An Introduction to the Monitoring of Invasive Species with Remote Sensing Tools

Part 1: An Introduction to the Monitoring of Invasive Species with Remote Sensing Tools

Sativa Cruz (BAERI/NASA Ames Research Center), Justin Fain (BAERI/NASA Ames Research Center) & Juan Torres-Perez (NASA Ames Research Center)

August 14, 2024

Part 1 – Trainers

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About ARSET

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- **ARSET provides accessible, relevant, and cost-free training on remote sensing satellites, sensors, methods, and tools.**
- Trainings include a variety of applications of satellite data and are tailored to audiences with a variety of experience levels.

AGRICULTURE

CLIMATE & RESILIENCE

DISASTERS

ECOLOGICAL CONSERVATION

HEALTH & AIR QUALITY

WATER RESOURCES

About ARSET Trainings

- Online or in-person
- Live and instructor-led or asynchronous and self-paced
- Cost-free
- Bilingual and multilingual options
- Only use open-source software and data
- Accommodate differing levels of expertise

- Visit the ARSET website to learn more.

Prerequisites

- Fundamentals of Remote Sensing

Invasive Species Monitoring with Remote Sensing

Overview

Invasive Species

In Alaska's ‘last frontier,' climate change provides new horizons for invasive species - NASA Science

Non-native organisms whose introduction causes, or is likely to cause, harm to the environment, human health, or the economy.

Impact of Invasives Species

"Invasive alien species are a significant factor that directly or indirectly caused **60 percent** of documented global animal and plant extinctions"

Estimated economic impact of **$423 Billion Dollars**.

IPBES Report

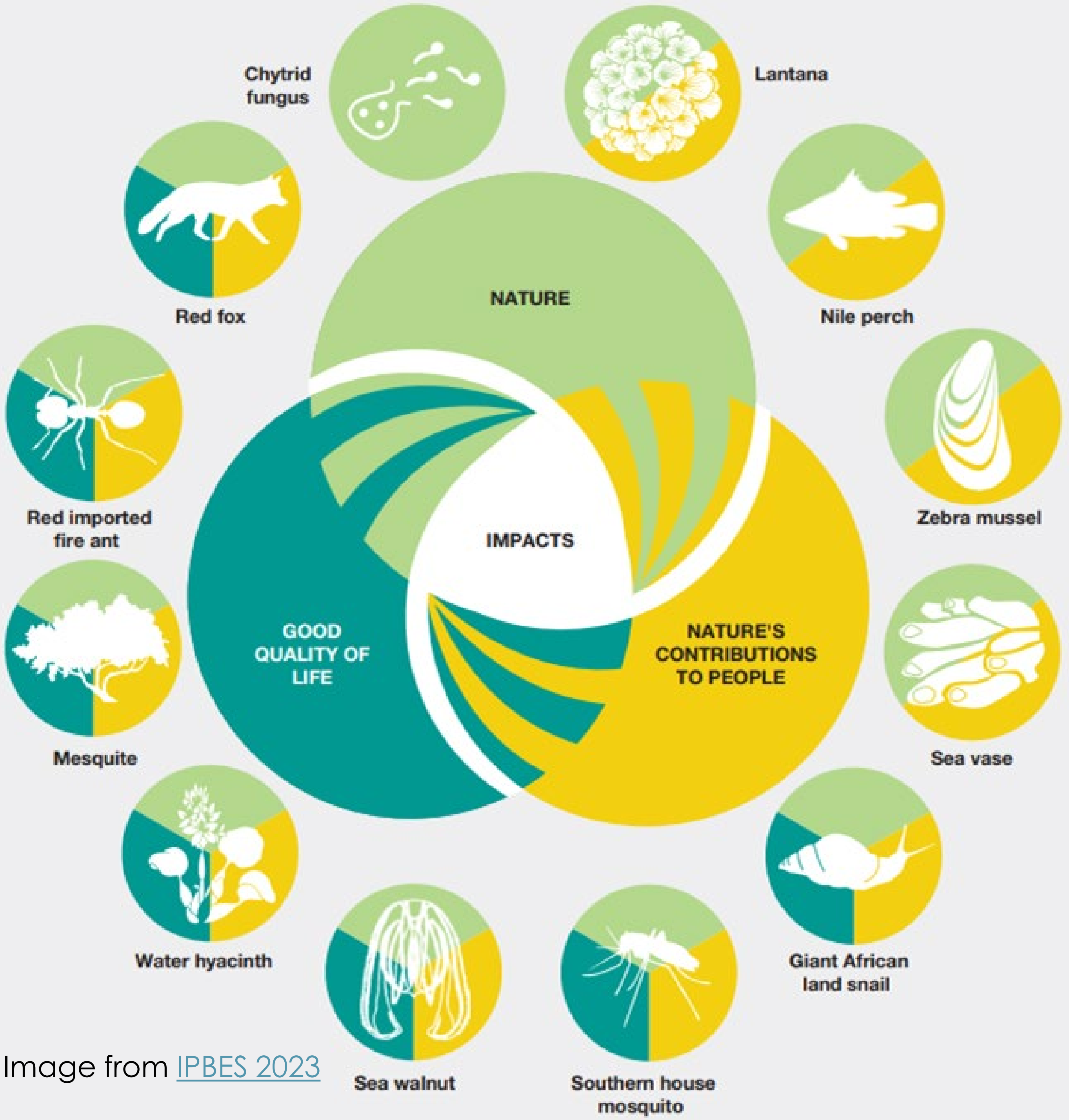

Image from IPBES 2023

Training Learning Objectives

By the end of this training attendees will be able to:

- Recognize the extent and impacts of invasive species on biodiversity and a changing climate.
- Identify the types of remote sensing data and products that can be used for invasive species mapping and monitoring.
- Explore key considerations, benefits and limitations of remote sensing data sets for invasive species.
- Identify where to access remote sensing data for monitoring invasive species and mapping relevant habitat and climate variables.
- Evaluate remote sensing methods used to monitor aquatic and grassland invasive plant species.

Training Outline

Part 1	Part 2	Part 3
An Introduction to the Monitoring of Invasive Species with Remote Sensing Tools	Monitoring of Aquatic Invasive Species with Remote Sensing	Monitoring Invasive Grassland Species with Hyperspectral Remote Sensing
August 14, 2024	August 21, 2024	August 28, 2024
10-11:30 PT (1-2:30pm ET)	10-11:30 PT (1-2:30pm ET)	10-11:30 PT (1-2:30pm ET)

Homework

Opens August 28 – Due September 11 – Posted on Training Webpage

A certificate of completion will be awarded to those who attend all live sessions and complete the homework assignment(s) before the given due date.

Training Outline

Part 1

An Introduction to the Monitoring of Invasive Species with Remote Sensing Tools

August 14, 2024

10-11:30 PT (1-2:30pm ET)

Part 2

Monitoring of Aquatic Invasive Species with Remote Sensing

August 21, 2024

10-11:30 PT (1-2:30pm ET)

Part 3

Monitoring Invasive Grassland Species with Hyperspectral Remote Sensing

August 28, 2024

10-11:30 PT (1-2:30pm ET)

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How to Ask Questions

- Please put your questions in the Questions box and we will address them at the end of the webinar.
- Feel free to enter your questions as we go. We will try to get to all of the questions during the Q&A session after the webinar.
- The remainder of the questions will be answered in the Q&A document, which will be posted to the training website about a week after the training.

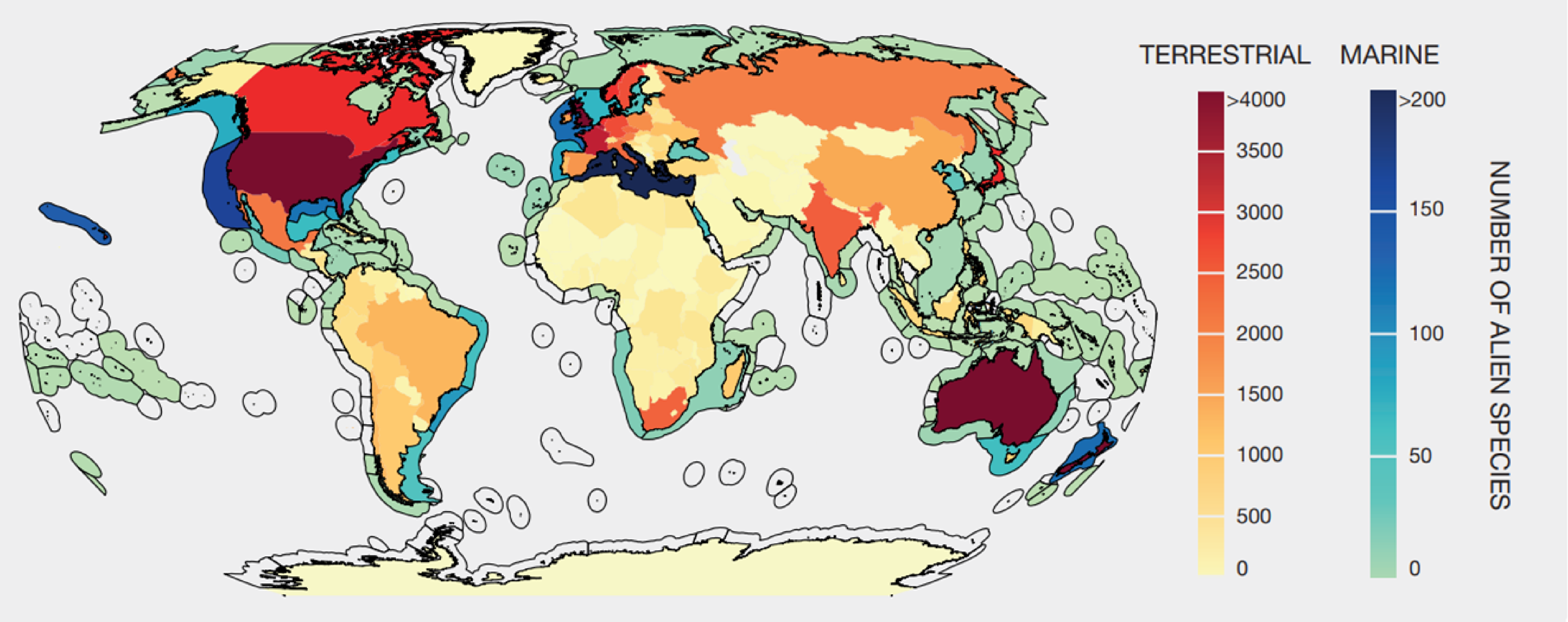
Invasive Species Monitoring with Remote Sensing
Part 1

Part 1 Objectives

By the end of Part 1, participants will be able to:

- Recognize the extent and impacts of invasive species on biodiversity and a changing climate.
- Identify commonly used types of remote sensing data and products that can be used for invasive species mapping and monitoring.
- Identify upcoming satellite missions with application for invasive species research.
- Identify where to access commonly used remote sensing data for monitoring invasive species and mapping relevant habitat and climate variables.
- Identify key considerations, benefits and limitations of remote sensing data sets for invasive species.
- Differentiate the properties of multispectral and hyperspectral datasets for monitoring of invasive species.
- Cite remote sensing methods used in invasive species monitoring from past NASA projects and recent literature.

Invasive Species Around the World



IPBES 2023

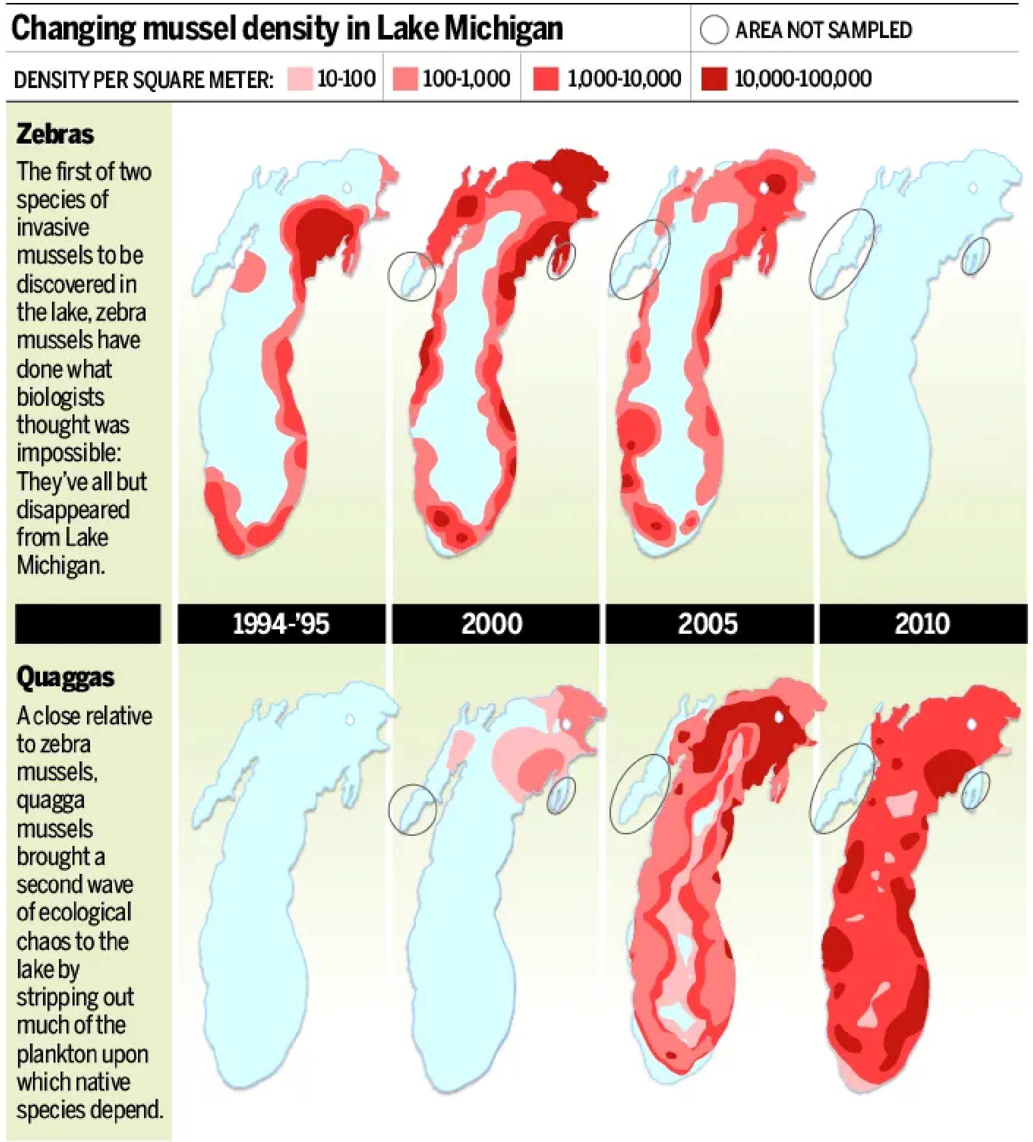
What Makes an Invasive Species?

