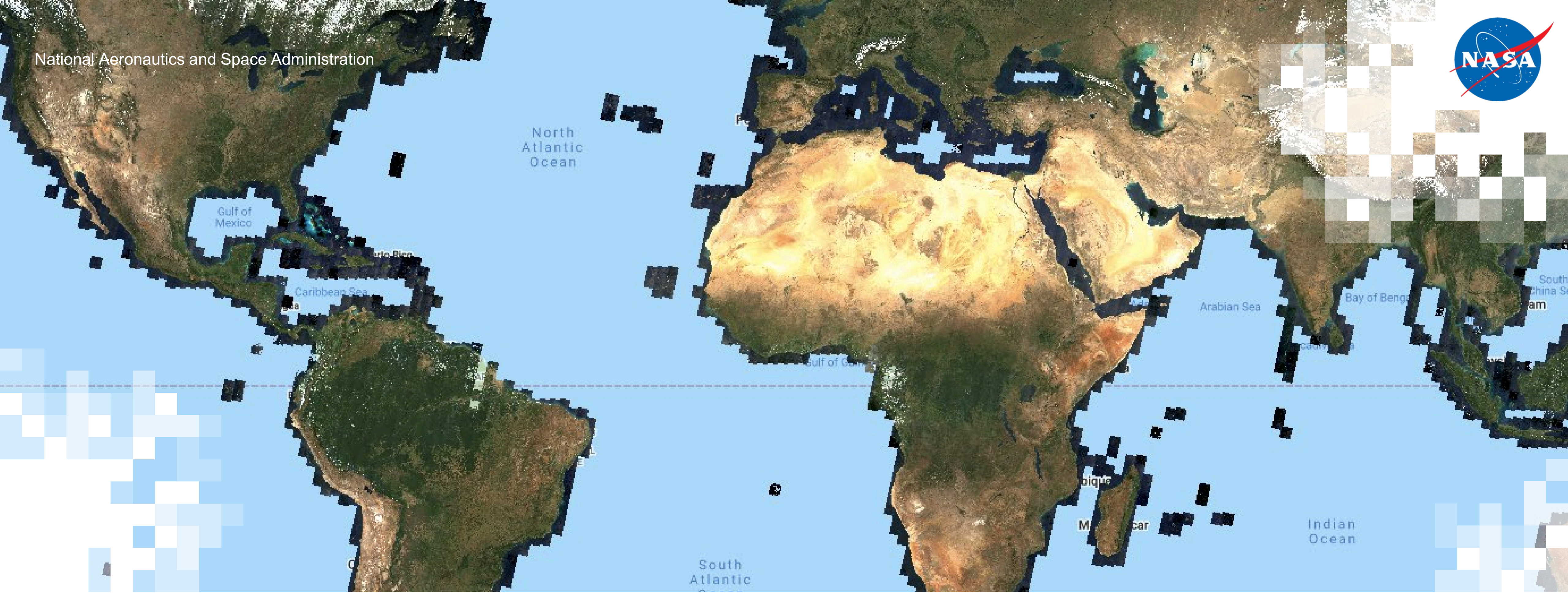
National Aeronautics and Space Administration



Part 3: Using Google Earth Engine for Land Monitoring Applications

Zach Bengtsson, Juan Torres-Pérez, and Amber McCullum

June 30, 2021

Course Structure and Materials

- Three 2-hour sessions on June 16, 23, & 30
- Sessions will be presented once in English 12:00-14:00 EDT
- One Google Form homework due on July 14
- Webinar recordings, PowerPoint presentations, and the homework assignment can be found after each session at:
  - https://appliedsciences.nasa.gov/join-mission/training/english/arset-using-google-earth-engine-land-monitoring-applications
  - Q&A following each lecture and/or by email at:
    - bengtsson@baeri.org
    - juan.l.torresperez@nasa.gov
    - amberjean.mccullum@nasa.gov

Webinar Agenda

Part 1: Google Earth Engine Basics & General Applications

Part 2: Land Cover Classification & Accuracy Assessment

Part 3: Time Series Analysis & Change Detection

Webinar Agenda

Part 3: Time Series Analysis & Change Detection

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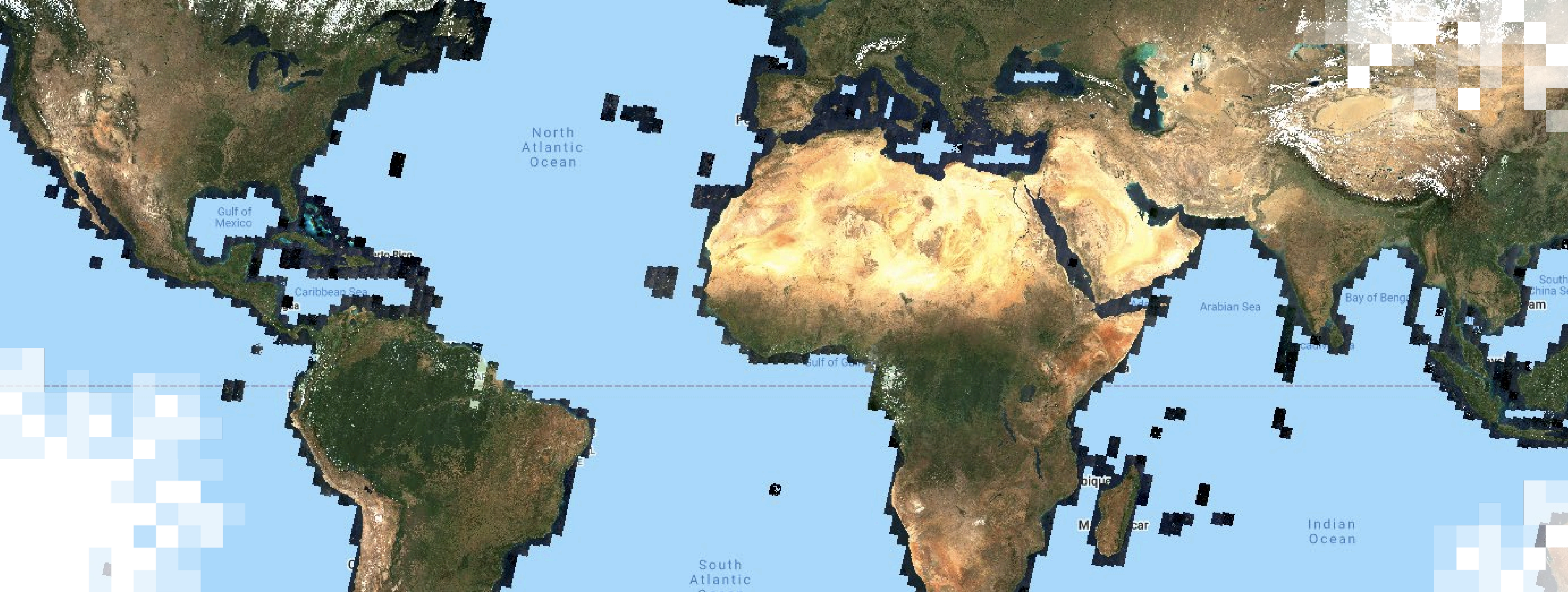
Juan Torres-Pérez

Amber McCullum

Session Outline

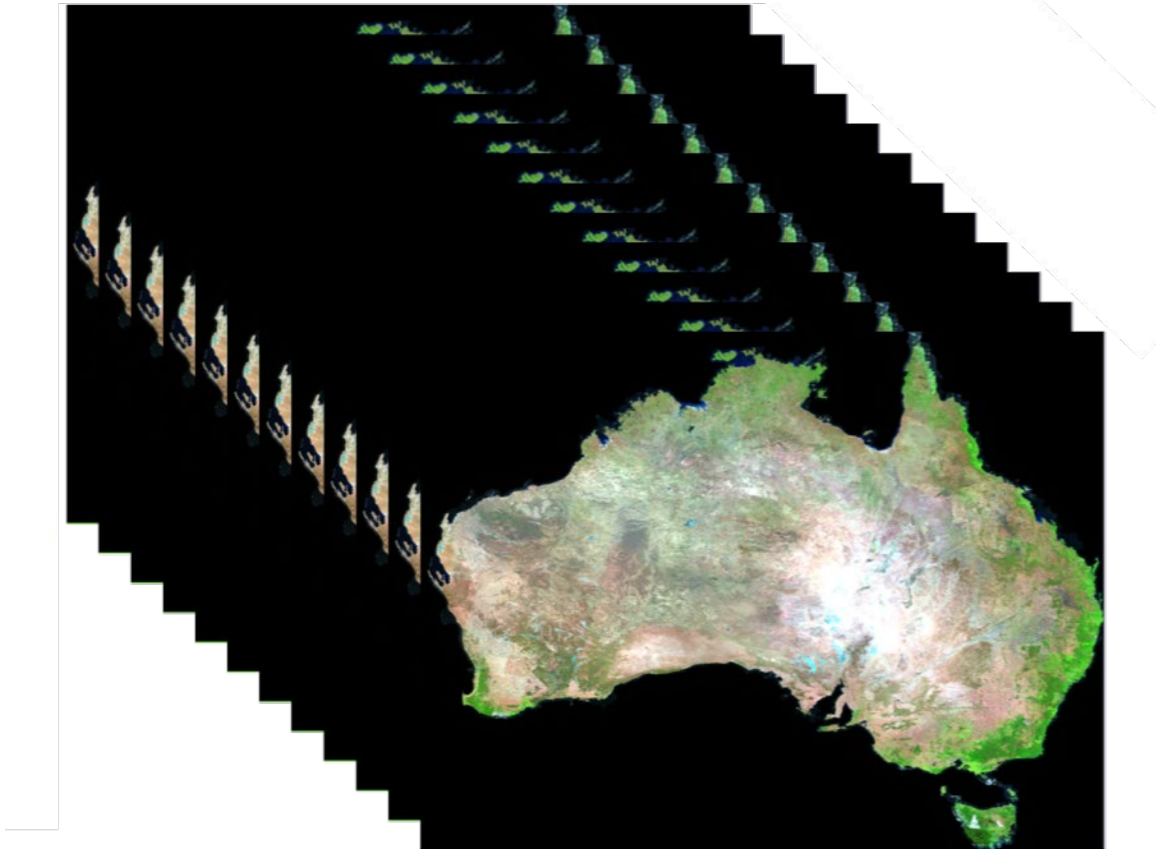
- **Time Series Analysis and Change Detection Overview**
  - Time series and change detection basics
  - Common time series and change detection methods
  - Techniques for time series analysis and change detection in GEE
- **GEE Code Editor Activity**
  - Landsat data retrieval and imagery preparation
  - Vegetation index time series analysis and data visualization
  - Change detection using visual inspection and image differencing
- **Question & Answer Session**



