Earth Observations for Ecosystem Restoration

Applications

Session Agenda

• How Earth Observations can aid Ecological Restoration
• Overview of Remote Sensing
  – Advantages
  – Caveats/limitations
  – Satellites and Sensors
  – Geophysical Parameters
• Applications
• Demonstration of Tools and Portals
• Resources
• Questions and Answers

Image Credit: NASA Earth Observatory images by Joshua Stevens, using Landsat data from the U.S. Geological Survey
How Earth Observations can aid Ecological Restoration

On the ground, in situ measurements cannot be replaced.

• Planning and Design
  – Changing climatic conditions
  – Land cover mapping
  – Landscape scale

• Assessing Ecological Condition
  – Degradation/vegetation health
  – Identify evidence of invasive species

• Measuring impact
  – Assess the effectiveness over time
  – Communicating with stakeholders

Landsat 8 (OLI) Image of Mississippi River Flooding (6/5/2018 compared to 5/7/2019)
See last slide for references
Overview of Remote Sensing
Remote Sensing

- Measurement of a quantity associated with an object by a device not in direct contact
- Usually involves “sensors” that can be ground-based, air-based or satellite-based
- The most useful platform depends on the application
- What information? How much detail?
- How frequent?
Electromagnetic Spectrum

- Earth-Ocean-Land-Atmosphere System:
  - Reflects solar radiation back into space
  - Emits infrared and microwave radiation to space
How Satellites Collect Data

Incident Solar Radiation

Atmosphere

Reflected Solar Radiation

*Image recreated from Natural Resources Canada image

Forest  Water  Grass  Soil  Paved Road  Built-up Area

National Aeronautics and Space Administration
Interaction with Earth’s Surface: Vegetation

- Example: Healthy, green vegetation absorbs Blue and Red wavelengths (used by chlorophyll for photosynthesis) and reflects Green and Infrared
- Since we cannot see infrared radiation, we see healthy vegetation as green
- The amount of reflected energy is dependent on the health of the vegetation, water content, and phenological stage

*Image Credits: NASA/Jeff Carns & Ginger Butcher
Satellite Remote Sensing Observations: What to Know

• Satellites vs. Sensors
• Types of satellite orbits around the earth
• Spatial and temporal coverage
• Geophysical quantities derived from the measurements
• Quality and accuracy of the retrieved quantity
  – Applications and usage
  – Availability, access, and format
Satellites vs. Sensors

- Satellites carry sensors or instruments
- Earth-observing satellite remote sensing instruments are named according to
  - the satellite (platform)
  - the instrument (sensor)

Aqua Satellite
- Instruments
  - MODIS
  - CERES
  - AIRS
  - AMSU-A
  - AMSR-E
  - HSB

Landsat 8 Satellite
- Instruments
  - OLI
  - TIRS
Remote Sensing Data Sources
Coarse Spatial Resolution (Optical)

• Greater than 250m
• Ex: MODIS, CBERS-2
• High temporal resolution useful for early warning and detection of forest clearing and degradation

* (bottom) FORMA alerts from Global Forest Watch
Remote Sensing Data Sources
Medium Spatial Resolution (Optical)

• 10m – 80m spatial resolution
• Most common: Landsat (30m) and more recently, Sentinel 2
• Benefits:
  – Historical archive (early 1980s)
  – Easily accessible and freely available
  – Global coverage
• Limitations: Areas of persistent cloud cover
• Example: Global Forest Watch (Hansen et al. 2013)
Remote Sensing Data Sources

High Spatial Resolution (Optical)

- Better than 10m spatial resolution
- Examples: Worldview 2 and 3
- Primarily used for accuracy assessment, sampling transects or hot spot assessment
- Benefits: Forest activity data can be monitored more accurately and with greater differentiation
- Limitations
  - Higher acquisition and processing costs
  - Spatial and temporal coverage may not be adequate
- Ex: Nilo Forest Reserve, Tanzania

*Image Credits: (top) DigitalGlobe; (bottom) DigitalGlobe and Norsk Regnesentral*
Remote Sensing Data Sources

Synthetic Aperture Radar

- 1-80m spatial resolution
- Examples: Sentinel 1A & B, Radarsat, ALOS
- Benefits
  - useful in areas of persistent cloud cover
  - can provide information on forest structure
  - complementary to optical data
- Limitations
  - difficult to process
  - not currently used operationally
- Example: Forest change in Borneo

* Source: Masanobu et al., 2014
Remote Sensing Data Sources

LiDAR

• Provides information on forest structure (e.g. tree height, canopy volume) and biomass
• Currently acquired using aircraft platform; no operational LiDAR satellites
• Benefits:
  – Provides detailed information of forest structure
  – Verification of biomass estimates; reduces need for ground sampling
• Disadvantages:
  – Expensive to acquire and process
• Example
  – National carbon map of Panama (right) by integrating field data with satellite image and LiDAR

