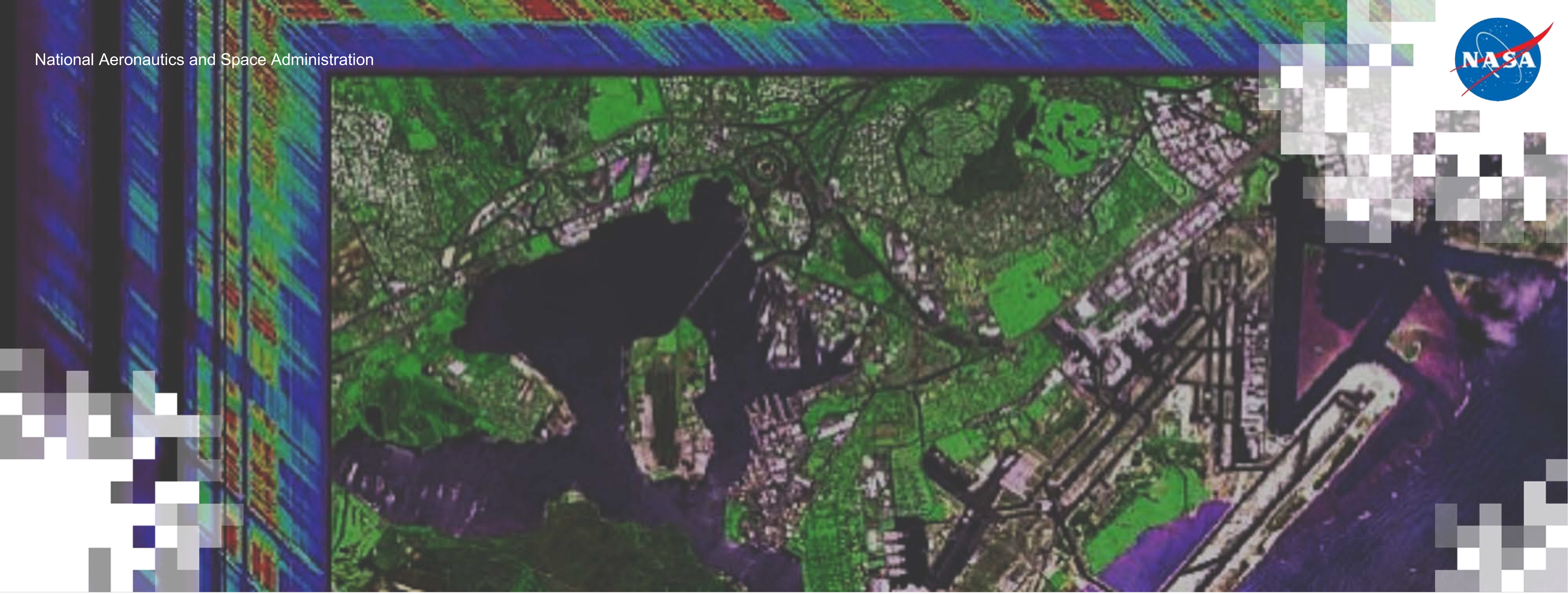
National Aeronautics and Space Administration



Hyperspectral Data for Land and Coastal Systems

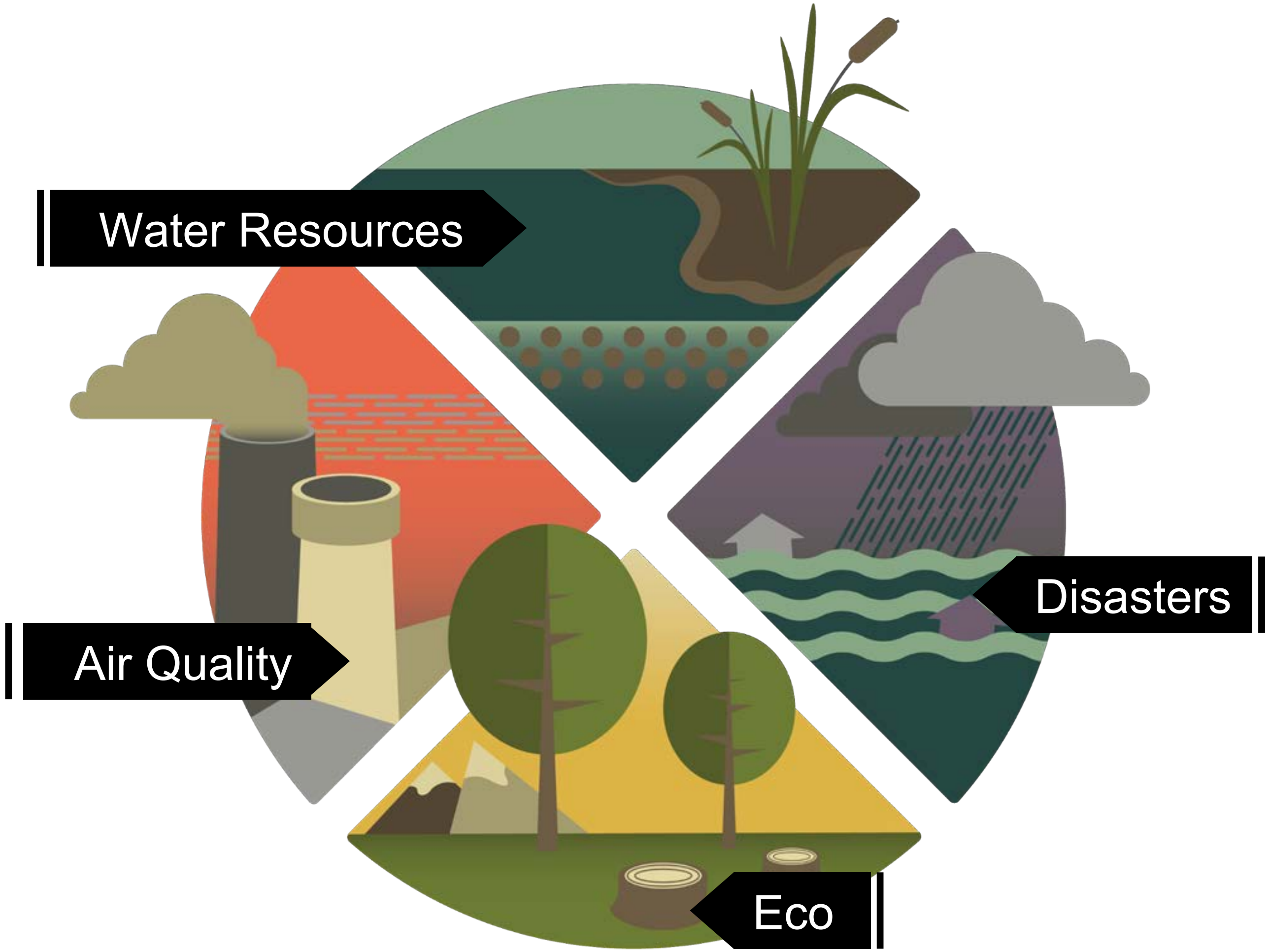
Amber Jean McCullum, Juan L. Torres-Pérez, and Zach Bengtsson

January 19, 2021

NASA's Applied Remote Sensing Training Program (ARSET)

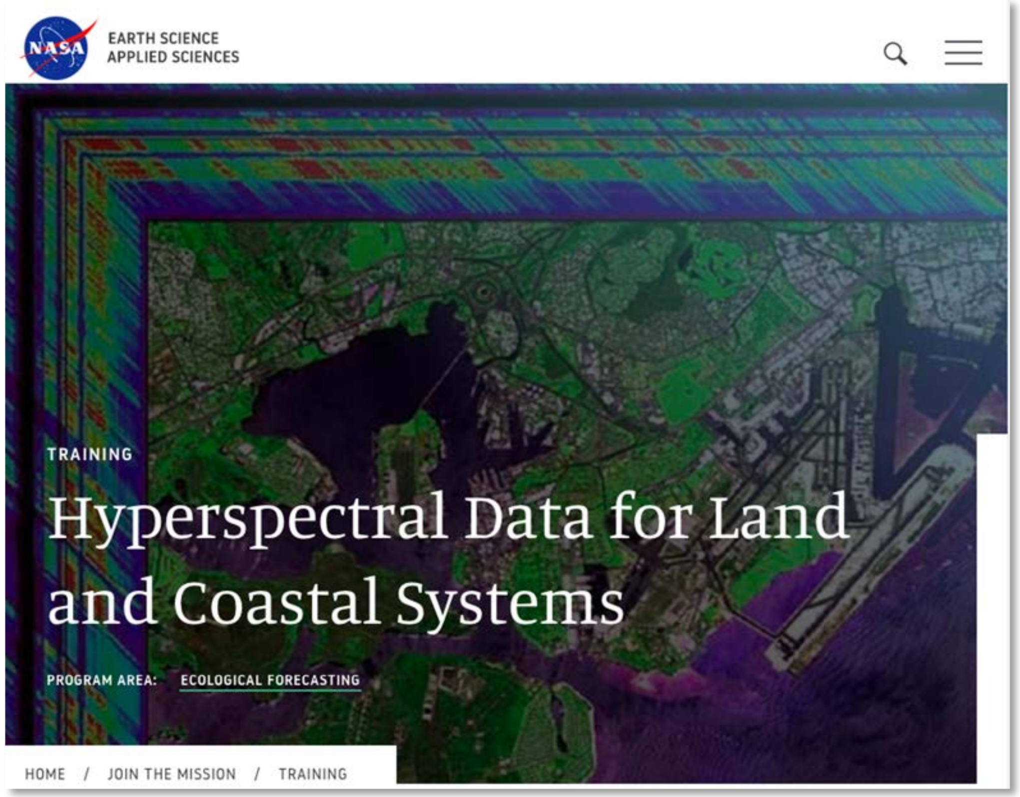
https://appliedsciences.nasa.gov/what-we-do/capacity-building/arset/about-arset

- Part of NASA's Applied Sciences Program
- Empowering the global community through remote sensing training
- Seeks to increase the use of Earth science in decision-making through training for:
  - Policy makers
  - Environmental managers
  - Other professionals in the public and private sector



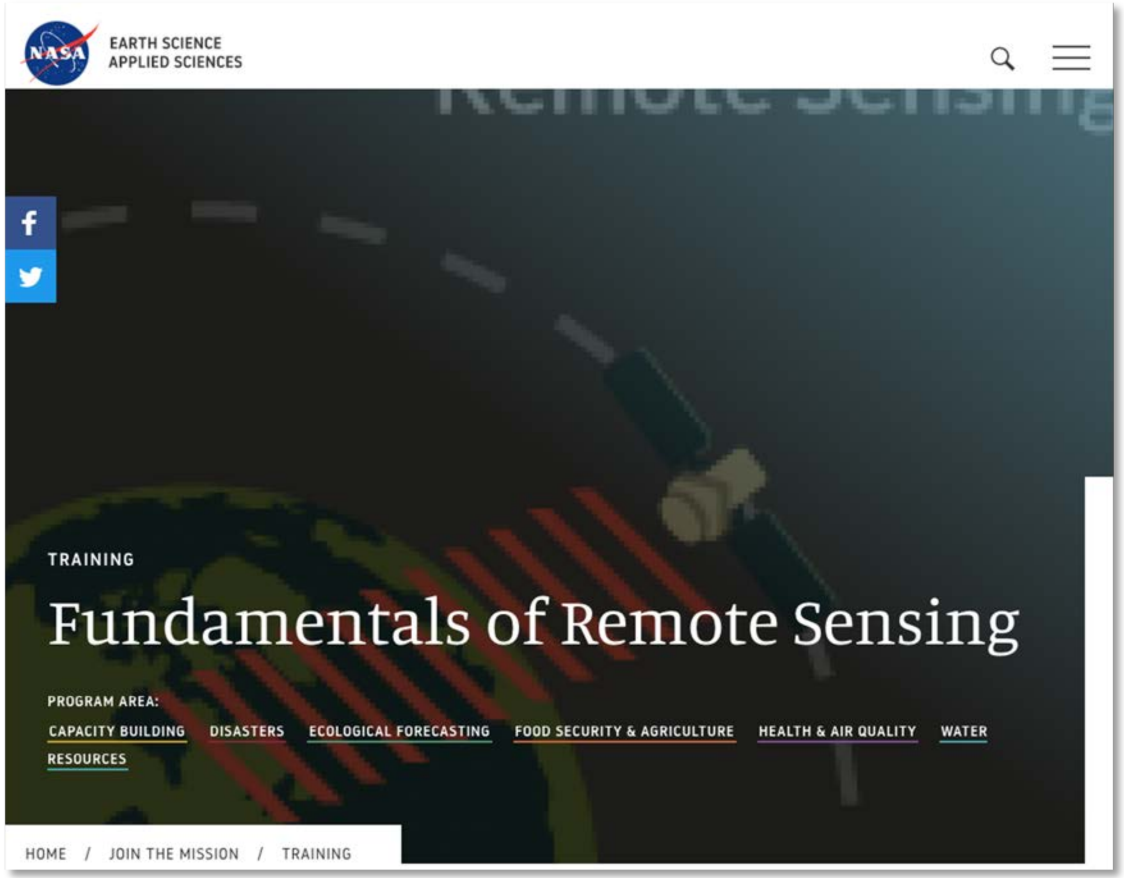
Course Structure and Materials

- Three, 1.5-hour sessions on January 19, January 26, and February 2
- The same content will be presented at two different times each day:
  - Session A: 11:00-12:30 EST (UTC-5)
  - Session B: 16:00-17:30 EST (UTC-5)
  - **Please only sign up for and attend one session per day.**
- Webinar recordings, PowerPoint presentations, and the homework assignment can be found after each session at:
  - https://appliedsciences.nasa.gov/join-mission/training/english/hyperspectral-data-land-and-coastal-systems
- Q&A following each lecture and/or by email at:
  - juan.l.torresperez@nasa.gov
  - amberjean.mccullum@nasa.gov or
  - bengtsson@baeri.org



Prerequisites

- Prerequisites:
  - Please complete Fundamentals of Remote Sensing or have equivalent experience.
- Course Materials:
  - https://appliedsciences.nasa.gov/join-mission/training/english/fundamentals-remote-sensing

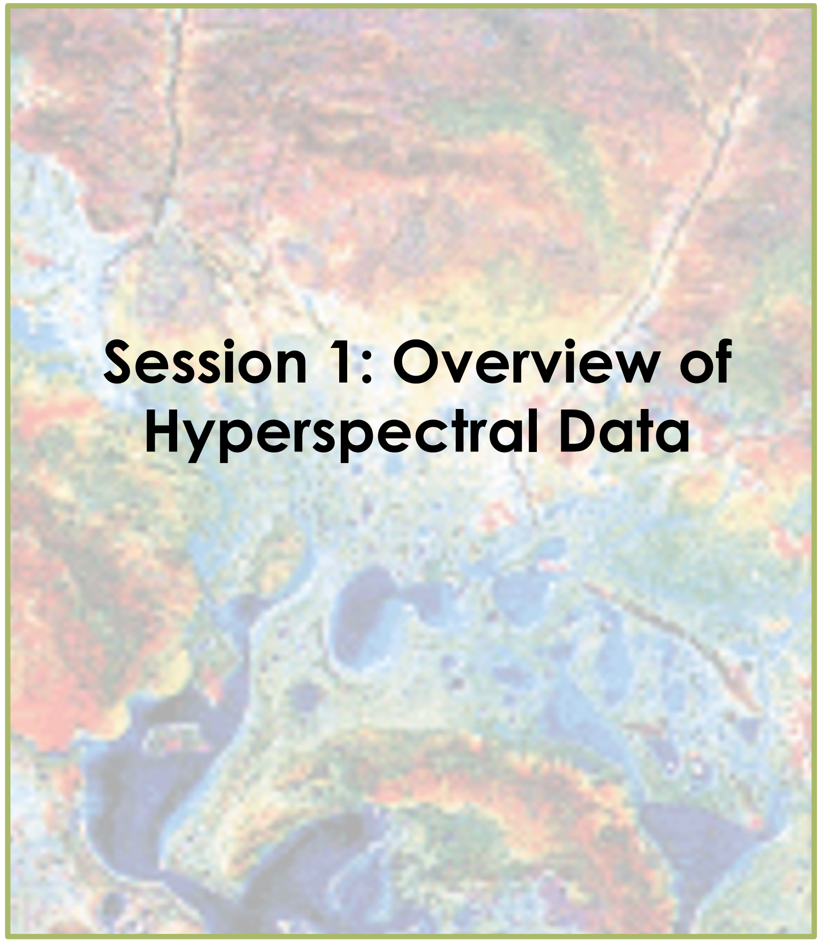


Homework and Certificates

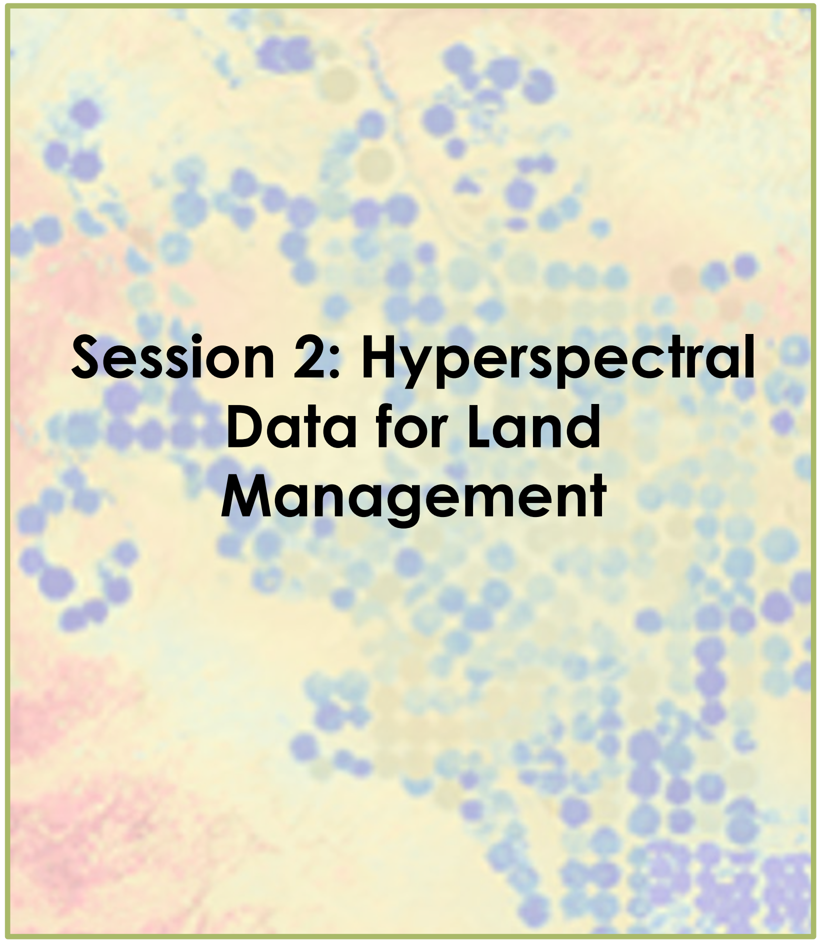
- **Homework:**
  - One homework assignment
  - Answers must be submitted via Google Forms
  - **HW Deadline: Tuesday February 16**