Time Series Analysis and Change Detection Overview

Time Series Analysis with Satellite Imagery

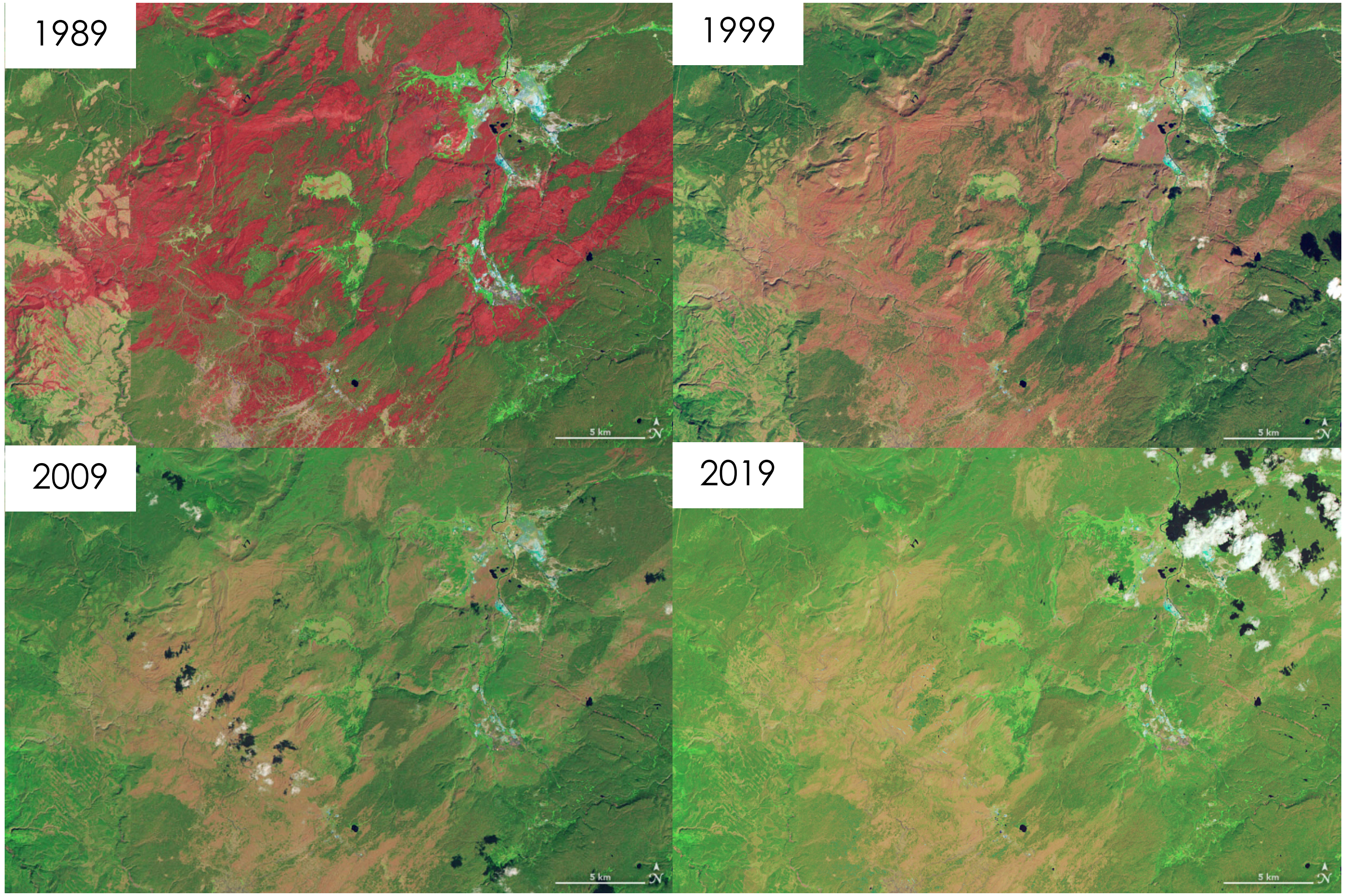
- Using satellite imagery to monitor landscape change continues to improve with data availability and access to imagery processing platforms
  - Availability of long term satellite data sets
    - Landsat (40+ years)
    - MODIS (20+ years)
  - Increased computing power and cloud computing platforms (like GEE)
  - Improved processing methods



Stack of Landsat images of Australia
Image credit: Data Cube.

Time Series Analysis Basics

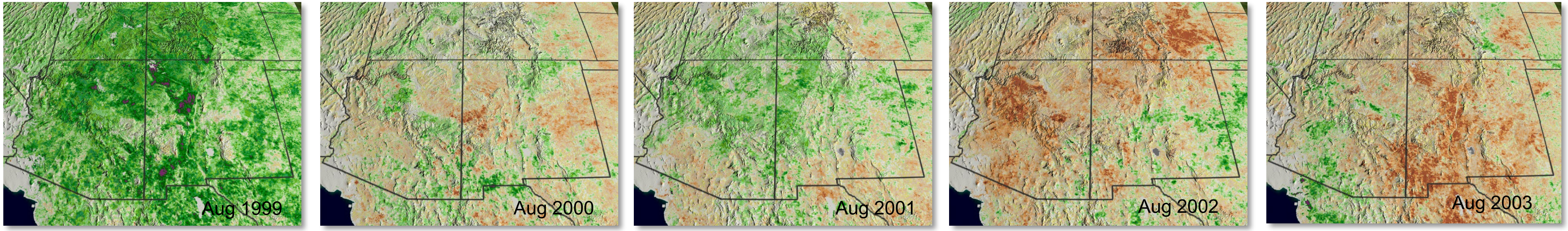
- Time series analysis looks at landscape change as a dynamic process over a number of months, years, and so on.
- Mapping the environment at various timescales can provide information about land monitoring parameters like land cover change trends and patterns in vegetation growth.
- Common uses for a time series approach include:
  - Identifying urban expansion
  - Mapping deforestation
  - Monitoring post-fire conditions



In the summer of 1988, lightning- and human-ignited fires consumed vast stretches of Yellowstone National Park. NDVI estimates over the course of 30 years show increase in greenness, indicating vegetation regrowth across the burn scar.
Image Credit: NASA

Imagery Collection Time and Dates for Time Series Analysis

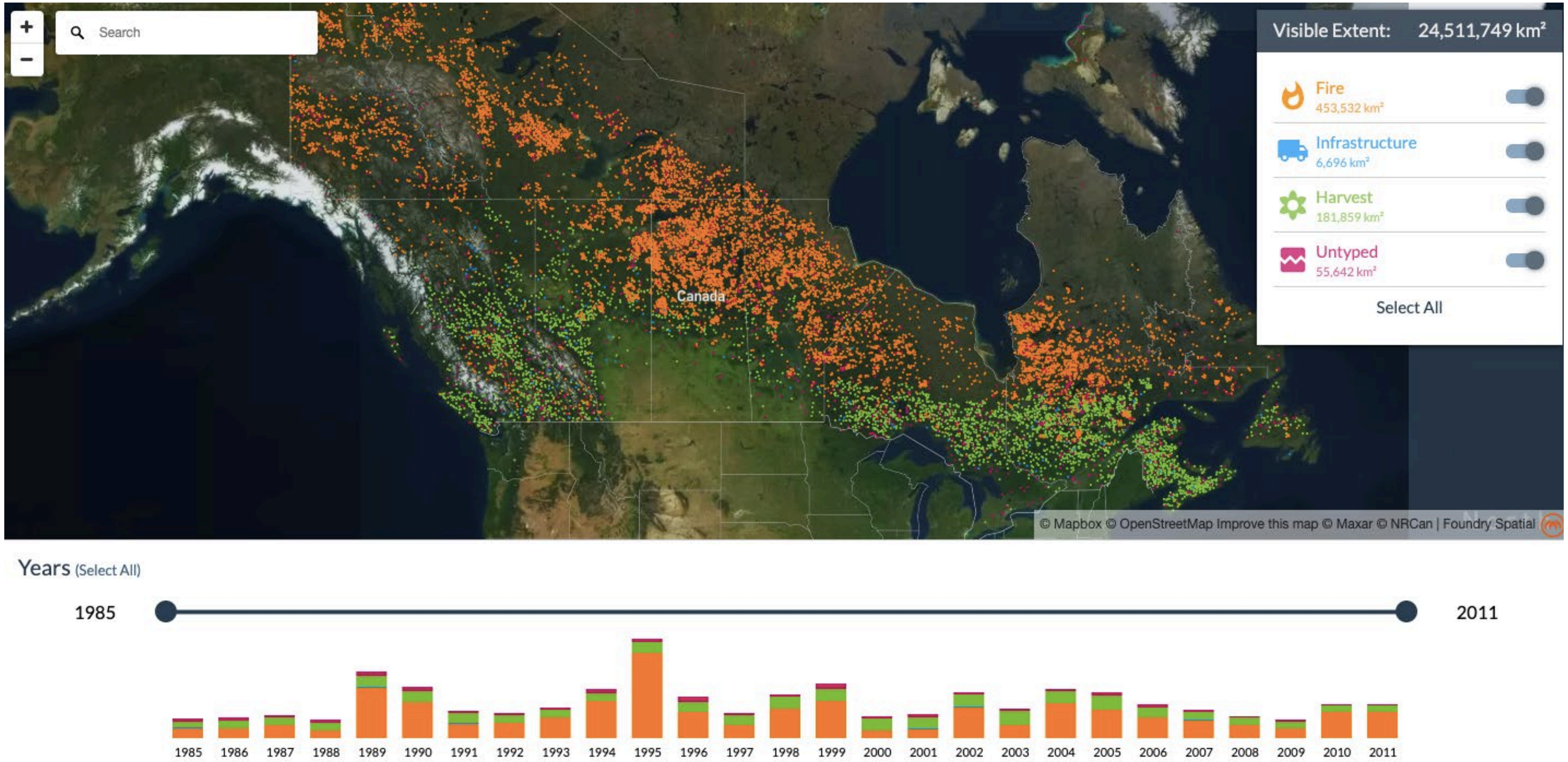
- Images should be collected at about the same time of day to reduce differences in sun angle
- Ideally, images from different years should be within the same month or season to avoid seasonal and phenological differences
  - Differences in vegetation greenness
- Be aware of different annual weather conditions
  - For example, drought years vs. non-drought years



NDVI Anomalies in the southwestern United States. Image Credit: NASA/Goddard Space Flight Center Scientific Visualization Studio.

