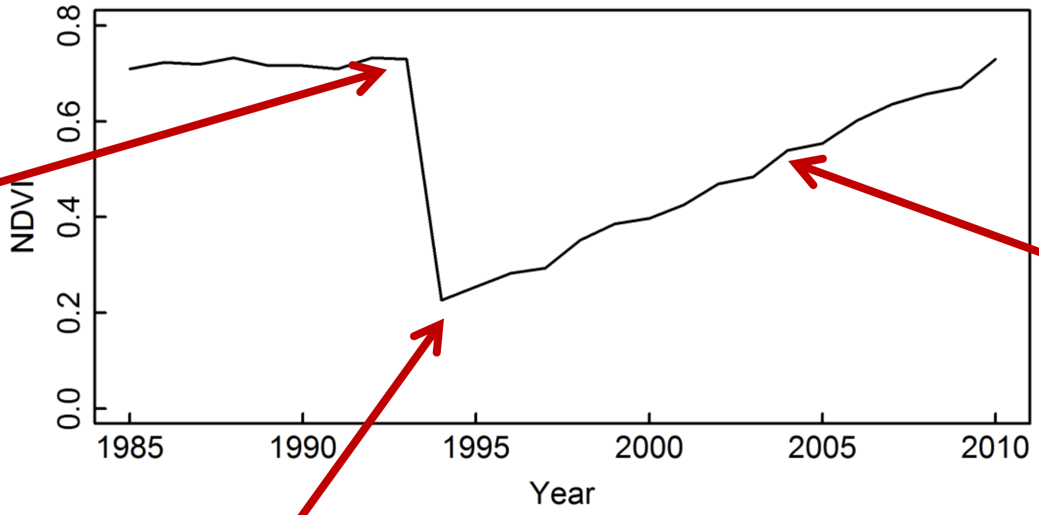
After fire

Brown vegetation = Low NDVI

Photo credit: USFWS   Photo credit: Douglas Bolton, UBC

Detecting Abrupt Changes

Before fire



Time series of satellite derived NDVI through time at a given study area`

Vegetation regrowth

After fire

What we know from this time-series of NDVI:

1. A disturbance occurred in 1994
2. The forest regrew after the disturbance

Photo credit: USFWS and Douglas Bolton

Detecting Abrupt Changes

- The shape and size of the disturbance
- Fires and harvests have very different shapes and sizes
- Fires
  - Irregular perimeters
  - Large area
- Harvest
  - Regular shapes
  - Small area

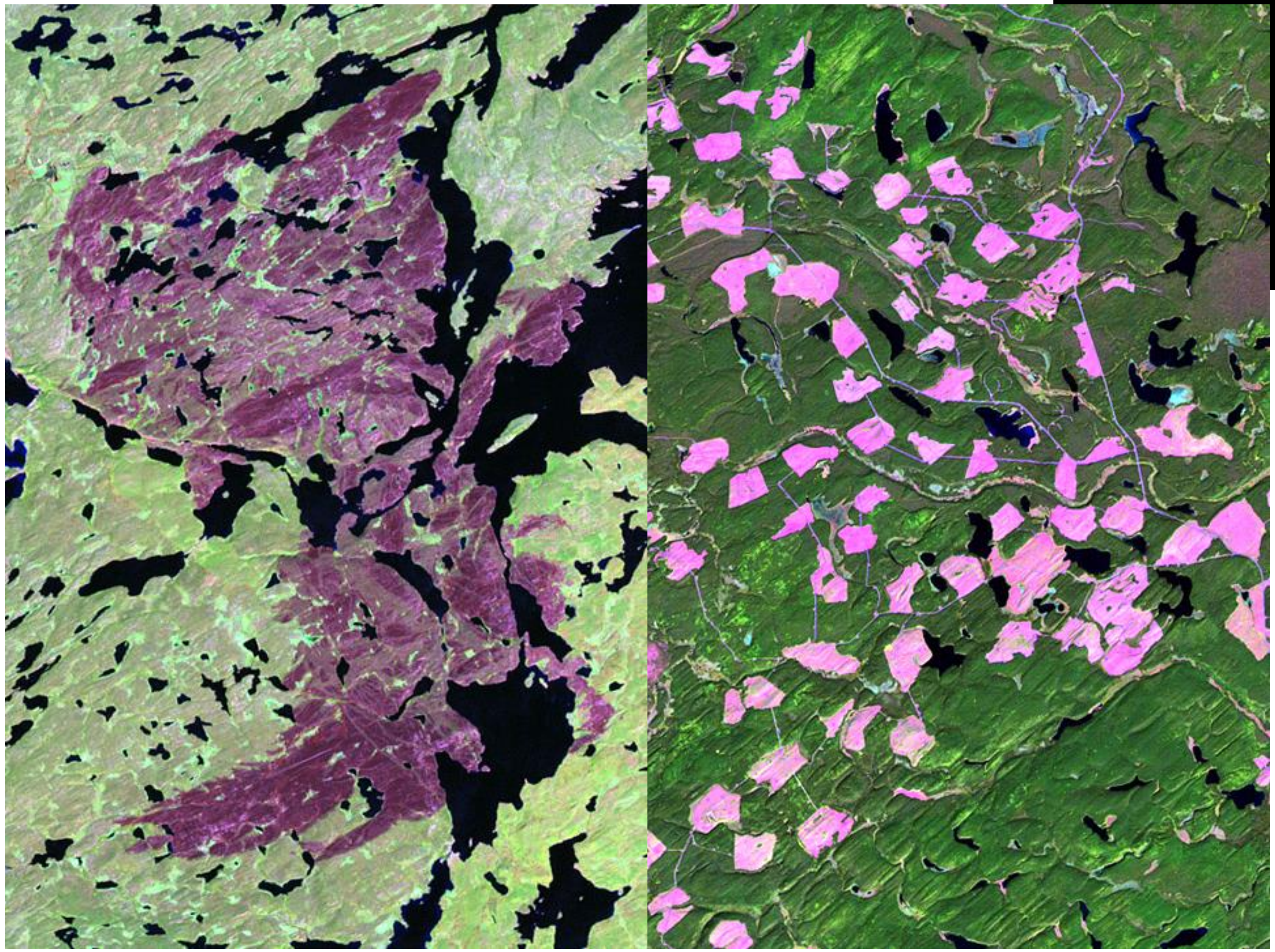


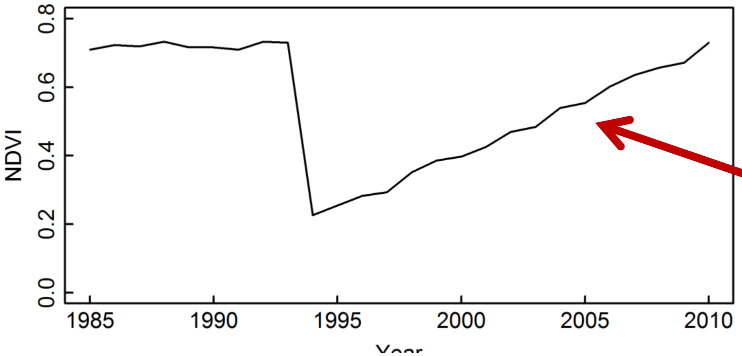
Photo credit: USGS

Detecting Abrupt Changes

How can you differentiate between a forest harvest and land conversion / land use change?

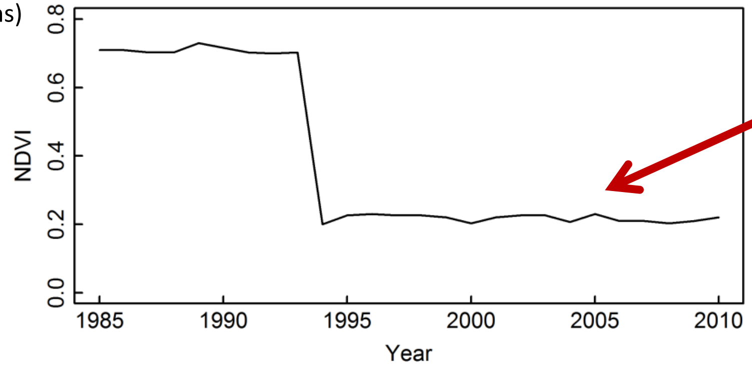
Forest regrows after a harvest

Timber harvesting in Kielder Forest (Source: Wikimedia Commons)



Regrowth!

Forest does not regrow when land is converted



No regrowth

Photo credit: Douglas Bolton, UBC

Review

Step 1: Detect change

- ***Where and when was the disturbance?***
  - Identify large changes in NDVI (or other spectral data)

Step 2: Identify change

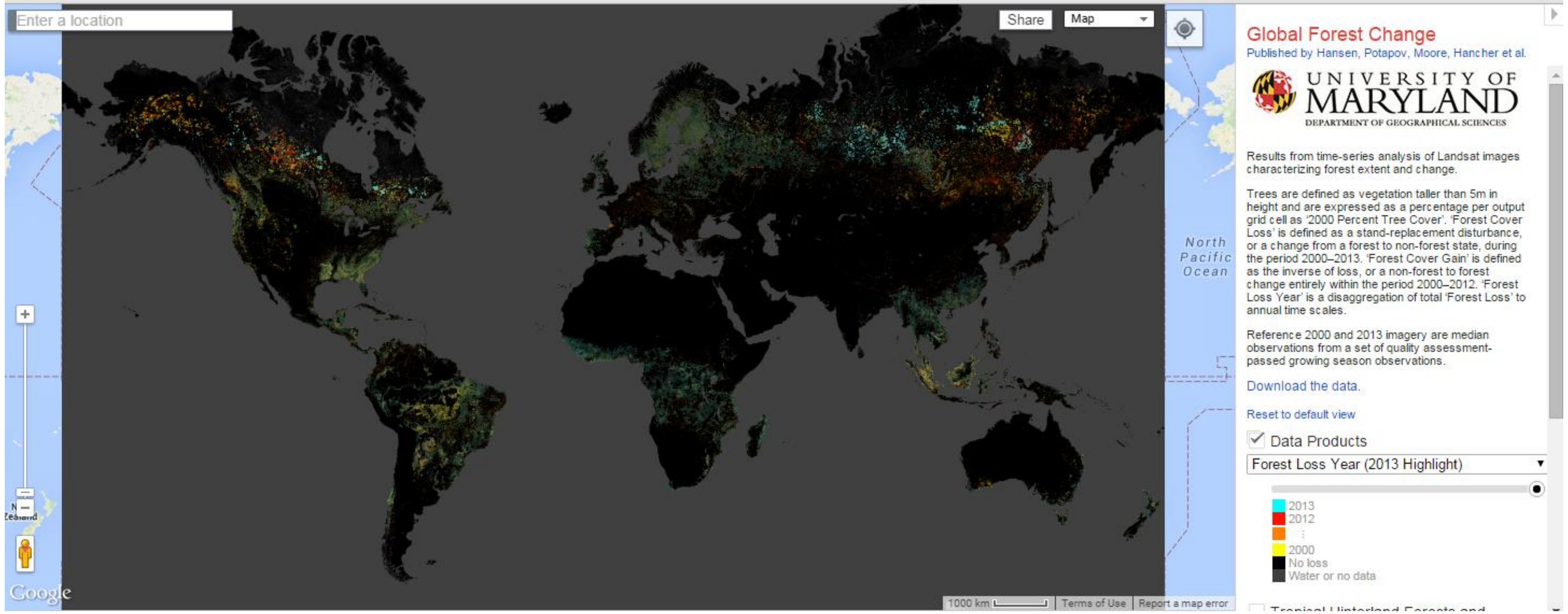
- ***What type of disturbance was it?***
  - Fire vs. harvest
    - Use information on the size and shape of the disturbance
  - Harvest vs. land conversion
    - See if forest comes back after the disturbance
      - If it does, it was a harvest

Fire - Forest (Source: Wikimedia Commons)

Timber harvesting in Kielder Forest (Source: Wikimedia Commons)