*Image Credit: Carnegie Institution
Orbits: Spatial Coverage & Temporal Resolution

**Polar Orbiting**
- Global coverage
- Varied measurement frequency (1 per day – 1 per month)
- Larger swath size means higher temporal resolution

**Non-Polar Orbiting**
- Non-Global coverage
- Varied measurement frequency (less than 1 per day)
- Larger swath size means higher temporal resolution

**Geostationary**
- Limited spatial coverage – more than one satellite needed for global coverage
- Multiple observations per day

TRMM Image

GOES Image
Temporal Resolution

• It takes time for a satellite to complete one orbit, this is called the revisit time

• Depends on the satellite and sensor capabilities, swath overlap, and latitude

• Some satellites may have greater temporal resolution
  – Some satellites are able to point their sensors
  – Some satellites have increasing overlap at higher latitudes so many have a greater repeat time

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Revisit Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landsat</td>
<td>16 days</td>
</tr>
<tr>
<td>MODIS</td>
<td>2 days</td>
</tr>
<tr>
<td>Commercial (OrbView)</td>
<td>1-2 days</td>
</tr>
</tbody>
</table>

This example shows a radar image path from NASA’s Soil Moisture Active Passive satellite where areas at high latitudes will be imaged more frequently than the equatorial zone due to the increasing overlap in adjacent swaths as the orbit paths come closer together near the poles.
Satellite Sensors: Passive

- Measure radiant energy reflected or emitted by the Earth-atmosphere system
- Radiant energy is converted to **bio-geophysical quantitates** such as:
  - temperature, precipitation, soil moisture, chlorophyll-a
- Examples:
  - Landsat, MODIS, TRMM Microwave Imager
Satellite Sensors: Active

• Emit beams of radiation and measure ‘back-scattered’ radiation
  – The back-scattered radiation is converted to geophysical quantities

• Advantages
  – Can be used day or night
  – Can penetrate cloud cover

• Disadvantages
  – Challenging to process
  – Some available only from aircraft

• Examples:
  – Radar, LIDAR
Advantages and Disadvantages of Remote Sensing Observations
Advantages of Earth Observations

- Available for large regions
  - Only source of global information for some parameters
- Long time series and data continuity
  - Track progress
  - Establish baseline and trends
- Consistency and comparability
  - Among multiple countries
- Diversity of measurements
  - Many different physical parameters
- Mostly free and open access
Disadvantages of Earth Observations

• Does not provide high level of detail at the ground level

• Cannot detect land cover under canopy (optical)

• Cannot detect much under water

• Cost (of some remote sensing data)

• Level of technical expertise required to process/interpret

• Impossible to have high spatial, spectral and temporal resolution
Geophysical Quantities
Vegetation Indices and Biophysical parameters

**Vegetation/Greenness Indices/Phenology**

- **NDVI - Normalized Difference Vegetation Index**
- **EVI - Enhanced Vegetation Index**
- **SAVI - Soil-Adjusted Vegetation Index**
- **MSAVI - Modified Soil-Adjusted Vegetation Index**
- **SATVI - Soil-Adjusted Total Vegetation Index**
- **Normalized Burn Ratio (NBR)**

**Biophysical Parameter Estimates**

- **fPAR - Fraction of Photosynthetically Active Radiation**
- **Fractional Cover**
- **GPP and NPP - Gross and Net Primary Productivity or Biomass**
- **LAI - Leaf Area Index**
Evaluating Impact of Restoration

Monitor growing seasons or vegetation patterns
Relationships with species richness and vegetation
Assessing Ecological Condition or Degradation/vegetation health

Center pivot irrigation with NDVI displayed. Image Credit: NASA/DRI
NDVI: Phenology

- Remote sensing is used to track the seasonal changes in vegetation.
- Monthly NDVI images from MODIS or Landsat can be used to monitor phenology.
Phenology: Ecological Importance

- Phenological events change from year to year.
- Timing of events (phenophase) such as flowering, leafing, migration, and insect emergence can impact how plants and animals are able to thrive in their environment.
- Influences abundance and distribution of organisms, ecosystems services, and global cycles of water and carbon.
Remote Sensing of Phenology

• Use of satellites and sensors to track seasonal patterns of variation in vegetated land surfaces

• **Land Surface Phenology (LSP)**
  – Regular monitoring of the entire global land surface
  – Gather information on entire ecosystems: broad scale trends

• Most useful when linked to ground observation networks

• Uses include:
  – Crop health assessments
  – Drought severity
  – Wildfire risks
  – Invasive species and pest tracking
  – Mapping infectious disease risk