Types of Time Series Analysis

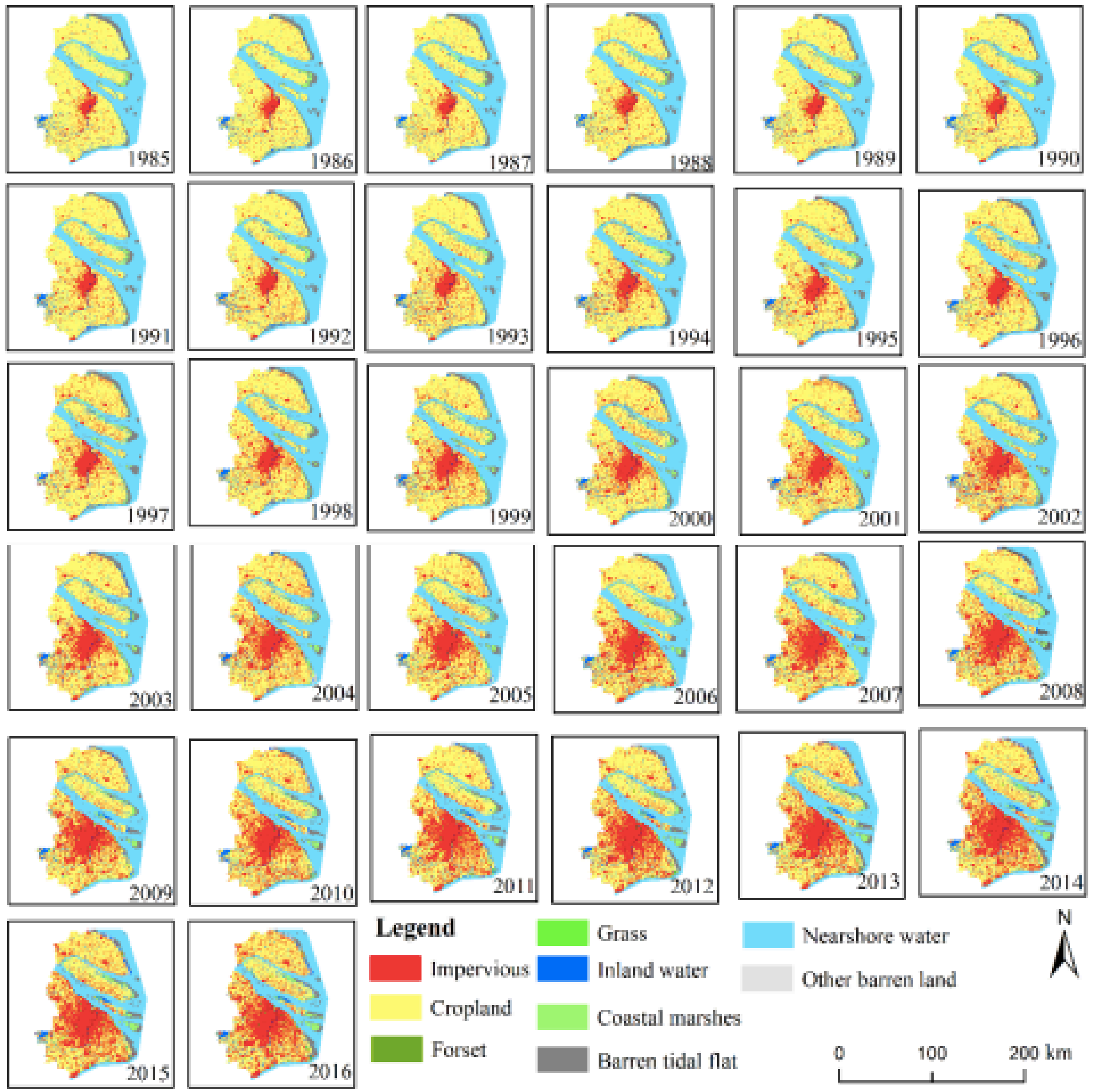
- Annual vs. seasonal trends
- Gradual vs. abrupt changes
- Anomalies
- Environmental Descriptors/Parameters



Satellite forest monitoring in Canada. Image credit: [Foundry Spatial]

Annual Trends

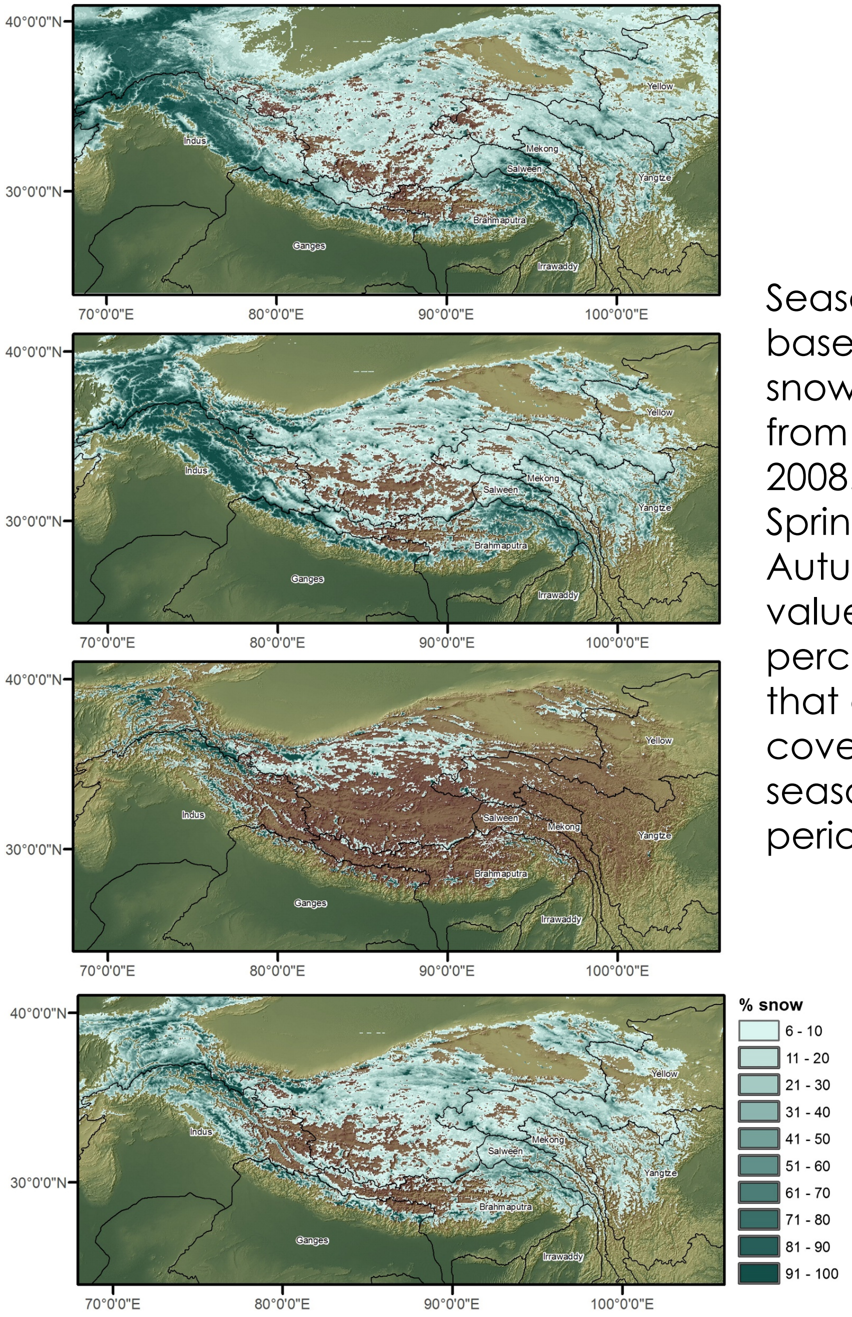
- Annual Trends
  - Assessment completed yearly, but for as many years as necessary
  - Number of years usually data limited
  - Useful for mapping annual land cover/land use changes over long time periods
  - Example: Annual time series of land use/land cover in the Yangtze River estuary region



Annual time series of LULC maps of the Yangtze River estuary region from 1985 to 2016.
Credit: Ai et al. 2020