Detecting Abrupt Changes

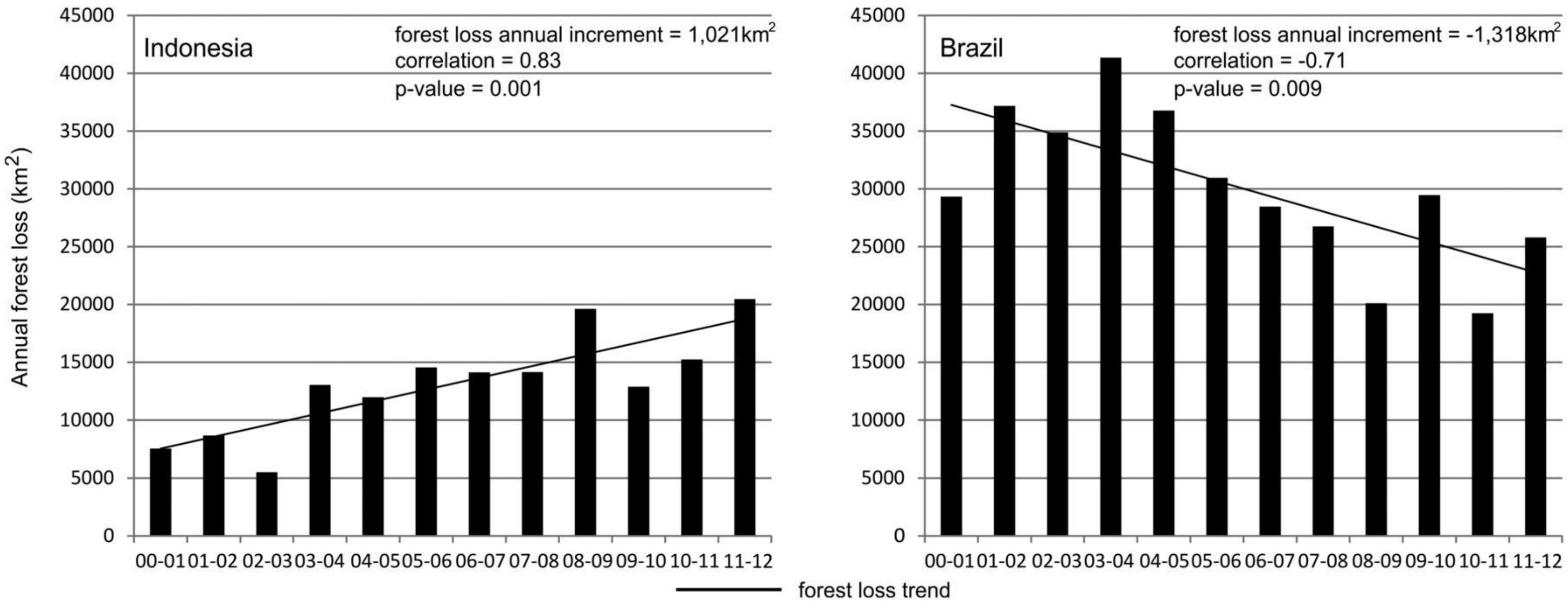
- Hansen et al. 2013 used Landsat data to map abrupt changes across the entire planet from 2000-2010
    - Why might Landsat be ideal for mapping abrupt changes (think back to data requirements)?



- Let's look at these changes:
    - http://earthenginepartners.appspot.com/science-2013-global-forest

Detecting Abrupt Changes

- From 2000-2012, Hansen et al. 2013 found:
  - 2.3 million km^2 of forest were lost
  - 0.8 million km^2 of forests were gained
  - Spatial trends of deforestation:
    - Deforestation in Brazil decreased through time, but increased in other tropical countries



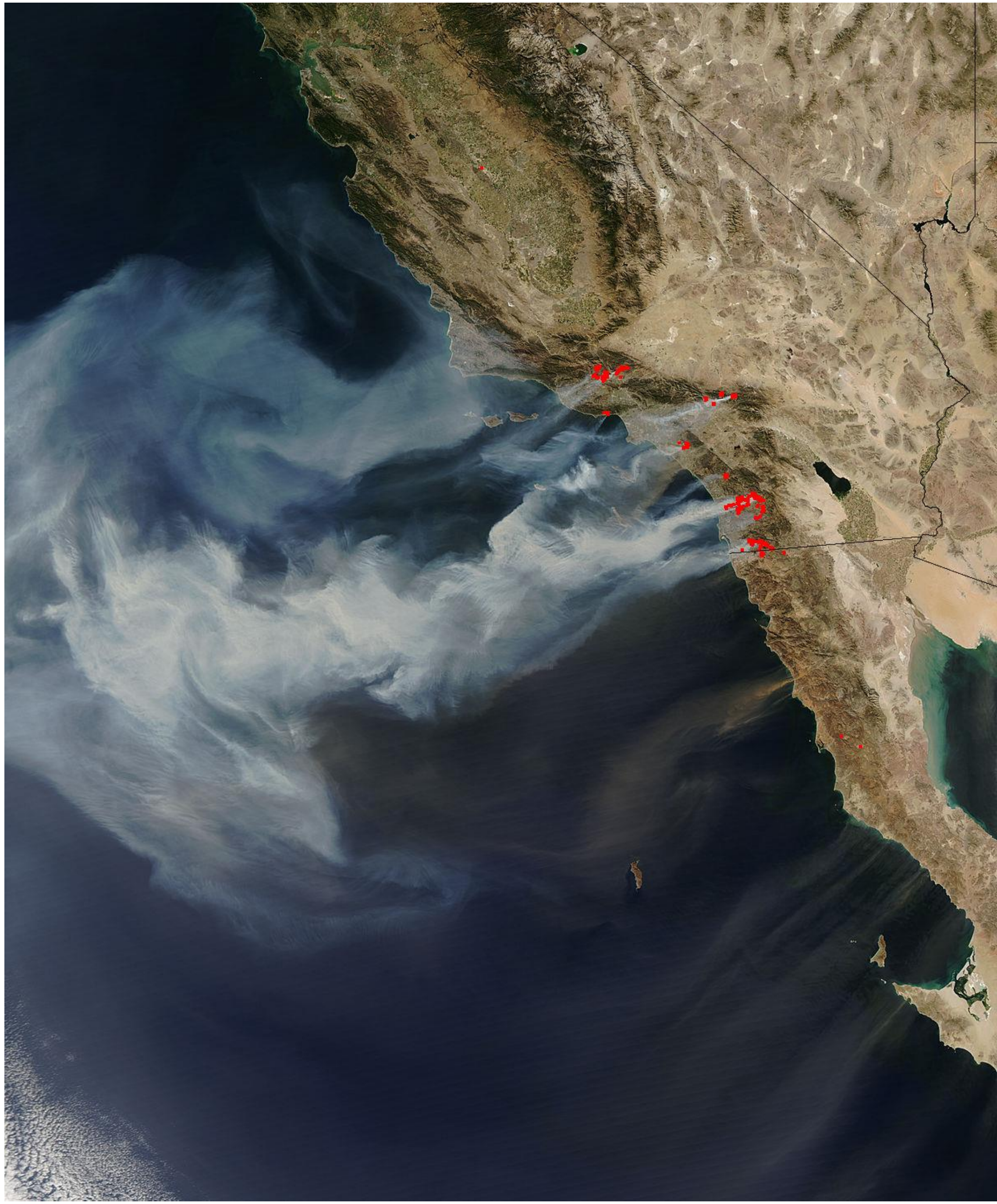
Abrupt Change Applications

- Some uses/applications of:
  - Wildfire detection
  - Forest harvest detection
  - Land cover / land use change
    - Definitions

Wildfires from Space

- With satellite imagery we can:
  - Detect fires
    - Monitoring hotspots
  - Monitor fire progression
  - Calculate burned area
  - Monitor vegetation recovery

- Data requirements for each of these?

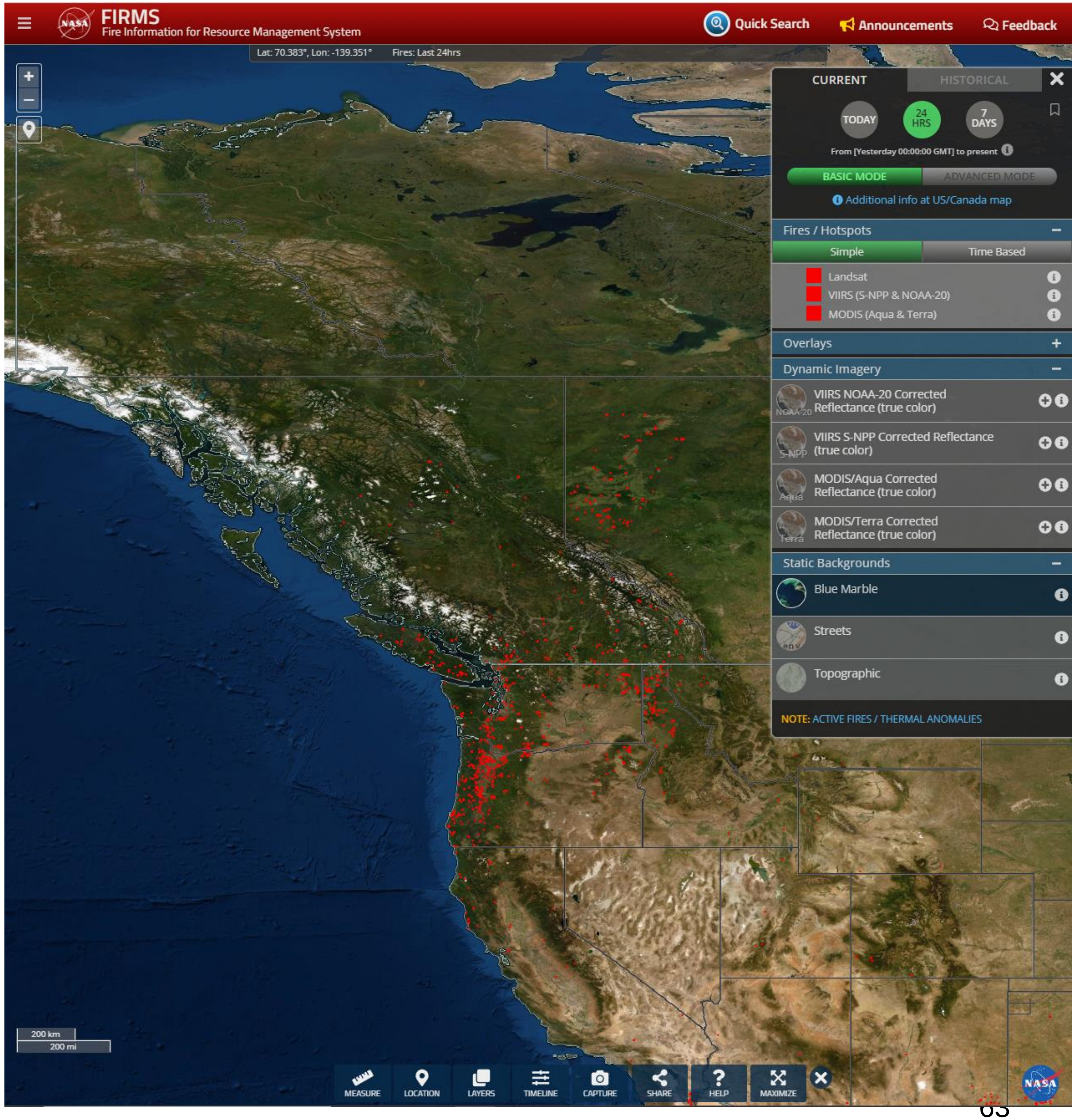


Hotspot Detection

- Areas on the ground that are distinctly hotter than their surroundings
- Thermal sensors measures the surface temperature and thermal properties of targets
- Early detection for coordination of forest fire fighting efforts