Center pivot irrigation with NDVI displayed. Image Credit: NASA/DRI
Normalized Difference Vegetation Index (NDVI)

• Based on the relationship between red and near-infrared wavelengths
• Chlorophyll strongly absorbs visible (red)
• Plant structure strongly reflects near-infrared
NDVI Applications

• Vegetation health
  – Crop health
• Phenology
• Drought Indicator
  – Soil moisture
• Leaf Area Index (LAI)
• Carbon Monitoring
• Can reveal where vegetation is thriving and where it is under stress

Credit: http://geovantage.com/applications/precision-agriculture/crop-hea
Enhanced Vegetation Index (EVI)

\[ EVI = G \times \left( \frac{(NIR-R)}{(NIR+C1*R-C2*B+L)} \right) \]

**Constants**
- \( G = 2.5 \)
- \( C1 = 6 \)
- \( C2 = 7.5 \)
- \( L = 1 \)

- Does not saturate over high biomass regions
- \( L = \) Adjustment for canopy background
- \( C = \) Atmospheric adjustment
- Use of the blue band
Soil Adjusted Vegetation Index (SAVI)

• Minimizes the influence of soil brightness
• Useful in areas with greater soil cover
  – Contains a soil brightness correction factor (L)
    • 0.5 typically used
    • Lower for areas with greater canopy cover
    • Higher for areas with less canopy cover

\[
SAVI = \left( \frac{NIR - R}{NIR + R + L} \right) \times (1 + L)
\]

SAVI: Image Credit: Grind GIS
Normalized Difference Moisture Index (NDMI)

- Measure of vegetation moisture
- Frequently used in drought monitoring
  – Detects more subtle changes in vegetation moisture
- Used in wildfire hazard potential

\[ NDMI = \frac{(NIR - SWIR)}{NIR + SWIR} \]
Land Cover Mapping and Classification and Change Detection
Land Cover

Mapping and Classification
• Planning and Design
• Assessing Ecological Condition

Change Detection
• Measuring impact

Global LAI from 2017. Image Credit: ESA
Turning Data Into Information: Image Classification

Landsat Image of Lake Tahoe  

Land Cover Map of Lake Tahoe

- Open Water
- Ice and Snow
- Low Intensity Residential
- High Intensity Residential
- Commercial/Industrial/Transportation
- Bare Rock/Sand/Clay
- Gameres
- Transitional
- Deciduous Forest
- Evergreen Forest
- Mixed Forest
- Shrubland
- Orchards/Vineyard
- Grassland/Herbaceous
- Pasture/Hay
- Row Crops
- Small Grains
- Fallows
- Urban/Recreational Grasses
- Woody Wetlands
- Emergent Herbaceous Wetlands
Image Classification

Overview

• Used for mapping forest/non-forest, land cover, or forest stratification
• There are many methods: visual interpretation, pixel-based (supervised, unsupervised), and object-based
• For improved results, often needs ground and/or other ancillary information (topographic or climatic data)
• Needs specialized software (commercial or open source) and training

Land Cover Map of Panama
Image Classification

Methods

Supervised

• Uses expert-defined areas of known vegetation types (training areas) to tune parameters of classification algorithms

• Algorithm then automatically identifies and labels areas similar to the training data

Unsupervised

• Uses classification algorithms to assign pixels into one of a number of user-specified class groupings

• Interpreters assign each of the groupings of pixels a value corresponding to a land cover class

• Credit: David DiBiase, Penn State Department of Geography
What is Change Detection?

- The comparison of information about an area on the Earth over two or more points in time
  - Where and when has change taken place?
  - How much change, and what type of change has occurred?
  - What are the cycles and trends in the change?

Santiago, Chile Urban growth (1975-2013), Landsat

Bark Beetle Infestation in Colorado (2005-2011)
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, 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)

Urbanization in Burkina Faso, 2006

Bark Beetle Infestation: Colorado, 2011
Change Detection Using Remote Sensing

• Changes on the landscape can be detected as changes in the spectral value of pixels
• Example pre and post burn:
  – Healthy vegetation has high reflectance in the G and NIR but low in the SWIR
  – Burned areas have low reflectance in the G and NIR but high in the SWIR
Change Detection Goals

- Identification of the geographical location and types of changes
- Quantification of changes
- Assessment of the accuracy of the change detection results

Identifying the location of and quantifying change is easy.

Identifying the cause of change is not.