Seasonal Trends

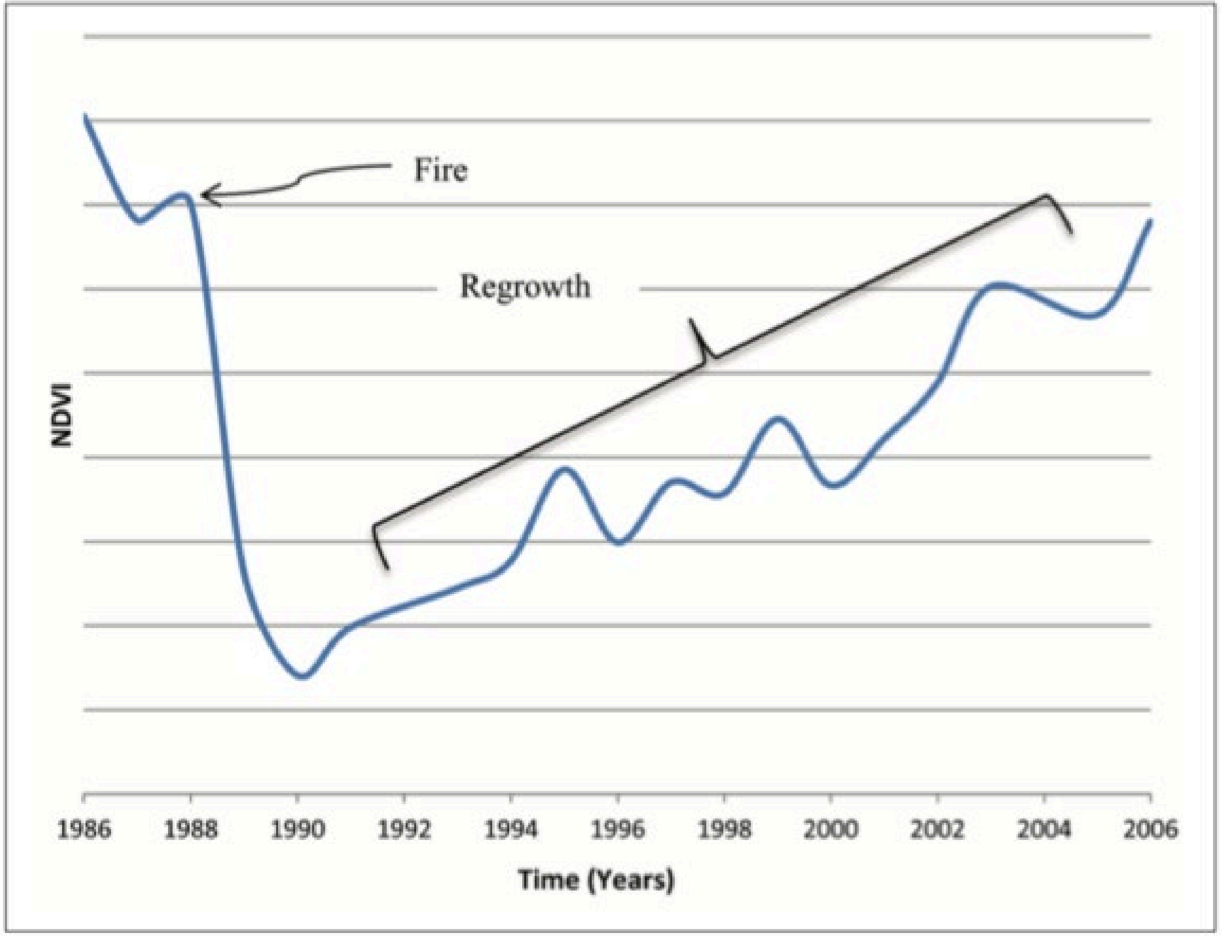
- Seasonal Trends
  - Driven by annual temperature and/or precipitation
  - Variation between seasons
  - Can measure change within a year timeframe
  - Useful in comparison of seasonal variation between years
  - Example: Snow cover monitoring in the Himalayas



Seasonal snow cover based on MODIS snow cover time series from Mar 2000 to Feb 2008. (Winter, (top), Spring, Summer Autumn (bottom). The values show the percentage of time that a pixel was snow-covered during the season within the time period.

Gradual vs. Abrupt Changes

- Gradual changes:
  - Insect infestation in forests
  - Land degradation
  - Forest recovery
- Abrupt changes:
  - Wildfire
  - Deforestation
  - Urban development
- Example: Forest recovery after wildfire in Yellowstone National Park



Changes in NDVI values between 1986 and 2006 for one site in Yellowstone National Park
Credit: Franks, Masek, & Turner 2013

Anomalies

- Relative difference from a long term average
- Example: FAO Global Normalized Difference Vegetation (NDVI) Anomalies

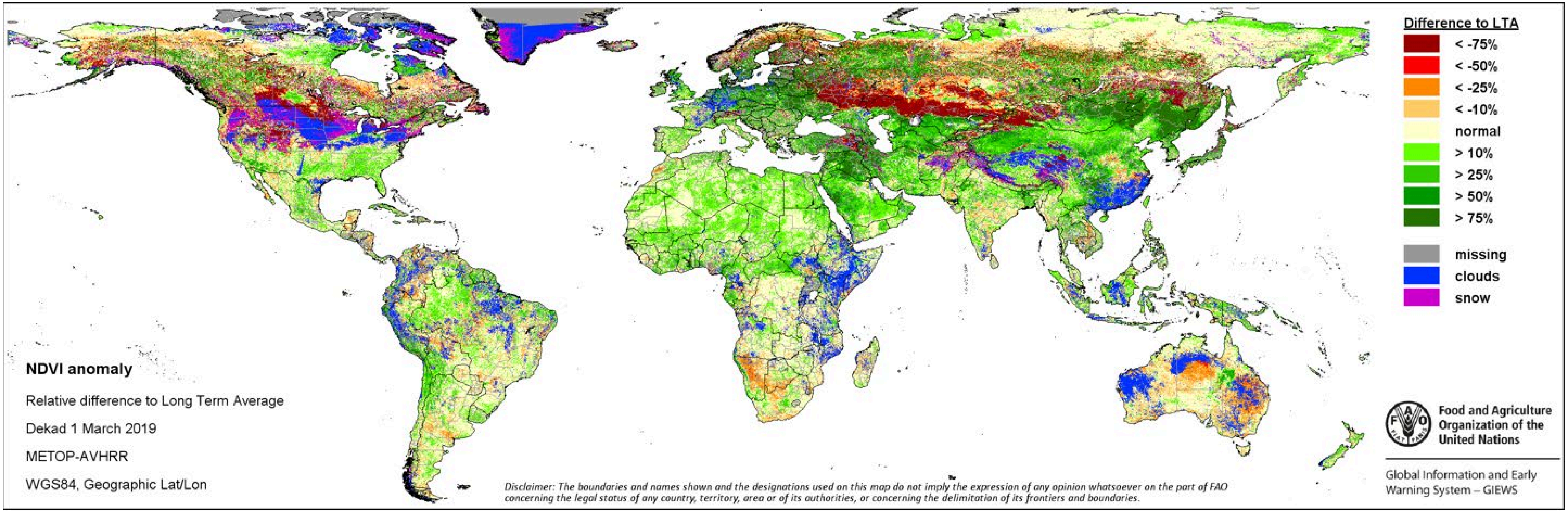
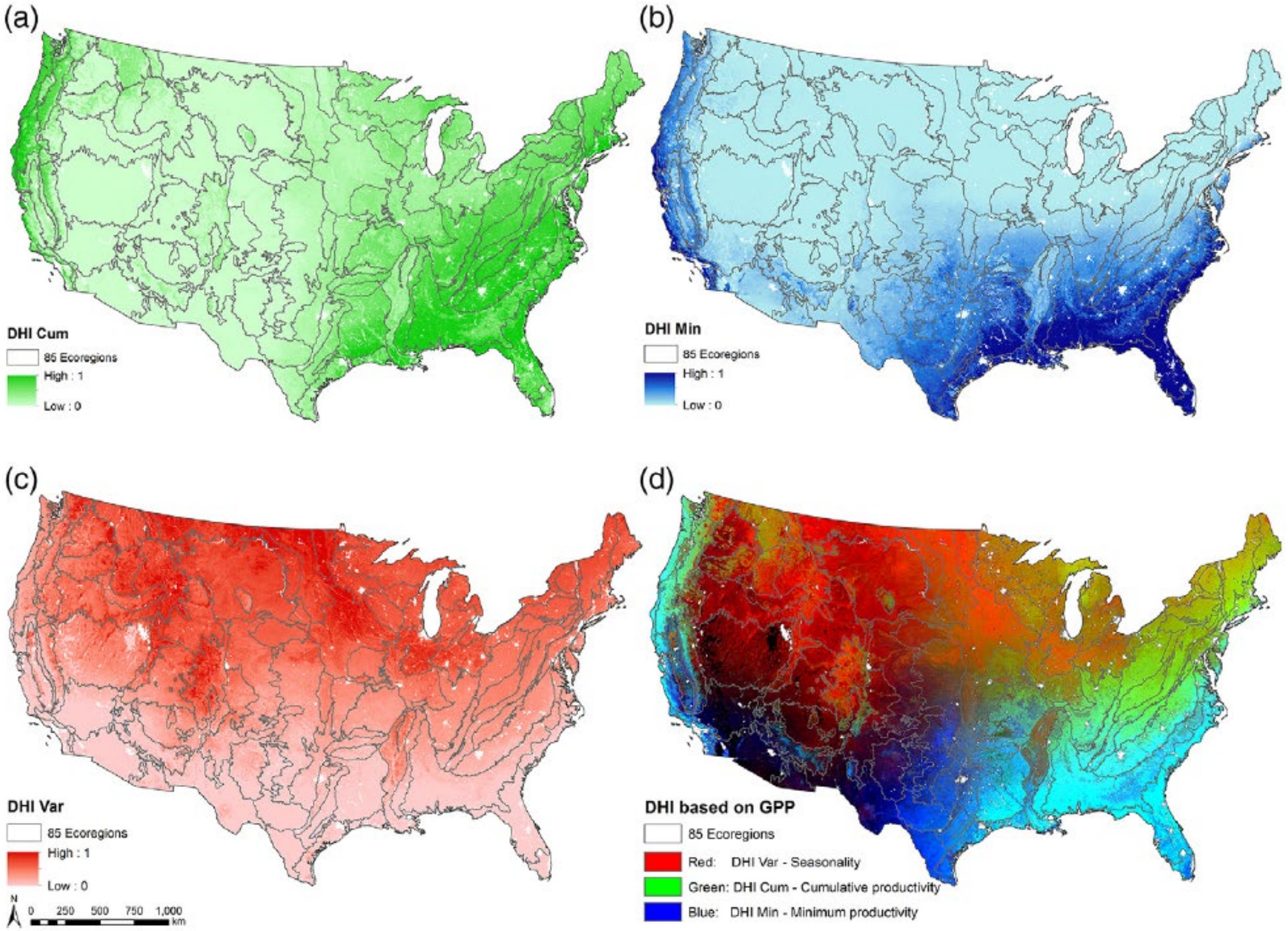