- **Certificate of Completion:**
  - Attend all live webinars
  - Complete the homework assignment by the deadline (access from ARSET website)
  - You will receive certificates approximately three months after the completion of the course from: marines.martins@ssaihq.com

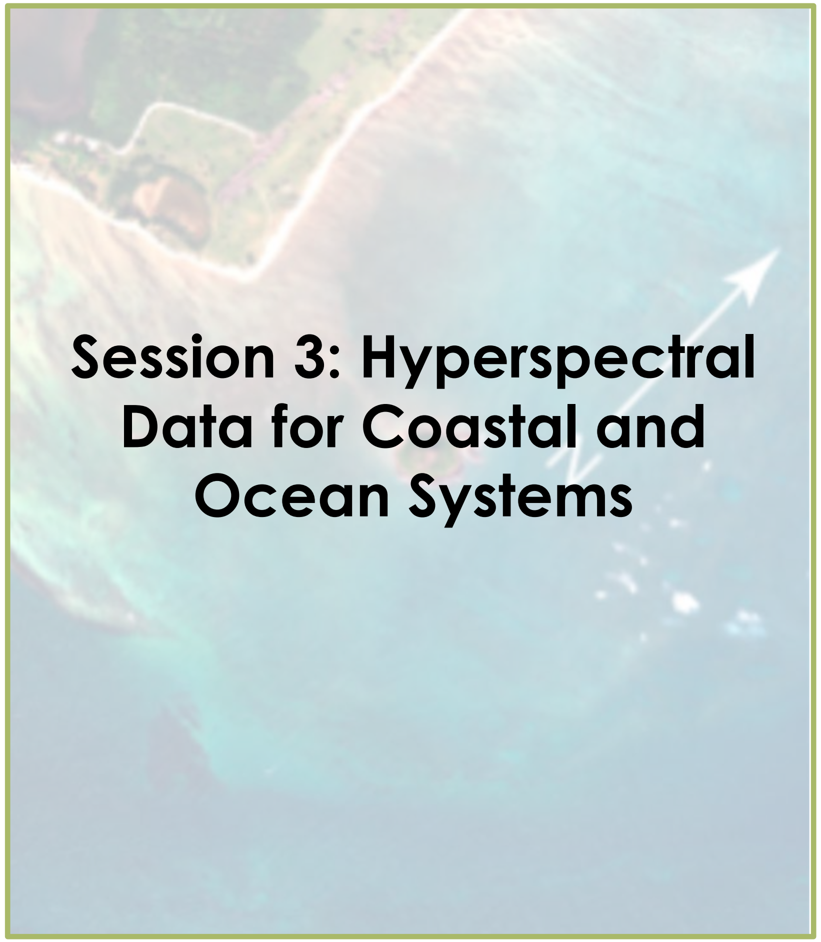
Course Outline



Session 1: Overview of Hyperspectral Data



Session 2: Hyperspectral Data for Land Management



Session 3: Hyperspectral Data for Coastal and Ocean Systems

Learning Objectives

- By the end of this session, you will be able to…
  - Recognize hyperspectral data and how it differs from multispectral data
  - Identify current hyperspectral sensors and future hyperspectral satellite missions of interest
  - Locate available hyperspectral data and identify data processing platforms

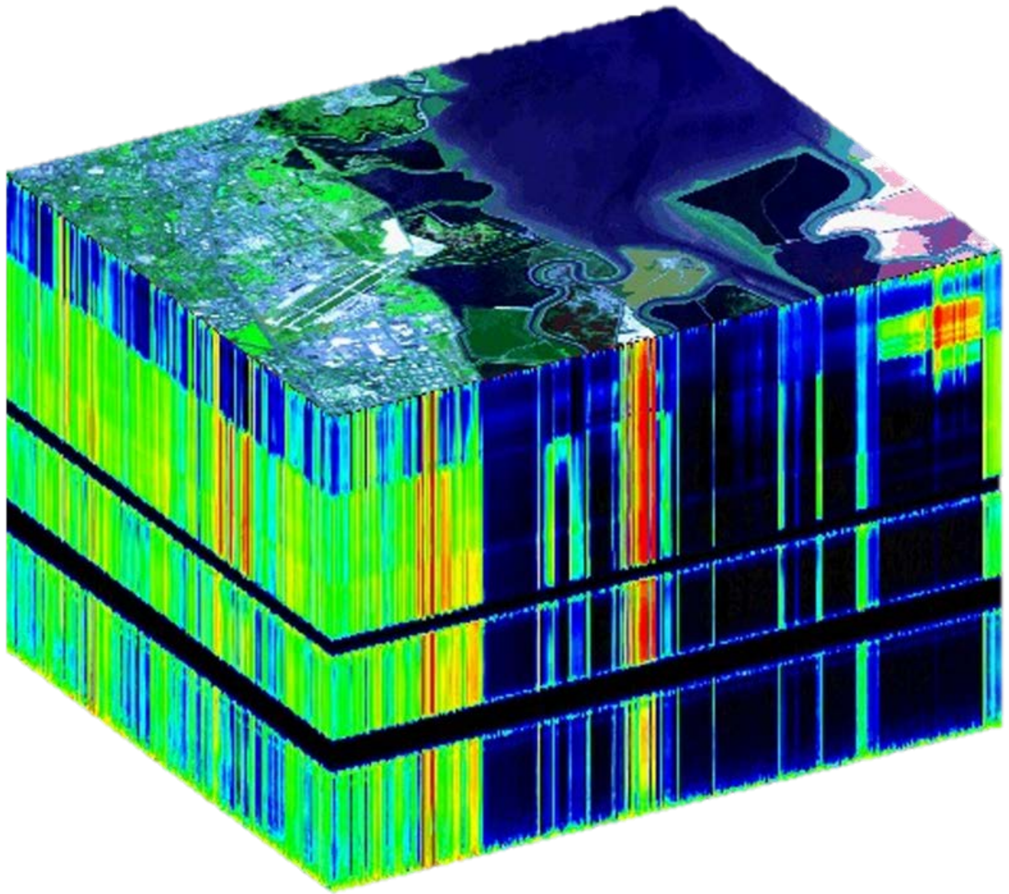
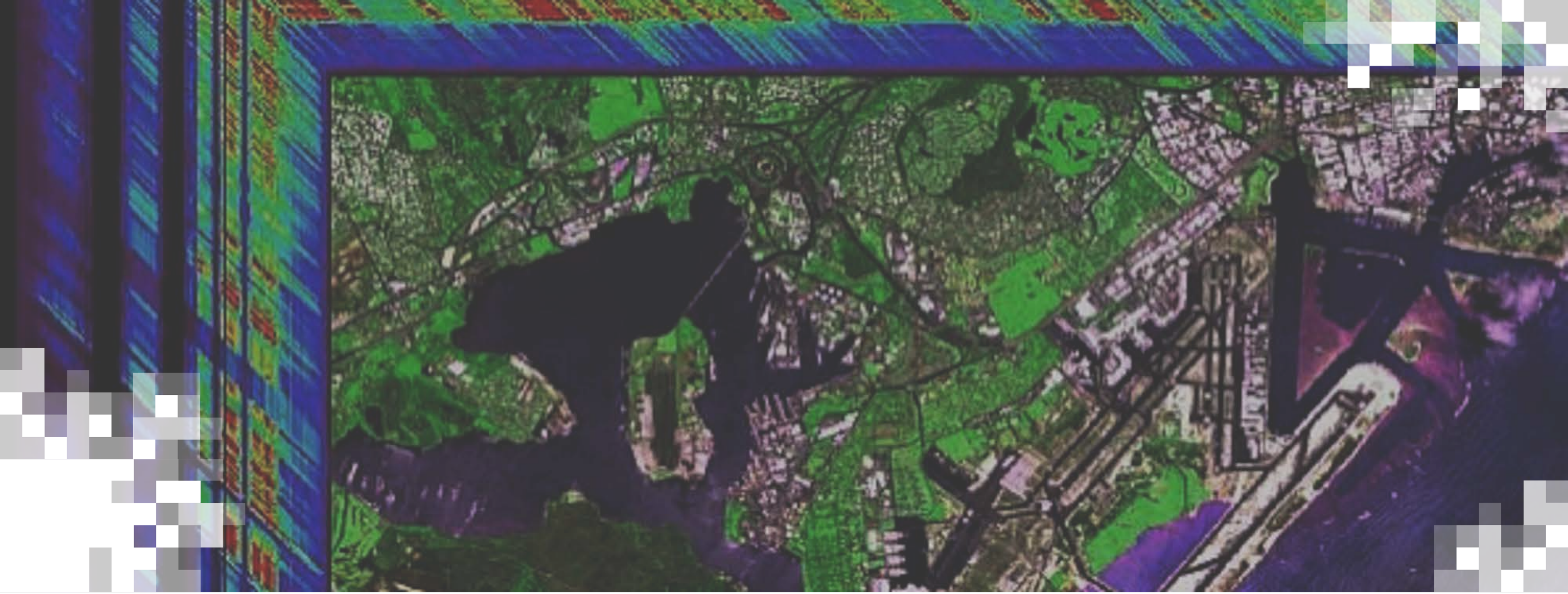
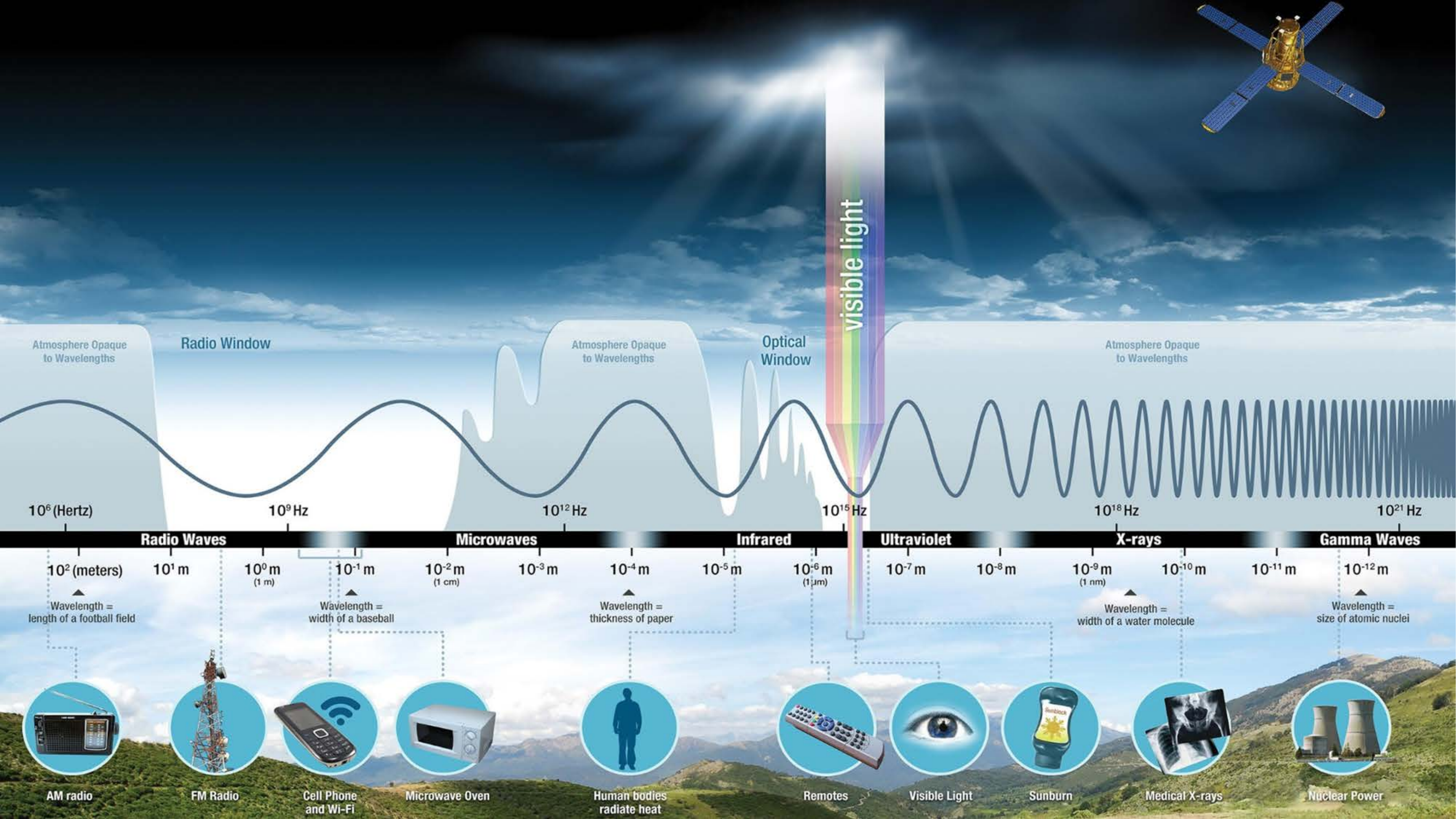


Image Credit: NASA JPL



Introduction to Hyperspectral Data



visible light
Atmosphere Opaque to Wavelengths
Radio Window
Atmosphere Opaque to Wavelengths
Optical Window
Atmosphere Opaque to Wavelengths
10^6 (Hertz)
10^9 Hz
10^12 Hz
10^15 Hz
10^18 Hz
10^21 Hz
Radio Waves
Microwaves
Infrared
Ultraviolet
X-rays
Gamma Waves
10^2 (meters)
10^1 m
10^0 m (1 m)
10^-1 m
10^-2 m (1 cm)
10^-3 m
10^-4 m
10^-5 m
10^-6 m (1 µm)
10^-7 m
10^-8 m
10^-9 m (1 nm)
10^-10 m
10^-11 m
10^-12 m
Wavelength = length of a football field
Wavelength = width of a baseball
Wavelength = thickness of paper
Wavelength = width of a water molecule
Wavelength = size of atomic nuclei
AM radio
FM Radio
Cell Phone and Wi-Fi
Microwave Oven
Human bodies radiate heat
Remotes
Visible Light
Sunburn
Medical X-rays
Nuclear Power

Spectral Resolution

- The ability of a sensor to define wavelength intervals.
- Each "band" represents a different part of the electromagnetic spectrum.
- The finer the spectral resolution, the narrower the wavelength range for a particular channel or band.