- The definition of invasive species is context specific
- All invasive species are native to *somewhere* but can become invasive when removed from their native ecosystem
- May outcompete native species, exert new pressures, disrupt ecosystem services

Climate Change & Invasive Species

- Invasive species are increasing globally at unprecedented rates.
- Human activities facilitate the spread of invasives.
- Climate change can open up new areas for invasives to spread
- "Climate change interacting with land- and sea-use change is predicted to profoundly shape and amplify the future threat from invasive alien species"

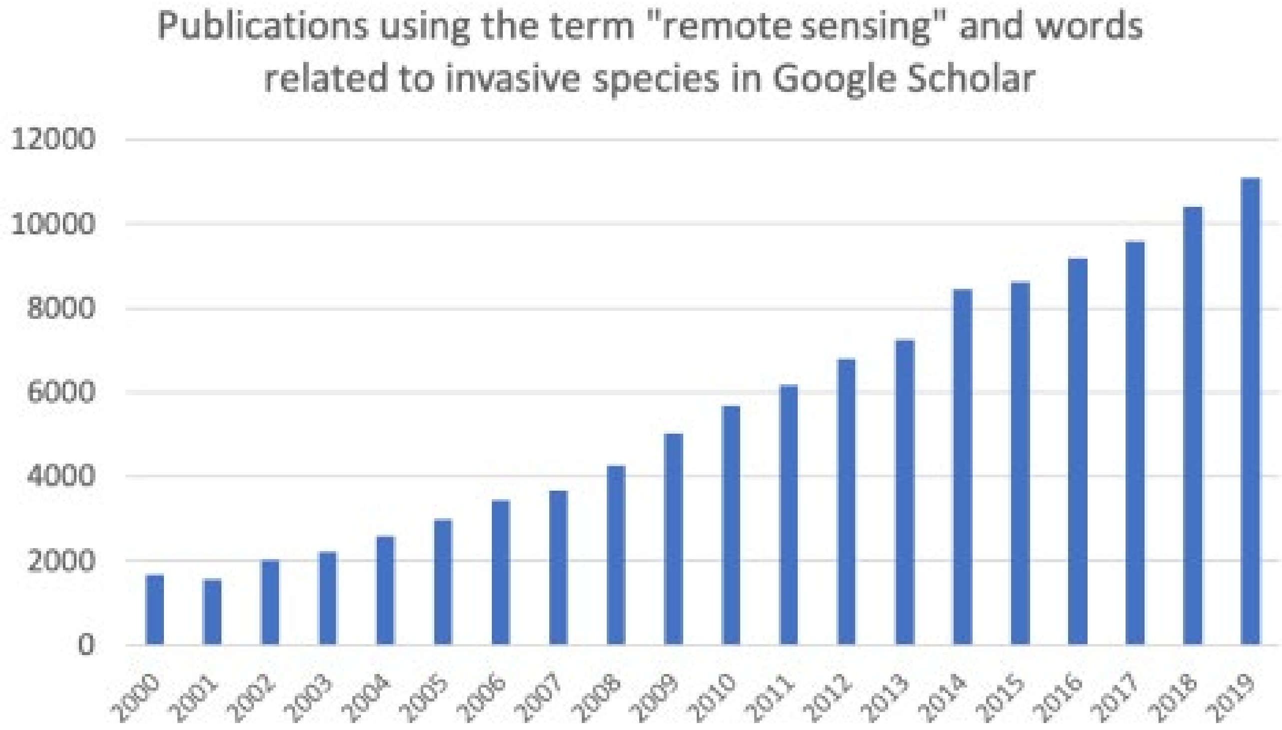
Source: [IPBES Report]



Tom Nalepa, NOAA

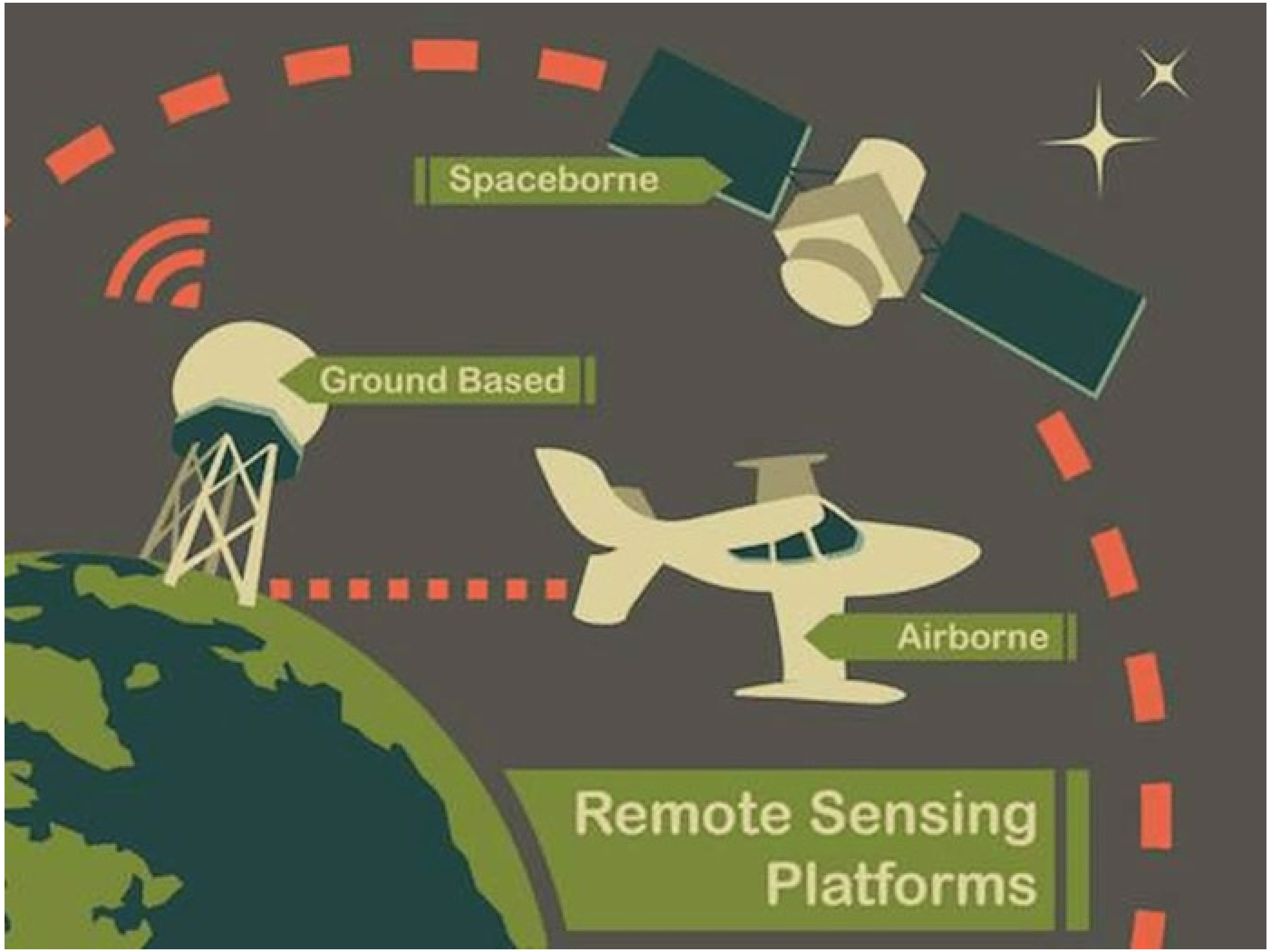
Sensing Invasive Species From Space

Tamarisk (Tamarix spp.) was introduced in the U.S. in the late 1800s and is now the second most common riparian tree in western North America. Public domain image courtesy of U.S. Geological Survey.
Source: Earthdata- sensing invasive species



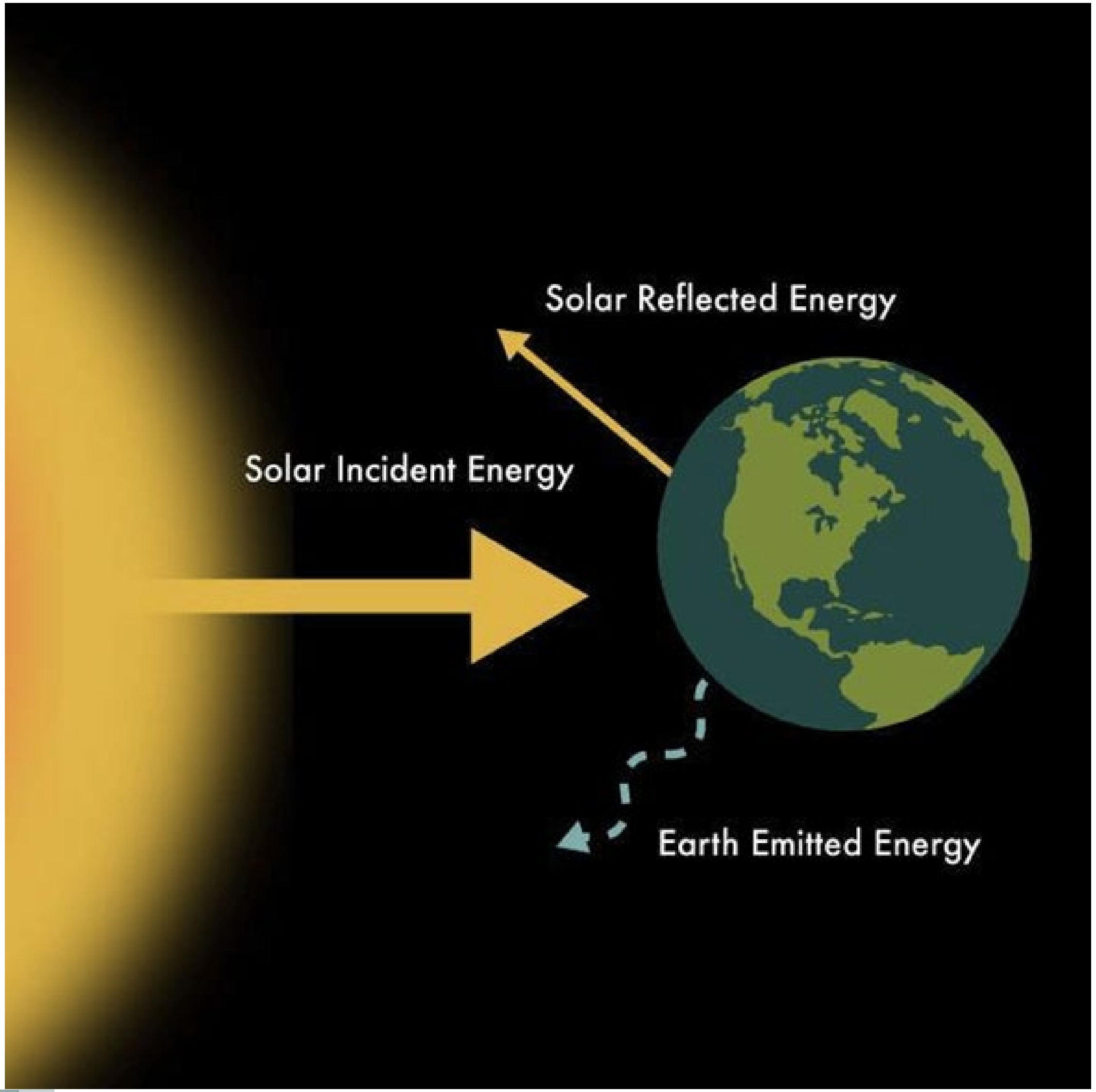
Google Scholar reveals an increasing number of publications each year using search terms related to invasive species and remote sensing.

Remote Sensing



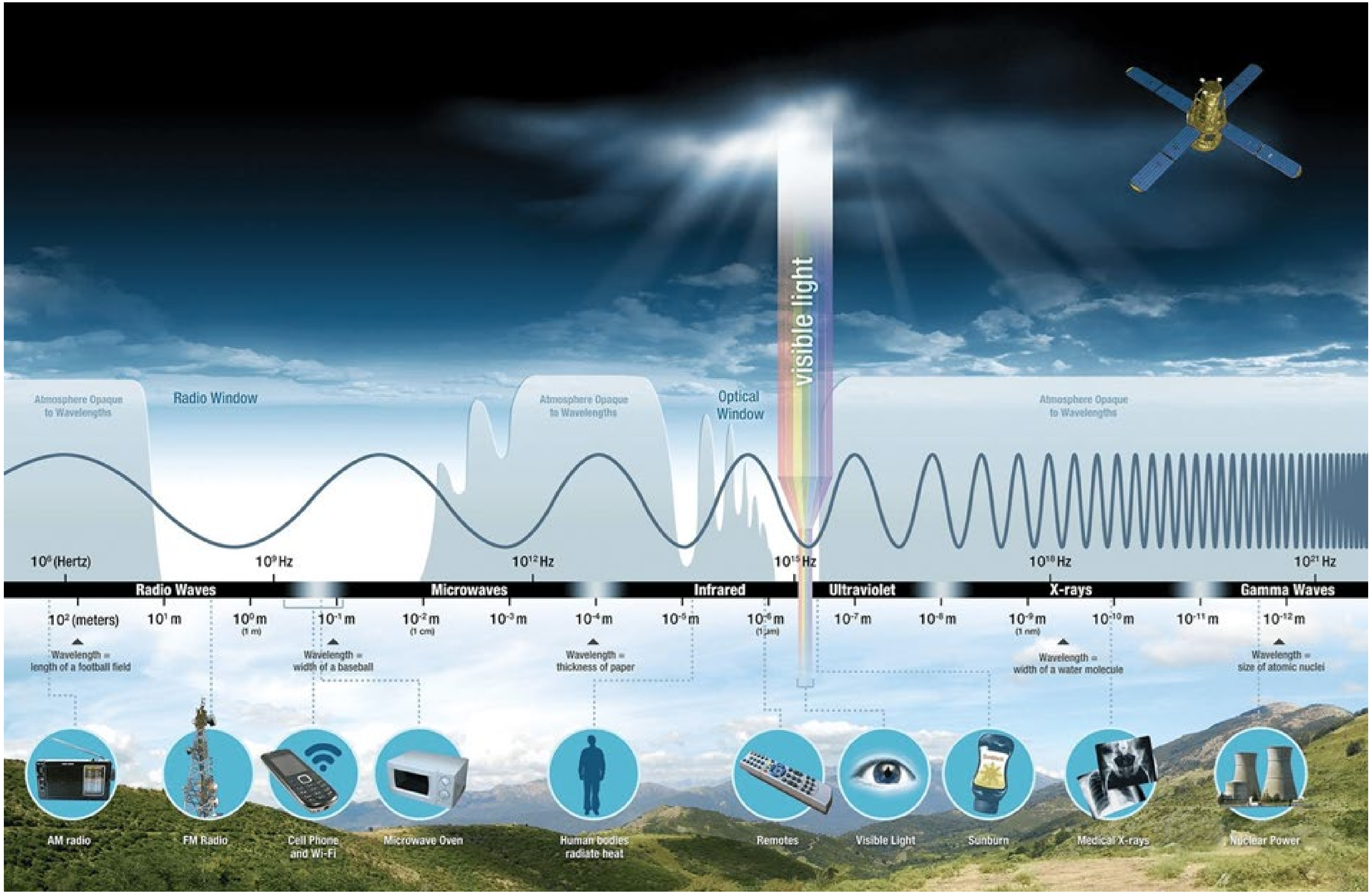
- Remote sensing is obtaining information about an object from a distance.
- There are different ways to collect data, and different sensors are used depending on the application.
- Some methods collect ground-based data, others airborne or spaceborne.