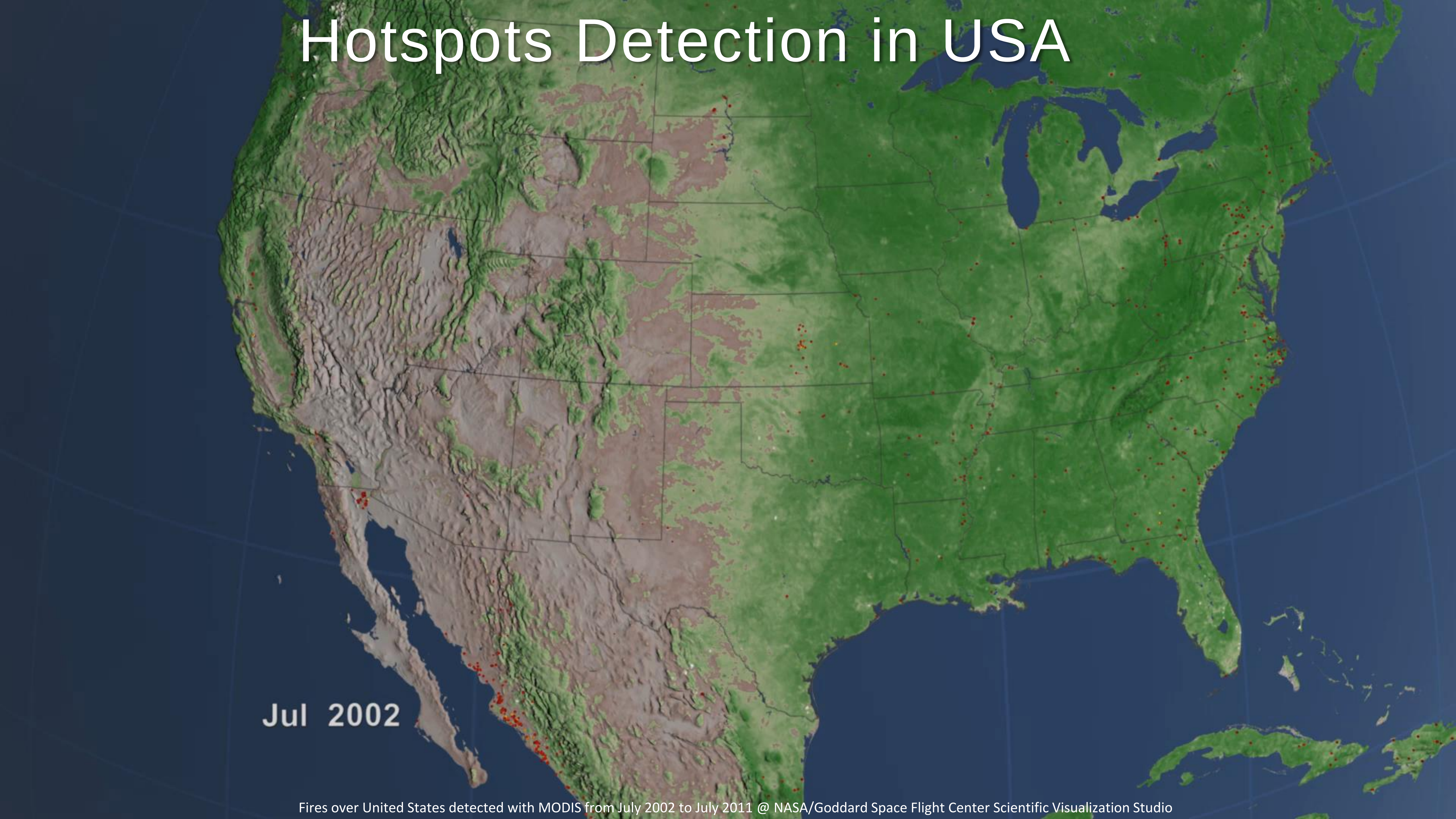
Instruments

- Landsat
- VIIRS
- MODIS



FIRMS Fire Map – Check out the online interactive map

Hotspots Detection in USA

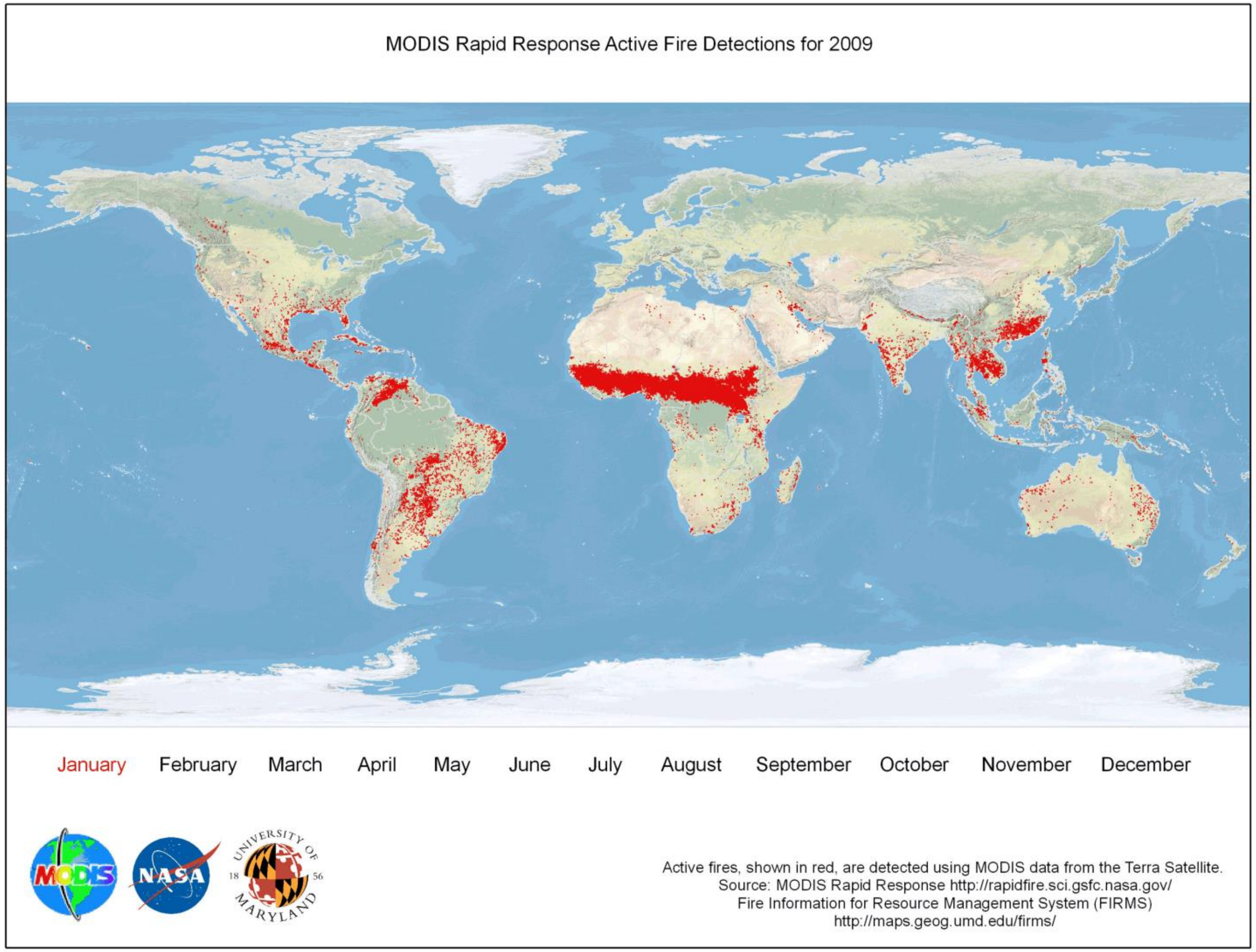


Fires over United States detected with MODIS from July 2002 to July 2011 @ NASA/Goddard Space Flight Center Scientific Visualization Studio

Detecting Active Fires

All active fires detected using MODIS

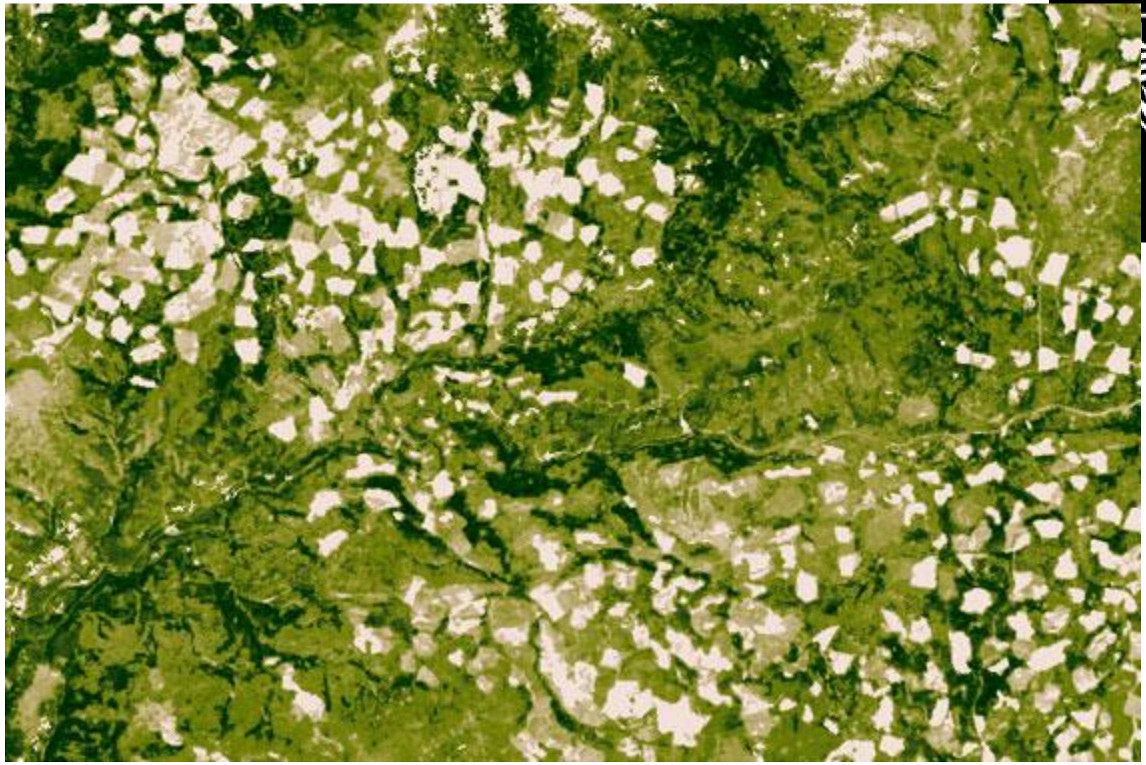
Can you see the seasonal cycle of fires?



Forest Harvest from Space

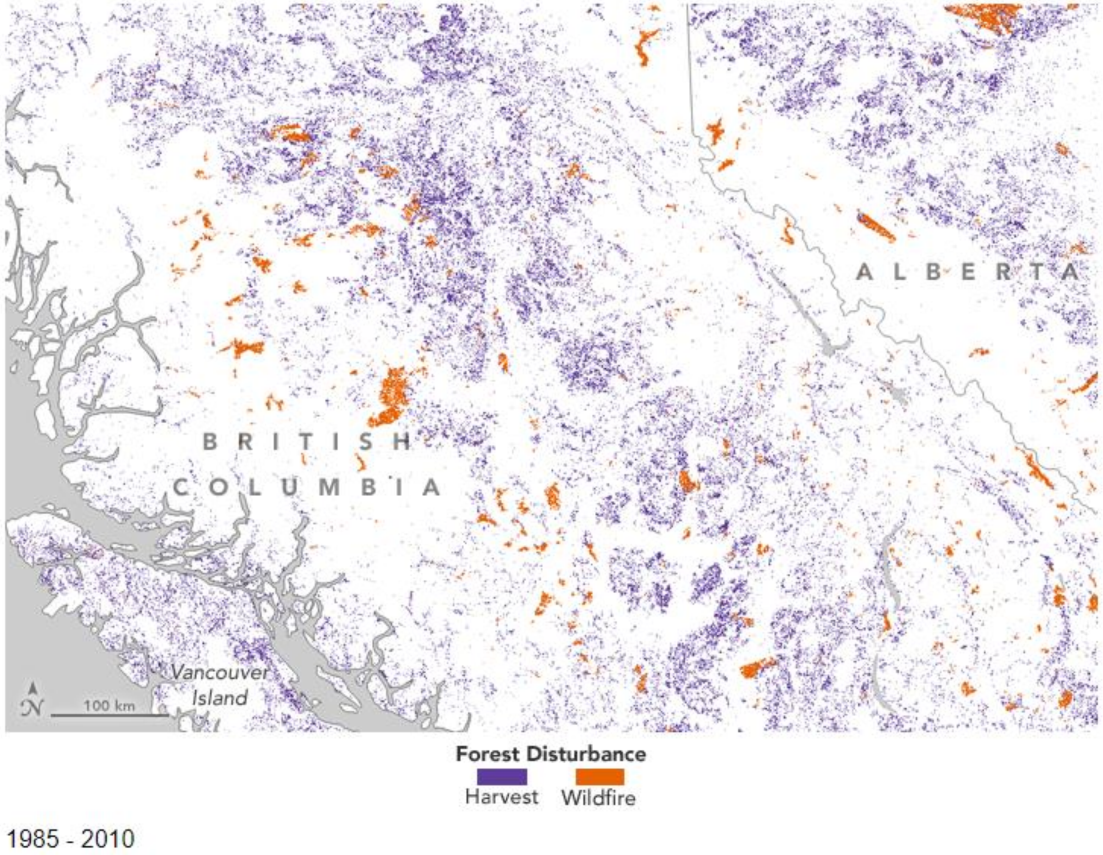
- With satellite imagery we can:
  - Detect forest harvest
  - Calculate harvested area
  - Monitor forest recovery

- Data requirements?



Confirming Forest Harvest Amounts

- Government and industry make targets on forest harvest
- And create reports about on-the-ground harvesting
- Satellite data is an independent, standardized, objective dataset that allows us to confirm numbers from government/industry



Land Cover vs. Land Use: Forest Harvest Example

Deforestation

- Forest is cut down
- Farms/plantations/communities are developed

- Land cover change:
  - Forest to soil/vegetation/buildings
- Land use change:
  - Forestry to farm/plantation/community

Forest Harvest

- Forest is cut down
- Trees are planted and re-grown

- Land cover change:
  - Forest to bare ground initially, then back to forest eventually
- Land use change:
  - Forestry to forestry (no change)

Land Cover and Land Use

- **Land cover** is the physical and biological cover over the surface of land, including water, vegetation, bare soil, and/or artificial structures.