Image Credit: Food and Agriculture Organization of the United Nations

Environmental Descriptors/Parameters

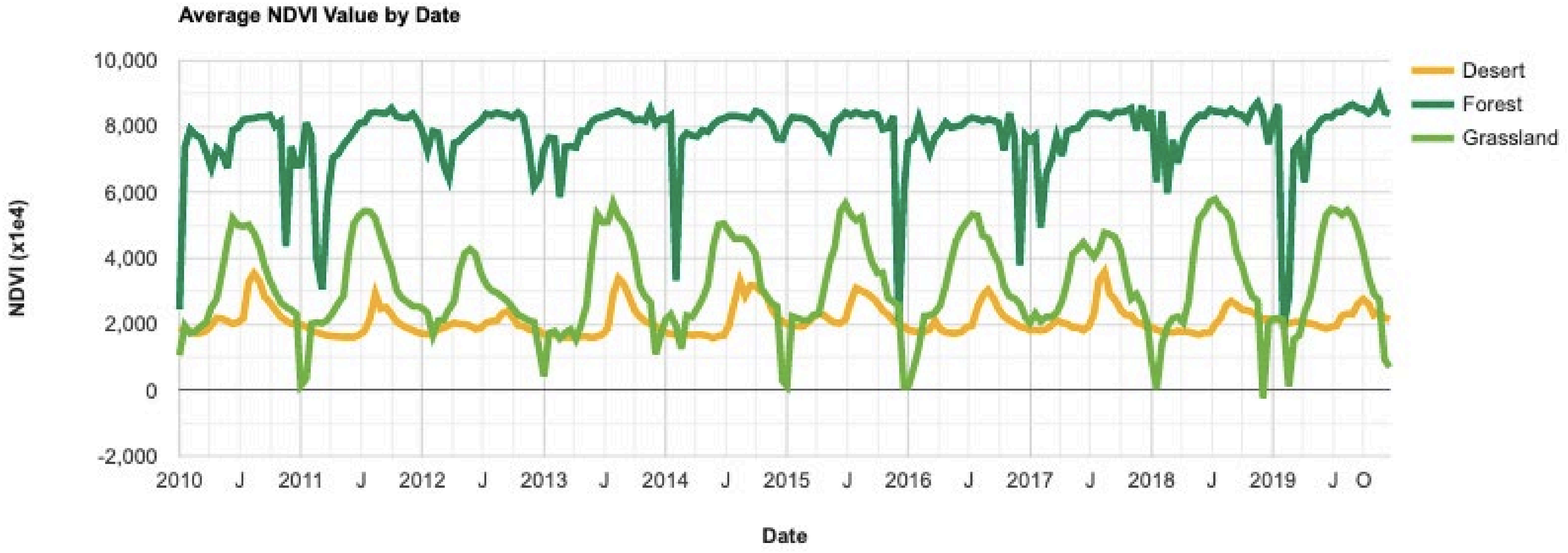
- Use time series of satellite observations to derive environmental descriptors/ parameters as proxies for environmental conditions on the ground
- Example: Dynamic Habitat Indices (DHIs) use time series of satellite observations of greenness to describe vegetation dynamics to understand bird species richness
  – Vegetation dynamics include: productivity, minimum level of perennial cover, degree of vegetation seasonality



Dynamic Habitat Indices derived from MODIS GPP 2003-2014 data (a) cumulative DHI; (b) minimum DHI; (c) variation DHI; (d) combined DHI.
Credit: Hobi, et al. 2017

Time Series Analysis in GEE

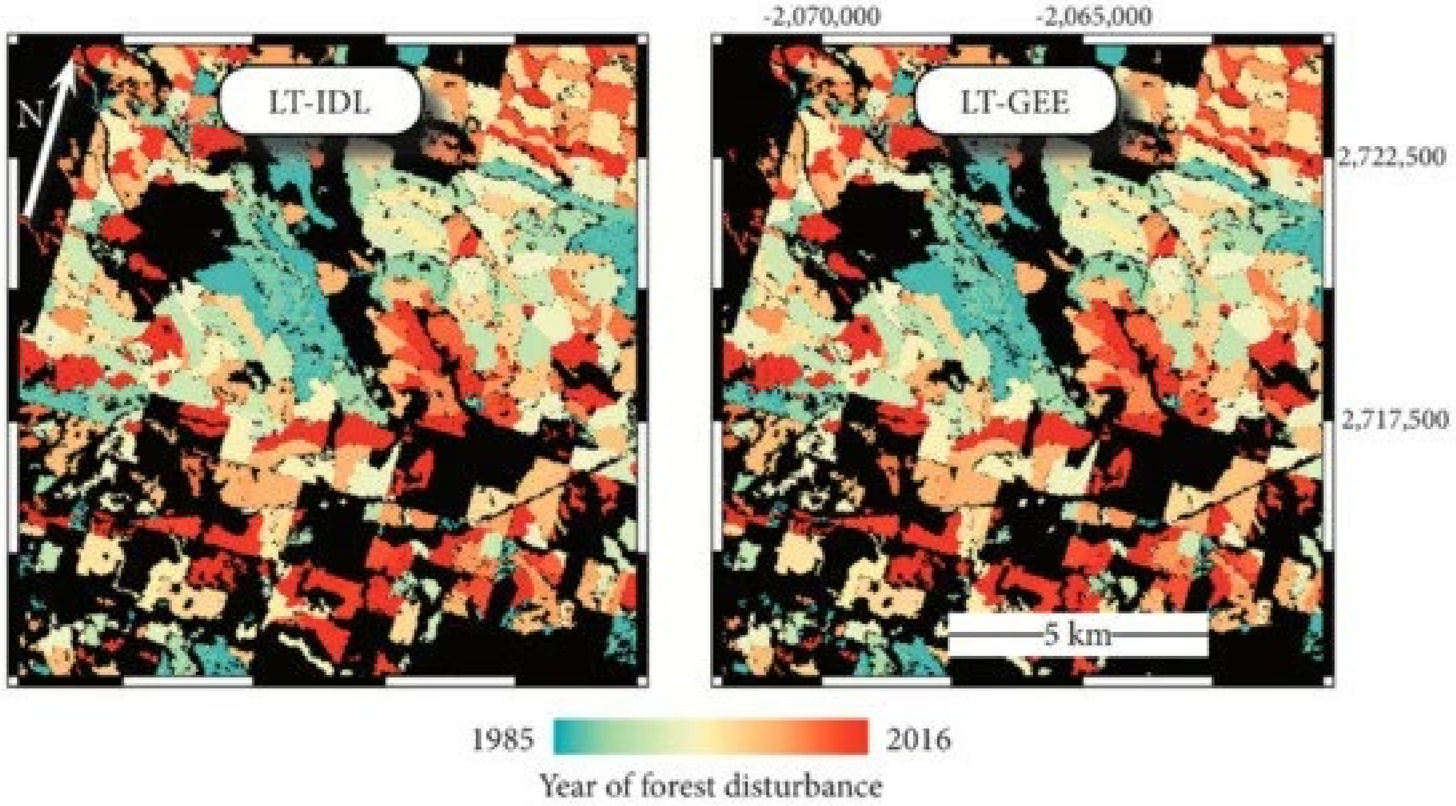
- GEE has a variety of functions useful for time series analysis:
  - Filtering and compilation of data across large datasets over time
  - Analysis using map visualizations and user interface generated charts and graphs



Example chart of time series NDVI data from MODIS plotted in GEE from 2010 to 2019. Image Credit: [GEE Developers]

Time Series Analysis in GEE: LandTrendr

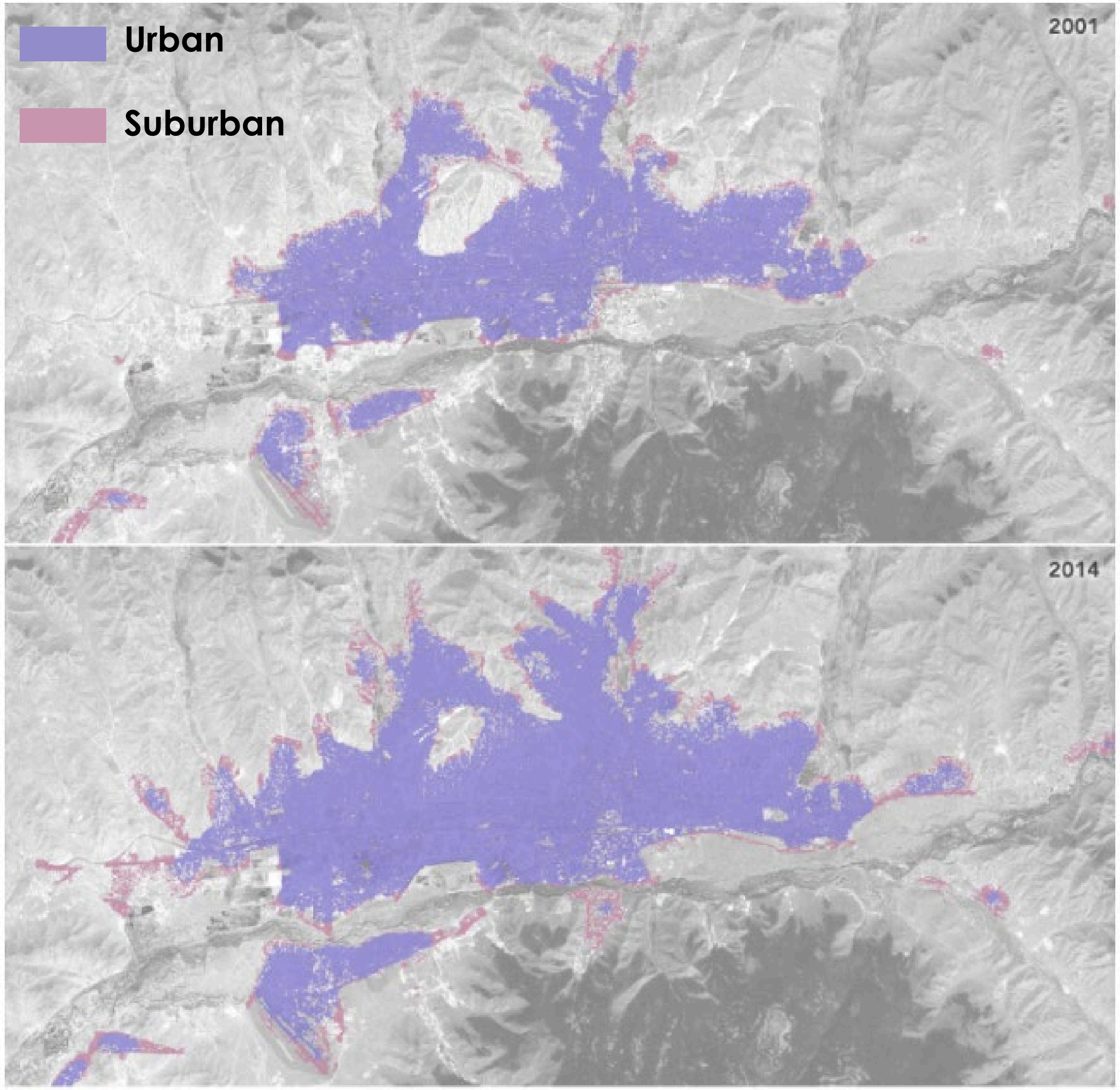
- Landsat-based detection of Trends in Disturbance and Recovery
  - Temporally segments a time-series of images by extracting the spectral trajectories of change over time
  - Use of LandTrendr in Google Earth Engine simplifies pre-processing steps and can make implementation of the algorithm easier
  - LandTrendr in GEE Guide: https://emapr.github.io/LT-GEE/introduction.html



Comparing year of disturbance maps derived from LT-IDL and LT-GEE algorithms. Maps show the year of detected forest disturbance, filtered to 11 pixels minimum mapping unit for an area of the western Cascade Mountains in Oregon.
Image Credit: [Kennedy et al. 2018]()

Change Detection Basics

- The conversion of a landscape from one dominant feature type to another
- Examples:
  - Changes in tree cover due to wildfire or deforestation
  - Urbanization
  - Land degradation due to over grazing
- Information that can be derived from satellites:
  - Where and when has change taken place?
  - How much and what kind of change has occurred?
  - What are the cycles and trends in the change?