Electromagnetic Radiation



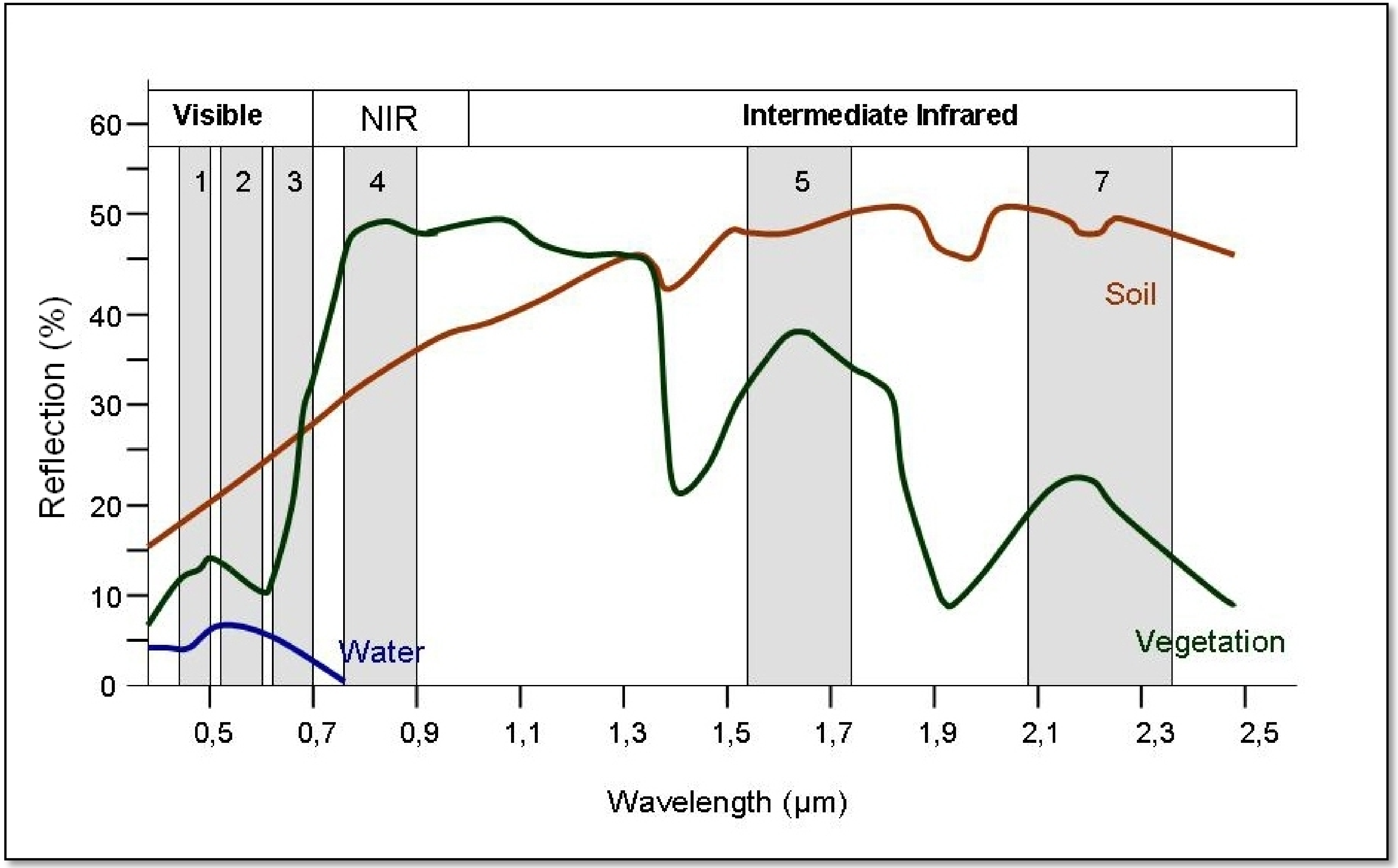
- The energy Earth receives from the sun is called electromagnetic radiation.
- Radiation is reflected, absorbed, and emitted by the Earth's atmosphere or surface, as shown by the figure on the left.
- Satellites carry instruments or sensors that measure electromagnetic radiation reflected or emitted from both terrestrial and atmospheric sources.

Electromagnetic Spectrum



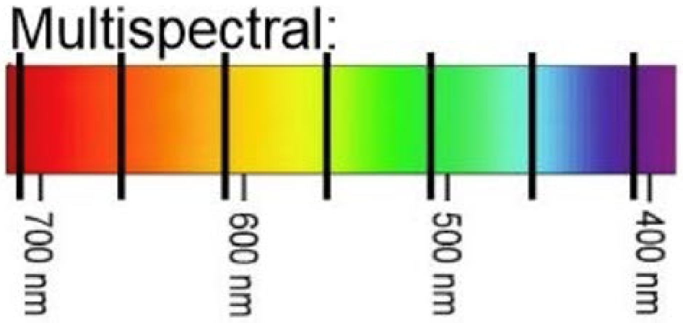
Spectral Signatures

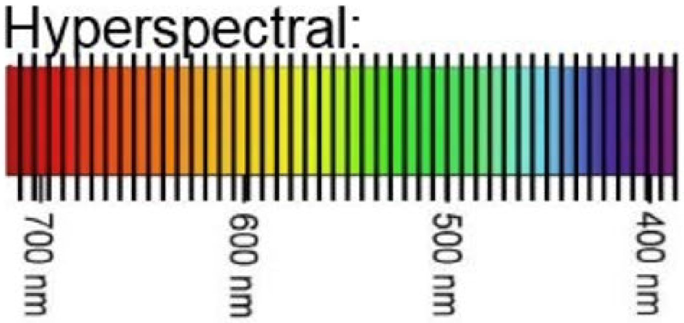
- Every material and surface reflects and absorbs energy in different ways
- Satellite-based sensors primarily record **reflected** energy
- Understanding the unique spectral signatures of different surfaces allows us to tell them apart



Spectral Resolution

- Multispectral sensors divide the electromagnetic spectrum into multiple bands
- Bands typically expand beyond the visible into the infrared spectrum and sometimes into the ultraviolet spectrum
- Hyperspectral sensors use smaller divisions to image hundreds of bands where each is a tiny slice of the spectrum





Low resolution

High resolution

Spatial Resolution

- Signifies the ground surface area that forms one pixel in the image.
- The pixel size of the image- the smallest possible feature that can be detected (usually in meters).
- The higher the spatial resolution, the less area is covered by a single pixel

Here is how the Wimbledon Tennis Complex (London, UK) appears at different resolutions associated with several of the satellites highlighted. All the images below are generated from a Worldview-4 image and resampled to be representative of the different spatial resolutions represented.

Aqua (MODIS)
250m Resolution

Landsat-8
30m Resolution

Sentinel-2
10m Resolution

PlanetScope (Dove)
3m Resolution

Pleiades
0.5m Resolution

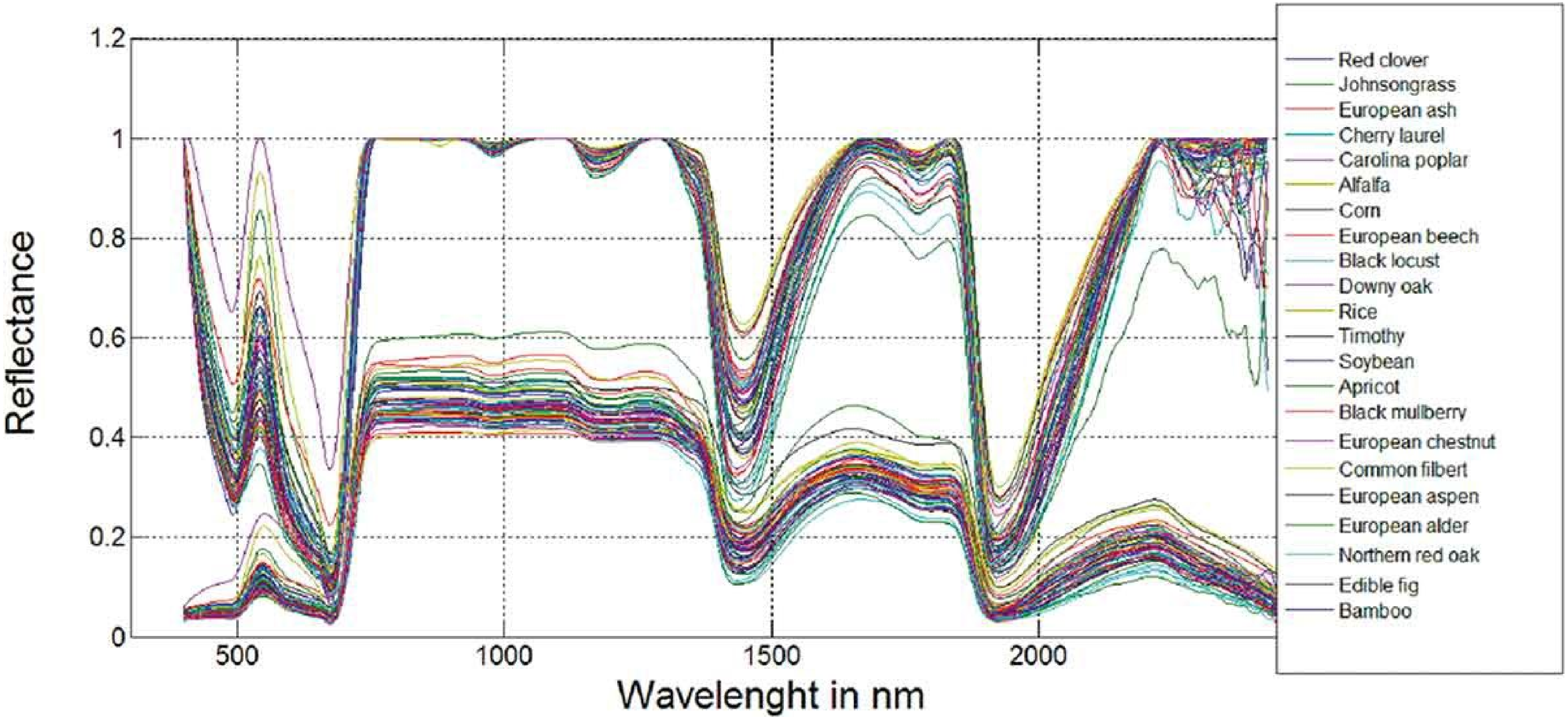
Worldview-4
0.3m Resolution

Temporal Resolution

- It takes time for a satellite to complete one orbit. This is called the revisit time or temporal resolution.
- Depends on the satellite and sensor capabilities, swath overlap and latitude.

Sensor	Revisit Time	Spatial Resolution
Landsat	16 days	30 m
Sentinel-2	10 days	10,20 m
MODIS/VIIRS	1 days	250m-1km/ 375m

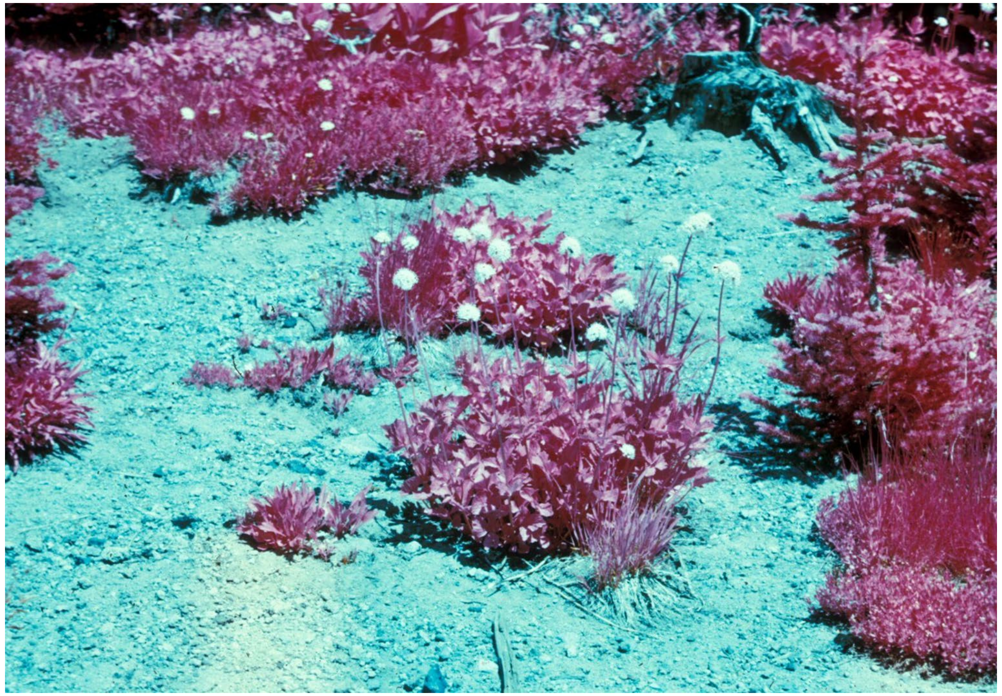
Remote Sensing Detection by Spectral Differences



Bahrami, M., & Mobasheri, M. R. (2020).

Classification

- Differences in spectral signatures are used to differentiate between surfaces through a process called classification
- With enough information it is sometimes possible to tell the difference between species of plants



Remote Sensing Detection by Phenology

Seasonal cycle of a tree, Image Credit: USGS/NPN)

Ecological Importance of Events on Phenology

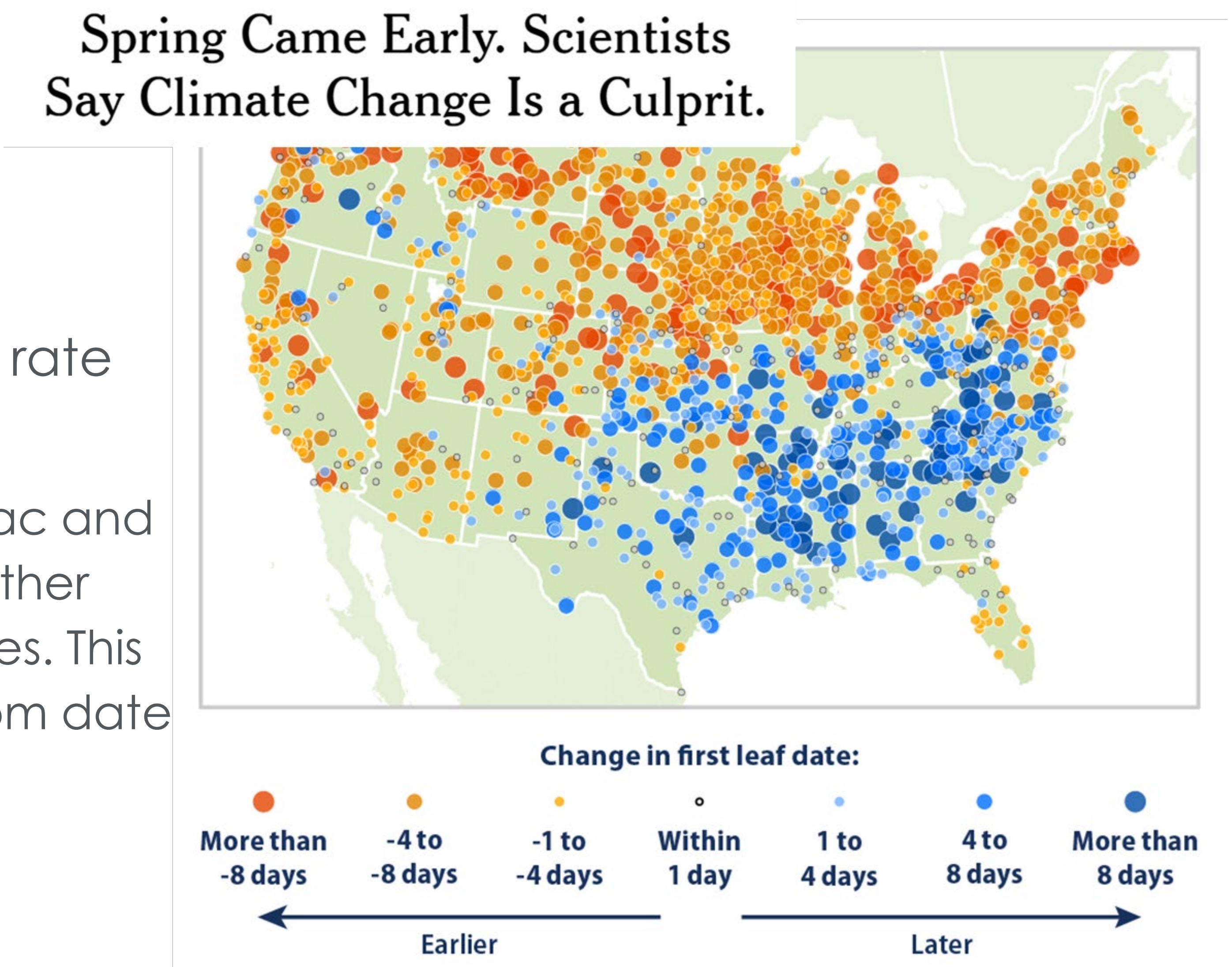
- Phenological events change from year to year
- Timing of events (phenophase) such as flowering, leafing, migration, and insect emergence can impact how plants and animals are able to thrive in their environment
- Influences abundance and distribution of organisms, ecosystems services, and global cycles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