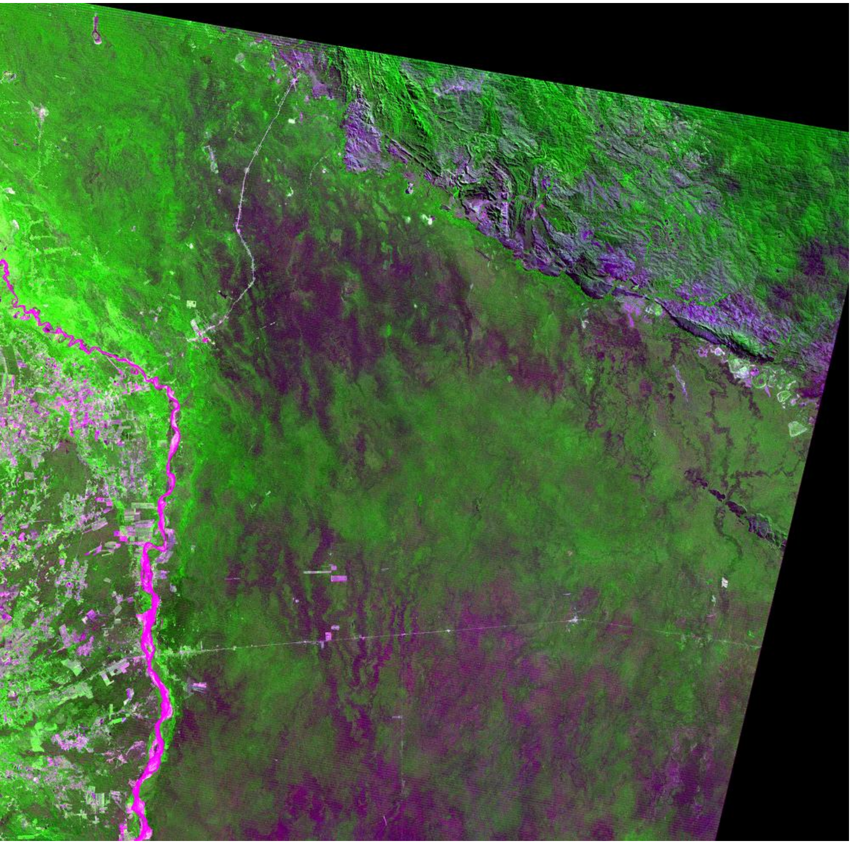
Land Cover and Land Use

- Land use is related to human activities such as agriculture, forestry and urban construction that alter land surface processes including biogeochemistry, hydrology and biodiversity.

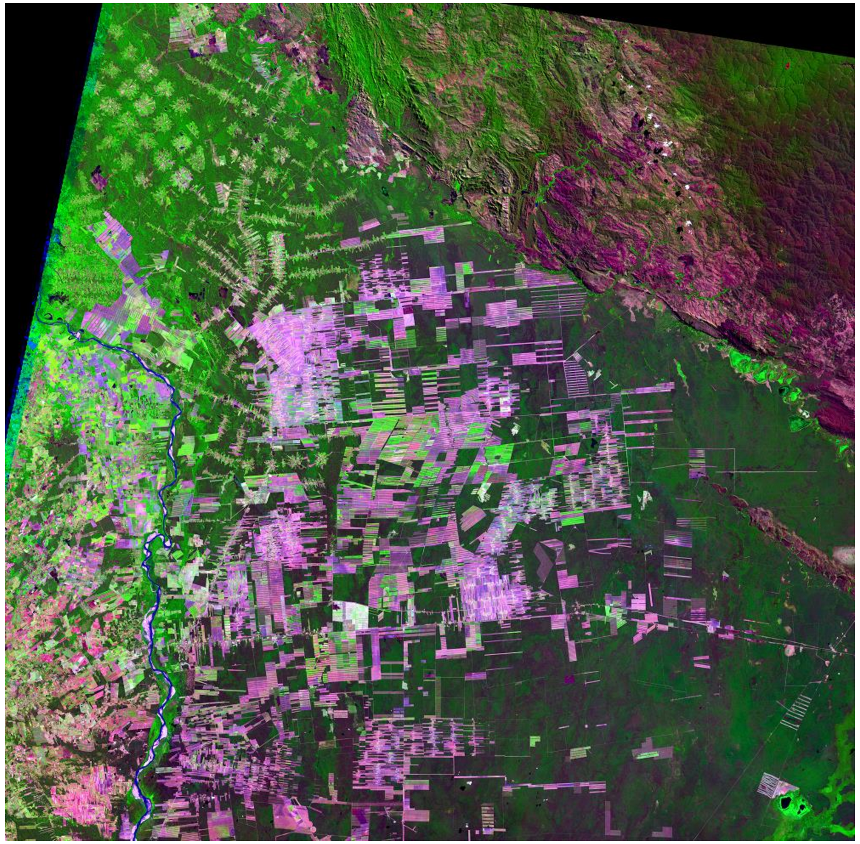
Land Cover / Land Use Change

- Often a change in land cover could be temporary:
  - Logging: land use does not change (managed forest)
    - Forest -> bare soil
    - Regrowth
    - Bare soil -> shrubs -> forest
- While a change in land use could be permanent/long-term:
  - Residential development: land use changes from natural ecosystem to residential area
    - Forest -> concrete
    - No regrowth
- Land use vs. land cover change is an important distinction
  - They each have different consequences