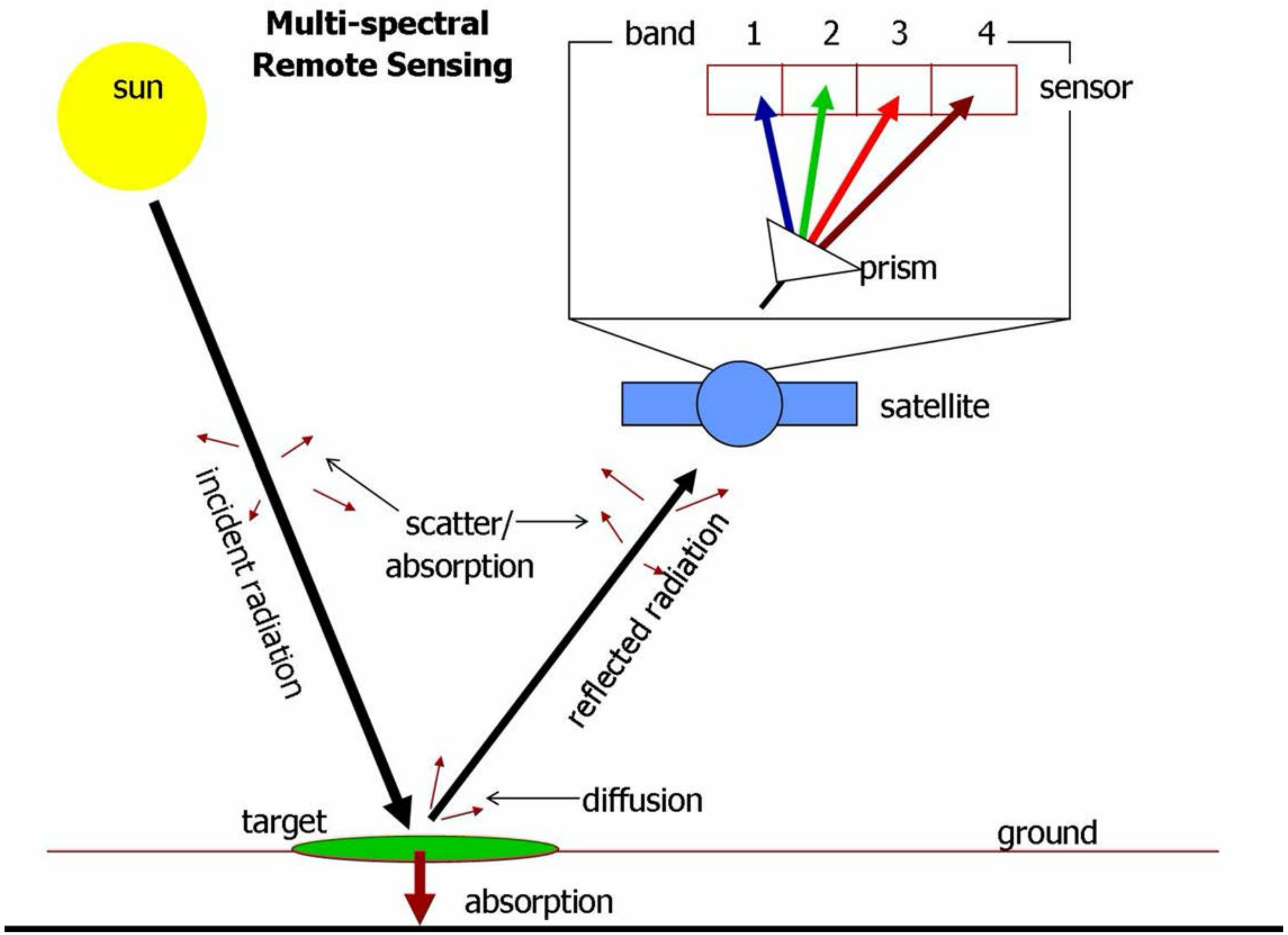
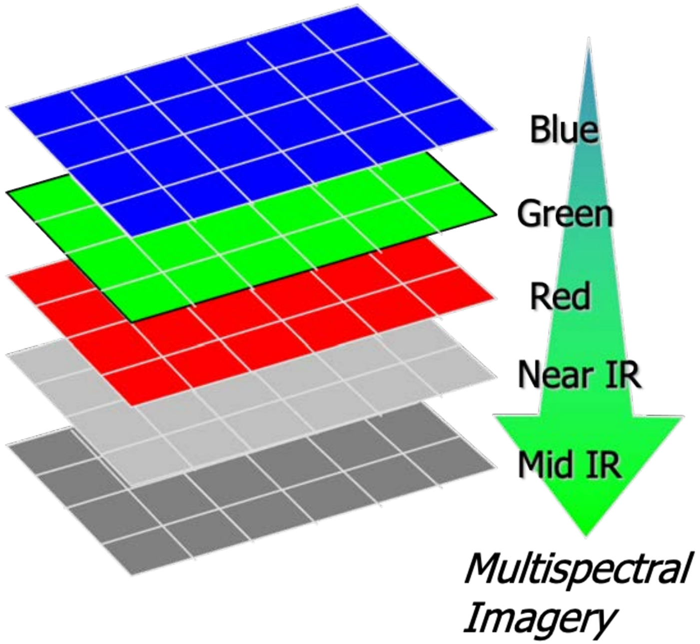


Image Credit: Cristina Milesi

Spectral Resolution

- Each image band is a different layer in an image.



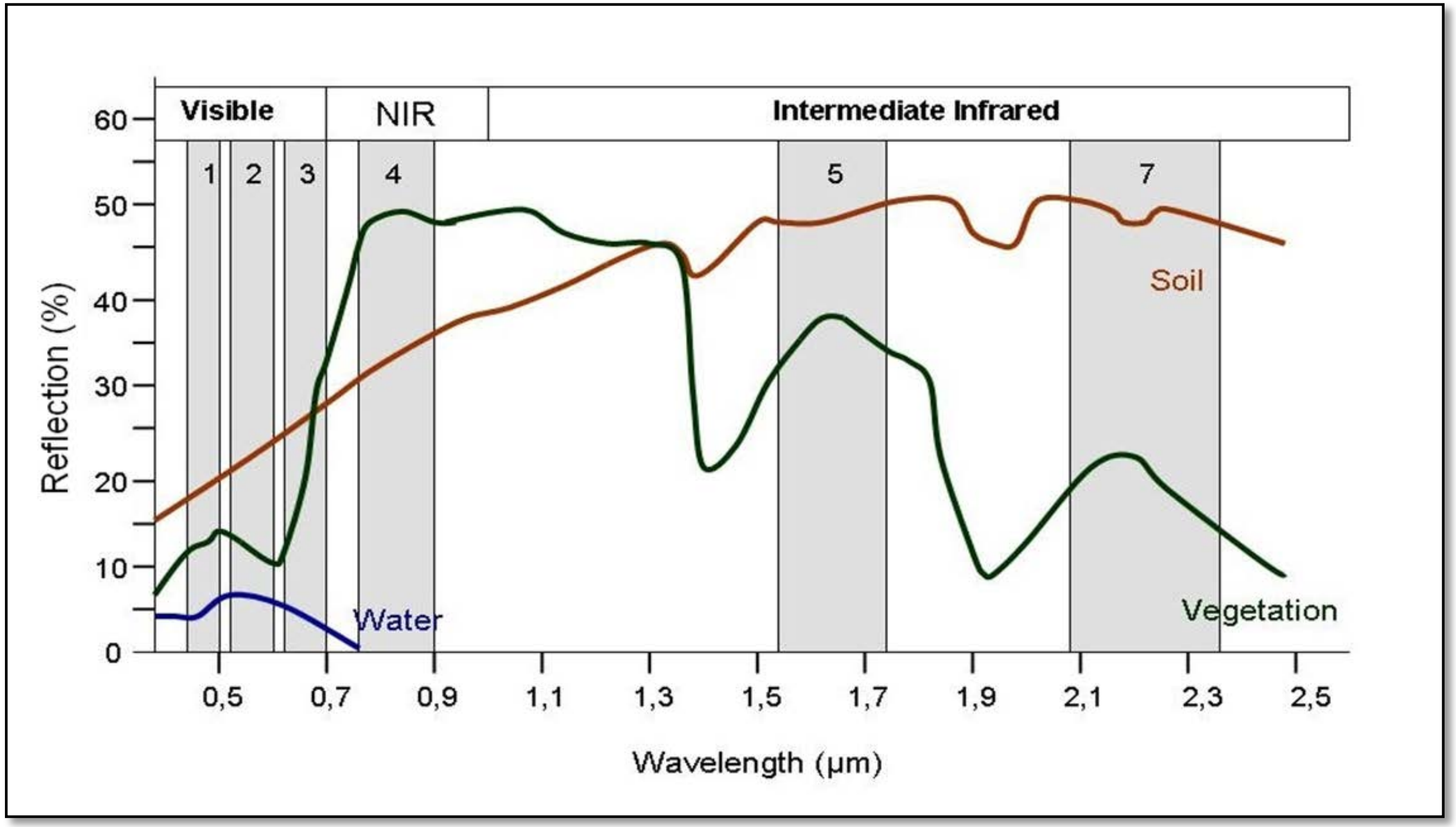


Image credit: USGS

What is hyperspectral remote sensing?

- The acquisition of imagery in **hundreds of contiguous spectral bands** such that a radiant spectrum can be derived for each pixel.
  - Measuring reflectance at close intervals on the electromagnetic spectrum
  - Bands are usually spaced 10 nm or less from one another

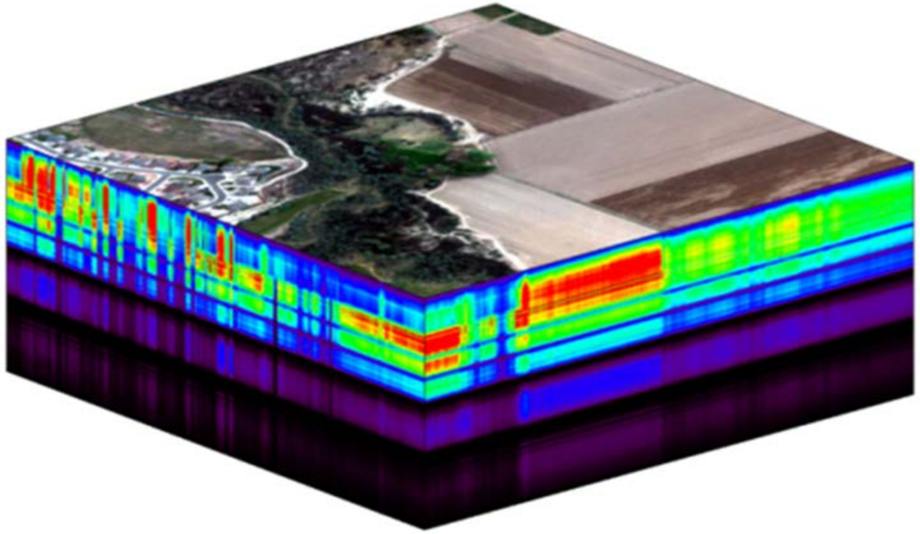
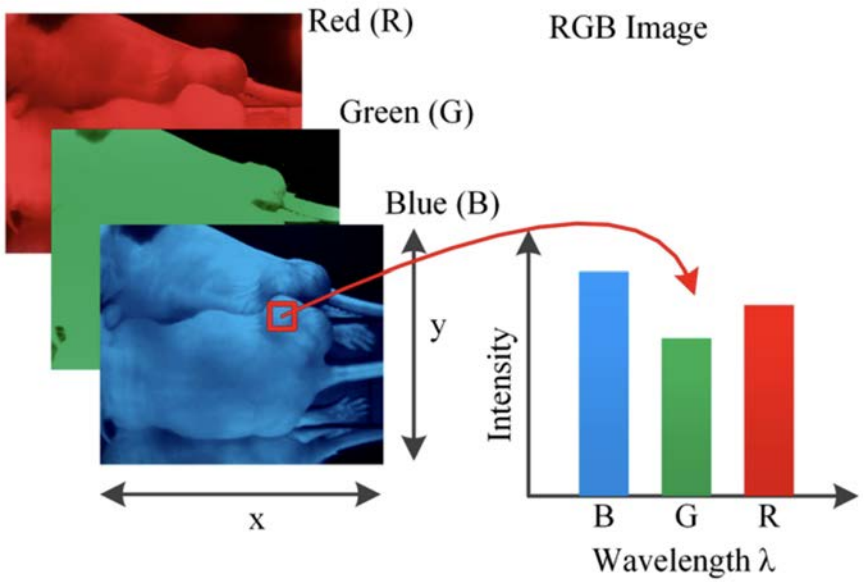


Image Credit: NSF NEON

Multispectral vs. Hyperspectral Data

Multispectral



Hyperspectral

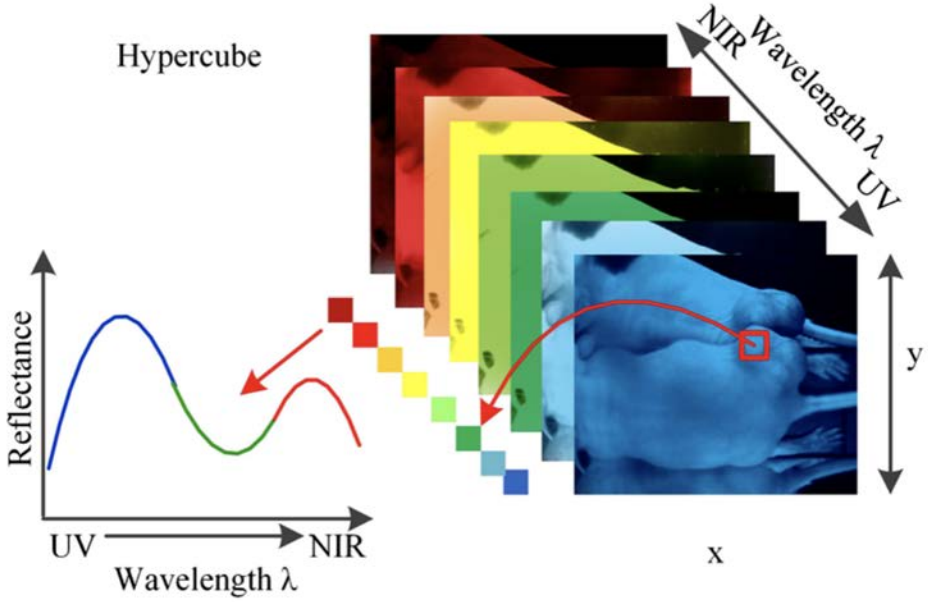
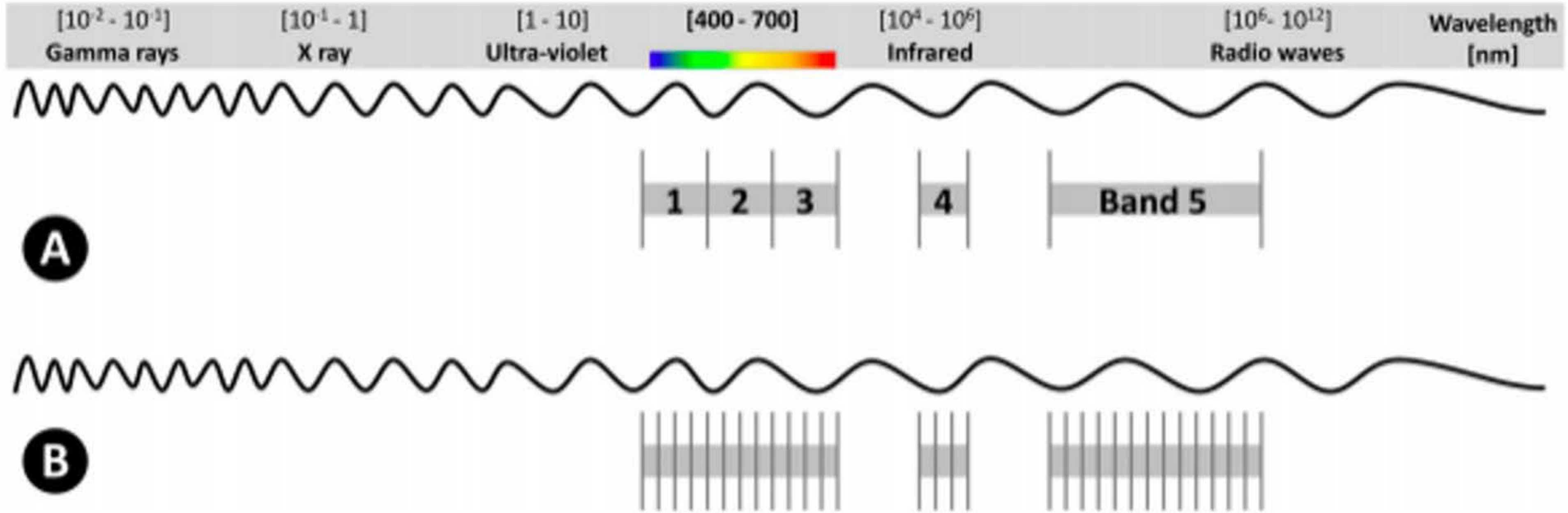


Image Credit: CIRES, University of Colorado

Multispectral vs. Hyperspectral Data



Spectrum representation including: (A) Multispectral example, with 5 wide bands; and (B) Hyperspectral example consisting of several narrow bands. Some hyperspectral sensors have several hundred bands. Image Credit: Adao, et al., 2017