Image: Landsat images of Saudi Arabia’s agricultural growth. Credit: NASA
Detecting Land Degradation
SDG: Target 15.3

Land Degradation Neutrality (LDN)

• By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world

• Achieving LDN will require avoiding or reducing new degradation, and restoring and rehabilitating lands that were degraded in the past

Land degradation threatens the natural capital on which livelihoods depend, including those of over 1.3 billion farmers.
Indicator 15.3.1

Proportion of land that is degraded over total land area

Sub-indicators

1) Land cover and land cover change
2) Land productivity
3) Carbon stocks above and below ground

• A combination of satellite Earth observations and site-based data will be needed to
  – set baselines to determine the initial status of the sub-indicators
  – detect change in each of the sub-indicators
  – derive the indicator by determining what areas of change are considered land degradation

Image Credit: Framework and Guiding Principles for a Land Degradation Indicator, United Nations Convention to Combat Desertification
SDG 15 Data Needs

Sub-indicators

• Global datasets for standardized reporting
  – Landcover
    • Forest Area and Forest Change (Landsat)
  – Protected Areas
  – Important sites for Biodiversity
  – Carbon Stocks
  – Land Productivity
  – Etc.

• Good Practice Guidelines

• Country reporting
• Identification of degraded lands
• Can set baselines, and track progress
• Best global datasets
• Allows use of best-available local information

Supports all three components of SDG Indicator 15.3.1
Remote Sensing Data Sources for Assessment of Land Cover
ESA Satellites and Sensors for Phenology

- **Sentinel-2**
  - Launched in 2015
  - 13 spectral bands
  - Spatial Resolution:
    - Red, Green, Blue (RGB) at 10 meters
    - Near-infrared and Shortwave infrared at 20 and 60 meters
  - Revisit Time: ~5 days
  - Often combined with Landsat for continuity
    - Harmonized Sentinel-2 and Landsat surface reflectance products available

- **SPOT (multiple satellites)**
  - National Centre for Space Studies (CNES), French government space agency
  - Spot 6 (2012), 7 (2014)
  - 4 multispectral bands
  - 6-meter spatial resolution
  - Revisit Time: ~2-3 days

Composite Sentinel-2 image of forests converted to farmland in Brazil, 2019. Image Credit: ESA
ESA Data Products

Copernicus Global Land Service

Providing bio-geophysical products of global land surface

- Home
- Products
- Use cases
- Product Access
- Viewing
- Library
- Get Support

Burnt Area
Dry Matter Prod.
FAPAR
FCOVER
Leaf Area Index
Land Cover

NDVI
Soil Water Index
Surf. Soil Moisture
VCI
VPI

Accessing Sentinel-2

Copernicus Open Access Hub: https://scihub.copernicus.eu/
Where to Obtain Landsat Images


Where to Obtain MODIS Products


ECHO Reverb: http://reverb.echo.nasa.gov

Worldview: https://earthdata.nasa.gov/labs/worldview

Earthdata Search: https://search.earthdata.nasa.gov/

National Snow and Ice Data Center: http://nsidc.org/data/modis/data_summaries
#snow
NASA Worldview

https://worldview.earthdata.nasa.gov/

- Interactive web-based tool for browsing satellite imagery
- Imagery is generally available within four hours of observation
- Daily imagery from May 2012 to present
- Data can be downloaded
- Image output in JPEG, PNG, GeoTIFF, and KML formats
Earthdata Search

https://search.earthdata.nasa.gov/
Application for Extracting and Exploring Analysis Ready Samples (AppEEARS)

- Cloud-based computing using MODIS and VIIRS
- Time series analysis of user-specified points or areas
- Outputs include time series data in .csv format for easy analysis
- Example: Monitoring changing reservoir levels in Cape Town, South Africa

https://lpdaac.usgs.gov/tools/appeears/
Climate Engine

http://app.climateengine.org/
Google Earth Engine

https://code.earthengine.google.com
Additional Resources
Group on Earth Observations (GEO)

https://www.earthobservations.org

• Intergovernmental organization working to improve the availability, access and use of Earth observations for the benefit of society
• Supports the UN 2030 Agenda for Sustainable Development, the Paris Climate Agreement and the Sendai Framework for Disaster Risk Reduction
• 105 member countries; 127 participating organizations
• 8 societal benefit areas:
  Biodiversity and Ecosystem Sustainability
  Disaster Resilience
  Energy and Mineral Resources Management
  Food Security and Sustainable Agriculture
  Public Health Surveillance
  Sustainable Urban Development
  Infrastructure and Transportation Management
  Water Resources Management
Capacity Building Programs

- NASA Applied Remote Sensing Training (ARSET)
- United Nations Institute for Training and Research (UNITAR)
- Working Group on Capacity Building and Data Democracy (WGCapD)
- Synthetic Aperture Radar Remote Sensing Capacity Building Center
- Just to name a few…so many more