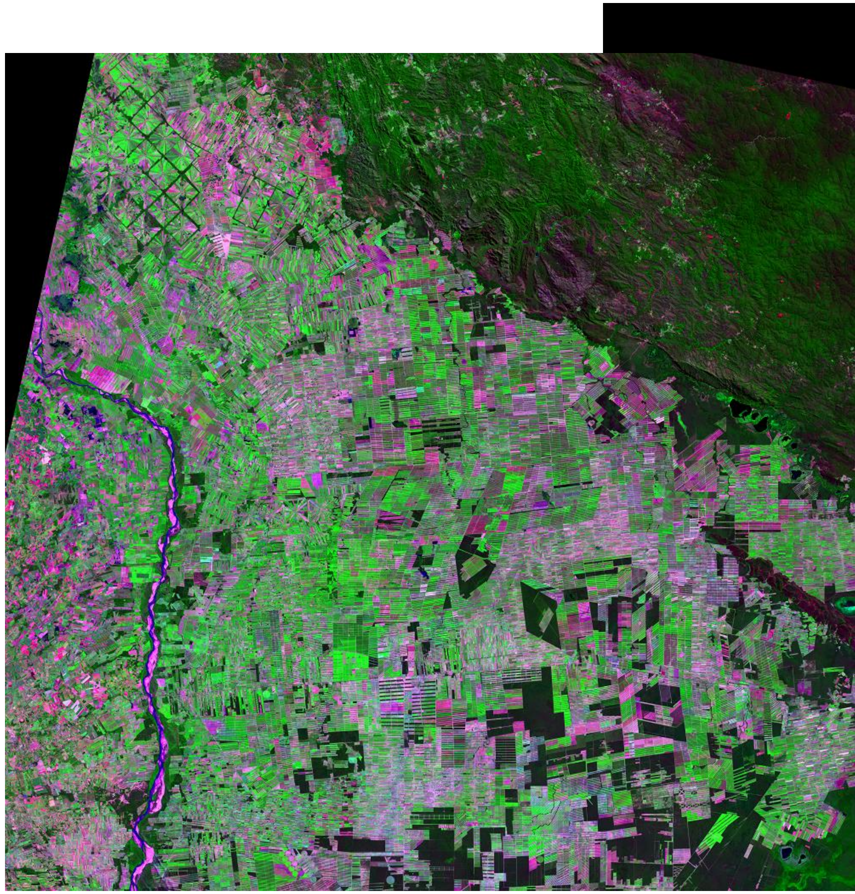
Soy Plantations in Bolivia



June 17, 1975, Landsat 2



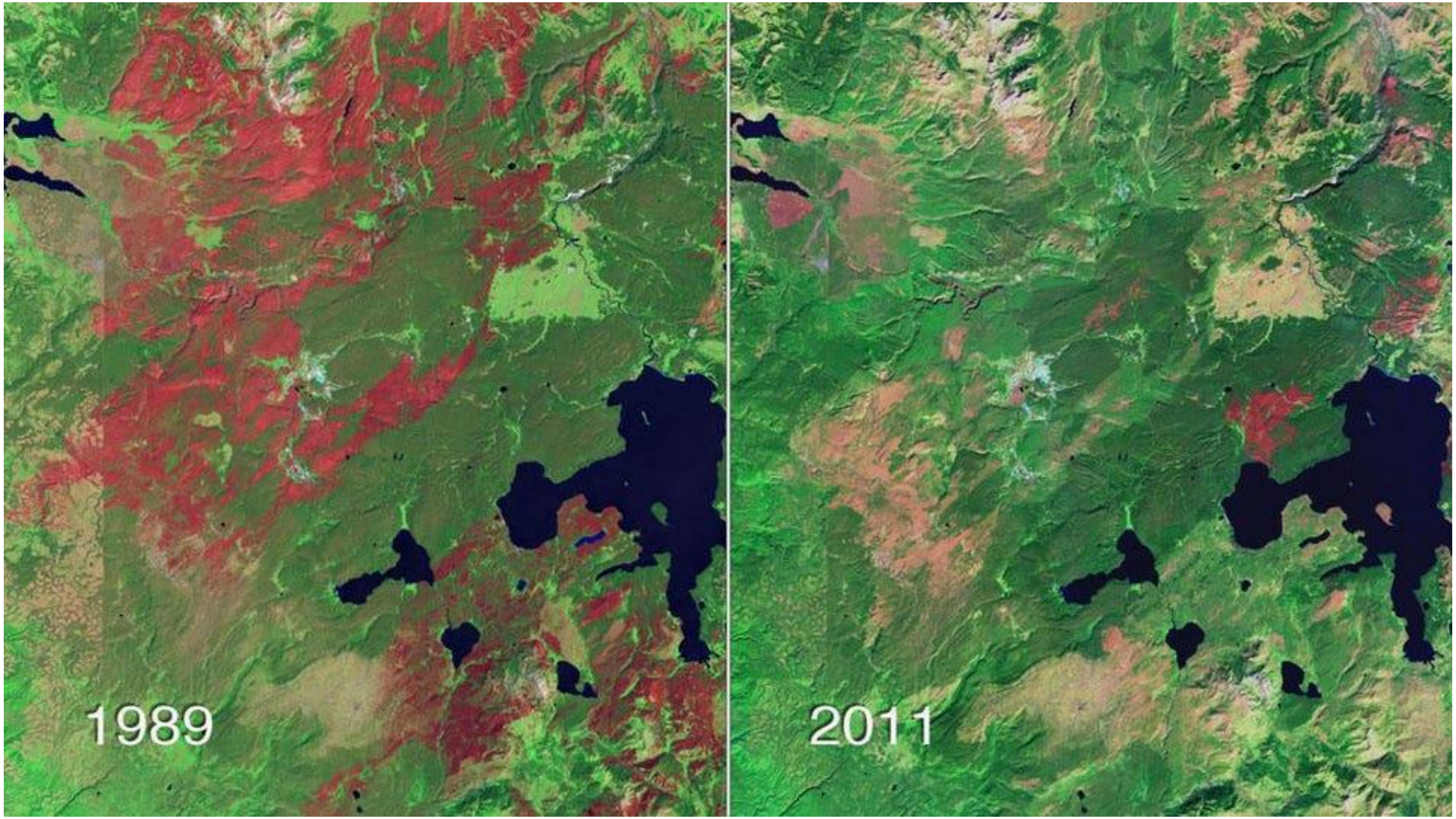
July 27, 1995, Landsat 5



July 23, 2017, Landsat 8

Source: USGS

Wildfire Recovery in Yellowstone



Three Types of Change from Remote Sensing

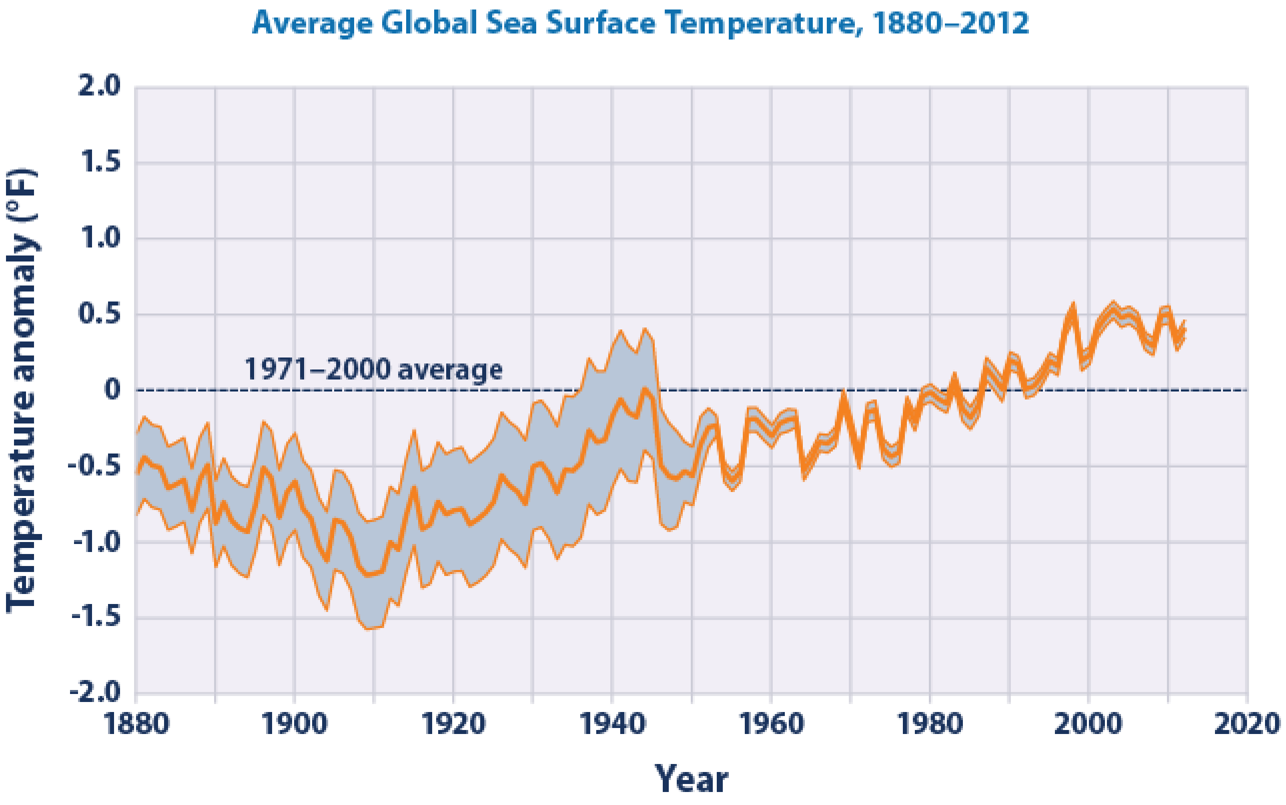
Cyclical

Abrupt

Gradual

Gradual Changes

- A gradual change is a slow shift from one state or condition to another, or a trend over time
- Key Example:
    - Rising sea surface temperatures



Data source: NOAA (National Oceanic and Atmospheric Administration). 2013. Extended reconstructed sea surface temperature (ERSST.v3b). National Climatic Data Center. Accessed February 2013. www.ncdc.noaa.gov/ersst/.

For more information, visit U.S. EPA's "Climate Change Indicators in the United States" at www.epa.gov/climatechange/indicators.

Gradual Changes in Forests

- What types of gradual trends do we see in forests?
  - Slow mortality of trees due to insects or disease
  - Gradual regrowth
  - Reforestation
    - Transition from agriculture or developed land back to forests

Mountain Pine Beetle

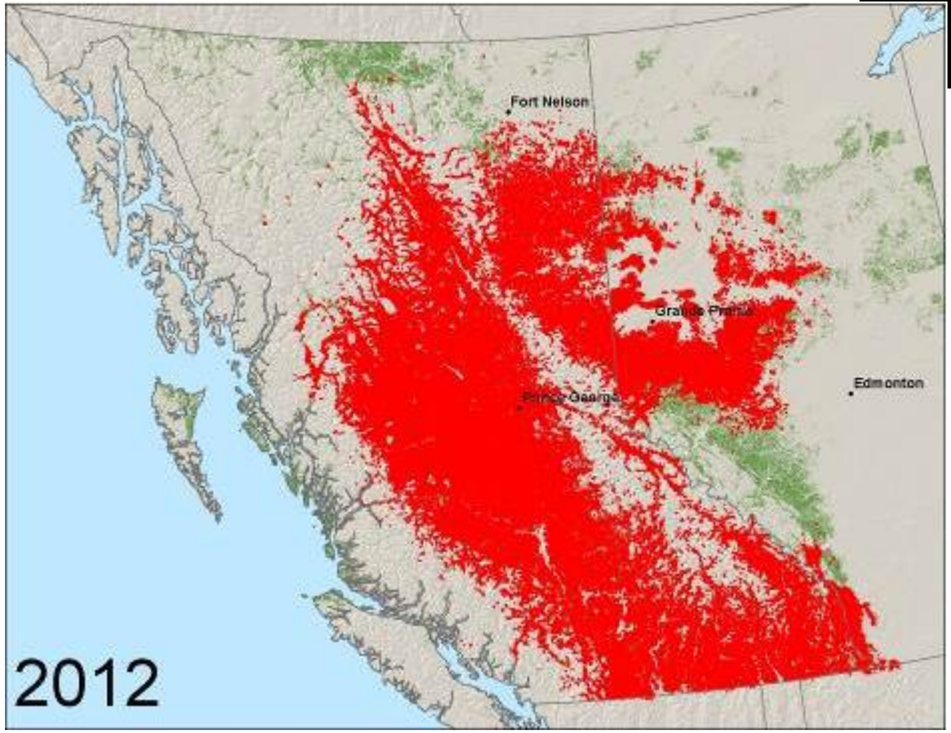
- Native insect to western North America
  - Live in the bark of trees

- Although only 5mm in size, these insects have caused significant damage to forests in BC

Mountain Pine Beetle

- In the most recent outbreak (1990s-2000s)
  - Affected 18.1 million hectares of BC forests
  - Killed 710 million cubic metres of timber

Mountain Pine Beetle attacked forest (Source: Flickr; UBC Micrometeorology)



Observed presence of mountain pine beetle from 1999 to 2012 (Source: Natural Resource Canada)

Mountain Pine Beetle

- How do Mountain Pine Beetles kill trees?
  - Adult beetles lay eggs under the bark of pine trees
  - The beetles prevent the movement of nutrients through the tree, effectively “choking” the tree
  - Adults also release a fungus that damages the tree

- Three stages of the attack
  - Green Attack – Adult beetles have tunneled under the bark. The tree begins to die, but the needles remain green
  - Red Attack – After the tree has been dead for several months, the needles begin to turn red
  - Grey Attack – The dead needles eventually fall, and a bare dead tree is left

Can you identify the stages of attack? (Green, Red, Grey)

Gradual Changes

Why does an insect outbreak appear gradual from space?

- The needles do not fall immediately when the tree dies
- Not all trees die at the exact same time
  - With Landsat, we are not measuring each tree individually!

Healthy Trees

Mix of healthy/dead trees

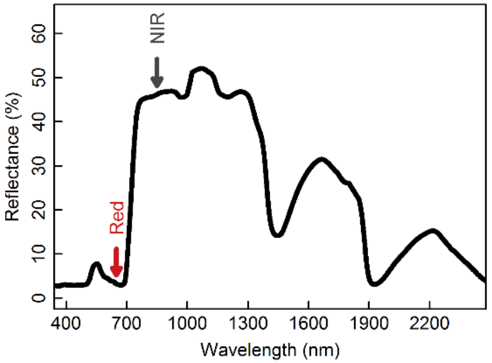
Dead trees

Photo credits: USGS, Michael McCullough

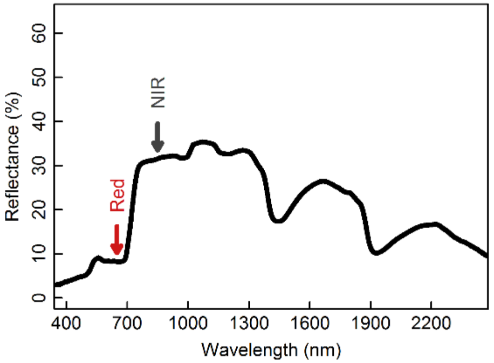
Mountain Pine Beetle

Landsat Pixel

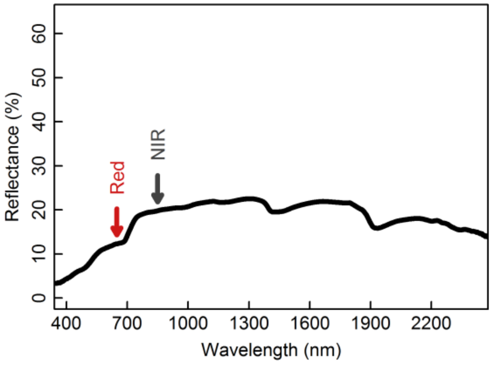
Healthy Trees =
High NDVI



Mix of healthy and dead trees =
Slightly lower NDVI



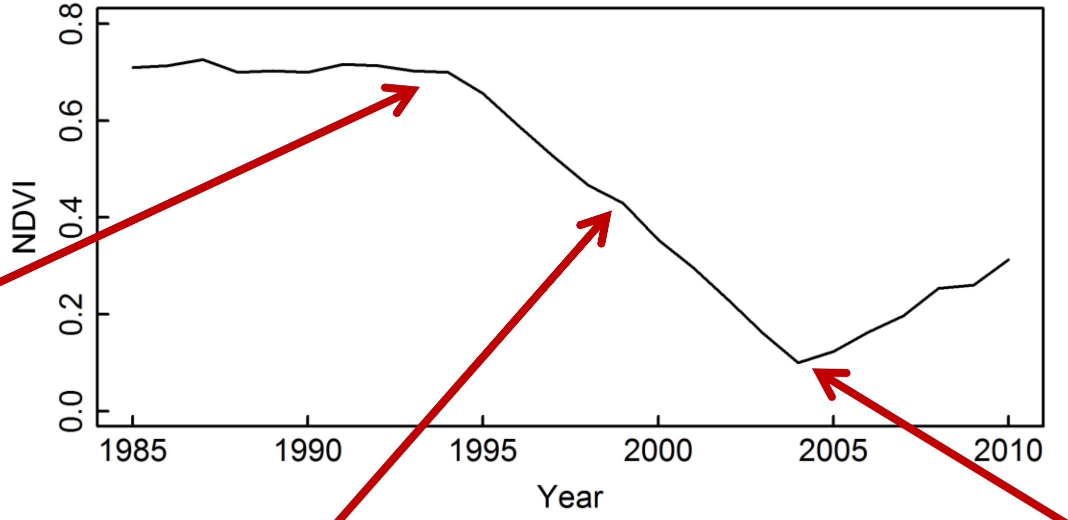
Most trees are dead =
Low NDVI



Gradual change in spectral signature as trees begin to die

Mountain Pine Beetle

Healthy Trees



Mix of healthy, dead, and dying trees

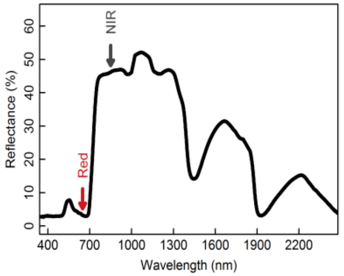
Most trees are dead

Photo credits: USGS, Michael McCullough, Douglas Bolton

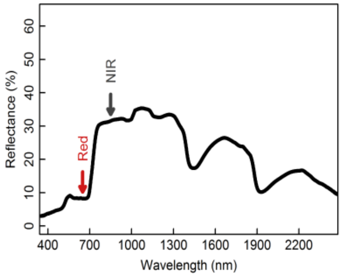
Gradual Change vs. Abrupt Change

Insect outbreak (Gradual)

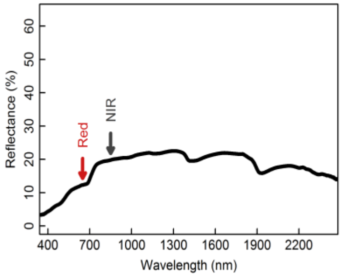
Healthy Trees



Trees begin to die

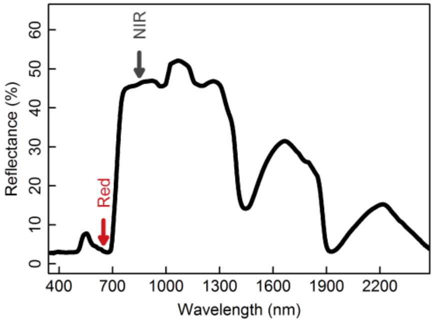


Most trees are dead



Fire (Abrupt)