Ecological Importance of Climate Change on Phenology

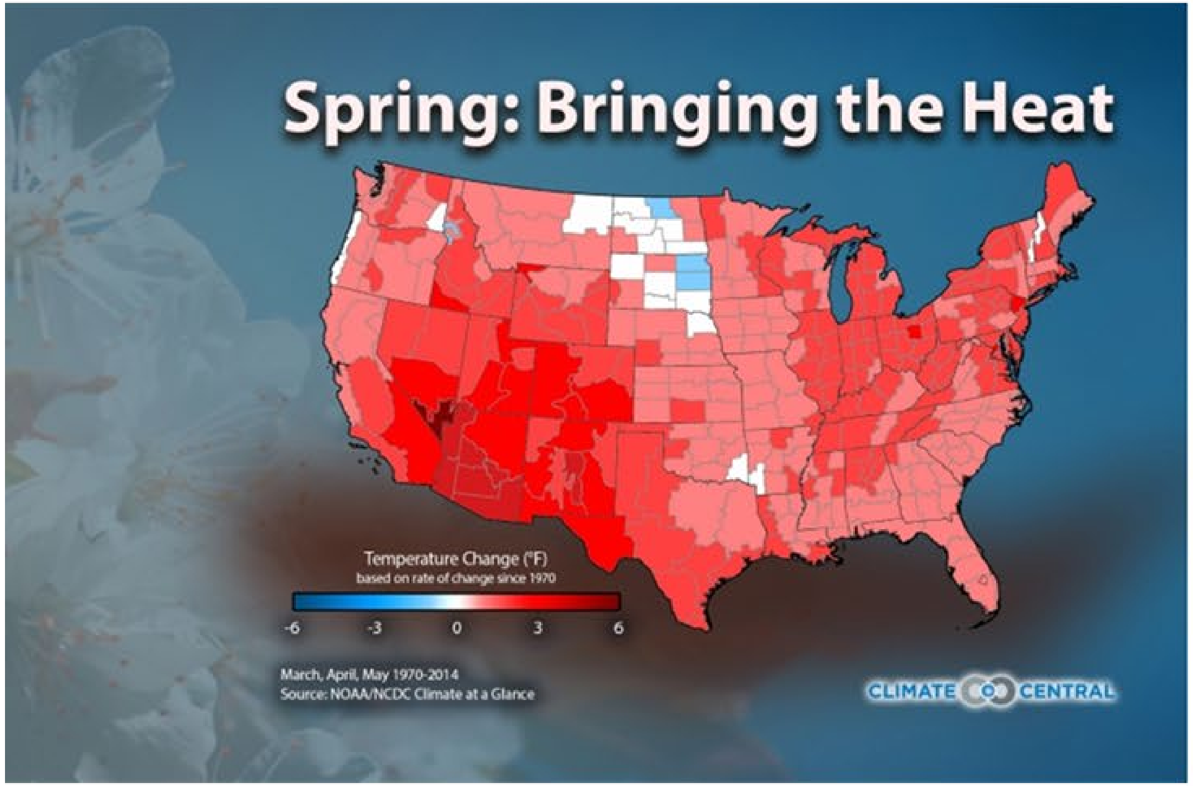
- These processes are sensitive to climate change
  - Earlier spring, later fall
- Not all species changing at same rate or direction

This figure shows modeled trends in lilac and honeysuckle first bloom dates at weather stations across the contiguous 48 states. This map compares the average first bloom date during two 10-year periods.

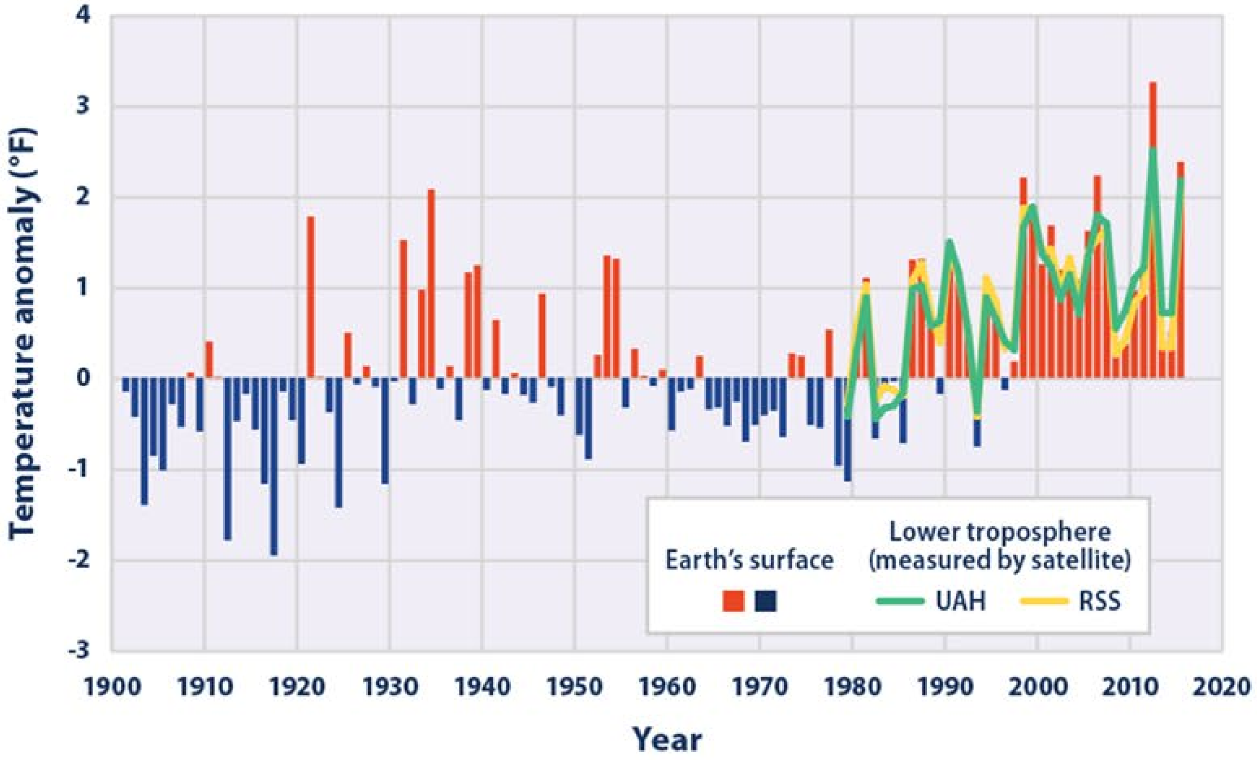
Image Credit: Schwartz, 2016



Drivers of Phenology: Temperature

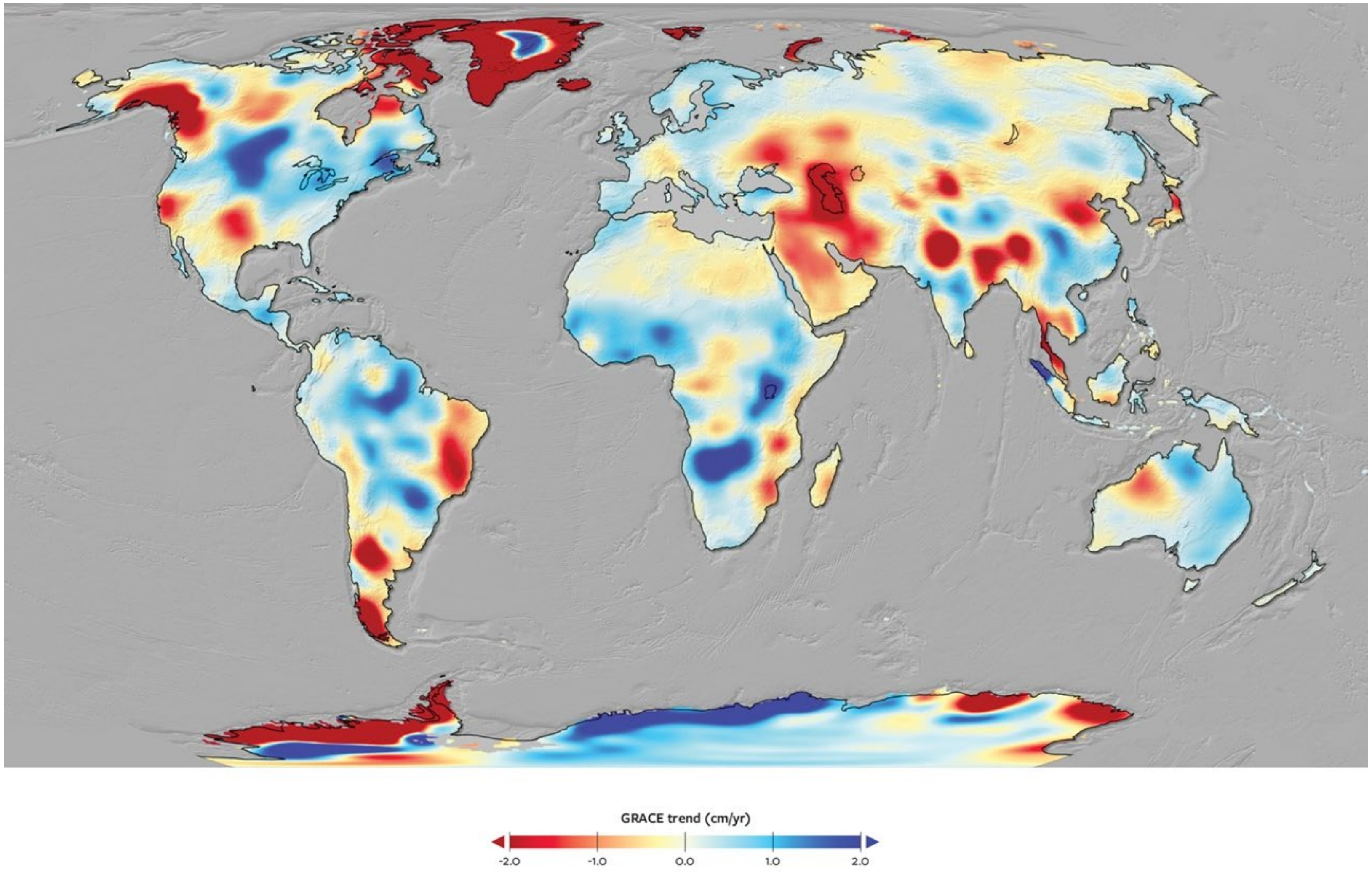


Spring temperature change from 1970-2014, based on rate of change from 1970.
Image credit: Climate Central.



Annual average temperatures in the contiguous 48 states from 1901-2016.
Image credit: NOAA, 2016.

Drivers of Phenology: Water Availability



A Map of the Future of Water | The Pew Charitable Trusts (pewtrusts.org)

Phenology: Applications

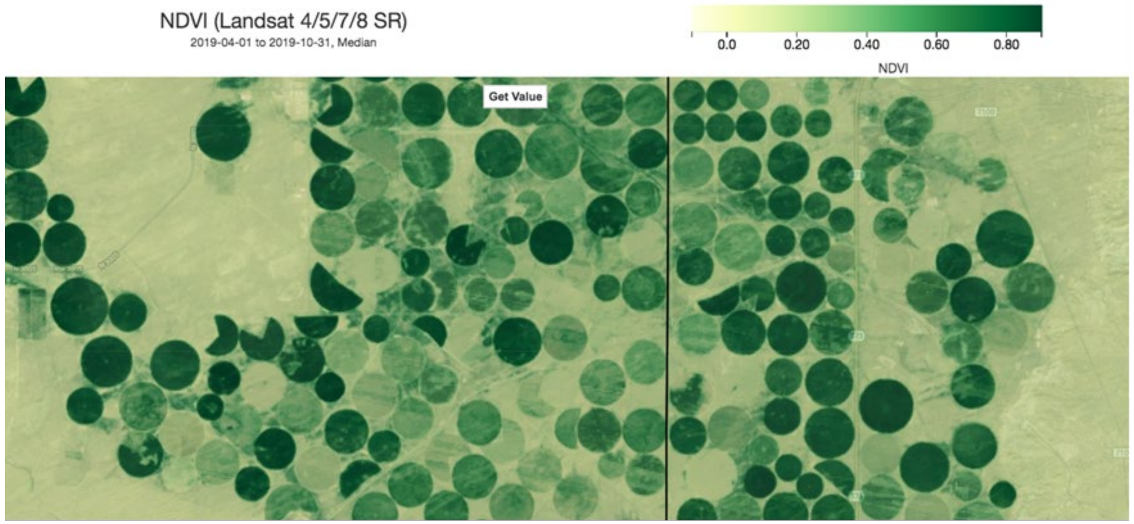
- Management of invasive species
- Predictions of human-health related events: allergies or mosquito-borne illness
- Crop management
- Understanding of carbon cycling
- Climate change vulnerability


Image credit: Pexels

Remote Sensing of Phenology

Land Surface Phenology

- 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
  - –Mapping infectious disease risk
  - –Invasive species and pest tracking



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

Full training:

ARSET - Understanding Phenology with Remote Sensing | NASA Applied Sciences

Part 2:
Examples

NASA DEVELOP: Invasive Plants in Alaskan Wetlands

- Purple loosestrife & Reed canarygrass are invasive to Alaskan wetlands
- Climate and terrain data were combined to highlight wetland areas with suitable growing conditions for these plants
- Knowing where invasive species are likely to grow allows resource managers to focus limited resources on those critical areas

NASA DEVELOP: Earth Observations for Invasive Pests

- US hemlock forests are threatened by the introduction of the hemlock wooly adelgid, a small parasitic insect which feeds on sap
- Remote sensing allowed the team to differentiate hemlock trees from other conifers
- At-risk hemlock stands can be targeted for preventative treatment to stop the spread of the pests

Connecticut Agricultural Experiment Station Archive, Connecticut Agricultural Experiment Station / © Bugwood.org

NASA DEVELOP: Forecasting Invasive Species Presence

- Sometimes it isn't possible to accurately map all areas or species which may be at risk
- Using climate data from remote sensing and predictive climate models in conjunction with known growing areas it is possible to estimate where invasive species or their hosts will grow in the future
- This means that landscape managers can rapidly respond to new and emerging threats and minimize damage