Multispectral vs. Hyperspectral Data

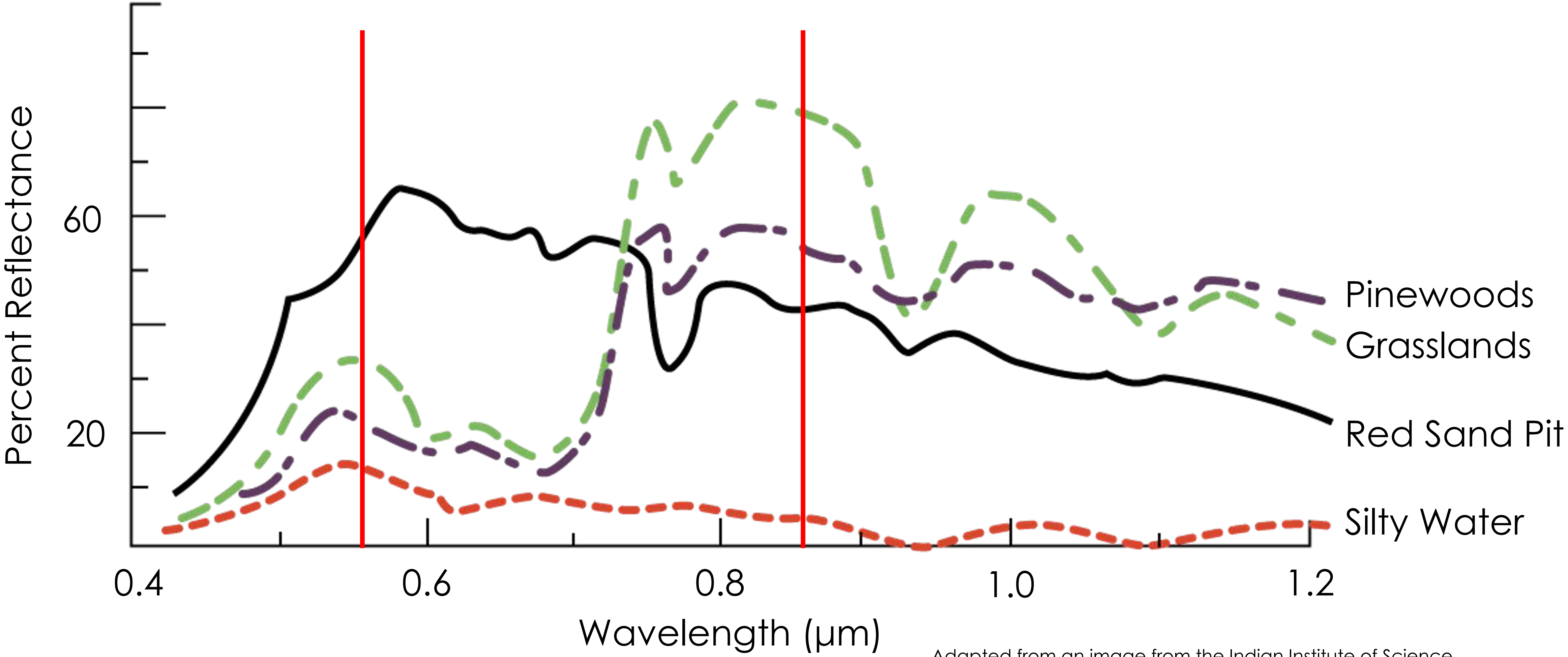
Multispectral:

- Popular sensors such as Landsat and MODIS
- Limited number of spectral bands
- Relatively high temporal resolution
- Global spatial extent

Hyperspectral:

- Limited in numbers of satellite sensors
- Some mission-specific sensors aboard the ISS
- Airborne sensors flown during flight campaigns
- Narrow bands that measure more characteristics of surface reflectance
- Low temporal resolution
- Less spatial coverage

Why is spectral resolution important?

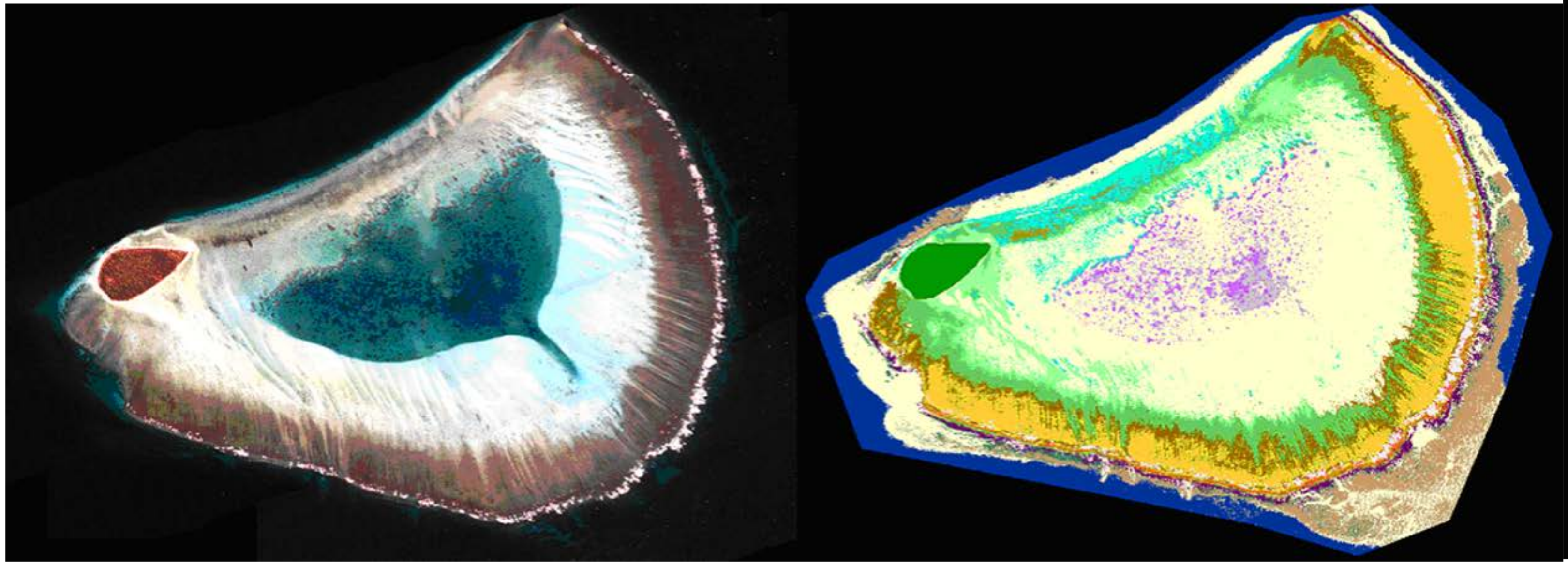


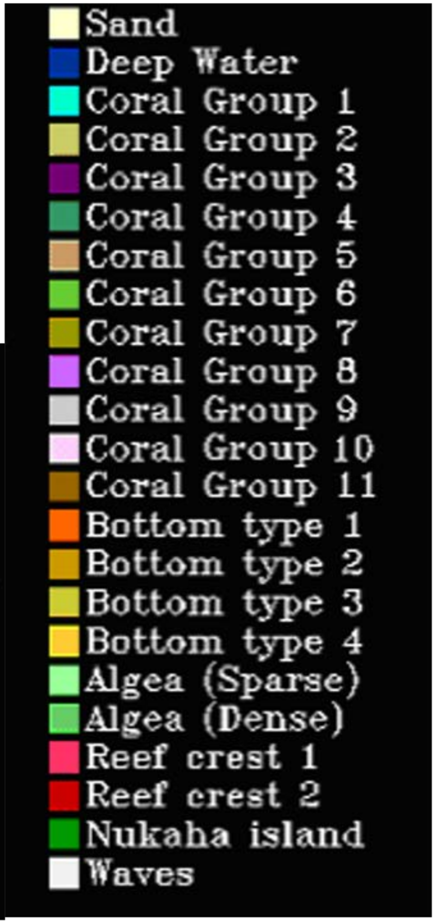
Adapted from an image from the Indian Institute of Science.

Applications of Hyperspectral Imagery

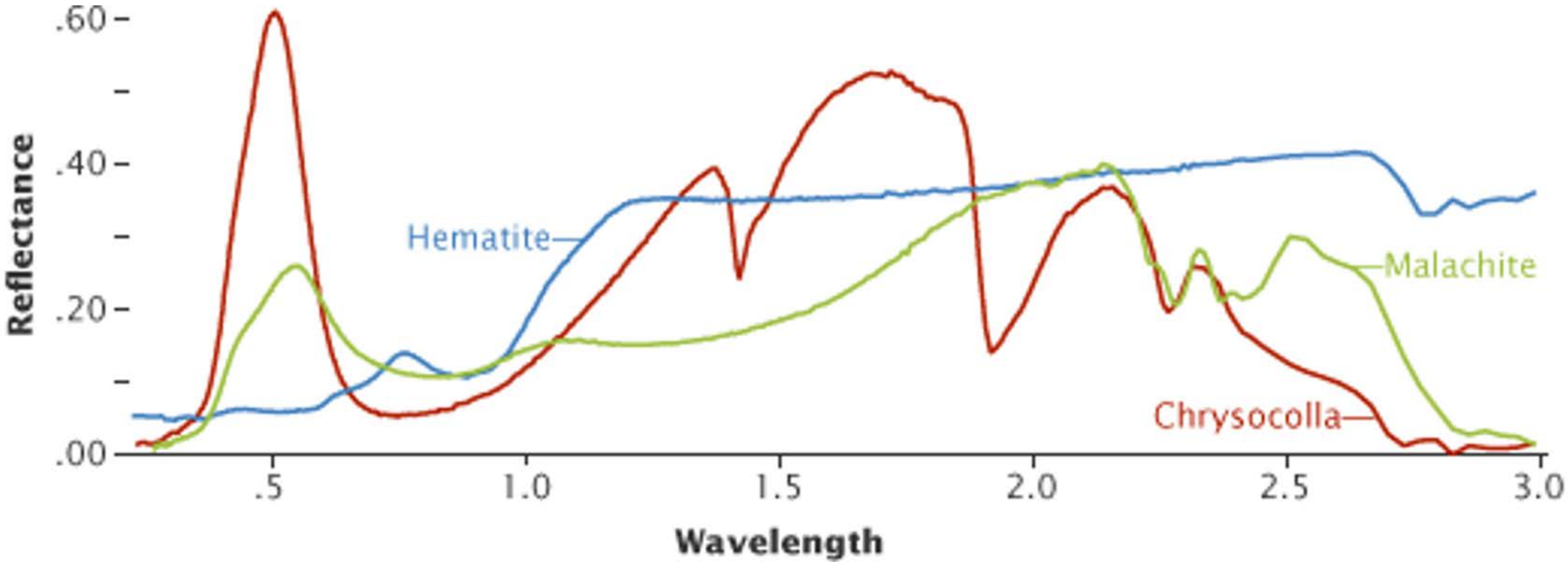
- Geology
- Invasive Species
- Coastal/Ocean monitoring
- Carbon monitoring
- Microbial life in the Arctic
- Volcanic Activity

Left: The island of Fordate in Tanimbar (Indonesia) by CASI hyperspectral data (resolution 2,5 m). **Right:** The bottom-type classification map made from the hyperspectral data. Image Credit: SEOS

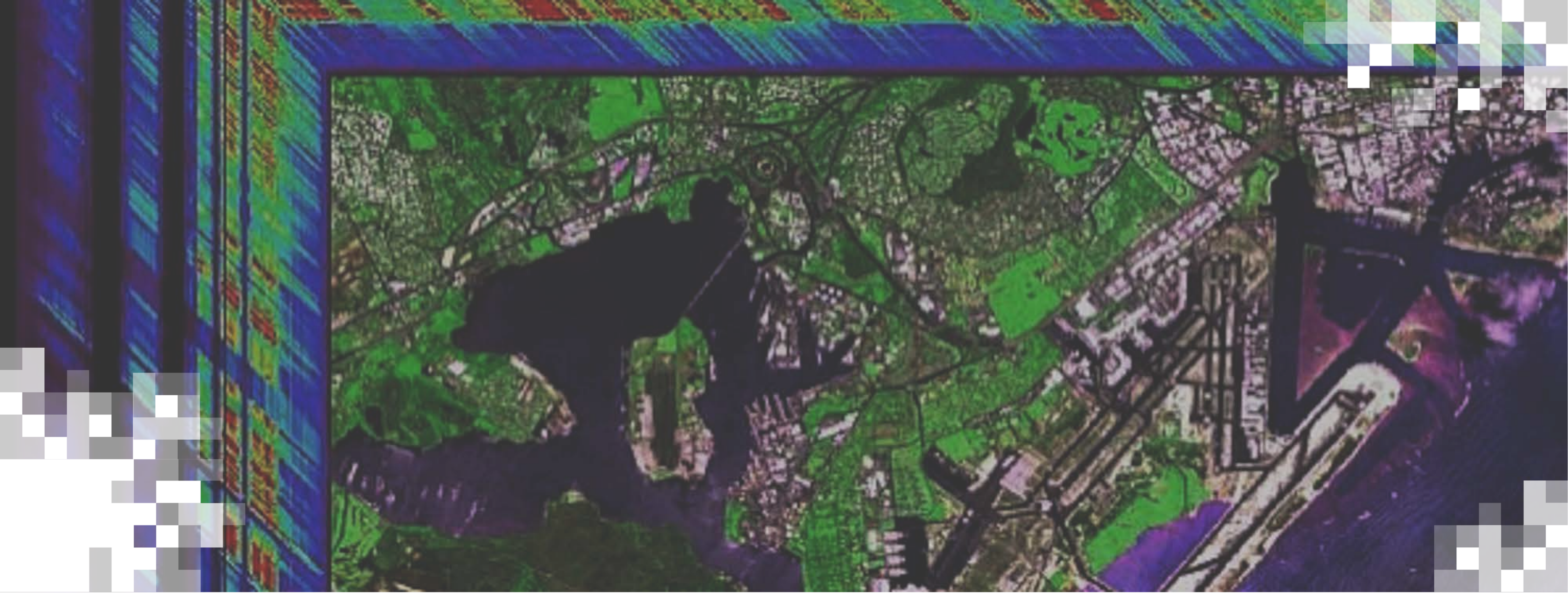




Applications of Hyperspectral Imagery



This graph compares the reflectance of hematite (an iron ore) with malachite and chrysocolla (copper-rich minerals) from 200 to 3,000 nanometers. Image Credit: NASA/USGS by Robert Simmon.



Satellite & Airborne-Based Hyperspectral Imagers

NASA Hyperspectral Imagers

Satellite/Space-Based

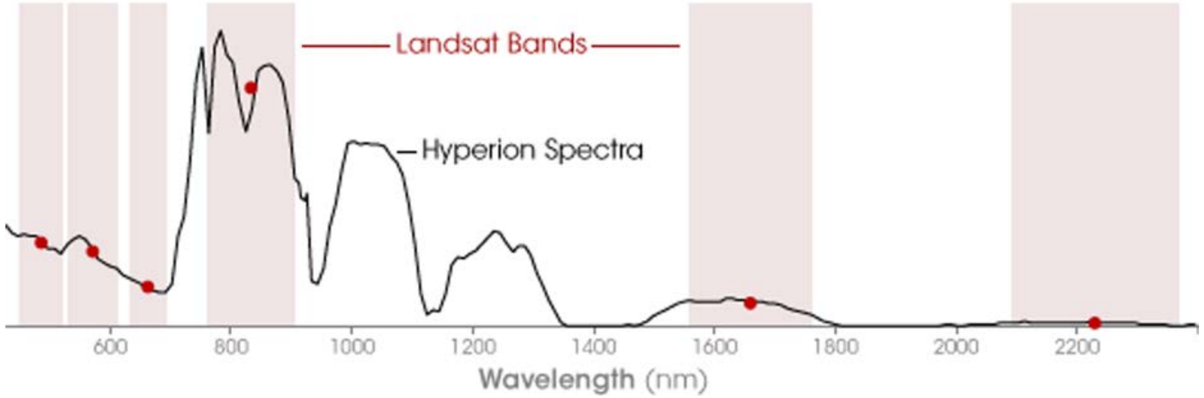
- EO-1 Hyperion
- Test missions onboard the International Space Station (ISS):
  - Hyperspectral Imager for the Coastal Ocean (HICO)
  - ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS)*
    - Thermal imagery prototype for future hyperspectral missions

Airborne

- Airborne Visible/Infrared Imaging Spectrometer (AVIRIS)
  - Campaigns flown around the world
  - Proof of concept for future hyperspectral satellite sensors
- Portable Remote Imagining Spectrometer (PRISM)
  - COral Reef Airborne Laboratory (CORAL)
  - Mission flown 2016-2019 to analyze coastal ecosystems and reef conditions

EO-1 Hyperion

- Date Range: 2000-2017
- 220 spectral bands
- 357 to 2567 nm
- 10 nm bandwidth
- 30 m spatial resolution
- 7.75 km swath
- 12-bit



Hyperion image of Mount. Fuji, 2000 (left), the Hyperion sensor (top), and a comparison of the Landsat bands and a spectra from Hyperion. Image Credit: USGS