Before fire



After fire

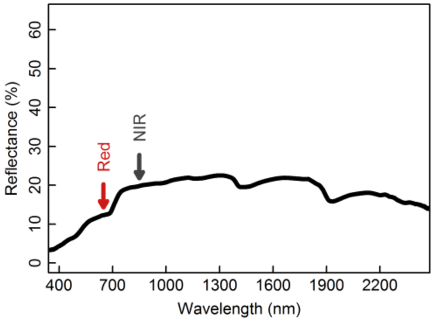
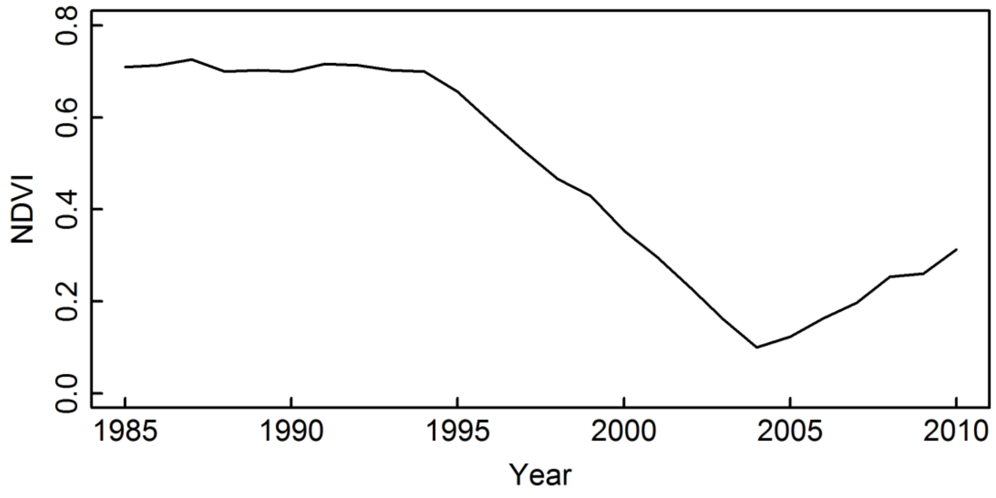


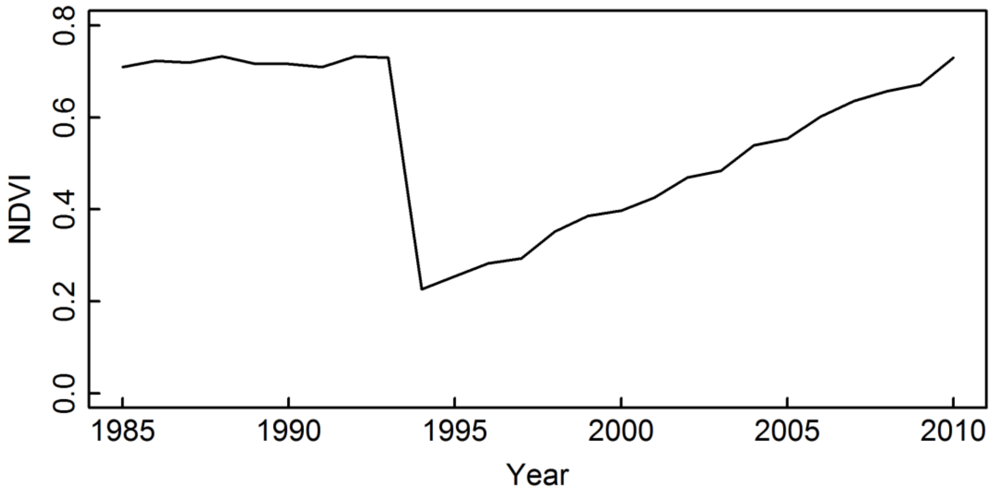
Photo credits: USGS, Michael McCullough, Douglas Bolton, Ryan Powers

Gradual Change vs. Abrupt Change

Insect outbreak (Gradual)



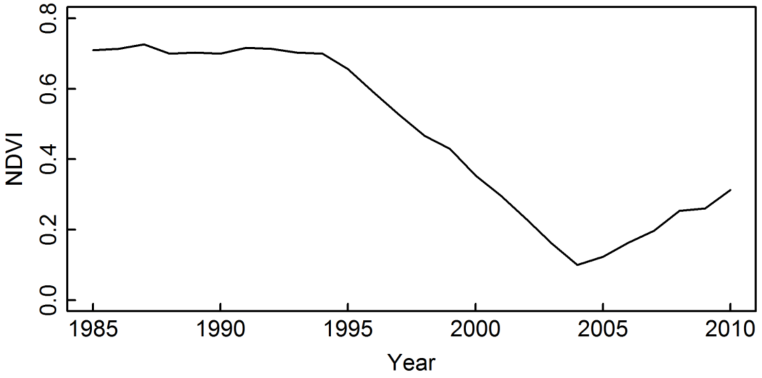
Fire (Abrupt)



Mountain Pine Beetle

- While fire burns most trees, mountain pine beetle only attacks certain tree species (mostly lodgepole pine).
  - Therefore, the amount of damage will depend on what species are in the forest!

All one species:
Most trees die



Mix of species:
Some trees die

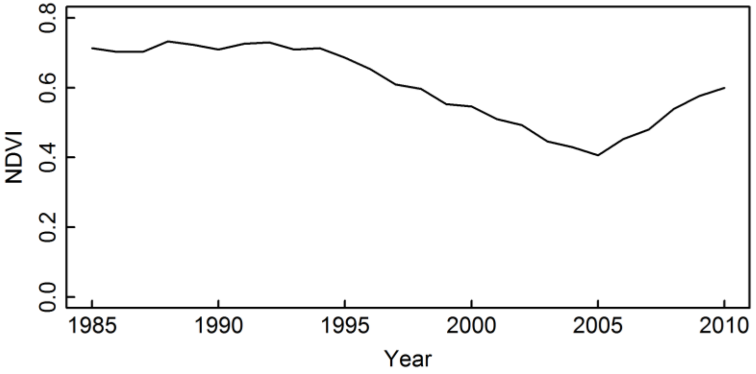
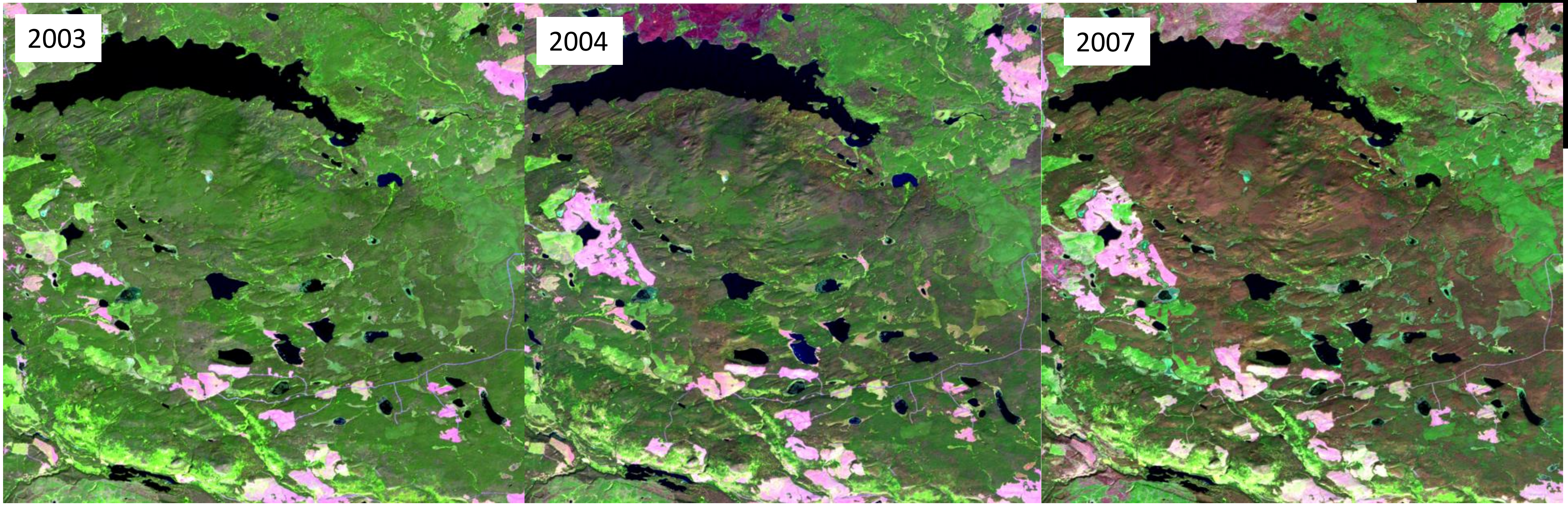


Photo credits: USDA, Douglas Bolton

What does damage look like from space?

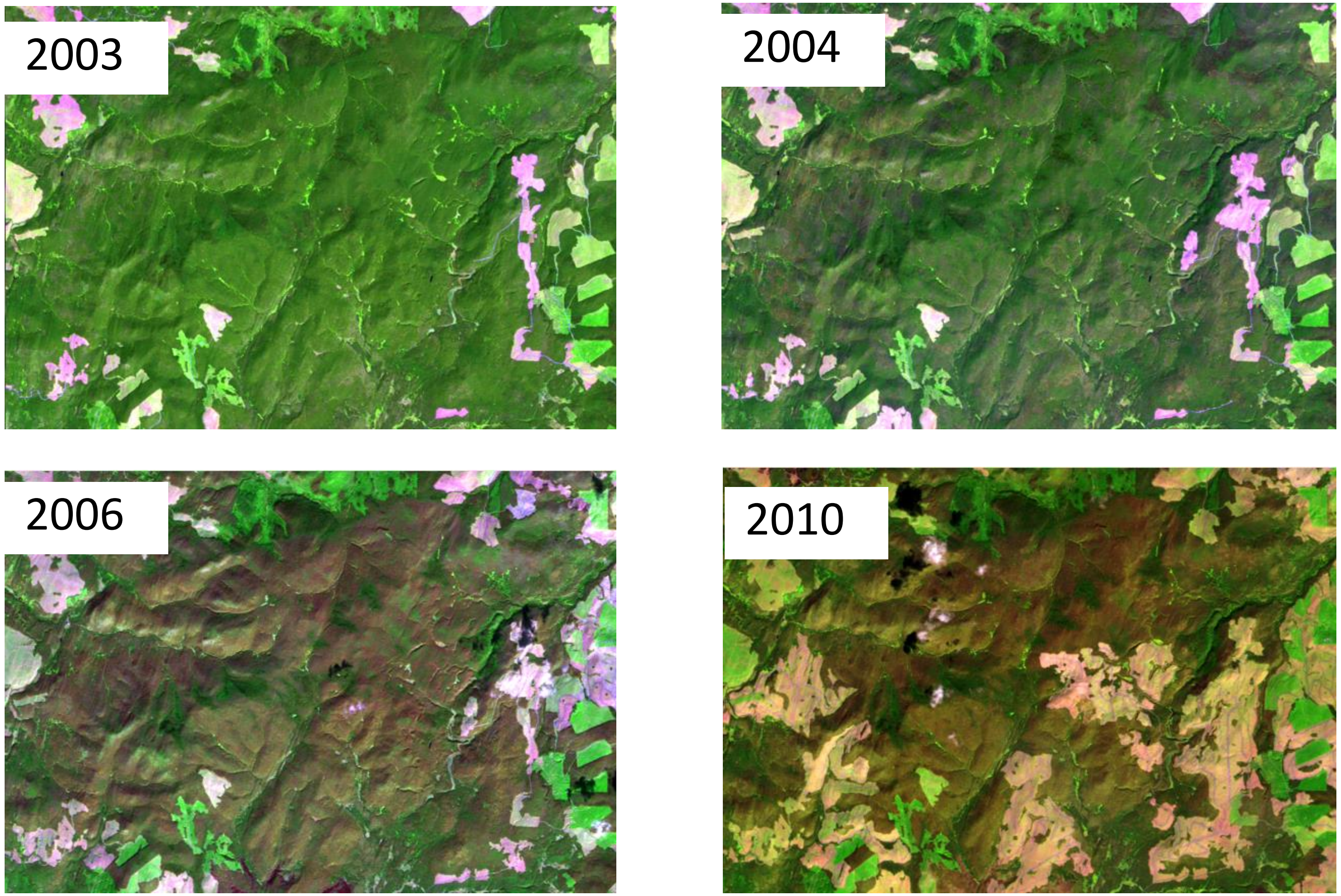
Damage first apparent here

Damage more apparent [redacted]



South of Prince George, BC

What does damage look like from space?



Damage first apparent here

Widespread damage here

Salvage logging follows!

