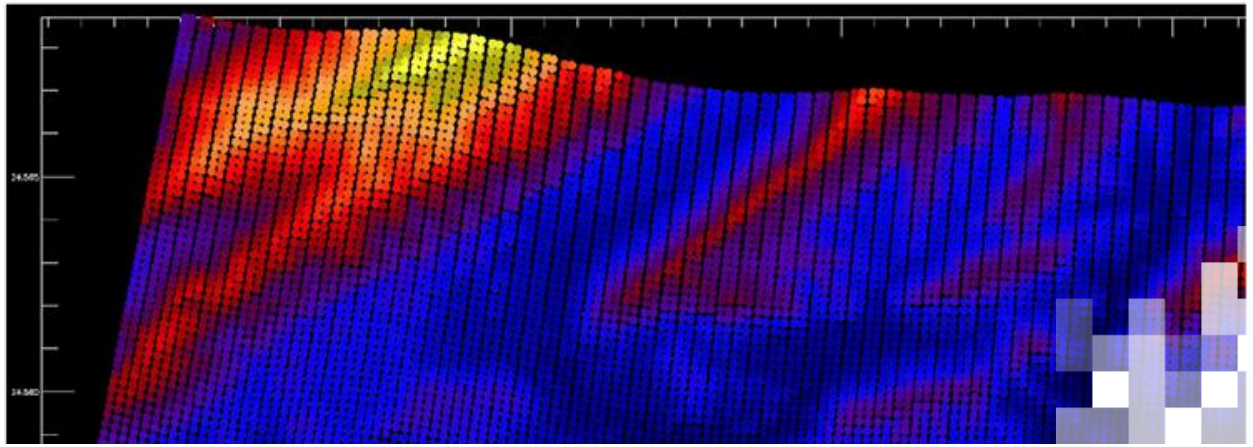




Biodiversity Applications for Airborne Imaging Systems

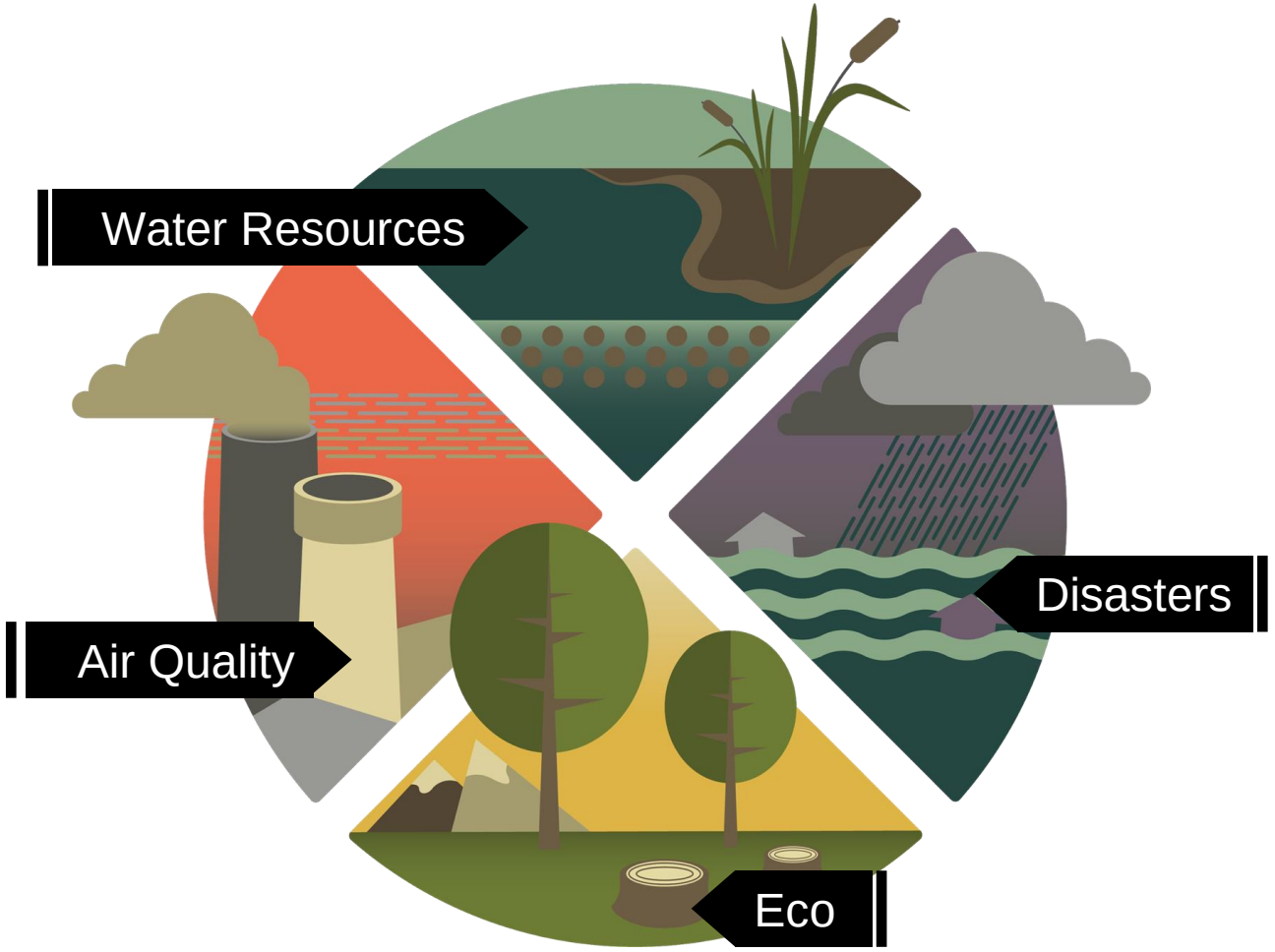
Juan L. Torres-Pérez, Britnay Beaudry, Sativa Cruz, Amber McCullum