Mapping of urbanization in Ulaanbaatar, Mongolia from 2001 to 2014.
Image Credit: [NASA EO]

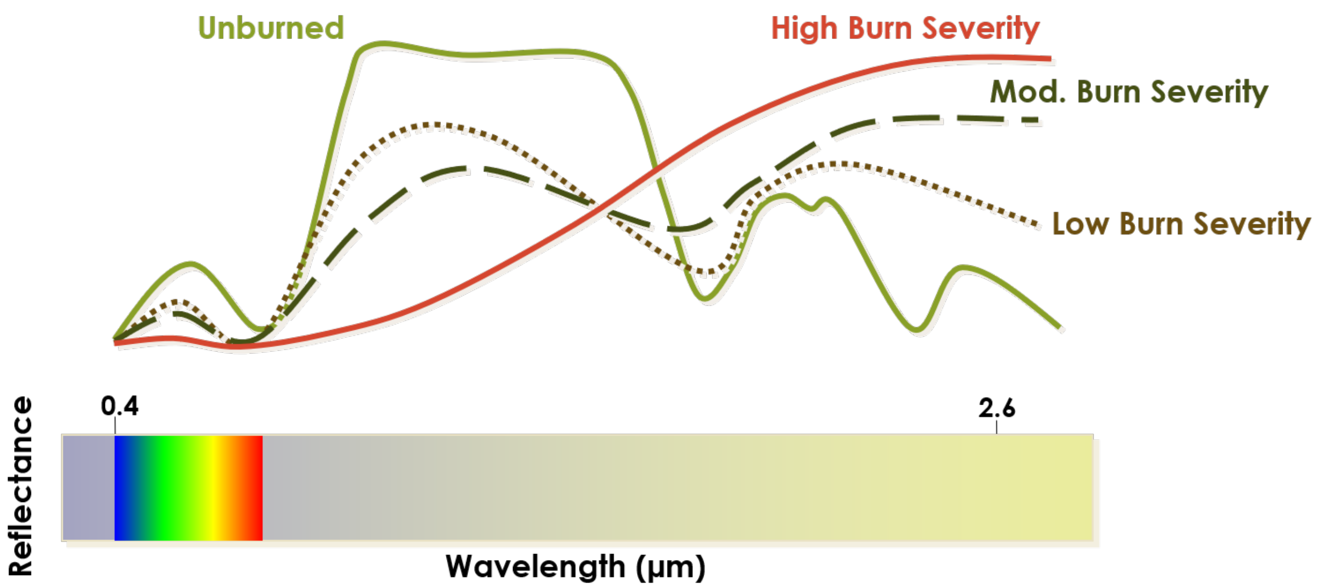
Characterizing Landscape Change

- **Types of Change**
  - Directional change
    - Example: urban development
  - Cyclic change
    - Example: seasonal phenology
  - Multidirectional change
    - Example: deforestation and forest regeneration
- **Broad Categories of Change**
  - Change in shape or size of patches of land cover types (urbanization)
  - Slow changes in cover type or species composition (succession) vs. abrupt land cover transitions (wildfire and deforestation)
  - Slow changes in condition of a single cover type (forest degradation due to insect or disease)
  - Changes in timing of extent of seasonal processes (drought monitoring)

Change Detection Using Remote Sensing

- Changes on the landscape can be detected as changes in the spectral values of pixels
- We can use spectral signatures to differentiate between cover types and calculate environmental indices
- Example pre-fire and post-fire conditions:
  - Healthy vegetation has high reflectance in the green and near-infrared but low in the short-wave infrared
  - Burned areas have low reflectance in the green and near-infrared but high in the S short-wave infrared

Exploiting Spectral Response Curves



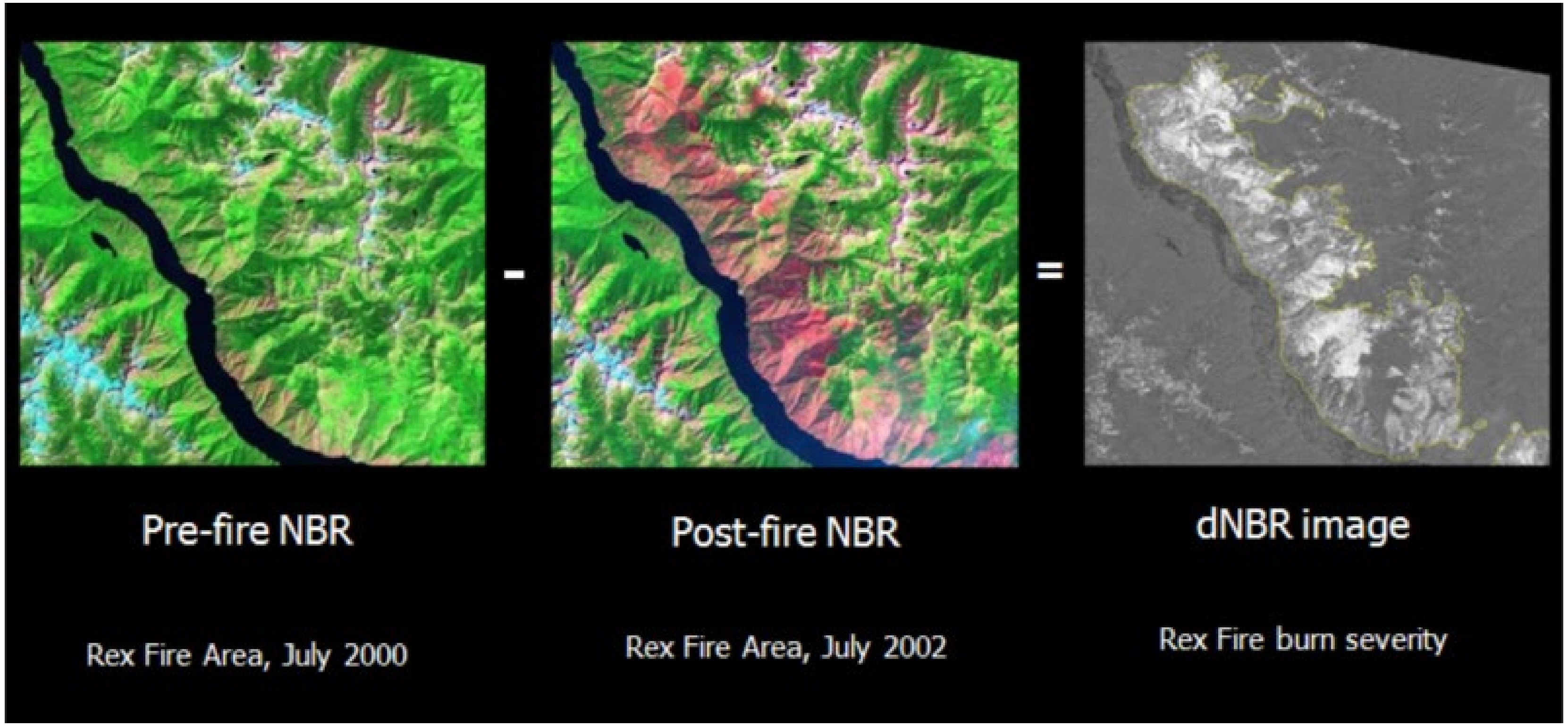
Healthy vegetation has a large peak in the near infrared, while soil or burned areas are much lower. Healthy vegetation also has low reflectance in the shortwave infrared, while burned areas have high reflectance .

Differenced Normalized Burn Ratio

- Compare pre- and post-burn images to identify burn extent and severity with a differenced map

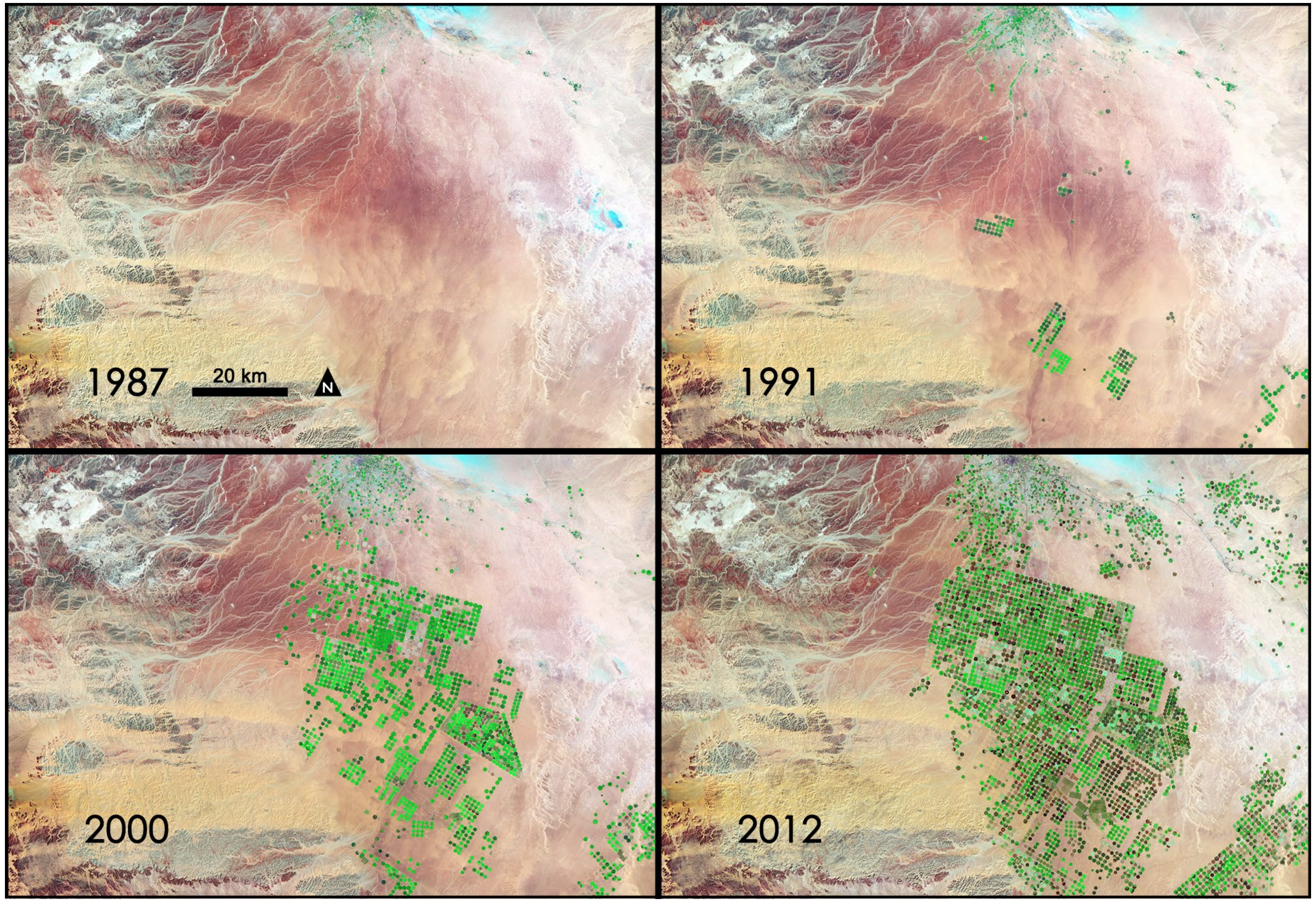
$$dNBR = NBR_{prefire} - NBR_{postfire}$$