Part 3:
Recent Literature

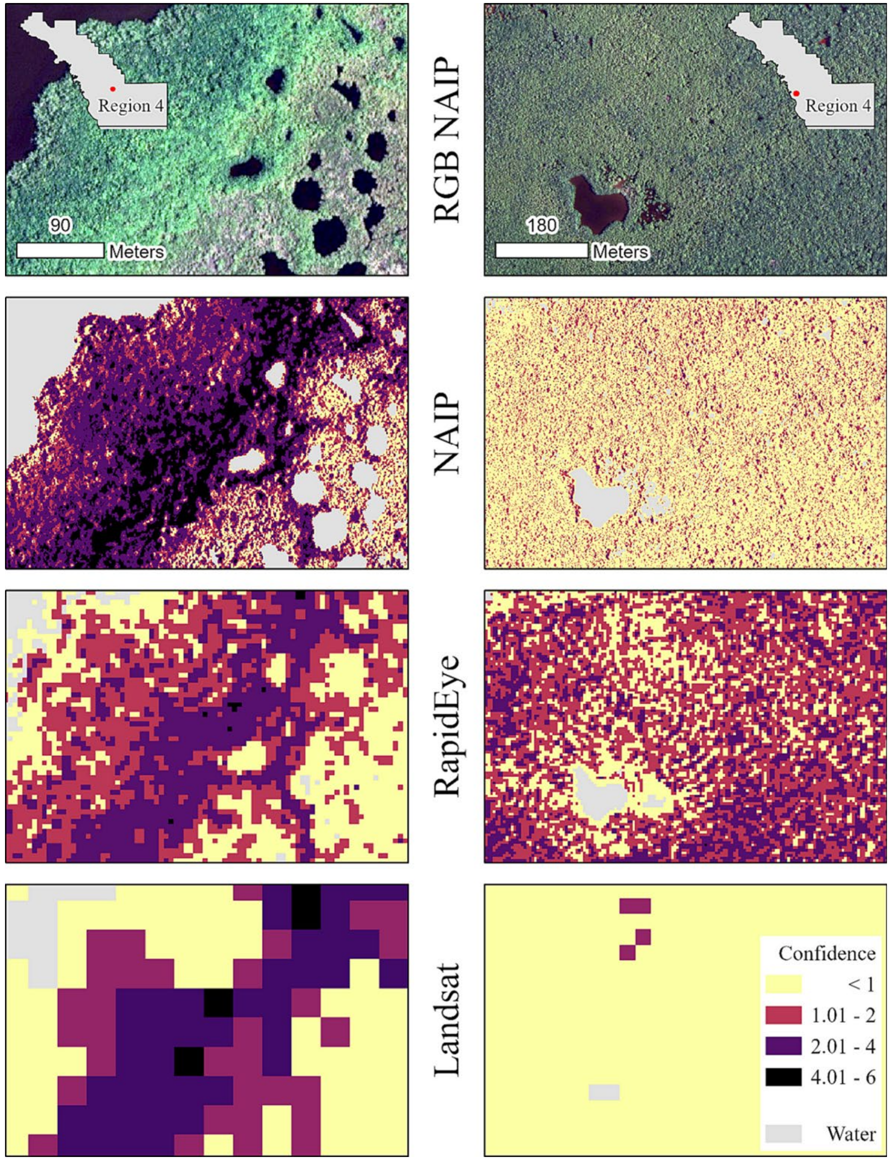
Airborne Hyperspectral Images and Machine Learning Algorithms for the Identification of Lupine Invasive Species in Natura 2000 Meadows

- Tested both supervised and unsupervised classification methods
- Imagery collected with HySpex sensor on UAV (430 bands)
- Bands reduced using Minimum Noise Fraction with only the first 30 bands giving classification improvement
  - This is similar to PCA, if you're familiar with how that works
- Showed that timing of the imagery is critical to good classification
  - It's important to know your species to optimize your data collection

Sabat-Tomala, A.; Raczko, E.; Zagajewski, B. Airborne Hyperspectral Images and Machine Learning Algorithms for the Identification of Lupine Invasive Species in Natura 2000 Meadows. Remote Sens. 2024, 16, 580. https://doi.org/10.3390/rs16030580

Dealing with imperfect data for invasive species detection using multispectral imagery

- More is more!
- Used 3 different multispectral products (Landsat, RapidEye, NAIP)
- Makes efficient use of training data
- Minimal computational load
- Essentially an ensemble of classifiers; establish consensus based on many observations which are individually noisy, but better together
  - More specifically: Multitarget multiple-instance spectral match filter (MTMI-SMF)
- Excitingly close to being able to say “Computer, enhance!” like the movies



Susan Meerdink, Drew Hiatt, S. Luke Flory, Alina Zare, Dealing with imperfect data for invasive species detection using multispectral imagery, Ecological Informatics, Volume 79, 2024, 102432, ISSN 1574-9541, https://doi.org/10.1016/j.ecoinf.2023.102432.

Review of Invasive Plant Functional Traits and Management Using Remote Sensing in Sub-Saharan Africa

- Reviewed remote sensing methods used for terrestrial invasive plant monitoring in the region between 2000 and 2024
- Highlights how the properties of invasive plants (functional traits, phenology, phenotypic plasticity, etc.) can be used to detect and predict invasives
- Using RS to quantify invasibility, identify vectors, assess impact, support eradication, and monitor restoration

Ojija, F.; Petruzzellis, F.; Bacaro, G. Review of Invasive Plant Functional Traits and Management Using Remote Sensing in Sub-Saharan Africa. *Int. J. Plant Biol.* **2024**, *15*, 358-374. https://doi.org/10.3390/ijpb15020029

Invasive Datura stramonium, one of the plants in the literature reviewed.

Considerations

There are many factors to consider when undertaking a remote sensing approach to monitoring invasive species. Many factors will be unique to your study, but these are some general considerations to keep in mind.

- Scale mismatch
- Temporal resolution
- Spectral signatures
- Availability
- Cost
- Complexity

Considerations: Scale mismatch

- Is the resolution of available imagery sufficient for the scale of the phenomenon you want to study?
    - A few individuals of a species won't be easily seen at lower resolutions
- Is the species spatially distributed in a way that would benefit from a drone or other aircraft-based system?

Considerations: Temporal resolution

- How quickly do things change in your study area?
  - Many popular satellite platforms have revisit times of 5-16 days
- Is there a particular time of year, or other temporal component, that will impact your results?

Considerations: Spectral signatures

- Is there a distinction between what you are interested in and what you are not?
- If you can't observe the invasives directly, can you instead observe them indirectly through their interaction the ecosystem?
- Is there another associated feature that could point you in the right direction?
  - Especially relevant in cases like hemlock wooly adelgid

Considerations: Availability

- Are there cloud-free images available for the time and place you want to study?
- For particularly long processes: Is there a sufficient catalog of imagery going back in time?
    - New sensors are developed, old ones decommissioned, and 1:1 band matches between them are rare

Considerations: Cost

- Is there free imagery available that will work for your purposes?
- If not, can you justify the price of purchasing commercial imagery?
- At the extreme end, it may make sense to consider flying your own mission

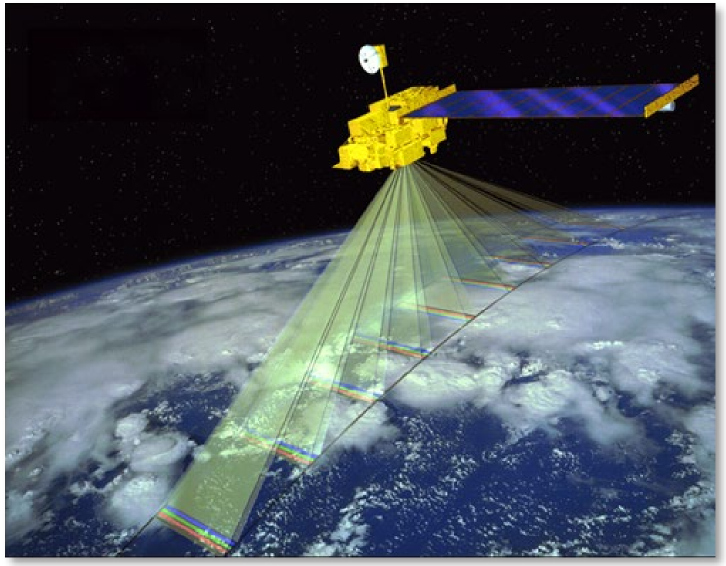
Considerations: Complexity

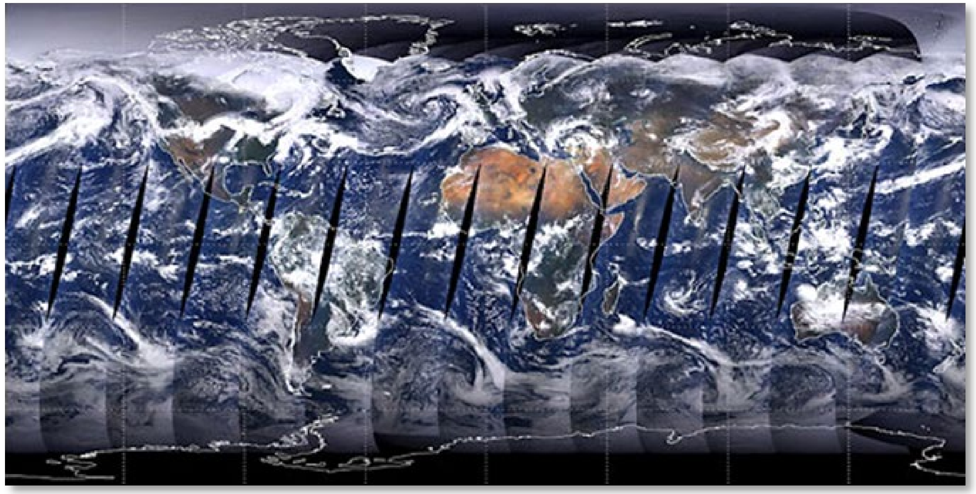
- Do you have access to the expertise required to conduct analysis and interpret the results?
- Do you have the technological resources to do the analysis?
- Would a simpler method achieve your goals without the extra overhead of something more complicated?

Part 4:
Satellites and Sensors

Moderate Resolution Imaging Spectroradiometer (MODIS)

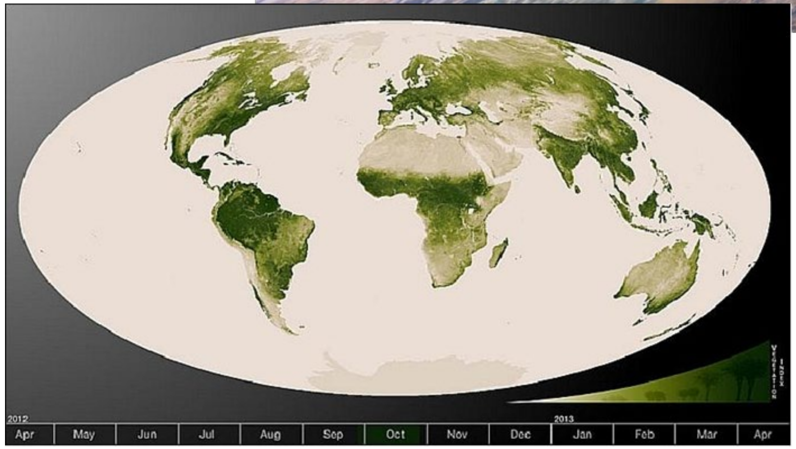
- Spatial Resolution
  - 250 m, 500 m, 1 km
- Temporal Resolution
  - Daily, 8 day, 16 day, monthly, quarterly, yearly
  - 2000–present
- Data Format
  - Hierarchical data format – Earth Observing System Format (HDF–EO8)
- Spectral Coverage
  - 36 bands (major bands include blue, green, red, IR, NIR, MIR)
    - Bands 1-2: 250 m
    - Bands 3-7: 500 m
    - Bands 8-36: 1000 m





Visible Infrared Imaging Radiometer Suite (VIIRS)

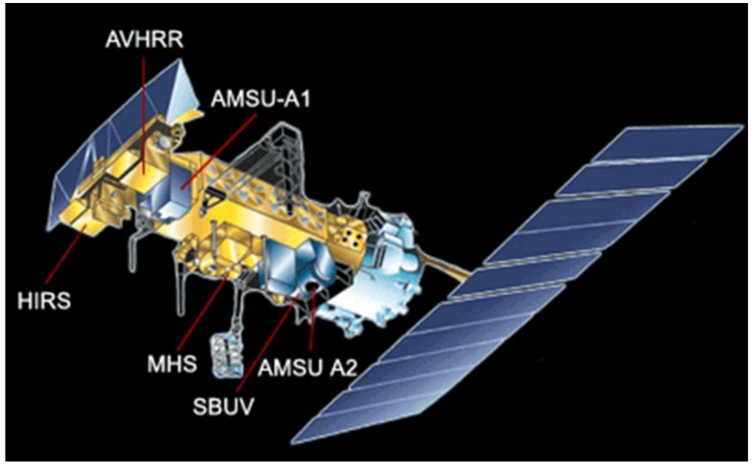
- A sensor onboard the Suomi National Polar-Orbiting Partnership (NPP)
- Data available globally from January 2012 to present
- Revisit Time: 16 day (1 day global)
- Spatial Resolution: 375m and 750m
- Similar to MODIS (with some differences)
- Visible, near-infrared channels (reflectance)
- Shortwave and longwave infrared (brightness temperature)
- Products:
  - Surface reflectance
  - Vegetation indices
  - Thermal anomalies



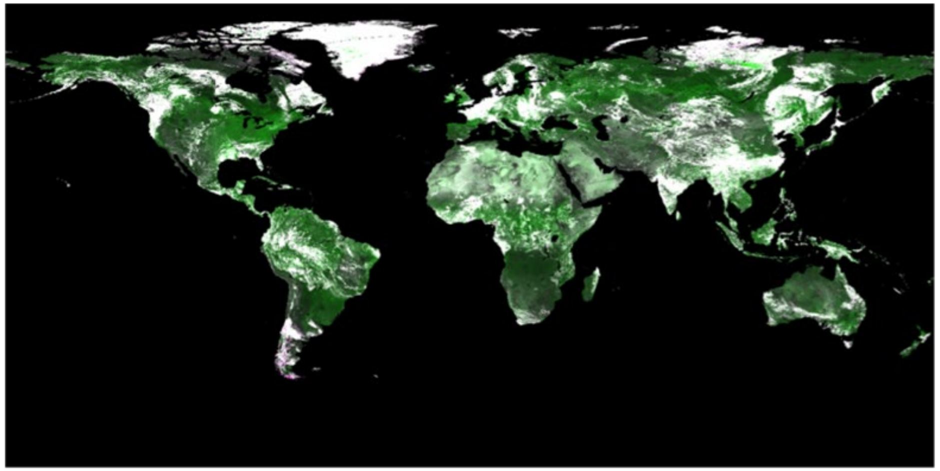
Suomi NPP satellite (above); Global vegetation map (left). Image Credit: NASA/NOAA)

Advanced Very High Resolution Radiometer (AVHRR)

- Produced and operated by the National Oceanic and Atmospheric Administration (NOAA)
- Onboard many NOAA Polar Orbiting Environmental Satellites (POES),
- Data available from 1978 to present
- Spatial Resolution: 1 km
- Temporal Resolution: Global coverage available twice daily (morning and afternoon)
- Spectral Resolution: 4-6 bands, multispectral,
- visible, near-infrared, and thermal bands
- Land cover and vegetation index products available