EO-1 Hyperion

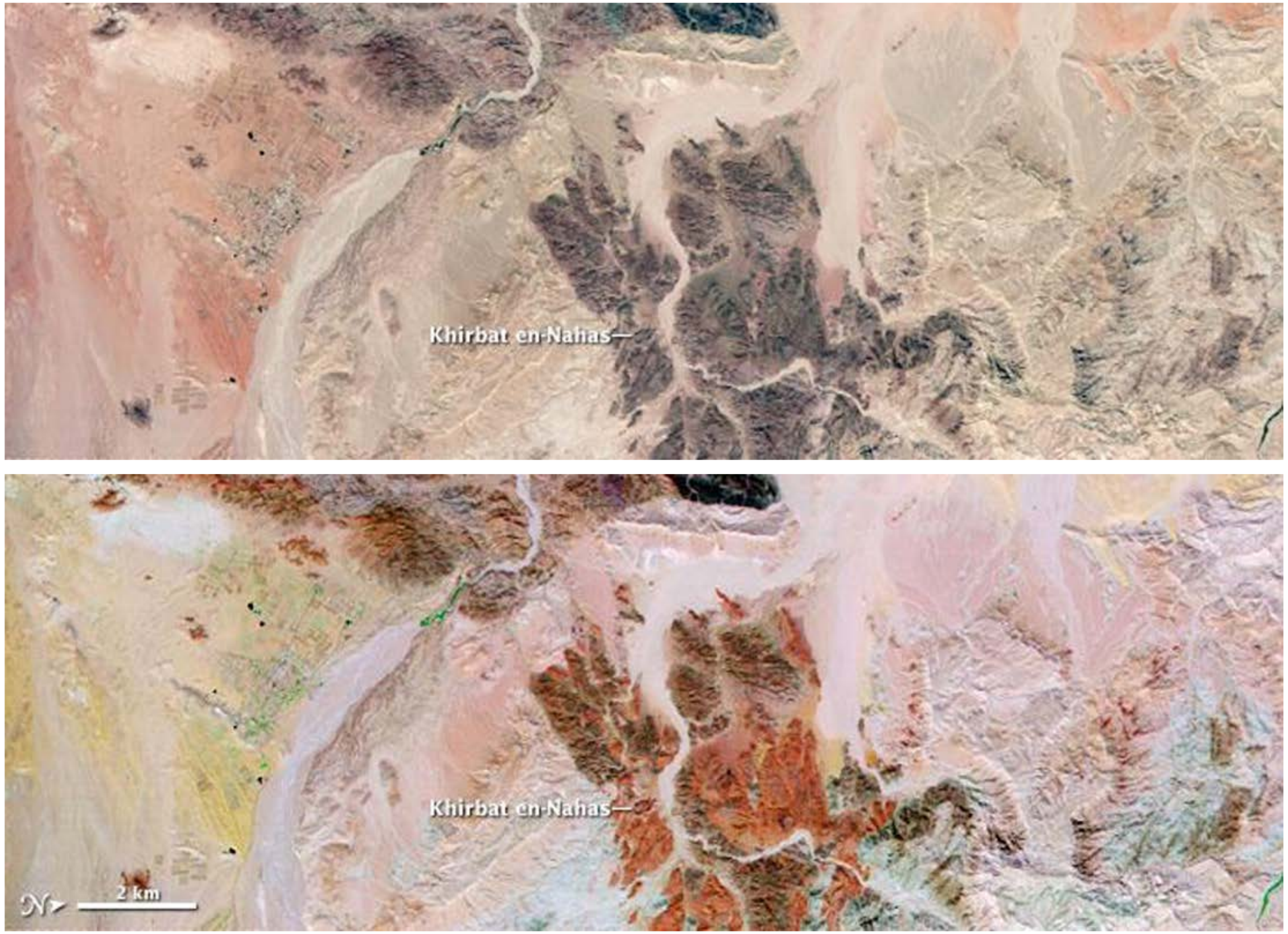


Image Credit: Robert Simmon and NASA

Hyperion Images of outcrops near one of the largest mining operations in Jordan (Khirbat en-Nahas)

With a natural color image (top) the minerals appear uniformly dark, but different rock types can be identified with the many spectral bands in Hyperion (bottom).

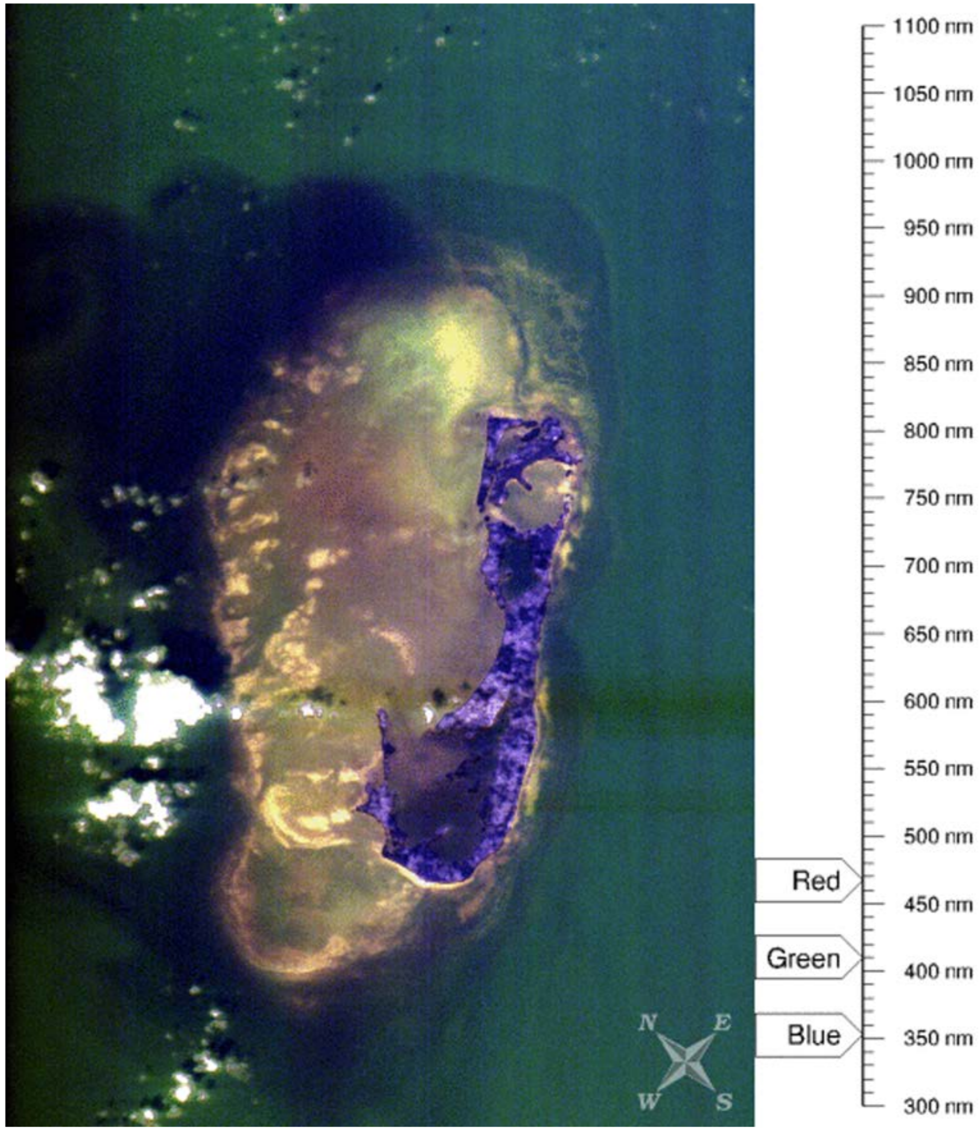
Hyperspectral Imager for Coastal Ocean (HICO)

- First spaceborne imaging spectrometer designed to sample the coastal ocean
  - Onboard the International Space Station (ISS)
- Date Range: 2009-2014
- Spatial Resolution: 90 m
- Spectral Resolution: 128 bands (400-900nm every 5.7nm)
- Temporal Resolution: ~3 days

HICO image of a massive Microcystis bloom in western Lake Erie, Sept. 3, 2011. Image Credit: NASA

HICO

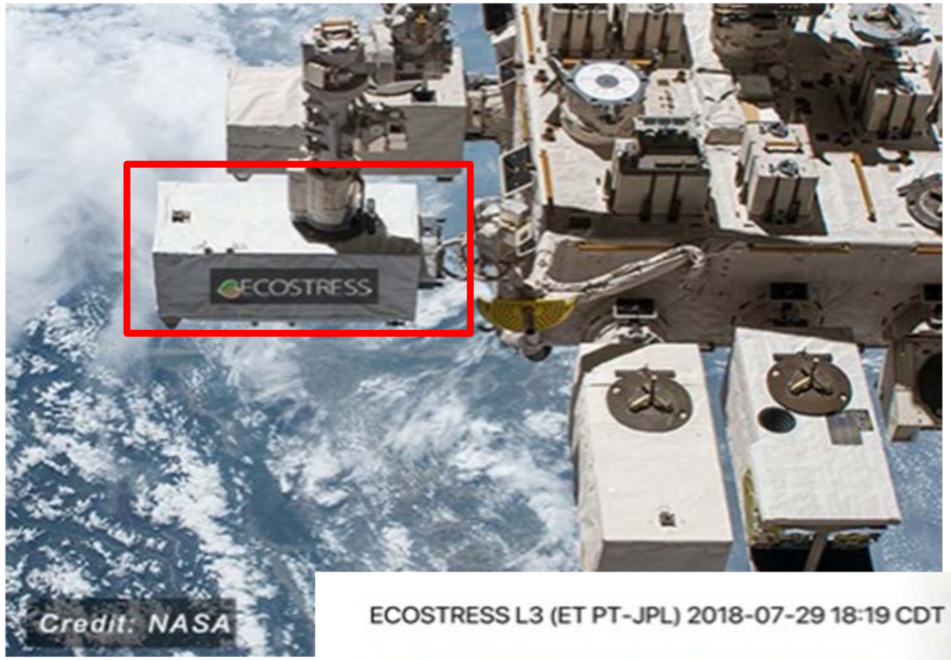
Image Credit: NASA



- Bermuda, August 2013
- This animation displays all 128 HICO bands, 3 at a time, to produce color.
- Island characteristics, shallow water components, and coral signatures can be examined.

ECOSTRESS

- Onboard the ISS
- Date Range: Aug 2018-Present
- Spatial Resolution: 70 m
- Spectral Resolution: 6 bands (160-1200 nm)
- Range: 53.6° N latitude to 53.6° S latitude
- Find Data At: Data Pool, NASA Earthdata Search, AppEEARS, and USGS EarthExplorer



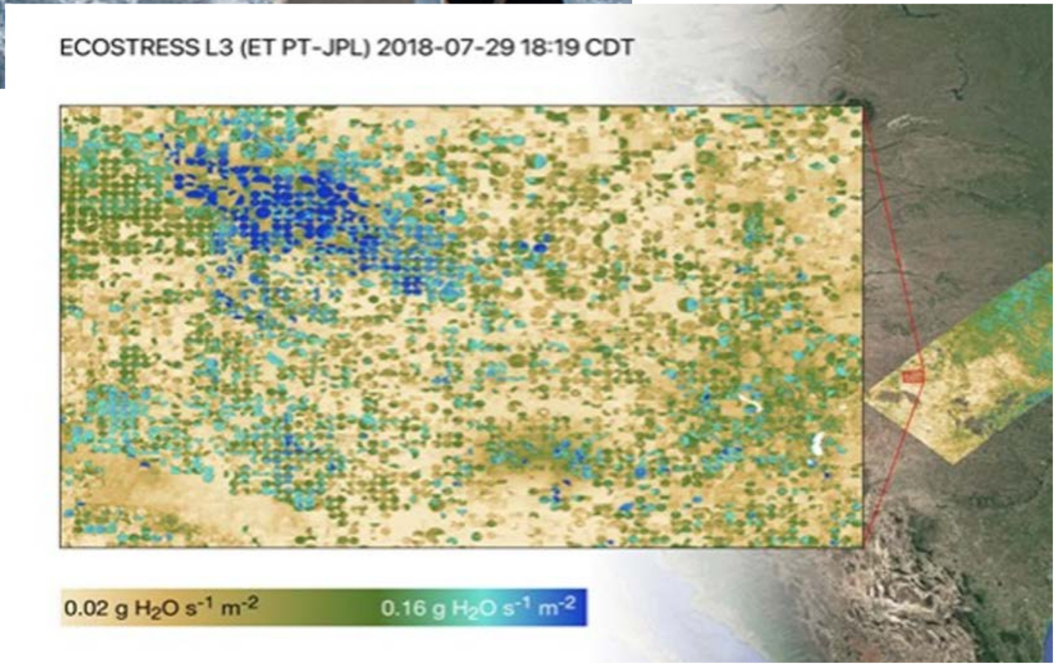


Image Credit: NASA

ECOSTRESS

ECOSTRESS data displaying evaporative stress from 2019 (top), 2020 (middle), and percent change in evaporative stress from 2019-2020 (bottom) near Farmington, NM in the NAPI farms region.

Blue colors represent low stress and high water use, whereas red colors represent high stress and low water use.

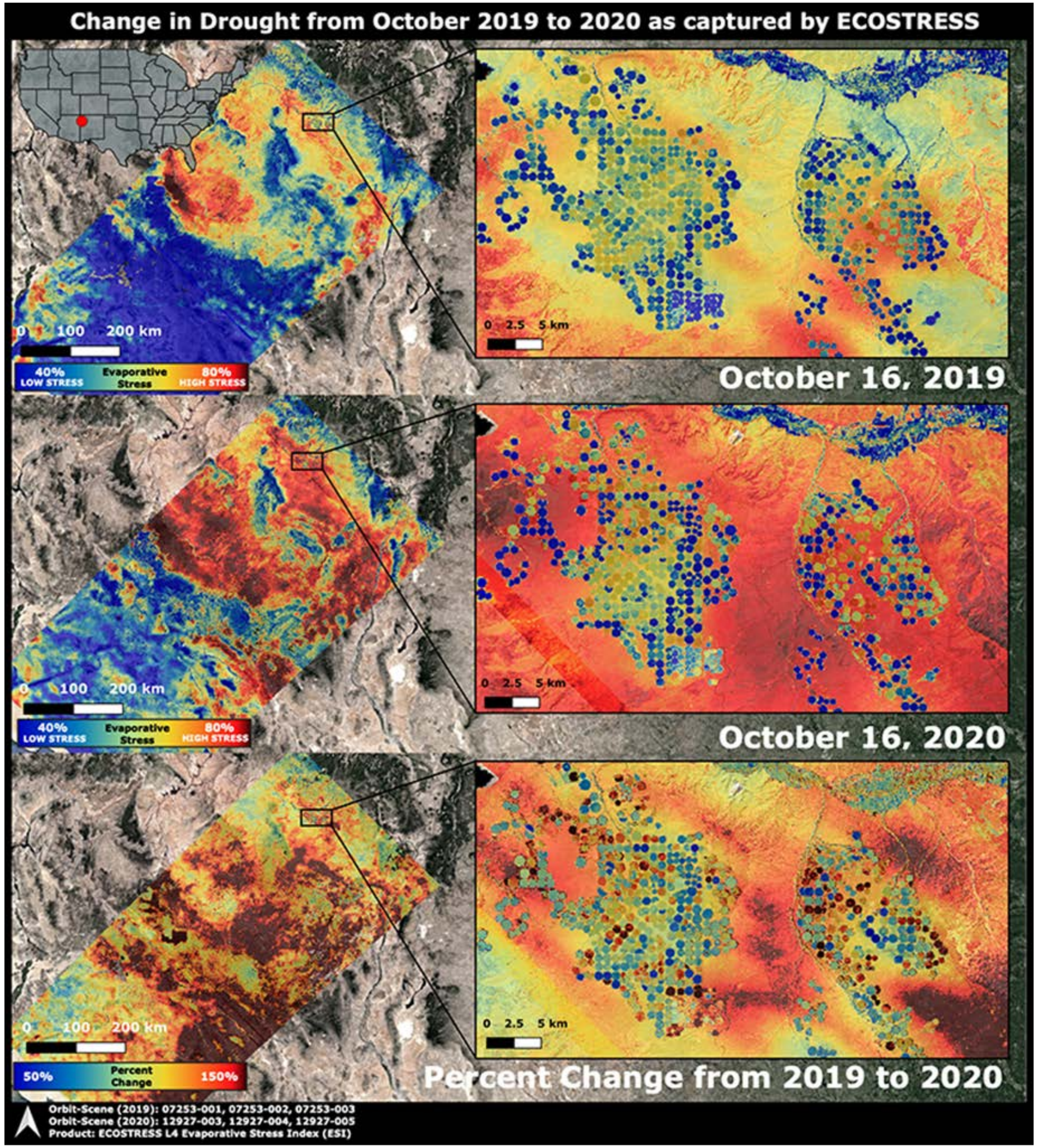


Image Credit: NASA

Airborne Visible/Infrared Imaging Spectrometer (AVIRIS)