$$NBR = \frac{(NIR - SWIR2)}{NIR + SWIR2}$$



Change Detection Goals

- Identification of the geographical location and types of changes
- Quantification of changes
- Assessment of the of the change detection results
- Identifying the location of and quantifying change is easier than identifying the cause of change.



Landsat imagery of Saudi Arabia used to map agricultural growth.
Credit: NASA

Change Detection Considerations

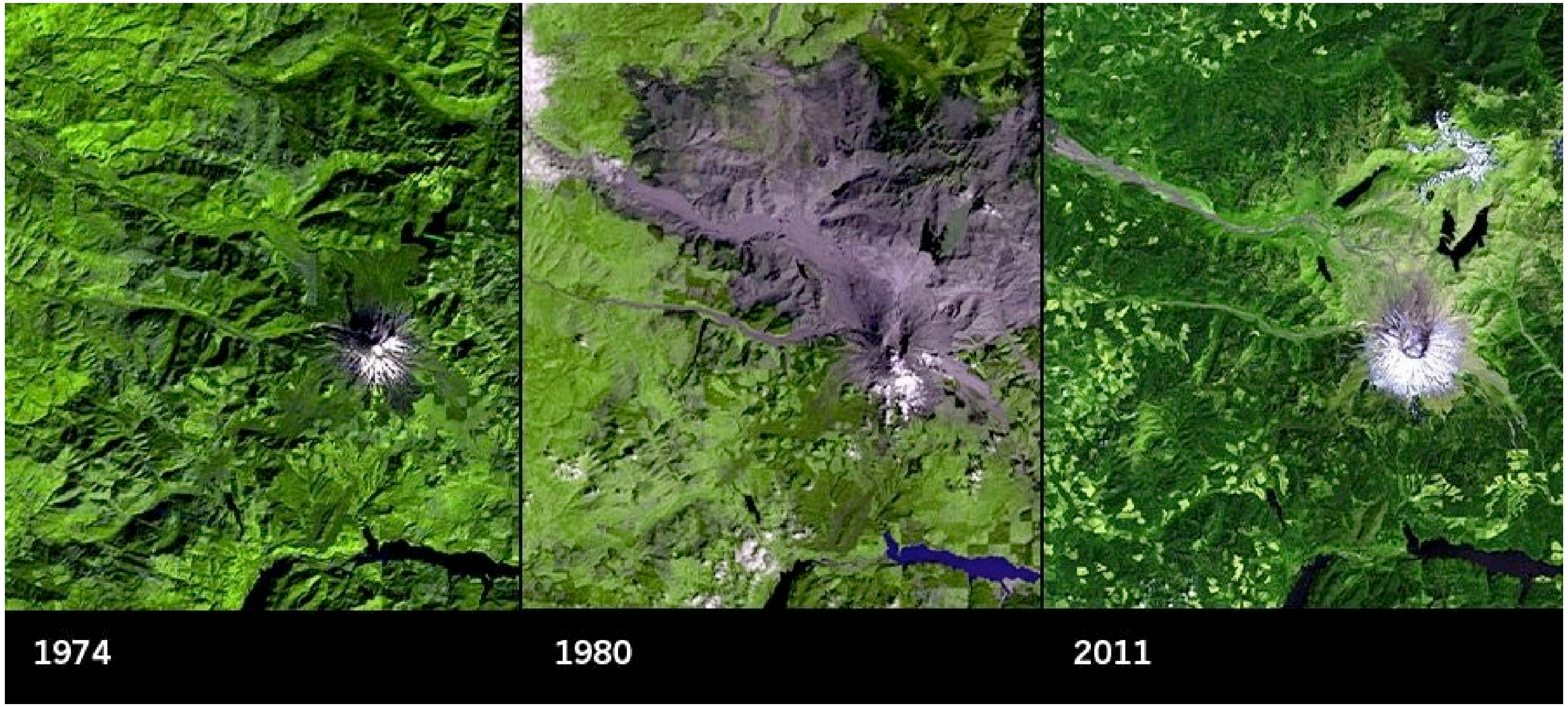
- Change detection requires multi-temporal datasets
- When selecting multi-temporal remote sensing data it is important to use:
  - The same sensor
  - The same spatial resolution
  - Data from the exact same or similar times of day, days of the year, and/or seasons
  - Data that is nearly cloud free
  - Radiometrically and atmospherically corrected data
- It's important to keep these factors in mind, because you need to minimze changes due to data characteristics you are not interested in, so that you can identify the changes you are interested in.

Change Detection Considerations

- **Between-class changes**
  - Answers the question:
    - "Has a pixel changed and what has it changed to?"
    - e.g. forest to agriculture conversion
- **Within-class changes**
  - Based on continuous spectral or transformed spectral information
  - Answers the question:
    - "How much and in what direction has a pixel changed?"
    - e.g. change in vegetation index values

Change Detection Methods

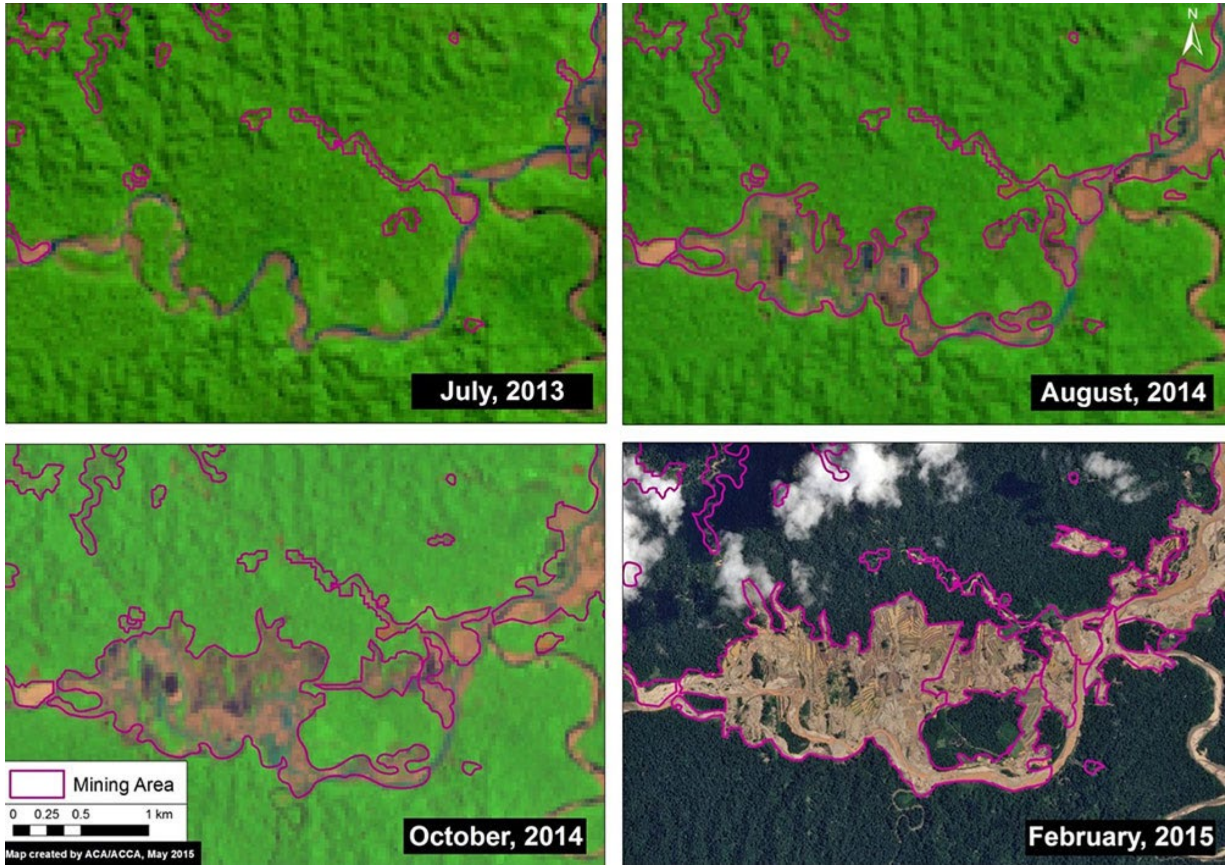
- **Visual Analysis**
  - Simple visual analysis comparing different timesteps
- **Image Differencing**
  - Use raster calculation methods to difference pixel values of images from different timesteps or average conditions



Mount Saint Helens eruption, 1980.
Image Credit: Pantaleo, 2013,

Change Detection: Visual Analysis

- Delineation of change through visual comparison, digitization, and/or band combinations
- Good for large changes like shape or size of large patches
- Not as good for subtle changes like land degradation
- Does not necessarily take advantage of spectral response



Deforestation along the Upper Malinowski in Peru due to mining from Landsat and SPOT 7.
Credit: Amazon Conservation Association