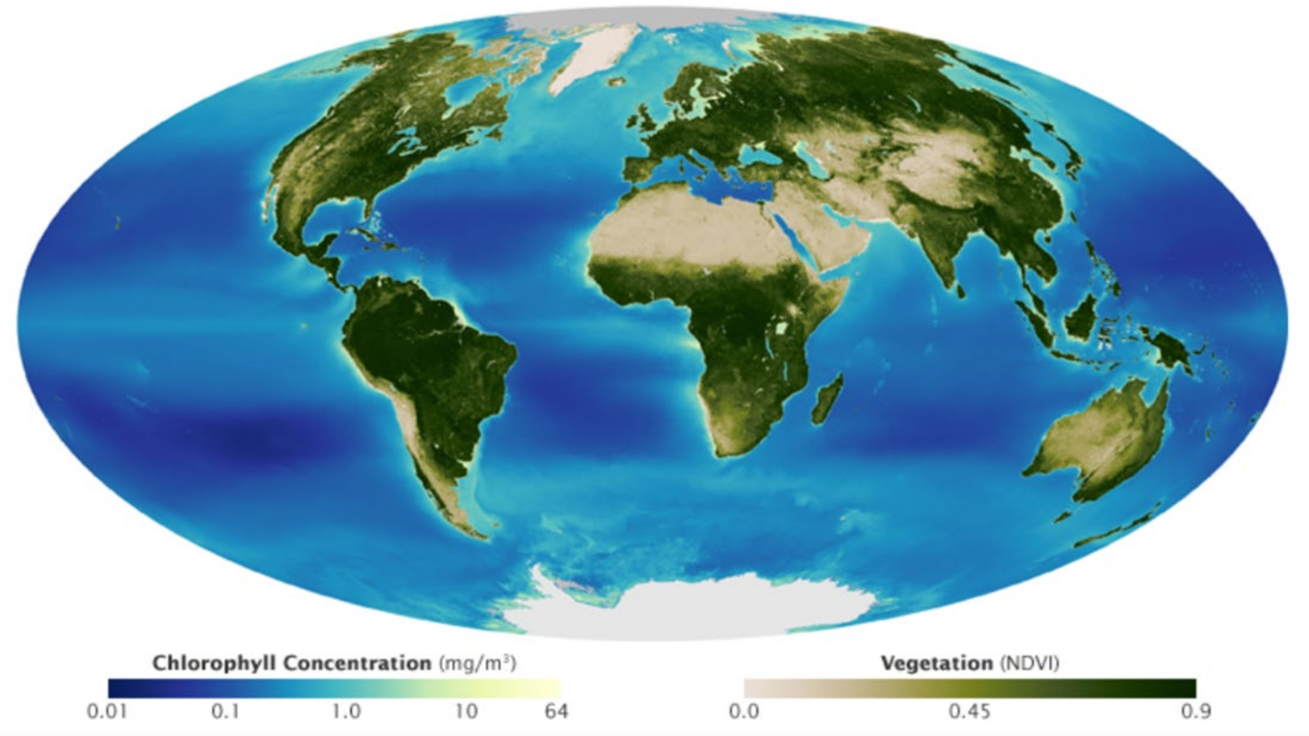
NOAA's N instrument, with the AVHRR sensor included. Image credit: NOAA



Surface reflectance from AVHRR (global, 1km). Image Credit: NOAA

Sea-viewing Wide Field-of-view-Sensor (SeaWiFS)

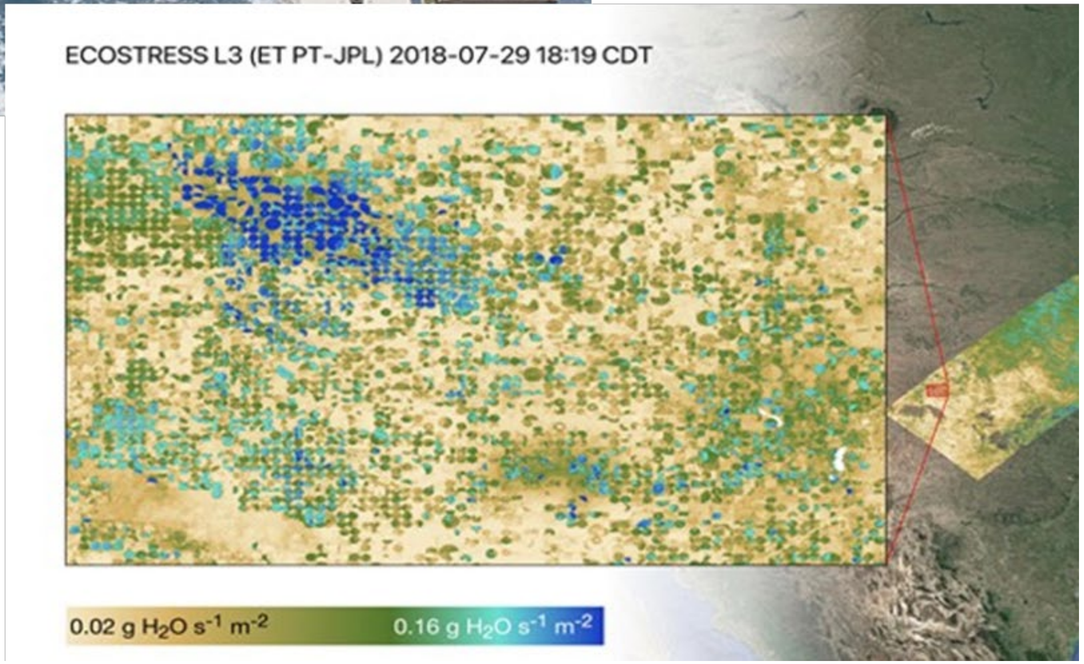
- Designed to measure ocean chlorophyll, but can be used for land applications too
- Built by private company: Orbital Sciences, onboard the OrbView-2 satellite
- Dates: 1998- 2010
- 8 bands
- 4km spatial resolution
- Global coverage every 16 days
- Applications:
  - Ocean color
  - Vegetation health (NDVI)



Ocean chlorophyll and NDVI from 1998-2010 via SeaWiFS. Image Credit: NASA

The ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS)

- Primarily used to measure Evapotranspiration (ET)
- Onboard the International Space Station (ISS)
- Spatial resolution: 400 km
- Data coverage: 12 key climate zones and Fluxnet sites
- Repeat time: hourly at those locations
- Data available on LP DAAC, Earthdata, AppEEARS, and USGS Earth Explorer



ECOSTRESS onboard the ISS (left) and ET from crop lands (below). Image Credits: NASA/Dr. Joshua Fisher

Surface Biology and Geology (SBG) Mission

New instrument in development: Guidance from the 2018 Decadal Survey

Hyperspectral and thermal data under consideration

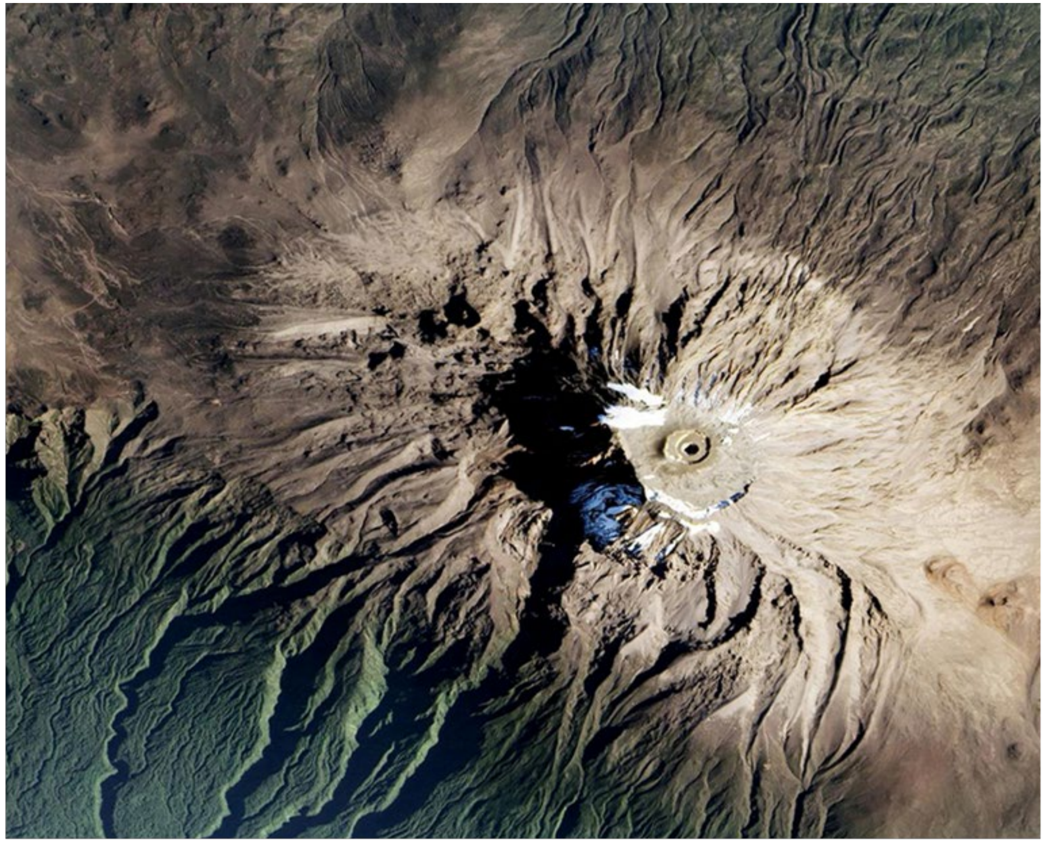
Applications could include:

- Water cycle and anthropogenic impacts
- Biodiversity
- Carbon fluxes
- Land surface/atmosphere interactions
- Volcanos
- Landscape change

The Applications Working Group is coordinating and integrating applications needs

Email list for updates: sbg@jpl.nasa.gov

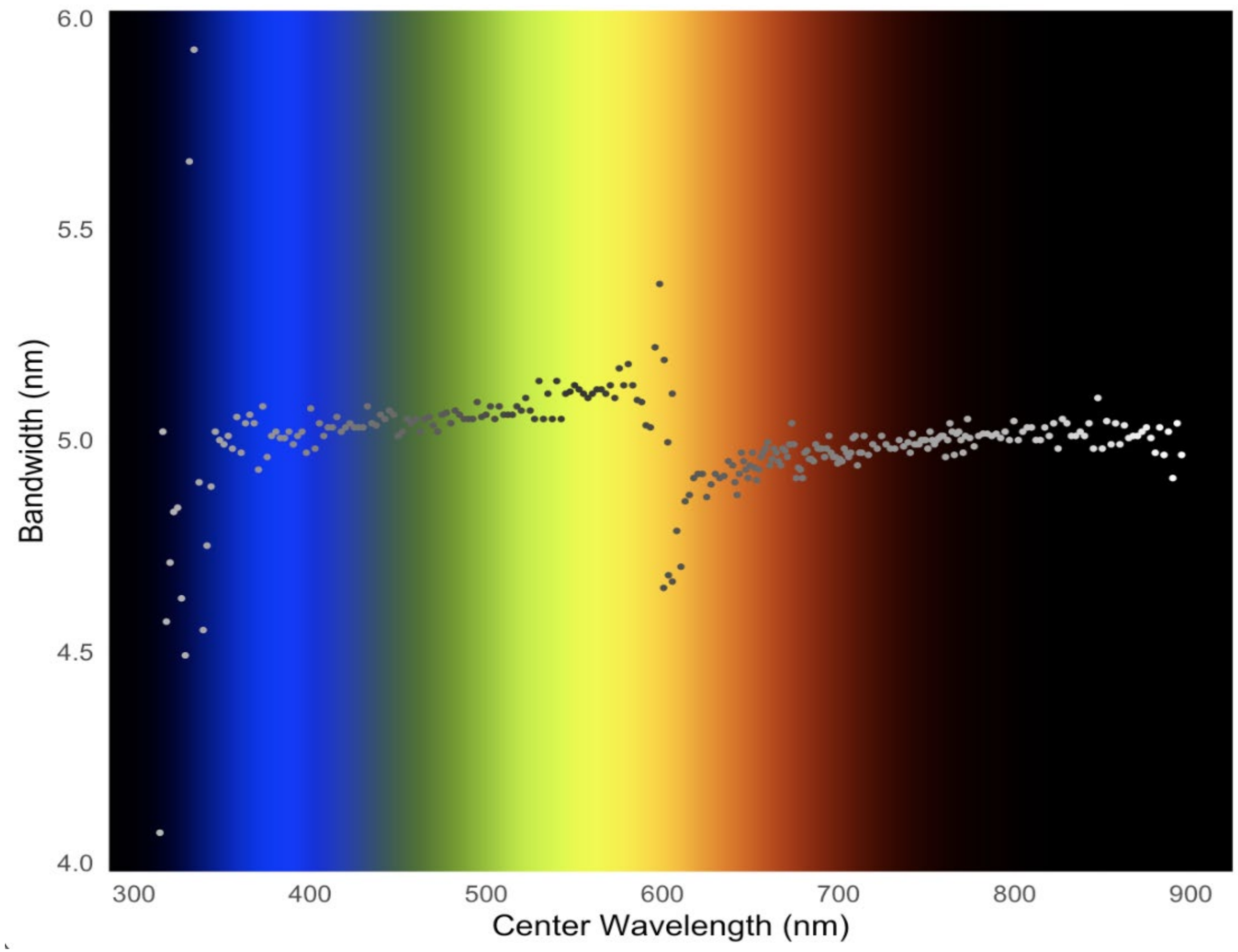
For more info: https://sbg.jpl.nasa.gov/



Mount Kilimanjaro Image Credit: JPL SBG

PACE (Plankton, Aerosol, Cloud, and ocean Ecosystem)

- Launched 8 February 2024
- Data release started 11 April 2024
- Ocean Color Imager (OCI)
- 250+ bands from UV to NIR
  - Some SWIR coverage
- Can differentiate between harmful algal blooms and harmless ones
- Very fine spectral resolution



PACE band centers and bandwidths from UV to NIR (SWIR not shown). Background approximates visible spectrum.