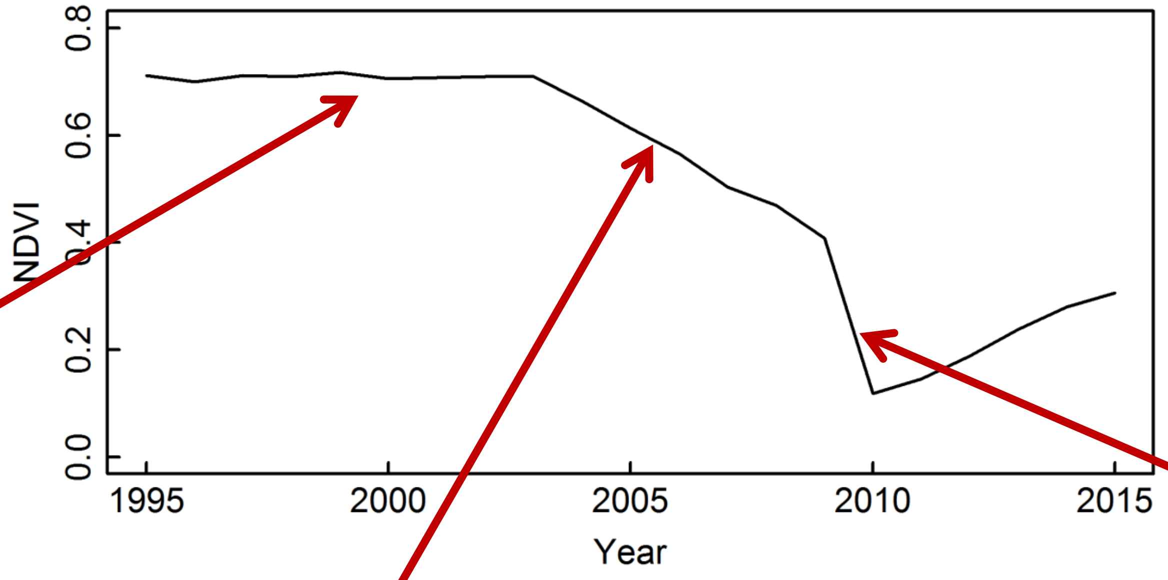
0 10 km

South of Prince George, BC

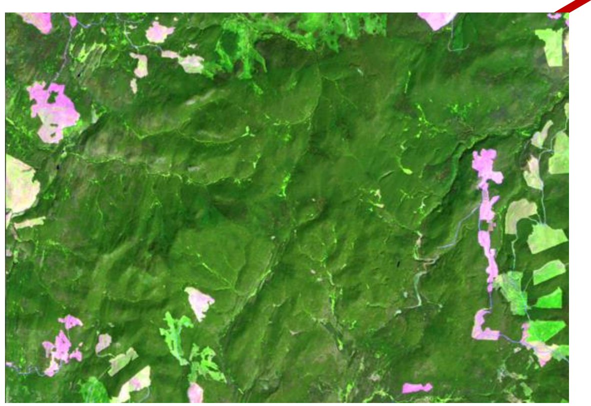
Photo credits: NASA

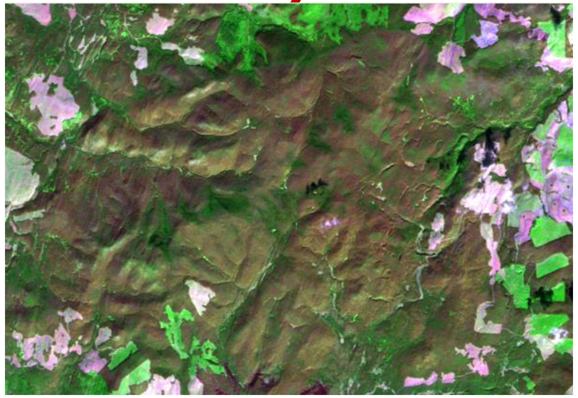
Mountain Pine Beetle

What does a gradual disturbance followed by an abrupt disturbance look like?



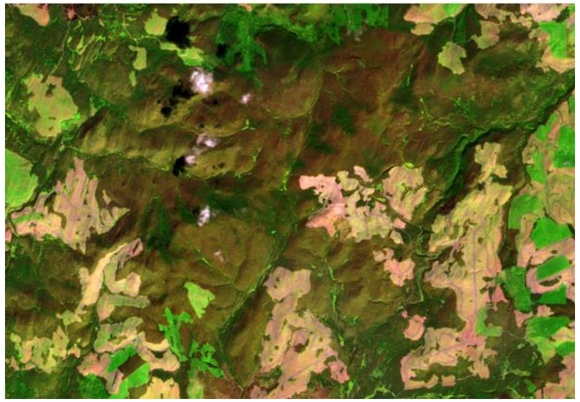
Healthy Forest





Gradual change:
Insect Damage

Abrupt change:
Salvage logging



Mountain Pine Beetle

- Forests that are impacted by mountain pine beetle are also more likely to burn:
- Mountain pine beetle followed by fire is another example of a gradual change followed by an abrupt change

Fire - Forest (Source: Wikimedia Commons)

Gradual Changes

What other types of gradual changes in forests could we observe with satellite imagery?

- Mortality from disease and change in forest health
- As the climate changes, areas may become unsuitable for forests
  - Too hot, or not enough rain
- Therefore, we might notice slow changes from areas of forest to other land covers

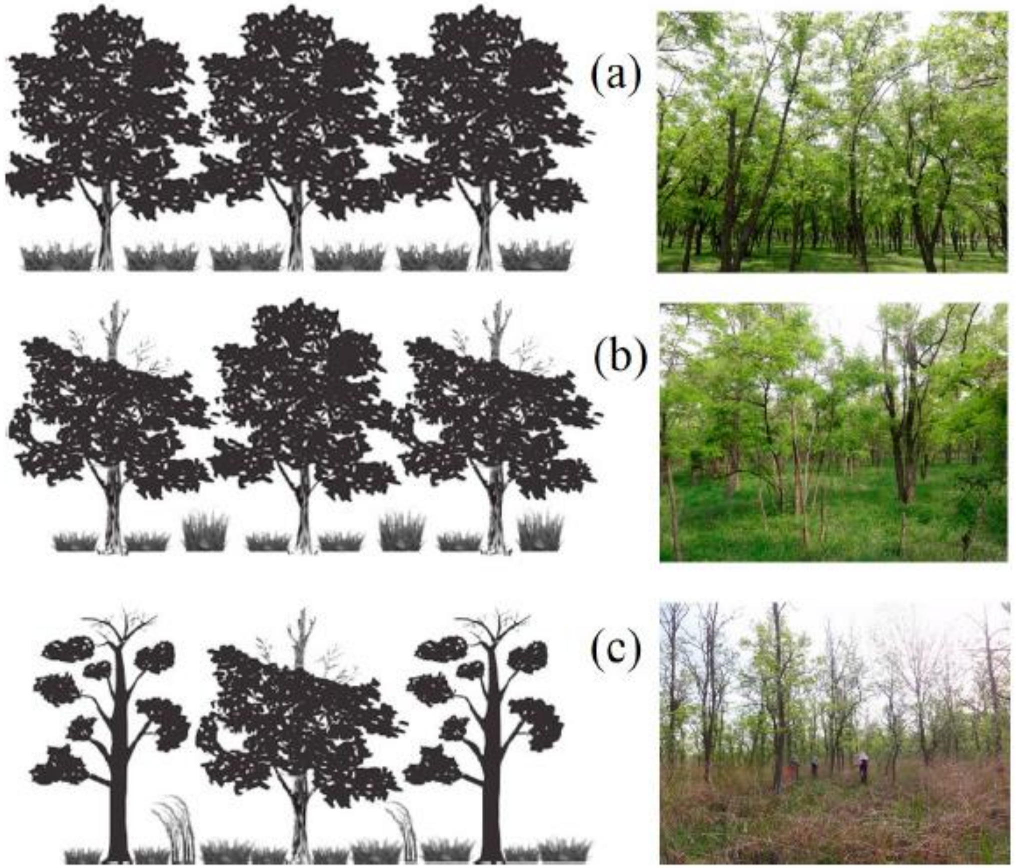


Photo credit: Wang et al. 2015

Gradual Changes

Why do we care about monitoring these gradual losses of forests?

- Although the changes are not abrupt, they can still have large impacts on carbon storage and habitat over time

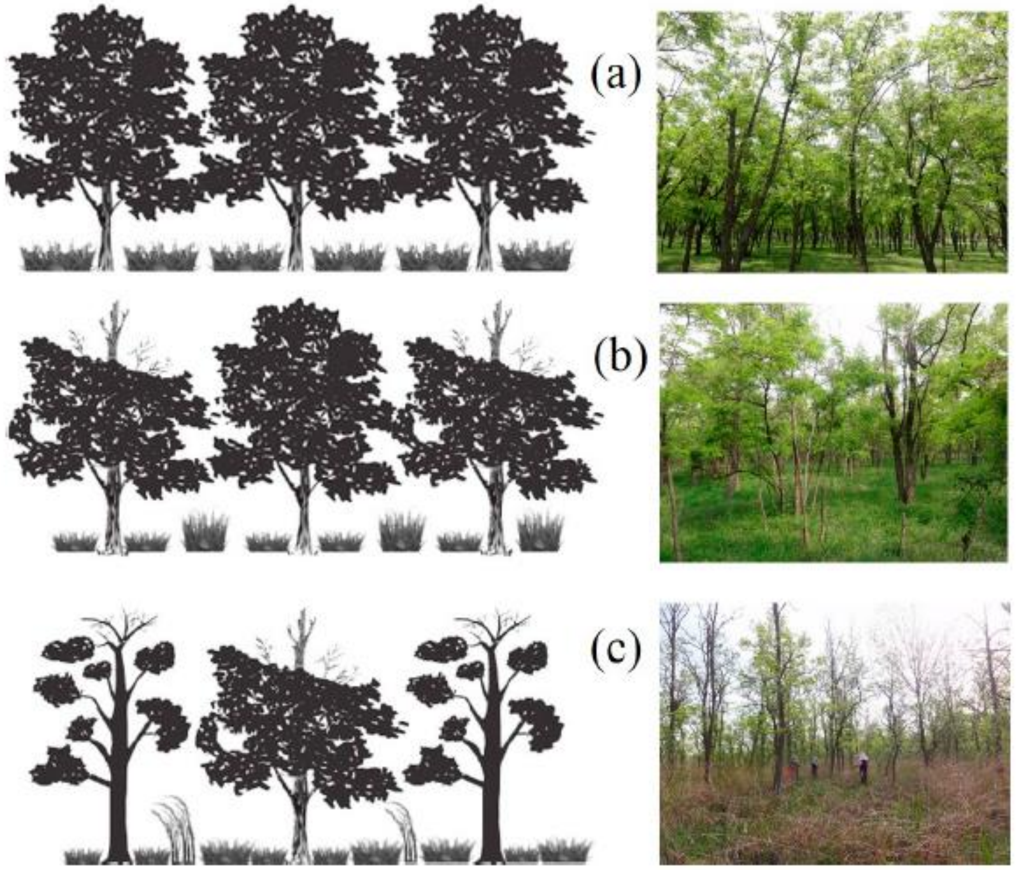


Photo credit: Wang et al. 2015

Gradual Changes

We talked about land conversion as an abrupt change

- The conversion of forests to development
- The conversion of forests to agriculture

However, not all land conversions are abrupt!

- Agriculture > Forest
- Developed land > Forest

Gradual Changes

We will use Detroit,
Michigan 77% decline in manufacturing jobs between 1978-2008

- Population of the city decreased from 1.8 million in 1950 to < 1 million in 2000
- With a decrease in population, many homes and neighborhoods were abandoned

While other areas in the US were being developed, the reverse was happening in Detroit!

- Developed areas were becoming overgrown

Gradual Changes

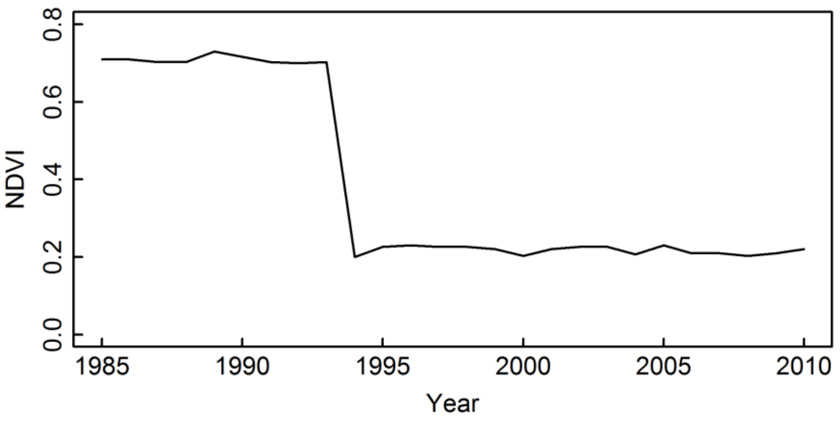
The development of these Detroit neighbourhoods would have been an abrupt change

- Forest > Developed Land

But the abandonment of Detroit neighbourhoods would be a gradual change

- Developed Land > Forest

It takes time for a forest to come back!