Change Detection: Image Differencing

- Subtract image date 1 from image date 2
- 0 means no change; positive or negative values indicate change
  - OR: you can set a threshold value to indicate change
- Image dates can be individual bands or image transformations (NDVI, NBR, etc.)
- Advantages
  - Can be used to detect subtle changes
  - Easy to compute
- Disadvantage: Can be difficult to interpret

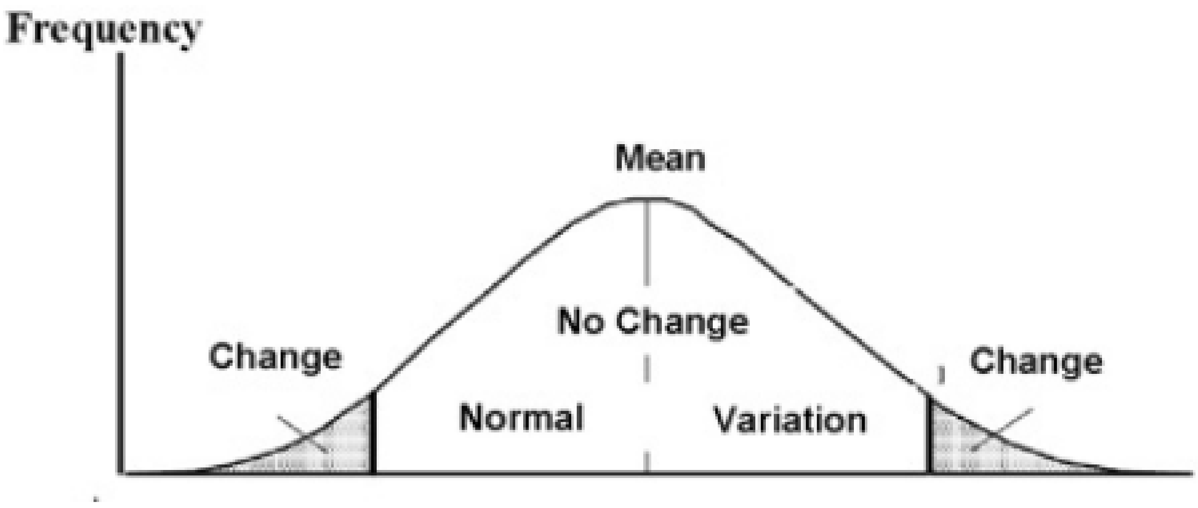


Image Differencing

- Image differencing takes place across the full extent of both images.
- Differences are calculated on a pixel-by-pixel basis.
- The pixel-based nature of image differencing allows for more specific delineation of change.
- Image differencing can be especially useful for examining change over continuous indices (like those that measure vegetation and soil).

Image Date 1

8	10	8	11
240	11	10	22
205	210	205	54
220	98	88	46

Image Date 2

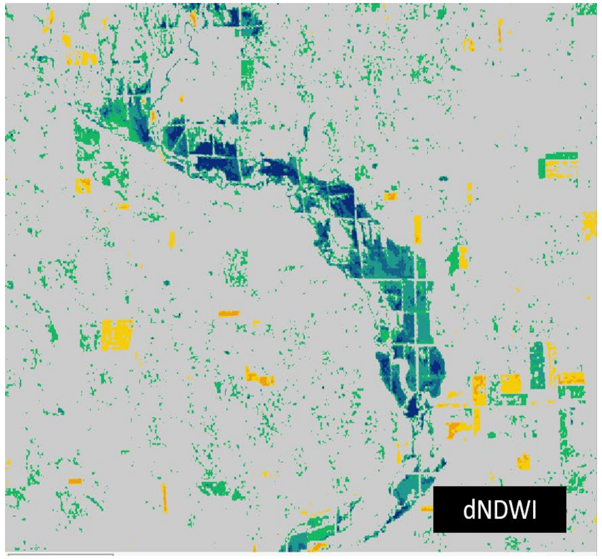
5	9	7	10
97	9	8	22
98	100	205	222
103	98	254	210

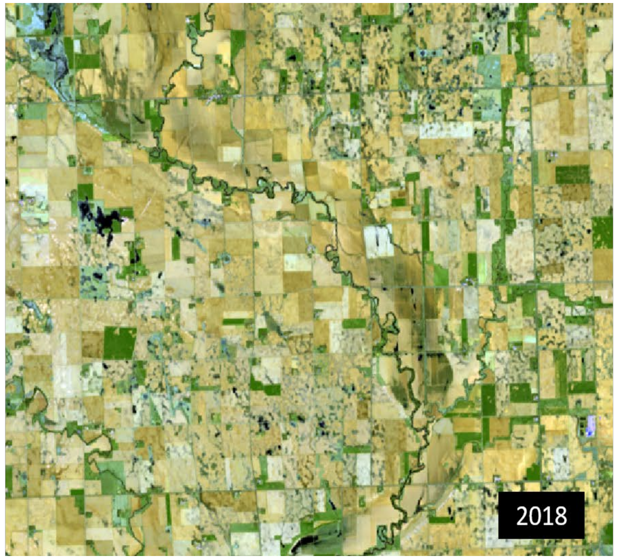
3	1	1	1
143	2	2	0
107	110	0	-168
117	0	-166	-164

Difference Image = Image 1 - Image 2

Image Index Calculation and Differencing

- Example Below:
  - Conduct index calculation (Normalized Difference Wetness Index) on each image
  - (Green-NIR)/(Green+NIR)
  - Subtract one image from the other





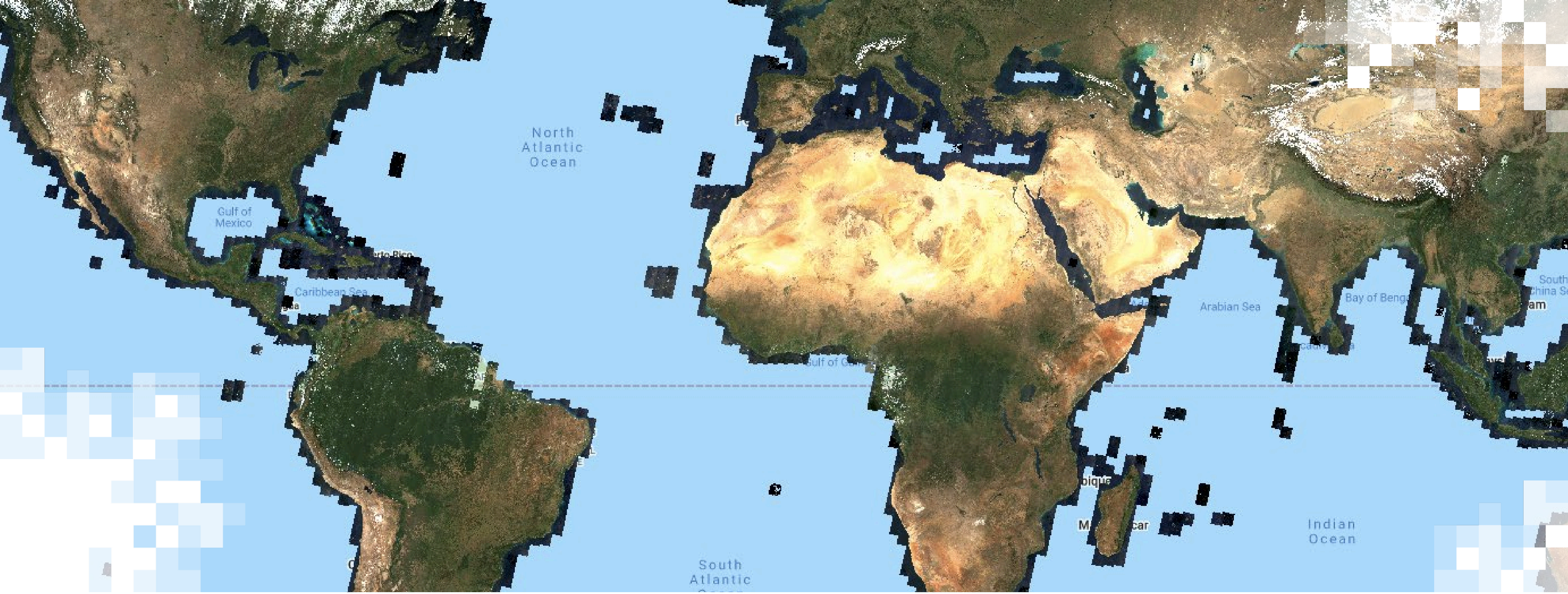
Previous ARSET Trainings

- Past ARSET trainings relevant to time series and change detection:
  - Investigating Time Series of Satellite Imagery
  - Change Detection for Land Cover Mapping
  - Remote Sensing for Mangroves in Support of the UN Sustainable Development Goals

GEE Developer Guides

- Relevant guides to GEE features and JavaScript Code:
  - Image Collection Charts
  - Time Series Animation
  - LandTrendr
  - Mathematical Operators
- The full list of guides and tutorials made available by the developers:
  - JavaScript and Python Guides

Image Credit: Google Earth Engine



Time Series and Change Detection in Google Earth Engine

https://code.earthengine.google.com/04b1c5c966b08430bbad2df4067c3175

Summary

- Time series analysis relies on the compilation of satellite data over a number of dates, weeks, months, seasons, and years to effectively monitor the progression of landscape change.
- Change detection is only possible if time series data is available to assess either gradual or abrupt changes to land cover types and features.
- GEE provides an "all-in-one" user experience for filtering and compiling large datasets at various timesteps and completing necessary raster calculations and data visualizations.
- A simple time series analysis in GEE can be completed by calculating a vegetation index across a collection of images compiled at an annual timestep and visualizing results in the GEE interface.
- Simple change detection in GEE can be completed through visual inspection and image differencing techniques.
- We demonstrated these functionalities in our activity examining vegetation change in the Amazon region from 2014-2020.

Homework and Certificate

- One homework assignment:
  - Answers must be submitted via Google Form, accessed from the ARSET website.
  - Due date for homework: **July 14, 2021**
- A certificate of completion will be awarded to those who:
  - Attend all live webinars
  - Complete the homework assignment by the deadline
  - You will receive a certificate approximately two months after the completion of the course from: marines.martins@ssaihq.com

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- Training Webpage:
  - https://appliedsciences.nasa.gov/join-mission/training/english/arset-using-google-earth-engine-land-monitoring-applications
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