Derived from:
https://oceancolor.gsfc.nasa.gov/data/pace/characterization/
http://www.cvrl.org/

HyMap

- Developed by HyVista Corporation, Australia
- First commercial hyperspectral instrument
- Designed to deliver high spatial and spectral resolution
- Aircraft-mounted, actively stabilized
- Hyperspectral (120 bands)
- 5 meter spatial resolution
- Applications include:
  - Geology/Mineral detection
  - Vegetation classification
  - Near-shore marine observation

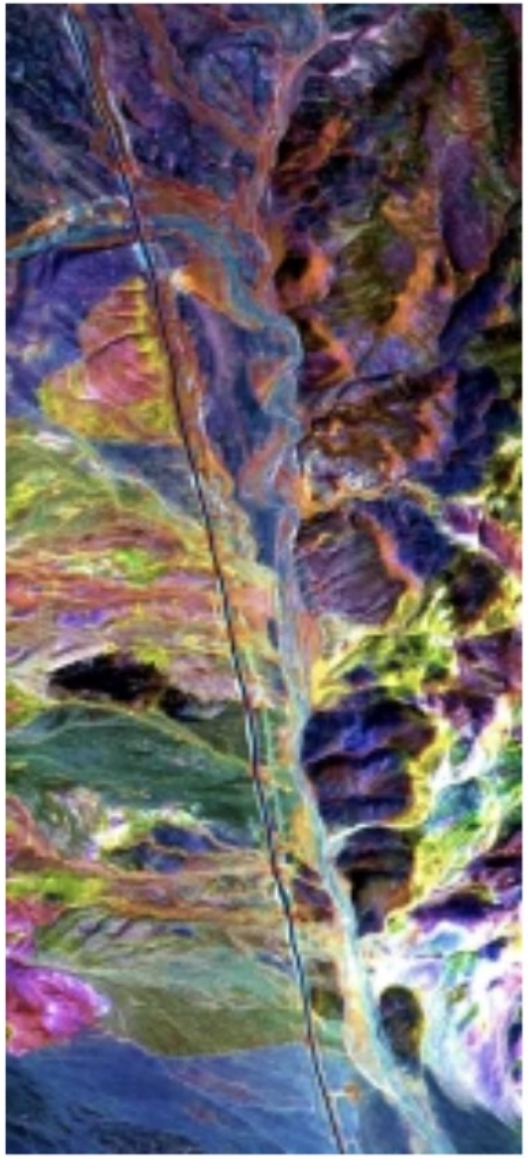


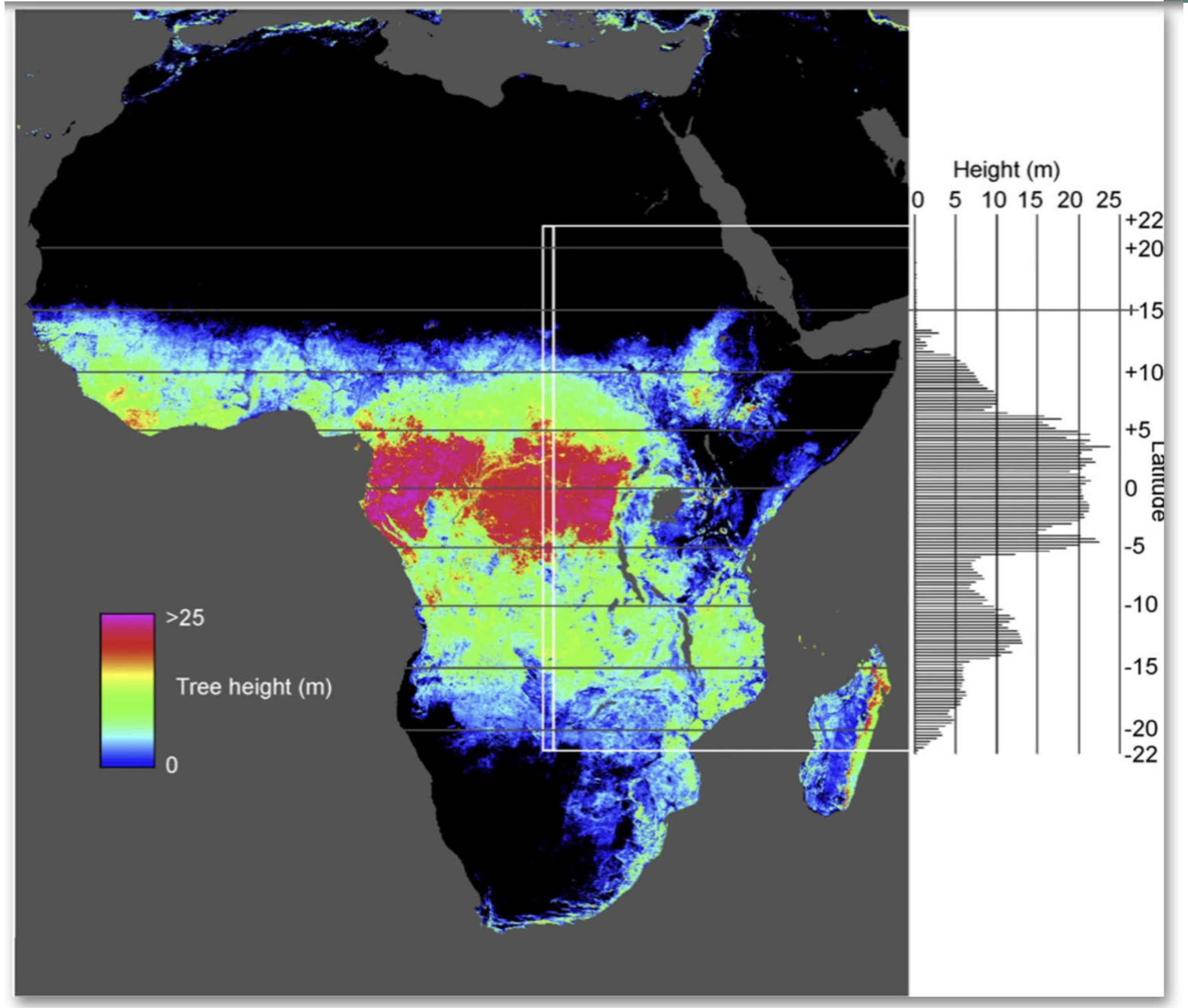
Image near Cuprite, NV.
(HyVista Corporation, 1998)

GLIMR (Geosynchronous Littoral Imaging and Monitoring Radiometer)

- Upcoming mission launching as early as 2026
- Designed to study the dynamics of water near river mouths
  - ocean biology
  - ecology
  - chemistry
- Focused on the Amazon river plume, southeastern US Coast, and Gulf of Mexico
- Learn more at: https://science.nasa.gov/mission/glimr/

GEDI

- Very high resolution lidar
- Uses the travel time of laser pulses to map surface features
- 4 main derived products:
  - surface topography
  - canopy height
  - canopy cover
  - vertical structure metrics
- High sample density allows GEDI to peer between the leaves of trees
- Accurate mapping of biomass change over time and potential as an input to biodiversity or species distribution models



Tree height over Africa (University of Maryland)

Part 5:

Accessing and Analyzing Data

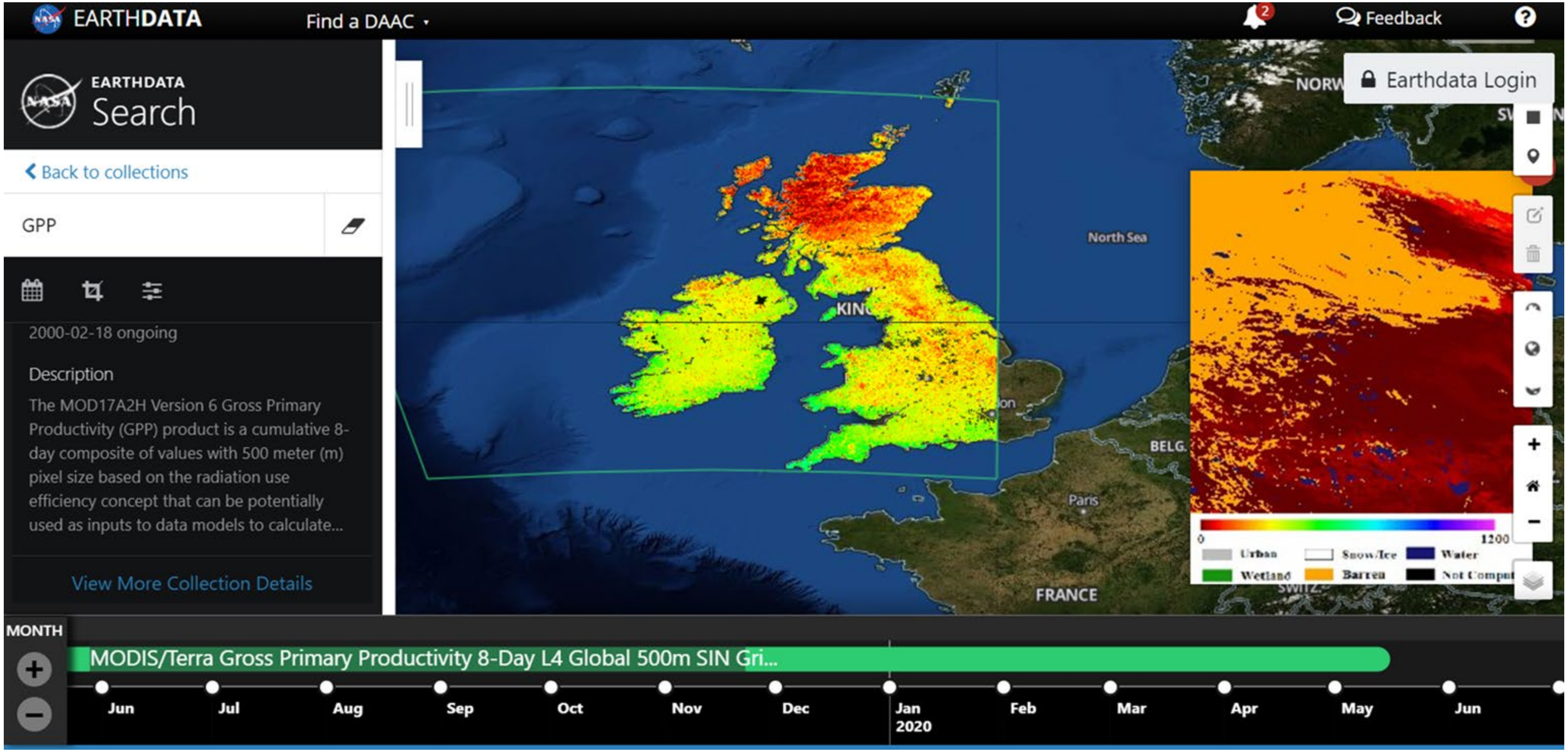
Data Products

[Earthdata | Earthdata (nasa.gov)]

To assist in invasive species research:

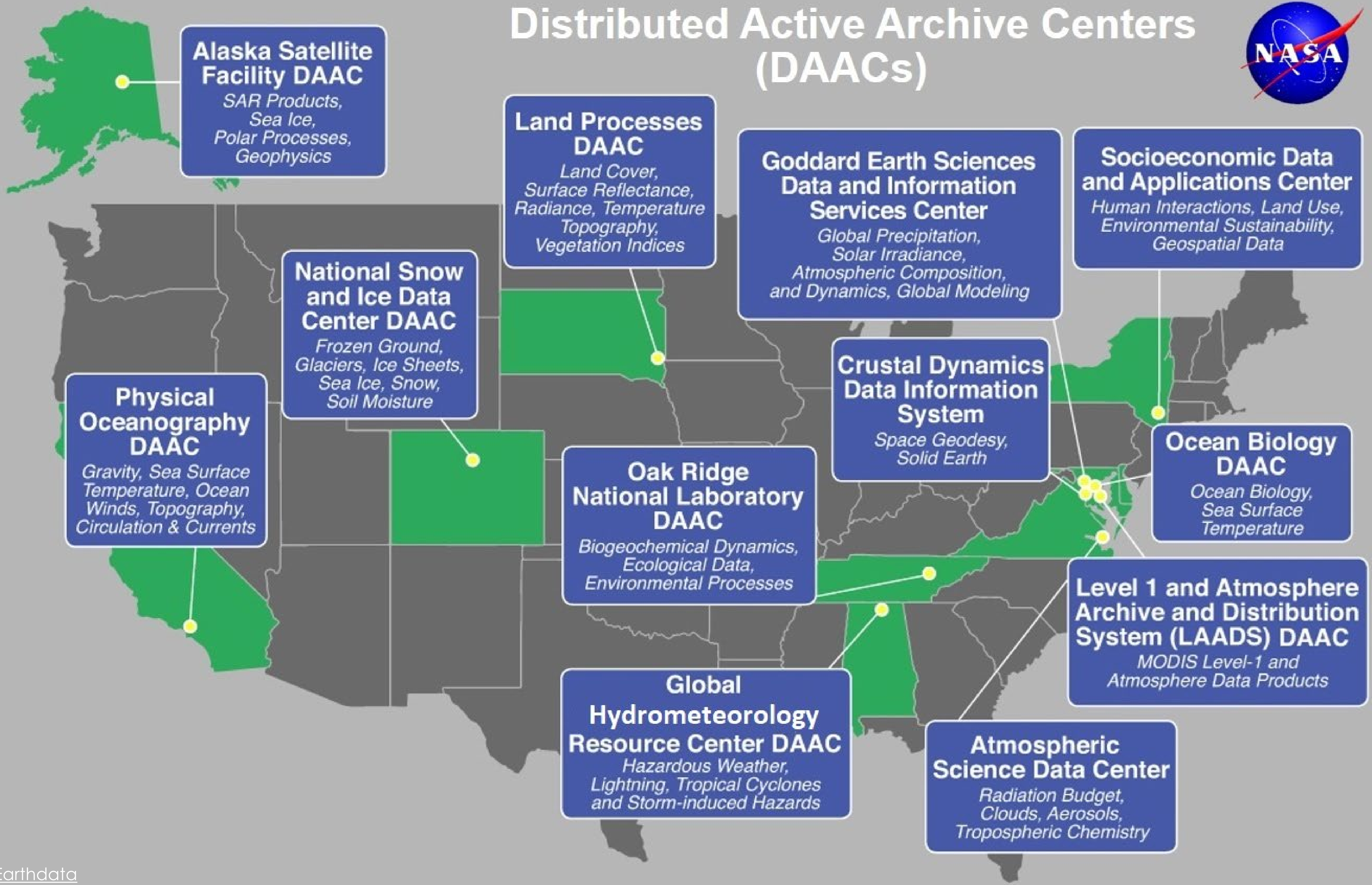
- Surface Reflectance
- Leaf Area Index
- Normalized Difference Vegetation Index
- Above Ground Biomass
- Canopy Height
- Precipitation
- Temperature

Earthdata Search



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

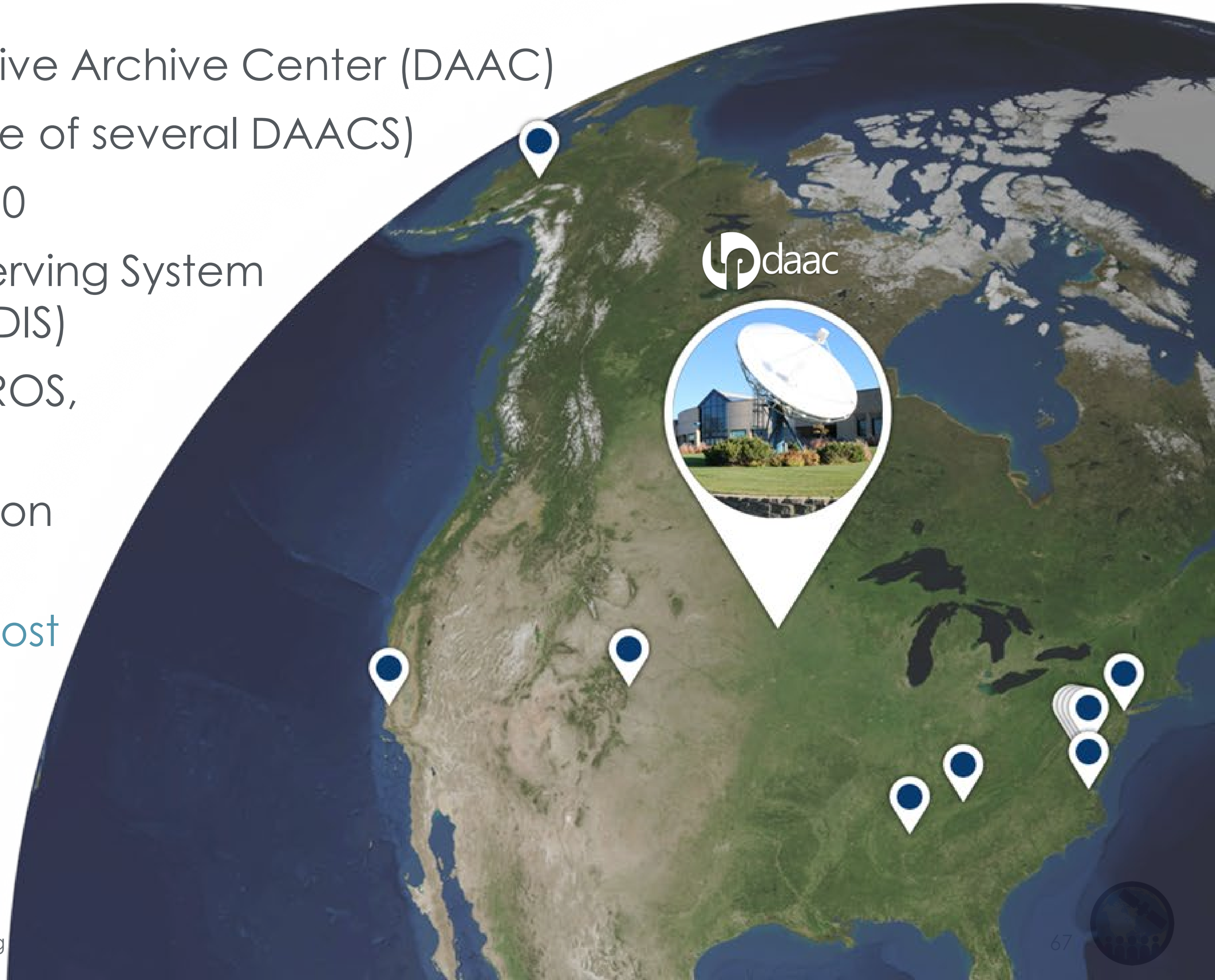
Distributed Active Archive Centers (DAACs)