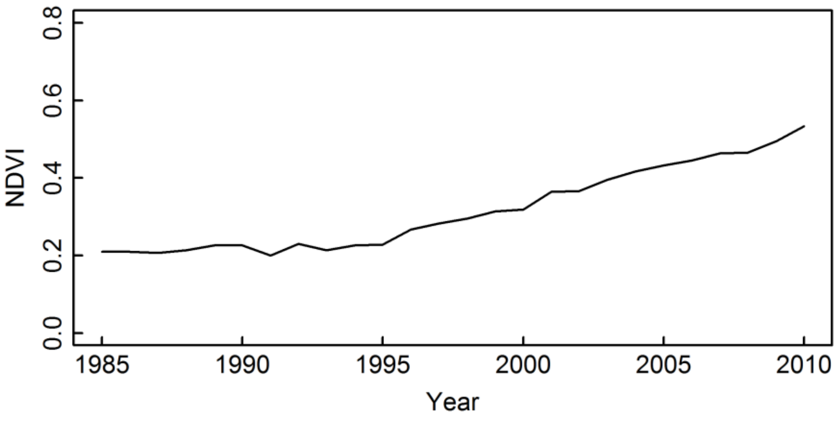


Photo credit: Douglas Bolton, UBC

Gradual Changes

Here are the changes in NDVI from 1975 to 2005 in Detroit derived from Landsat images

We see increases in NDVI across the city

- This is not because they put in more parks…this is because homes and neighbourhoods have been abandoned

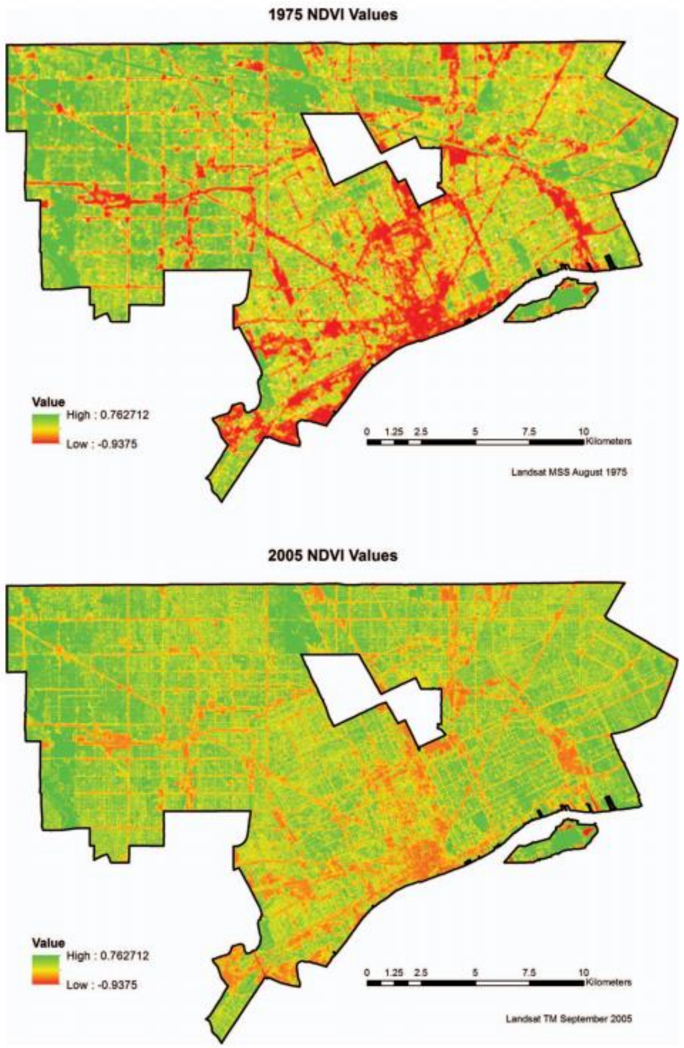


Figure 2. Observed NDVI in Detroit in (a) 1975 and (b) 2005.

Photo credit: Hoalst-Pullen et al. 2011

What do the results from Detroit tell us?

The changes we map using Landsat data are not always disturbances or habitat loss

- There is also forest gain

It is important to track the gradual recovery of forests if we want to paint a complete picture of how the planet is changing

Review

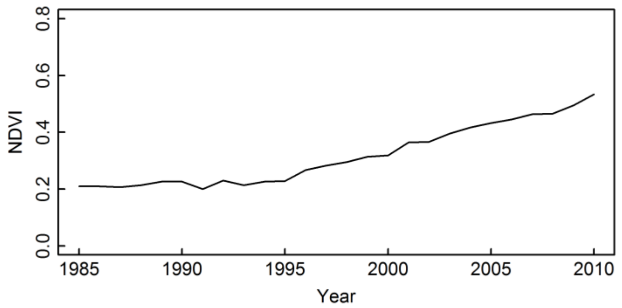
- Data requirements to detect change:
    - Spatial detail
    - Re-visit time
    - Region of the EMS
    - Temporal dimension
- Types of change:
    - Cyclical
        - Vegetation phenology
    - Abrupt
        - Fires, forest harvest, land cover/land use change
    - Gradual
        - Insect infestation, forest recovery, land cover/land use change

Can you label these changes?

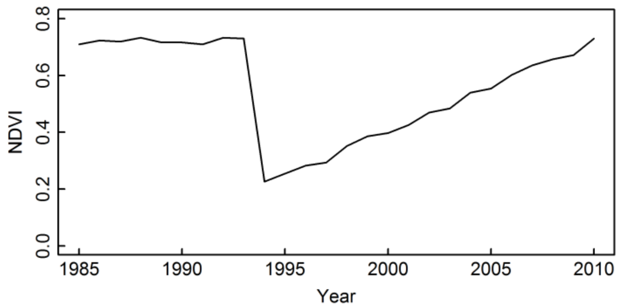
1. Vegetation phenology
2. Fire
3. Clearing a forest and building a parking lot
4. Insect damage
5. Reforestation

Label the disturbance and class as cyclical, abrupt, or gradual

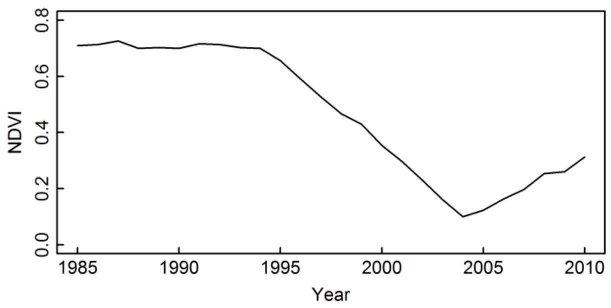
A.



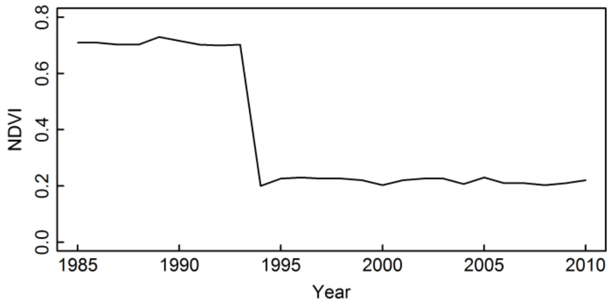
B.



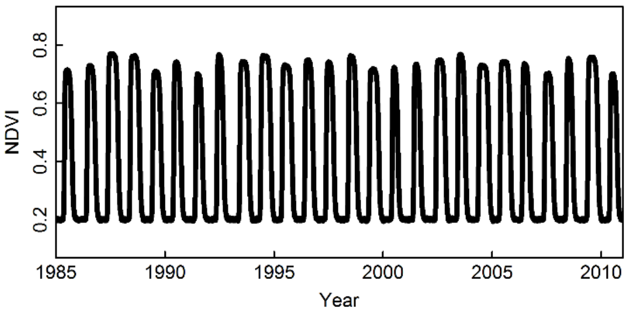
C.



D.



E.



Important Topics

- What are the four data requirements to consider when using satellite data to detect change?
  - Describe the data requirements necessary to detect sea surface temperature rise due to climate change?
- What is the difference between land cover and land use?
  - Use a specific example to explain the difference
- Classify the following changes as cyclical, abrupt, or gradual:
  - A single wildfire
  - The seasonal change in frequency of wildfire occurrence
  - A insect outbreak in a forest, followed by salvage logging and regrowth
  - Sea surface temperature

Images and Videos Cited

Wildfire Yosemite (Source: Wikimedia Commons). This file is licensed under the Creative Commons Attribution-Share Alike 4.0 International license. Image retrieved from https://commons.wikimedia.org/wiki/File:Wildfire_Yosemite.jpg

Briksdalsbreen Norway 2003 & 2008 (Source: Wikimedia Commons). This file is licensed under the Creative Commons Attribution 2.5 Generic license. Image retrieved from https://commons.wikimedia.org/wiki/File:Briksdalsbreen_Norway_2003_%26_2008.JPG

Hopetoun falls (Source: Wikimedia Commons). This file is licensed under the Creative Commons Attribution-Share Alike 3.0 Unported license. Image retrieved from https://commons.wikimedia.org/wiki/File:Hopetoun_falls.jpg

Natural resources professionals from the U.S. Forest Service (Source: Wikimedia Commons). Image licensed for use under Some rights reserved. Image retrieved from https://www.flickr.com/photos/usdagov/30131853095

Decreasing spatial resolution from l715m panchromatic (Source: Wikimedia Commons). This file is licensed under the Creative Commons Attribution 3.0 Unported license. Image retrieved from https://commons.wikimedia.org/wiki/File:Decreasing_spatial_resolution_from_l715m_panchromatic.svg

The Equinox (Source: paukrus). Image licensed for use under Some rights reserved. Image retrieved from https://www.flickr.com/photos/paukrus/8573370691

Source: National Geographic; John Nelson. Image retrieved from https://blog.nationalgeographic.org/2013/08/14/mesmerizing-gifs-of-breathing-earth/

Caribou Migration (Source: CARMA research Group). Image retrieved from http://carma.caff.is/

Artist's rendering of NASA's Aqua Satellite Orbiting Earth (Source: Flickr; AIRS). Image licensed for use under Some rights reserved. Image retrieved from https://www.flickr.com/photos/atmospheric-infrared-sounder/8263869886

caribou Rangifer tarandus caribou (Source: Paul Asman and Jill Lenoble; Flickr). Image licensed for use under Some rights reserved. Image retrieved from https://www.flickr.com/photos/pauljill/33795981865

Alberta oil field (Source: Wikimedia Commons). This file is licensed under the Creative Commons Attribution-Share Alike 3.0 Unported license. Image retrieved from https://commons.wikimedia.org/wiki/File:Alberta_oil_field.JPG

Fire - Forest (Source: Wikimedia Commons). This file is licensed under the Creative Commons Attribution 2.0 Generic license. Image retrieved from https://commons.wikimedia.org/wiki/File:Fire-Forest.jpg

Timber harvesting in Kielder Forest (Source: Wikimedia Commons). Permission is granted to copy, distribute and/or modify this document under the terms of the **GNU Free Documentation License**. Image retrieved from https://commons.wikimedia.org/wiki/File:Timber_harvesting_in_Kielder_Forest.JPG

Wildfires in Alberta and Saskatchewan (Source: NASA). Image retrieved from https://earthobservatory.nasa.gov/images/86147/wildfires-in-alberta-and-saskatchewan

Fires over United States detected with MODIS from July 2002 to July 2011 (Source: NASA/Goddard Space Flight Center Scientific Visualization Studio). Video retrieved from https://svs.gsfc.nasa.gov/3873

Images and Videos Cited

Bush fire at Captain Creek central Queensland Australia (Source: Wikimedia Commons). This file is licensed under the Creative Commons Attribution-Share Alike 3.0 Unported license. Image retrieved from https://commons.wikimedia.org/wiki/File:Bush_fire_at_Captain_Creek_central_Queensland_Australia..JPG

Slash and burn agriculture in the Amazon (Source: Flickr; **Matt Zimmerman**). Image licensed for use under Some rights reserved. Image retrieved from https://www.flickr.com/photos/16725630@N00/1524189000

Deforestation in Peru between 5 October 2012 and 28 August 2013 (Source: NASA Earth Observatory images by Jesse Allen and Robert Simmon). Image retrieved from https://earthobservatory.nasa.gov/images/82076/landsat-8-detects-new-deforestation-in-peru

Soy Plantations in Bolivia (Source: USGS). Images retrieved from https://earthshots.usgs.gov/earthshots/node/55#ad-image-0-7

Mountain Pine Beetle attacked forest (Source: Flickr; UBC Micrometeorology). Image licensed for use under Some rights reserved. Image retrieved from https://www.flickr.com/photos/140969380@N07/28371273132

Observed presence of mountain pine beetle from 1999 to 2012 (Source: Natural Resource Canada). Image retrieved from https://www.nrcan.gc.ca/forests/fire-insects-disturbances/top-insects/13397

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Thank you!