- Flown on four aircraft platforms: NASA's ER-2 jet, Twin Otter International's Turboprop, Scaled Composites' Proteus, and NASA's WB-57
- Flown in North America, Europe, portions of South America, and Argentina
- 224 continuous spectral bands
- 400 to 2500 nm
- Bandwidth: < 10 nm
- Objective: Identify, measure, and monitor constituents of Earth's surface and atmosphere based on molecular absorption and particle scattering signatures

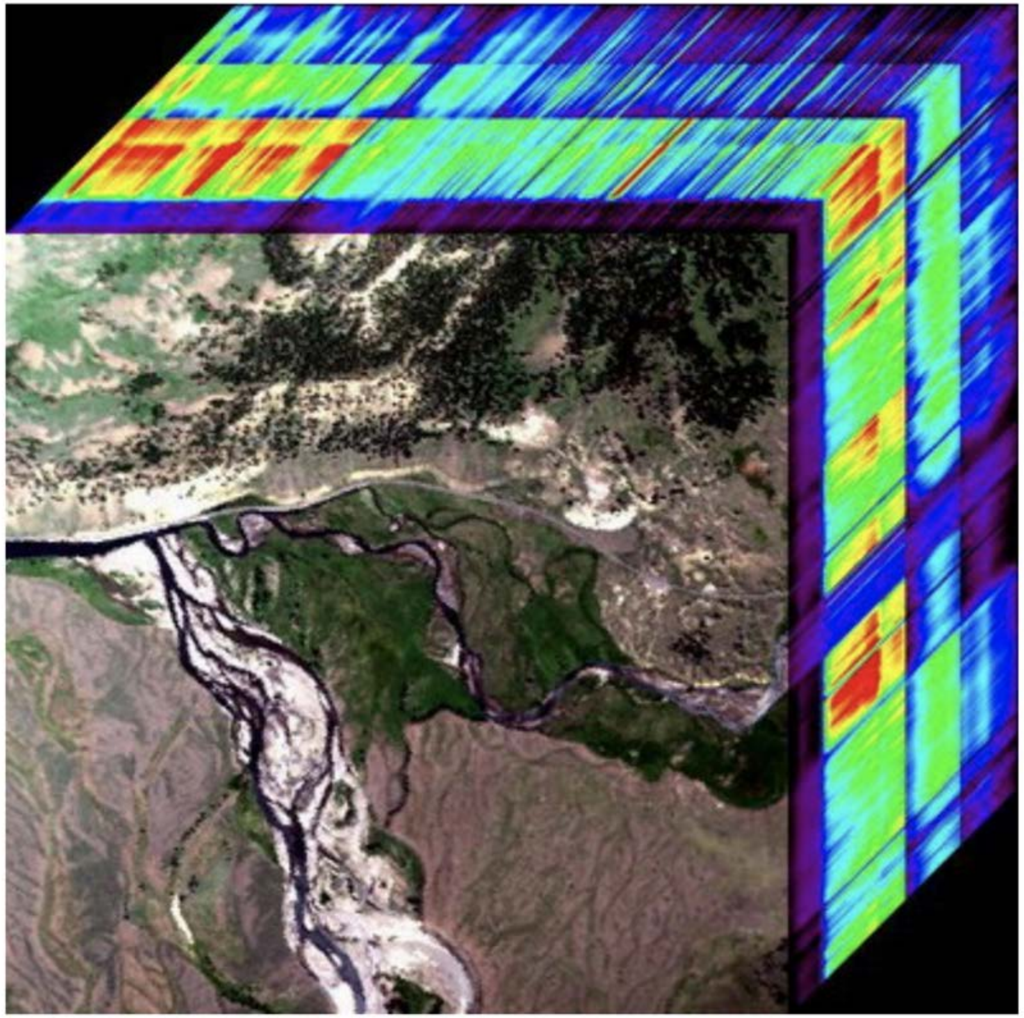


Image Credit: Lu et al., 2020

Airborne Visible/Infrared Imaging Spectrometer (AVIRIS)

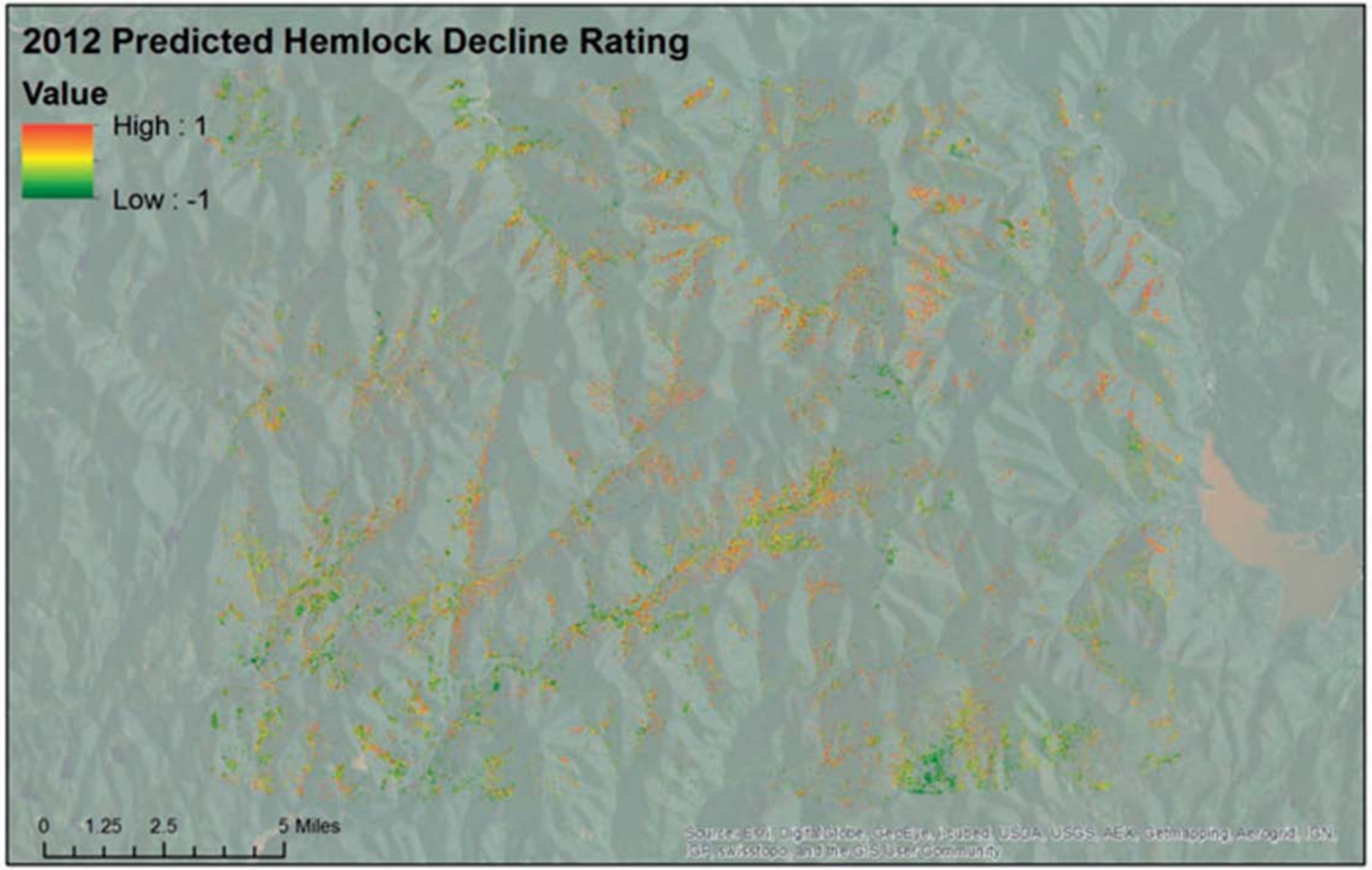


Image Credit: Hanavan et al, 2015

Hemlock health monitoring in Catskill State Park using AVRIS imagery from July 2001

Hemlocks in this region are prone to elongate hemlock scale, *Fiorinia externa* Ferris, which can result in branch dieback and tree mortality.

COral Reef Airborne Laboratory (CORAL)

- Airborne mission flown using the Portable Remote Imaging Spectrometer (PRISM) to evaluate health and conditions of coral reef ecosystems
- Date Range: 2016-2019
- Spectral Resolution: 349.9-1053.5 nm (3.5 nm sampling)

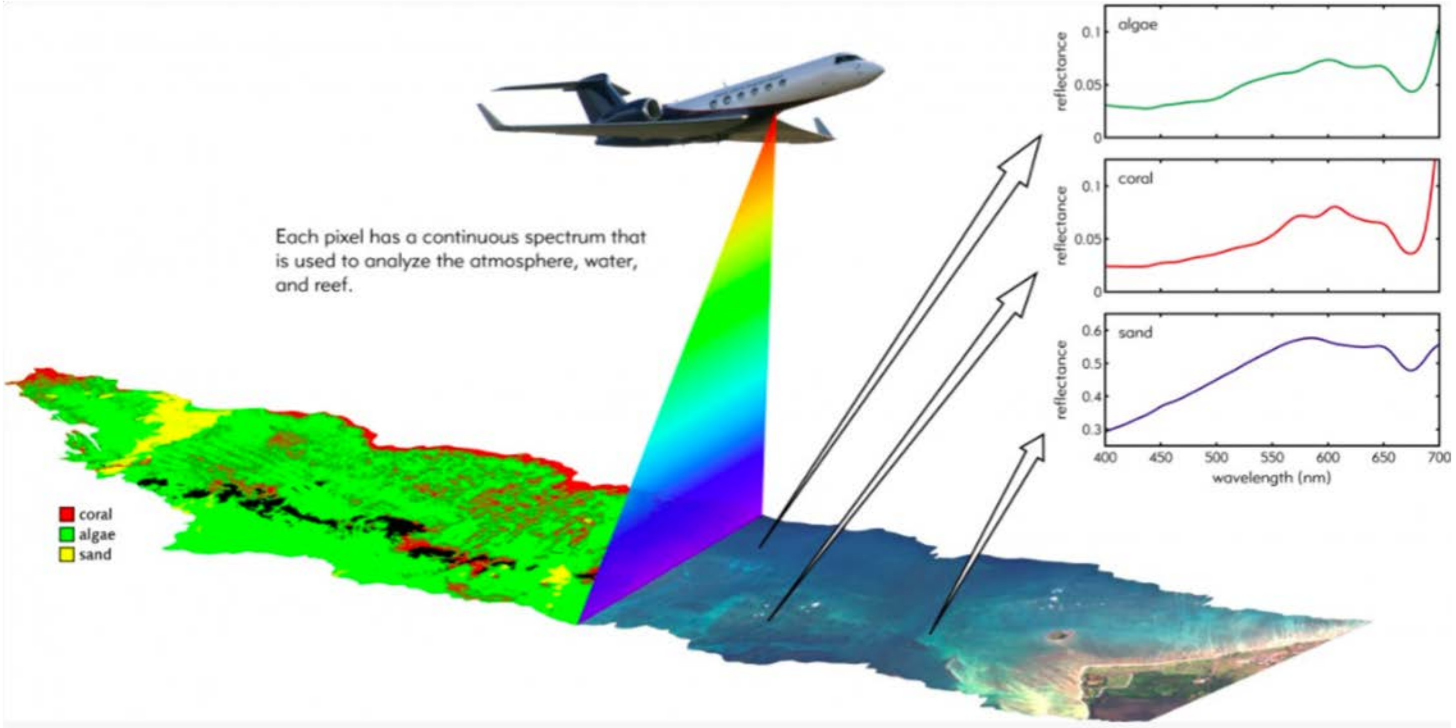
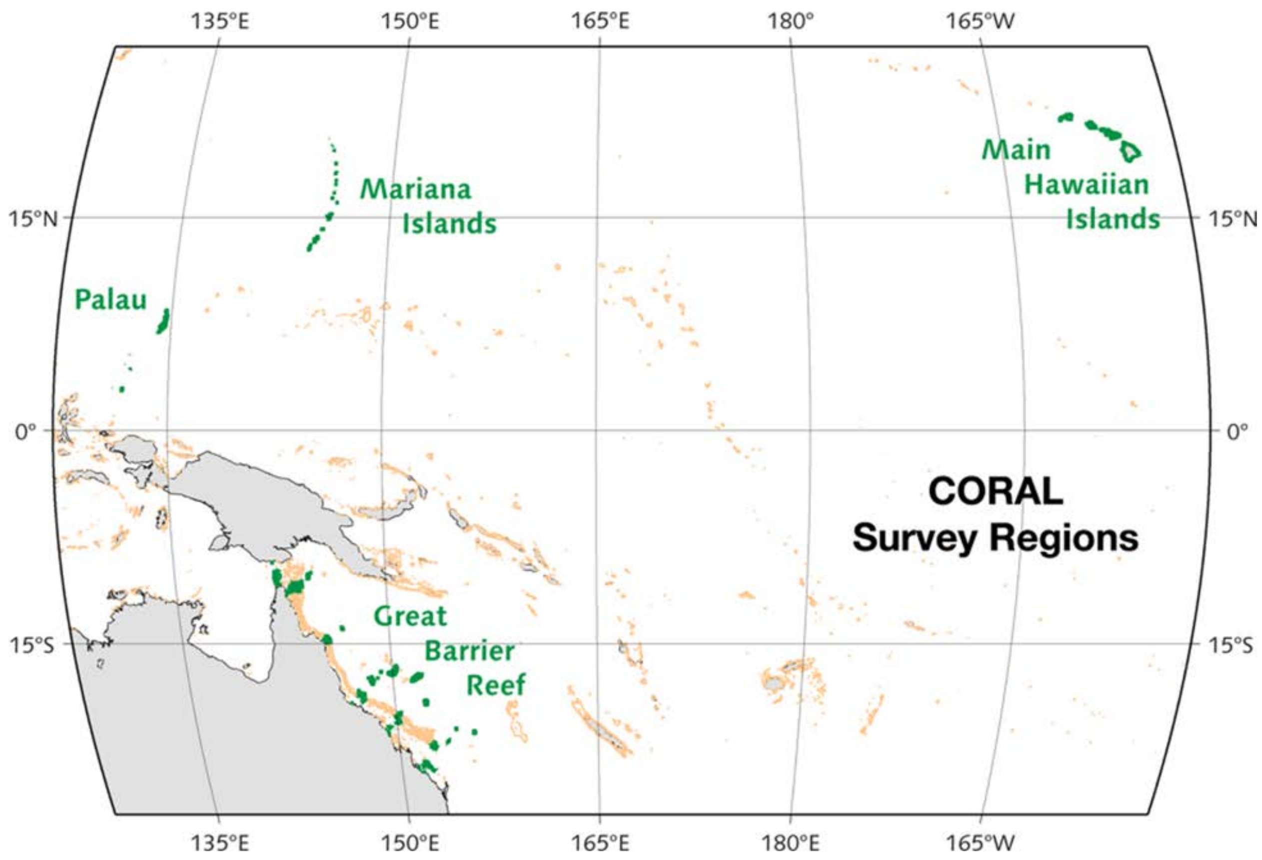
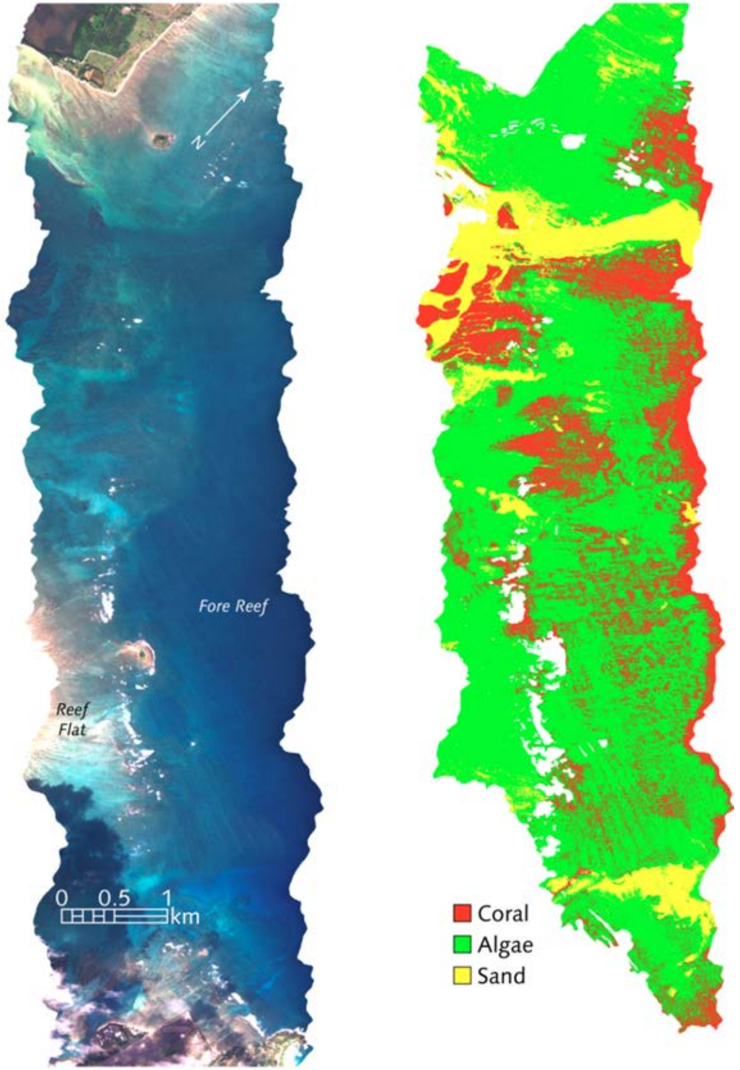