Source: NASA Earthdata

The LP DAAC

- Land Processes (LP) Distributed Active Archive Center (DAAC)
- NASA's Land Discipline Archive (one of several DAACS)
- A NASA-USGS Partnership since 1990
- Sponsored by the NASA Earth Observing System Data and Information System (EOSDIS)
- Located and Managed at USGS EROS, Sioux Falls, SD
- GEDI data products can be found on GEDI Data Resources Github
- Data & resources available at no cost

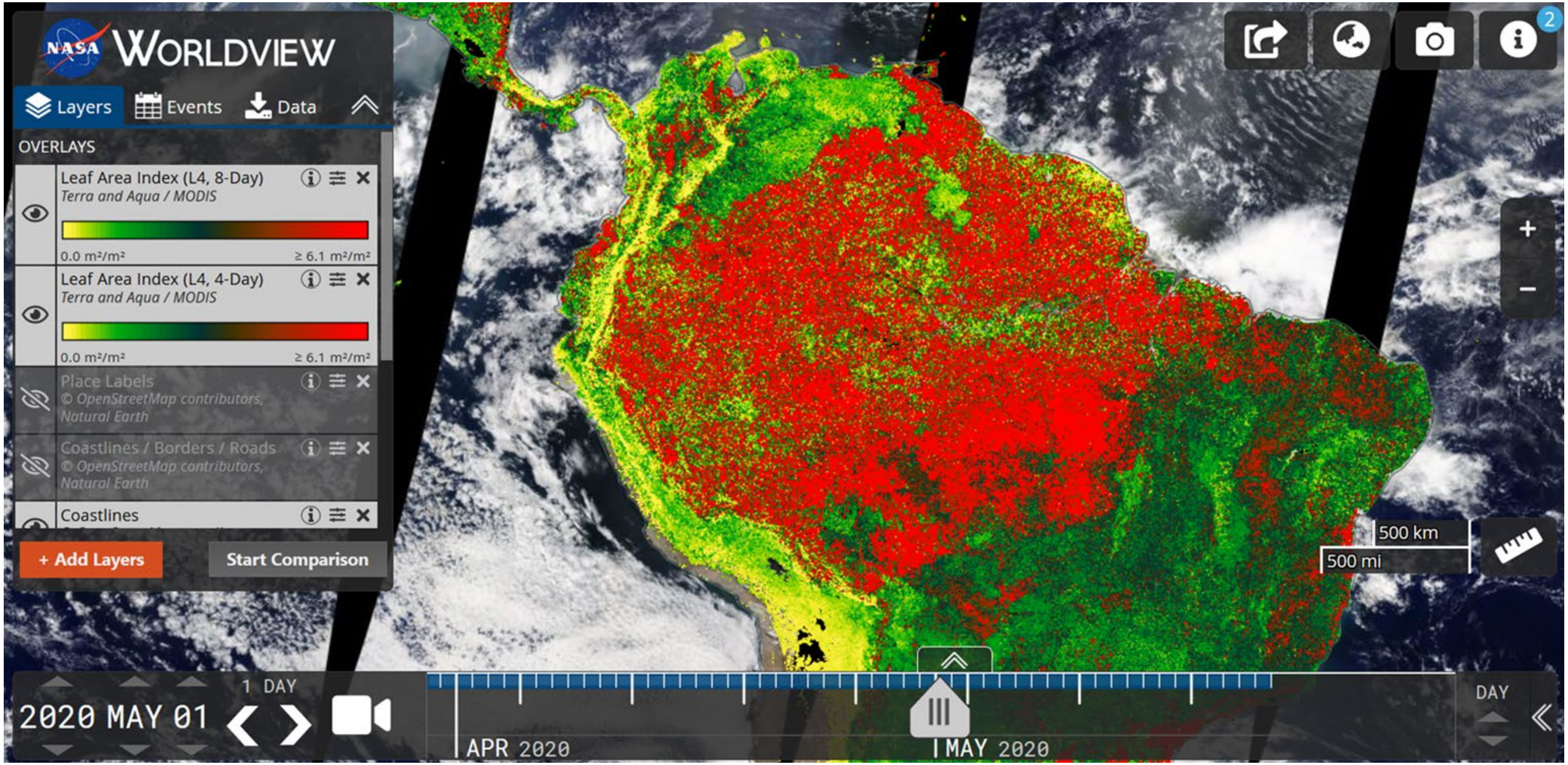


EOSDIS
NASA'S EARTH OBSERVING SYSTEM
DATA & INFORMATION SYSTEM

Application for Extracting and Exploring Analysis Ready Samples (AppEEARS)

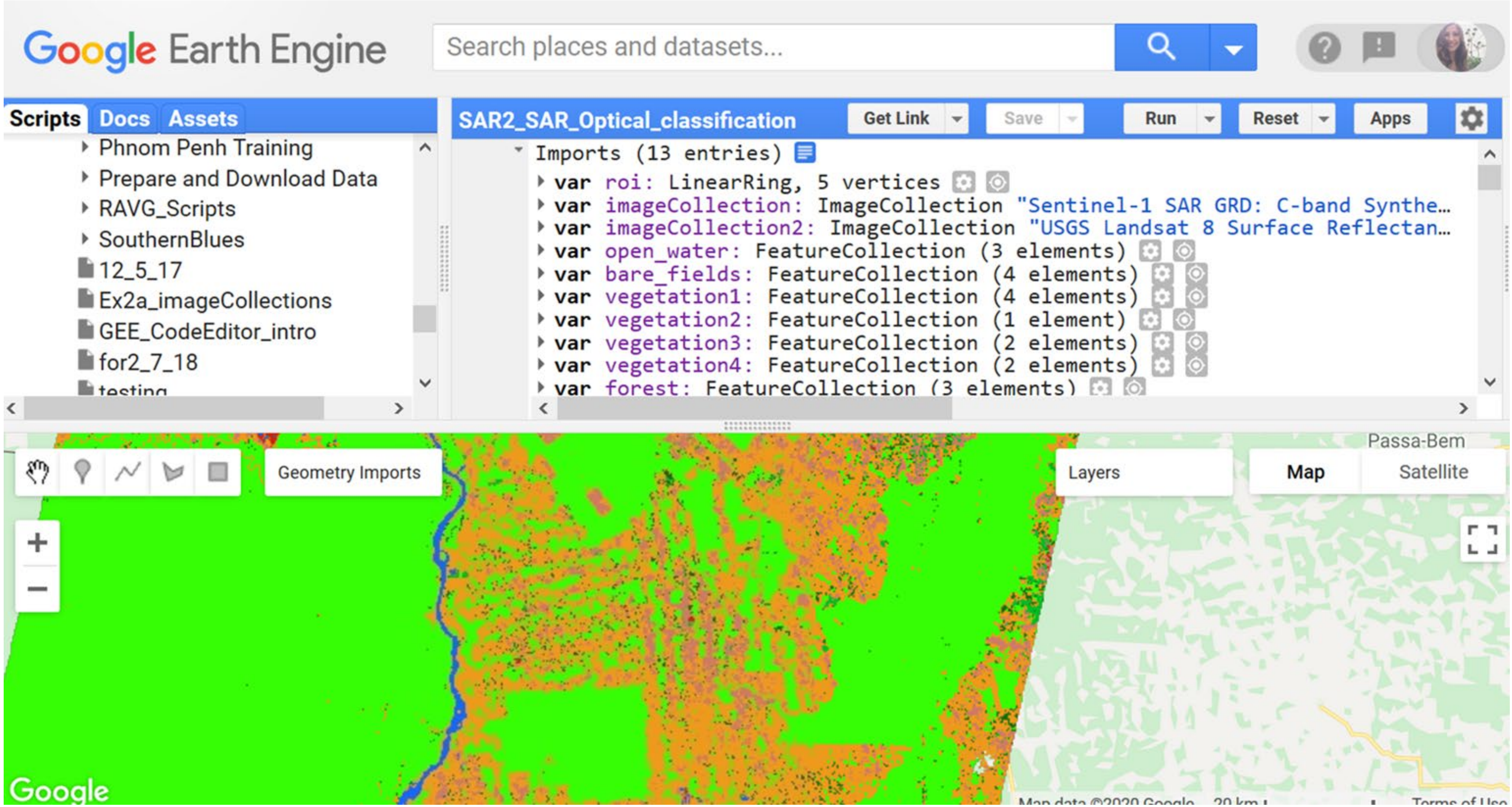
- Cloud-based computing using MODIS and VIIRS
- Time series analysis of user-specified points or areas
- Outputs include time series data in csv format for easy analysis
- Example: Monitoring changing reservoir levels in Cape Town, South Africa
- AppEEARS data products found on [LPDAAC AppEEARS site]

Worldview



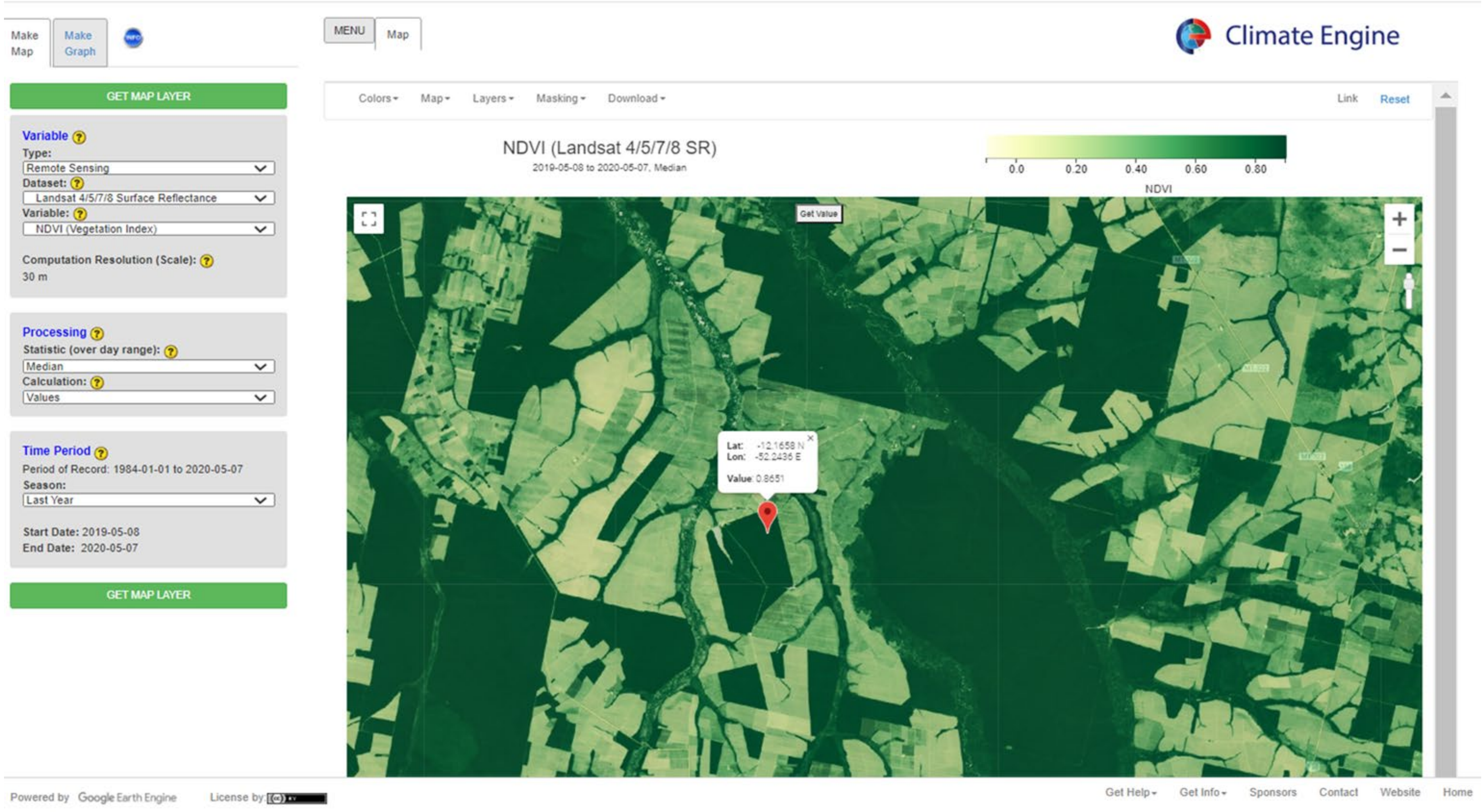
https://worldview.earthdata.nasa.gov/

Google Earth Engine



https://code.earthengine.google.com

Climate Engine



http://app.climateengine.org/

Summary

Summary

- Invasive Species are nonnative species with negative impacts to the environment, biodiversity, economy and human health worldwide.
- Invasives are predicted to increase with climate change.
- Remote sensing can be used for the detection and monitoring of invasive species.
- Use remote sensing to identify invasives through phenological and spectral differences.
- NASA has a variety of available data and resources to aid in monitoring of invasive species:
  - Satellites and sensors: MODIS, VIIRS, AVHRR, SeaWIFS, ECOSTRESS, SBG, PACE, HyMap, GLIMR, GEDI
  - Platforms: LPDAAC, AppEEARS, Worldview, Earthdata, GEE, Climate Engine

Looking Ahead to Part 2

Monitoring of Aquatic Invasive Species with Remote Sensing

- Describe the extent and impacts of aquatic invasive species on biodiversity, ecosystem functions, and nature's contributions to people.
- Describe key considerations, benefits and limitations of remote sensing of invasive species.
- Identify applications of airborne data for monitoring aquatic invasive species.
- Identify relevant NASA multispectral and hyperspectral data for mapping and monitoring or invasive species.
- Compare remote sensing methods used to monitor aquatic invasive species.

Homework and Certificates

- **Homework:**
  - One homework assignment
  - Opens on 08/28/2024
  - Access from the training webpage
  - Answers must be submitted via Google Forms
  - **Due by 09/11/2024**

- **Certificate of Completion:**
  - Attend all three live webinars (attendance is recorded automatically)
  - Complete the homework assignment by the deadline
  - You will receive a certificate via email approximately two months after completion of the course.

Contact Information

Trainers:

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- ARSET Website
- Follow us on X (formerly Twitter)!
  - @NASAARSET
- ARSET YouTube

Visit our Sister Programs:

- DEVELOP
- SERVIR

Resources

- ARSET - Understanding Phenology with Remote Sensing | NASA Applied Sciences
- Earthdata
- LPDAAC
- IPBES Report on Invasive Species
- AppEARS
- GEDI Data Resources

Thank You!