Image Credit: NASA

COral Reef Airborne Laboratory (CORAL)



Six sub-campaigns near the Mariana Islands, Palau, portions of the Great Barrier Reef, and the Hawaiian Islands (top). CORAL image and classification (right) from the French Frigate Shoals in northwestern Hawaii. Image Credit: NASA



Additional Hyperspectral Missions

Instrument	TianGong-1	PRISMA	HISUI	EnMAP	SHALOM	HypXIM
Organization	Chinese Academy of Science and Physics	Italian Space Agency (ASI)	Japanese ministry of Economy, Trade, and Industry	German GFZ-DLR	Italy-Israel Space agencies (ASI-ISA)	France Space Agency (CNES)
Date Range	2011-2013	2020-Present	2021	2021	2022	2021/2022
Spectral Range	400-2500 nm	400-2500 nm	400-2500 nm	420-2450 nm	400-2500 nm	400-2500 nm
Spectral Bands	128	249	185	244	275	210
Spatial Resolution	10-20 m	30 m	30 m	30 m	10 m	10 m
Objective	Land imaging in China	Natural resources and atmosphere	Energy, vegetation monitoring	Earth observation	Land and ocean observation	Soil, urban, coastal applications

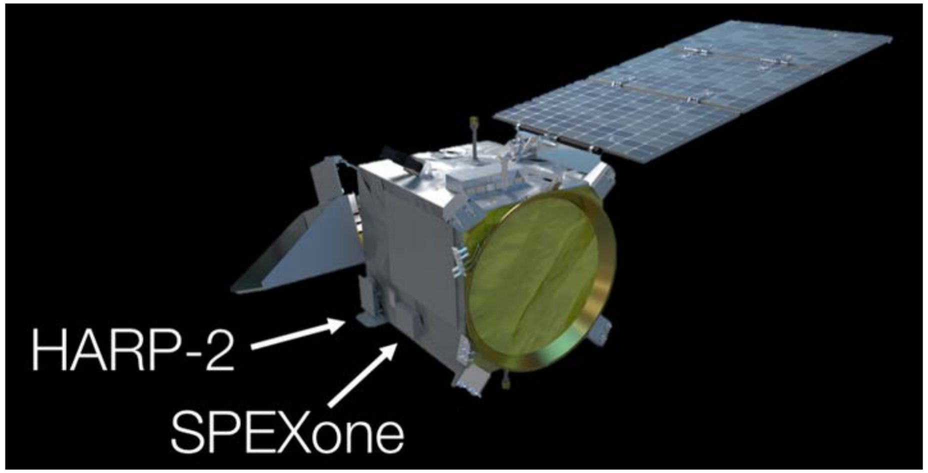
Future NASA Hyperspectral Satellite Initiatives

- **Plankton, Aerosol, Cloud, and Ocean Ecosystem (PACE)**
  - Observations of the global oceans, atmosphere, and terrestrial ecosystems
  - Ultraviolet through the visible and into the shortwave infrared region of the electromagnetic spectrum, specifically from 340-890 nm sampled at every 2.5 nm with 5 nm resolution
- **Surface Biology and Geology (SBG)**
  - Applications across a variety of focus areas
  - Precursor to SBG: Hyperspectral Infrared Imager (HyspIRI) mission concept activity (2007-2018)
    - Imaging spectrometer measuring from the visible to short wave infrared (VSWIR: 380 nm - 2500 nm) in 10 nm contiguous bands
- **Geosynchronous Littoral Imaging and Monitoring Radiometer (GLIMR)**
  - Observations of ocean biology, chemistry, and ecology in the Gulf of Mexico, portions of the Southeastern US coastline, and the Amazon River plume
  - Hyperspectral ocean color radiometer

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

https://pace.gsfc.nasa.gov/

- PACE is NASA's next great investment in hyperspectral earth imagery and multi-angle polarimetry.
  - Launch Date: 2023
  - 3-year design life; 10-year propellant
- Hyperspectral Imager: **Ocean Color Instrument (OCI)**
  - Spectral Resolution: UV to SWIR (340-890 nm every 2.5 nm, with 940, 1038, 1250, 1378, 1615, 2130, & 2250 nm)
  - Temporal Resolution: 2 days
  - Spatial Resolution: 1-km^2 at nadir
- Two Multi-Angle Polarimeters
  - **HARP-2**: Wide swath, hyper-angular, 4 bands across the VIS & NIR
  - **SPEXone**: Narrow swath, hyperspectral (UV-NIR), 5 viewing angles



PACE Applications Program

Air Quality

Water Resources

Disasters

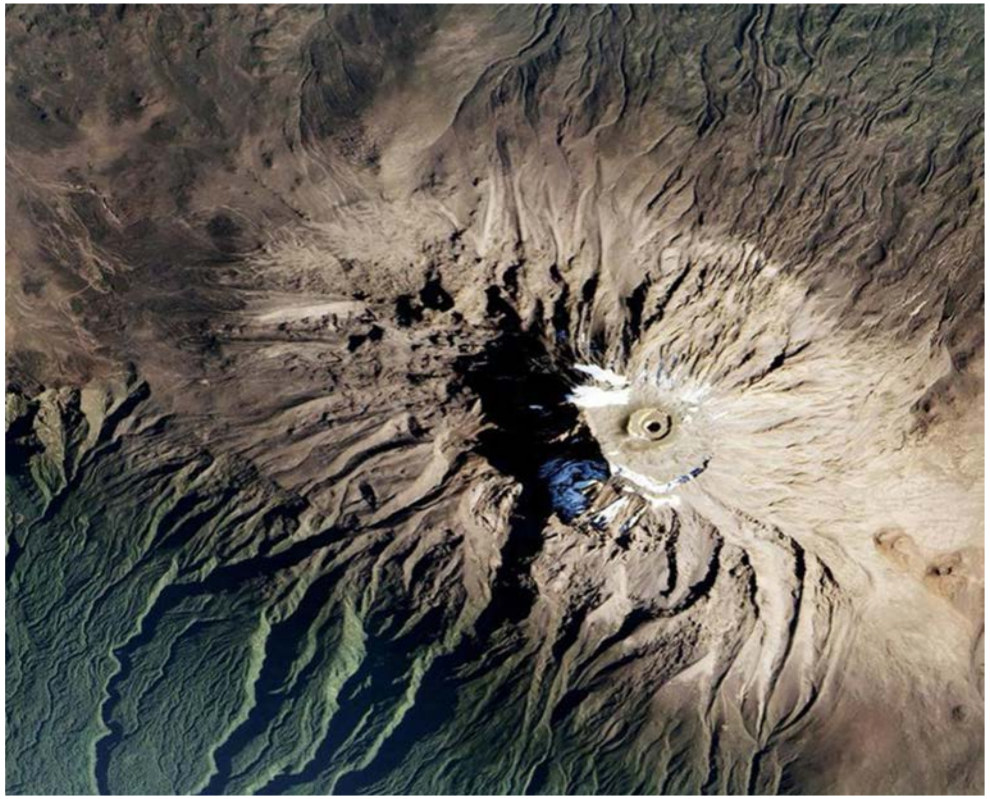
Ecological Forecasting

Climate

Surface Biology and Geology (SBG) Mission

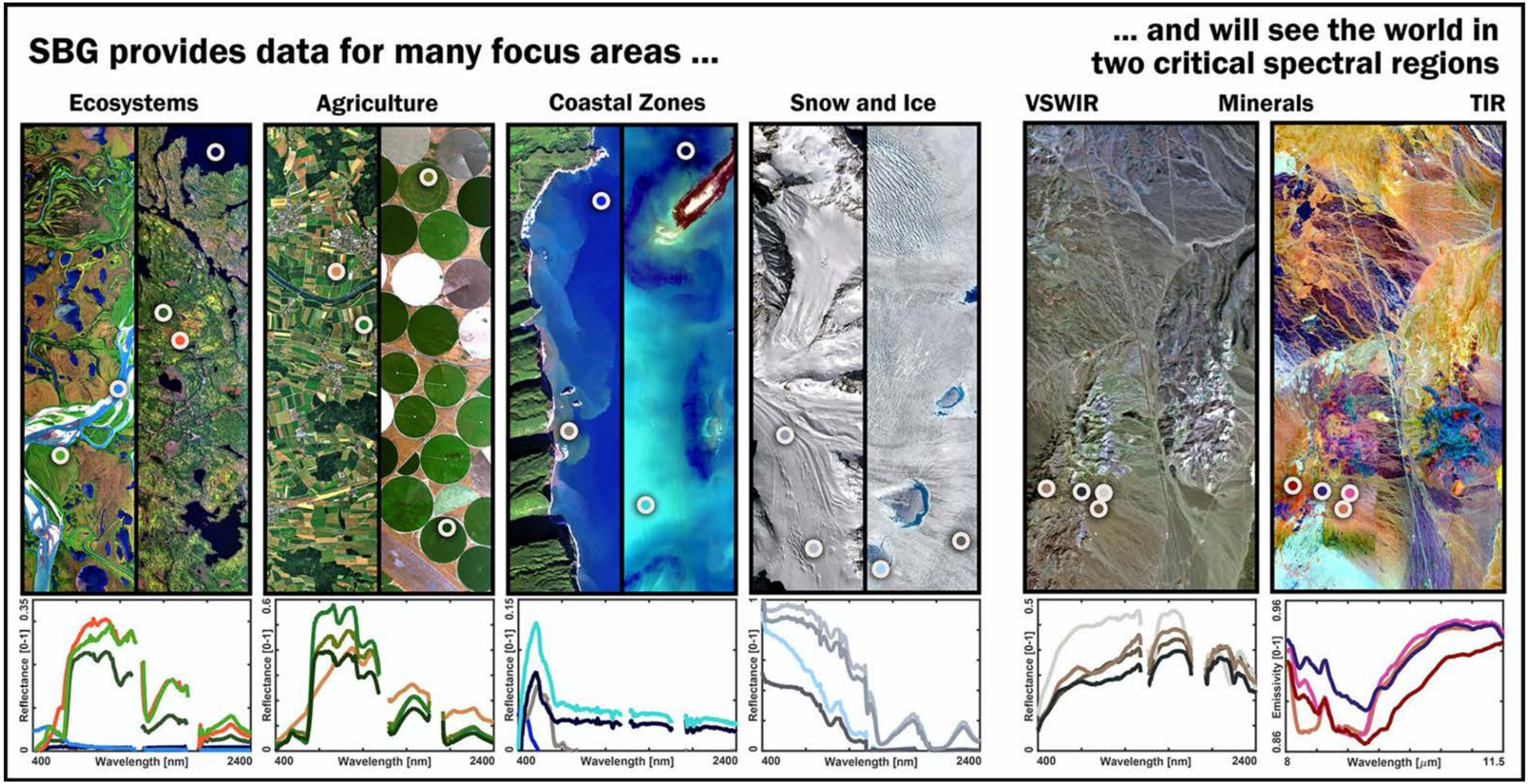
https://sbg.jpl.nasa.gov/

- In development via guidance from the 2018 Decadal Survey
- Potential Parameters:
  - Visible to Shortwave Infrared Bands:
    - Spectral Range: 350 or 400 to 2500 nanometers
    - Spectral Resolution: 10 nm or better
    - Global with 2- to16-day revisit times
  - Thermal Bands:
    - Spectral Range: 800 to1200 or 300 to 500 nanometers
    - Spectral Resolution: Greater than 5 bands
    - Global with 1- to 70-day revisit times



Mount Kilimanjaro Image Credit: JPL SBG

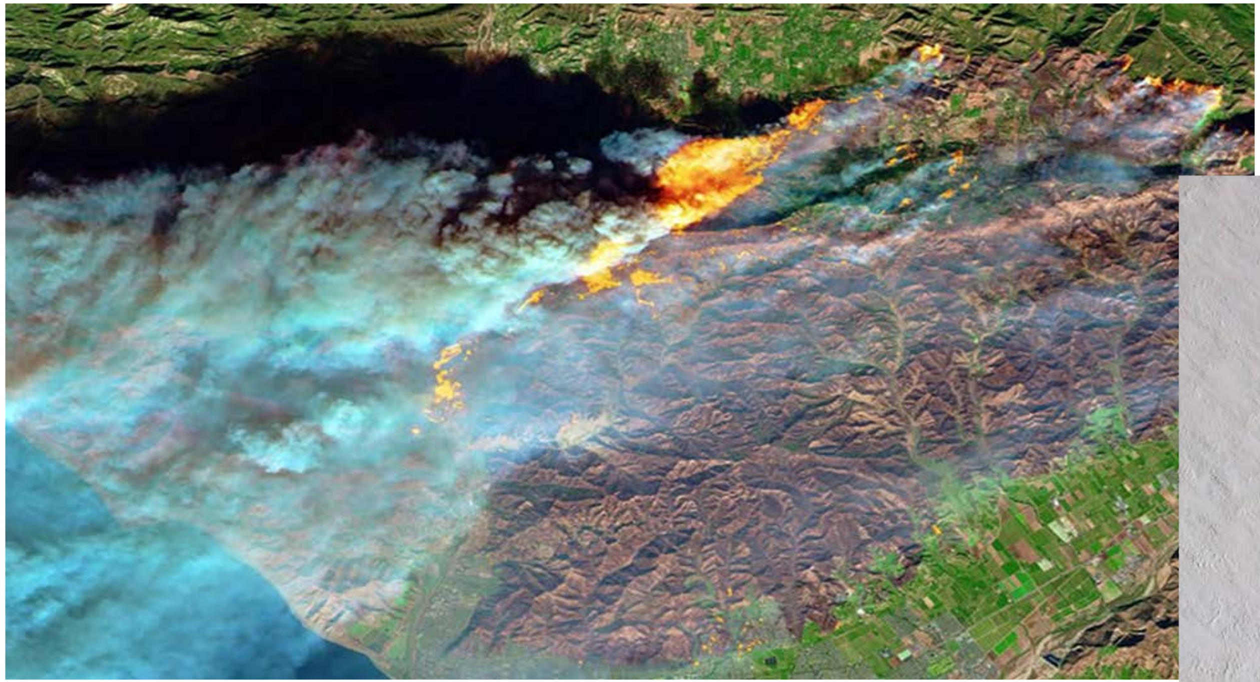
SBG Mission



SBG Potential Applications; Image Credit: JPL SBG

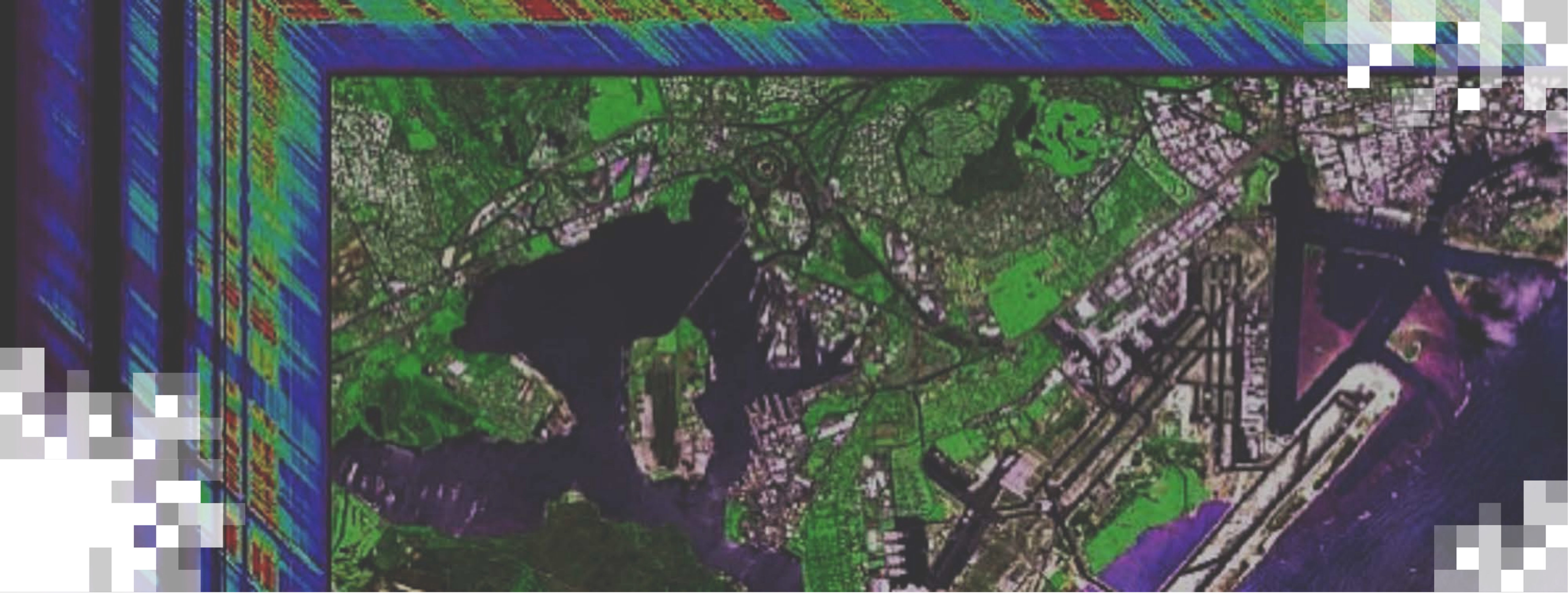
SBG Mission

- Get involved with SBG! https://sbg.jpl.nasa.gov/news-events



Thomas Fire; Image Credit: JPL SBG

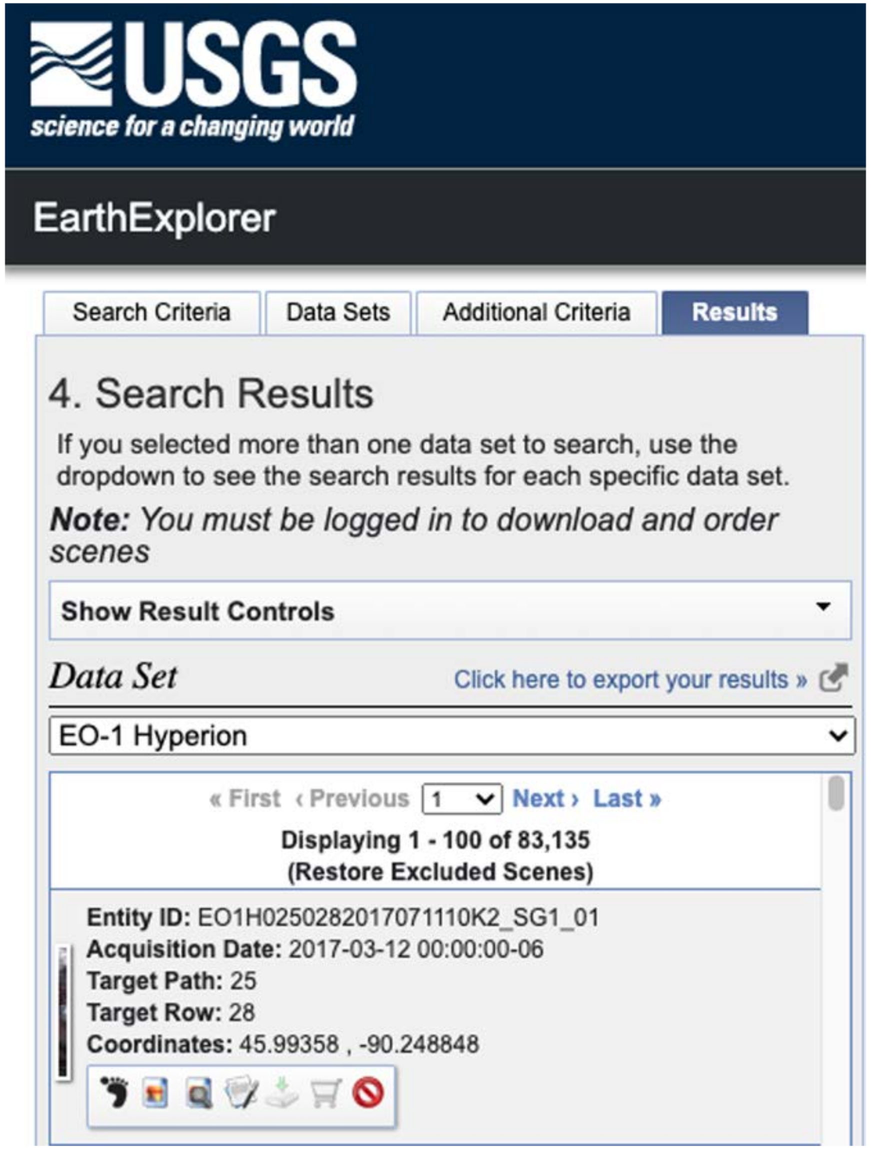
Larsen-C Ice Shelf; Image Credit: JPL SBG



Assessing & Processing Hyperspectral Data

Hyperspectral Data Access

- Some hyperspectral data is available on websites you may already be familiar with.
  – USGS EarthExplorer
  – USGS GloVis
  – NASA EarthData
  – Google Earth Engine



EarthExplorer User Interface; Image Credit: USGS

Hyperspectral Data Access

- Data are also available through the NASA Distributed Active Archive Centers (DAACs).
  - Data is separated by application area, such as Land Processes and Ocean Biology.
  - You can find AVIRIS, HICO, CORAL and other hyperspectral datasets through the online resources of DAACs.

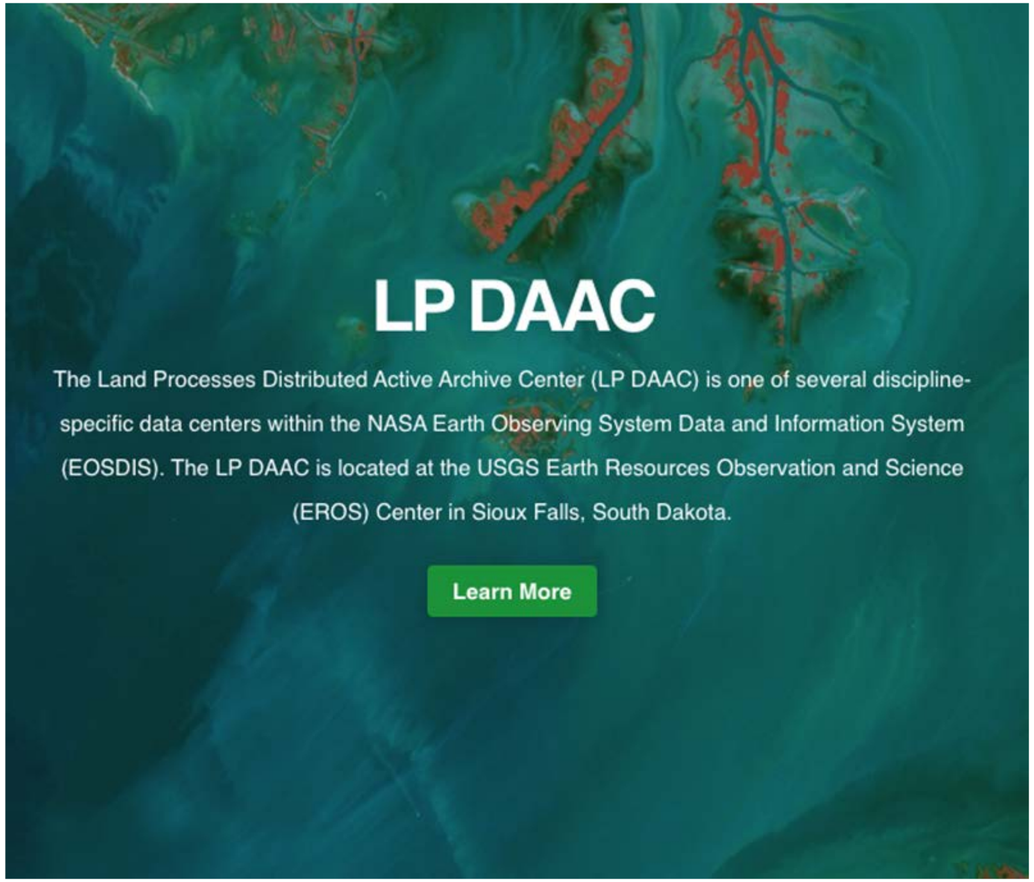


Image Credit: USGS

Data Availability Considerations

Satellite Test Mission Data

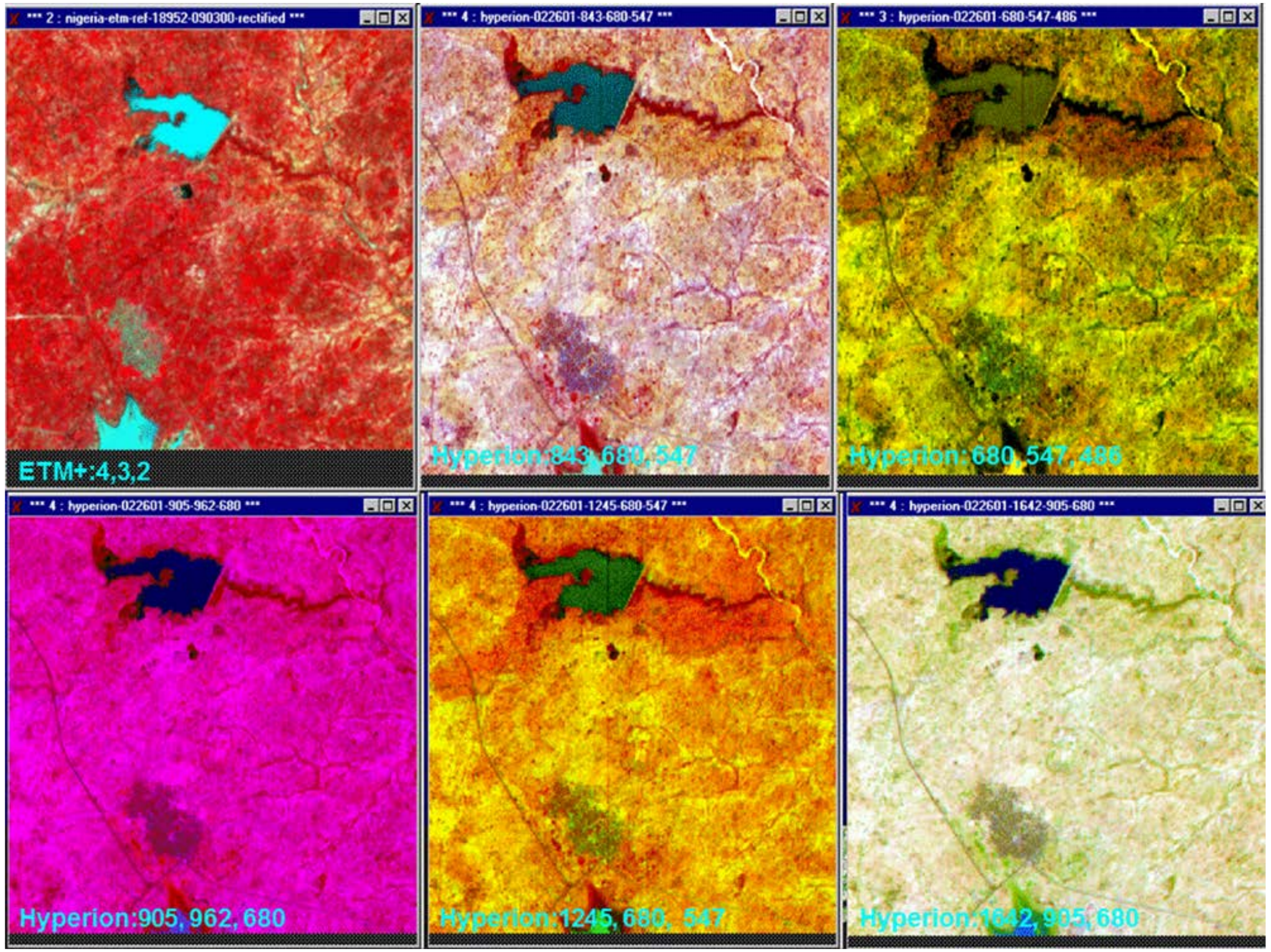
- Data access might be limited to specific geographic region.
- Raw data may need to be processed by a NASA scientist.
- Contact with mission or program scientists may be necessary to access appropriately pre-processed data for your region.

Airborne Data

- Limited to flight paths set by mission objectives.
- Temporal resolution is often seasonal or yearly.
- Campaigns can be limited to just a few years or a single test mission.
- Many research flights were grounded in 2020 due to COVID.

Hyperspectral Data Processing

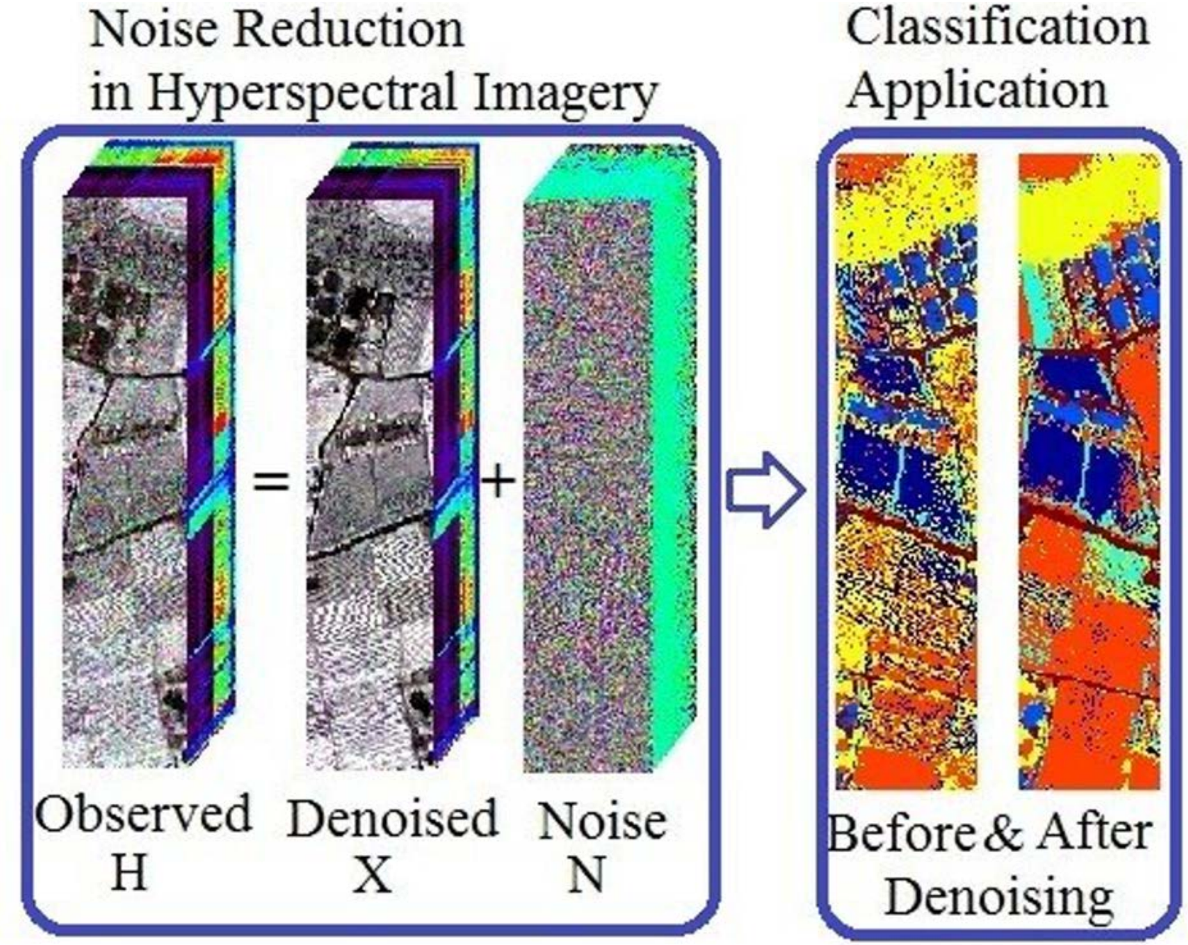
- Data is available at different processing levels depending on the sensor.
  - Level 1: Radiance
  - Level 2: Surface Reflectance
- Atmospheric correction must be applied.
- Dimensionality Reduction Techniques:
  - Principal Component Analysis (PCA)
  - Minimum Noise Fraction (MNF)
- Processing and analysis can be conducted in:
  - ArcGIS
  - QGIS
  - ENVI
  - Erdas Imagine
  - Google Earth Engine
  - R
  - Python



False color composites (FCCs) of Landsat and Hyperion data. Hyperspectral data provides many possibilities and combinations of FCCs as illustrated here for a few combinations using some of the Hyperion bands. Image Credit: USGS

Data Processing Considerations

- Large data files
  - 100-250 bands
  - Increased storage and processing power needed
- Bands may display similar reflectance properties/high correlation among bands
  - May be difficult to determine which bands are most appropriate for the specific application
- May be high signal to noise ratios



Noise reduction in hyperspectral imagery. Image Credit: Rasti et al., 2018

Summary

- Hyperspectral Data: Generally, hundreds of contiguous spectral bands such that a radiant spectrum can be derived for each pixel.
  - Measuring reflectance at close intervals on the electromagnetic spectrum
  - Bands are usually spaced 10 nm or less from one another
- Multiple satellite and airborne sensors (Hyperion, AVIRIS, etc.)
- Data Considerations:
  - Benefits: Ability to differentiate different vegetation types, minerals, drought indicators, etc.
  - Limitations: Large datasets, potential for large signal to noise ratio, regional not global
- Next Two Sessions: Applications of Hyperspectral Data for Land and Coastal/Ocean Systems

Thank You!