March 27, 2023

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



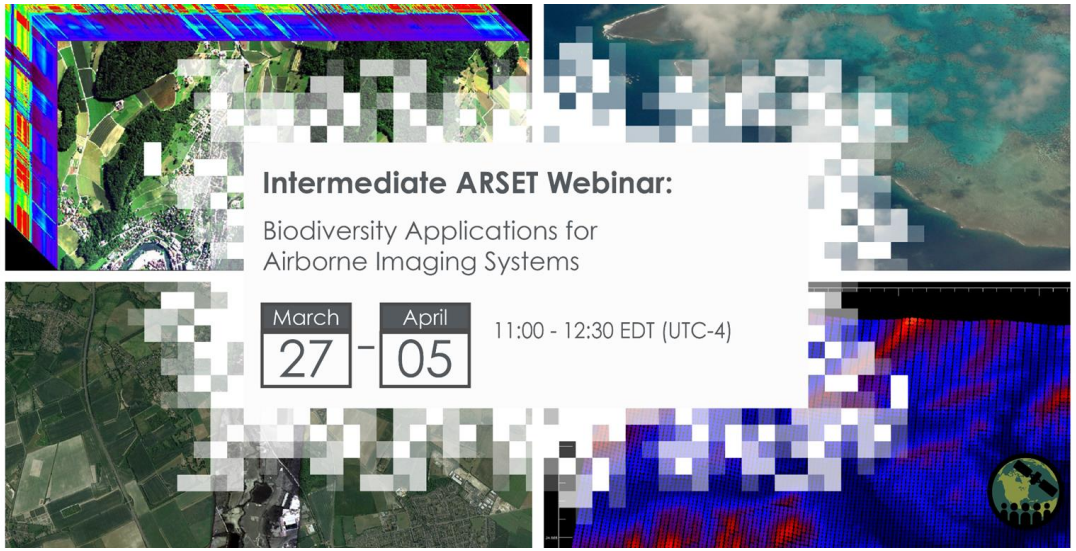
Course Structure and Information

- Four, 1.5-hour sessions on March 27, 29 & April 3, 5
  - 11:00 am - 12:30 pm EDT (UTC-4:00)

- Each session will feature a lecture and a Q&A session where instructors will be online to answer questions.

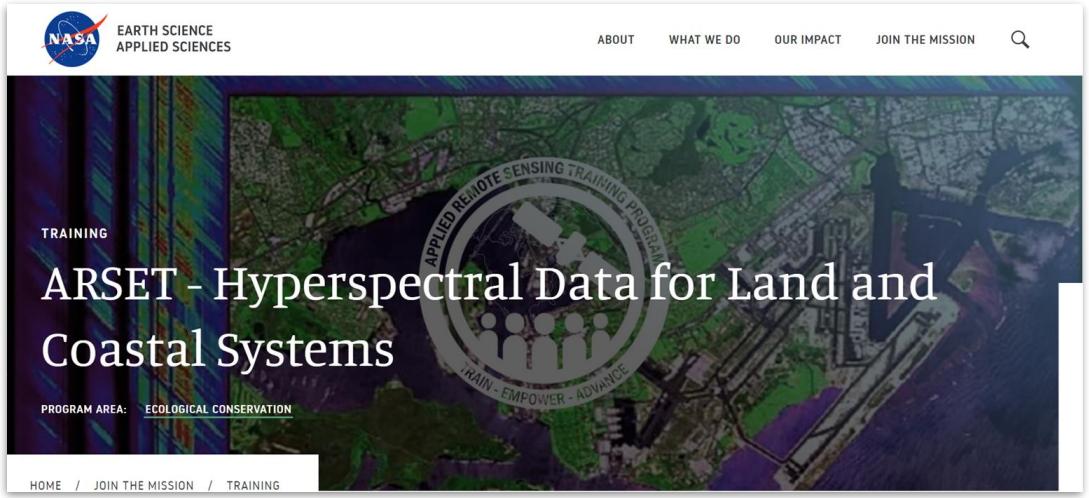
- Webinar recordings and PowerPoint presentations can be found after each session at: https://appliedsciences.nasa.gov/join-mission/training/english/arset-biodiversity-applications-airborne-imaging-systems

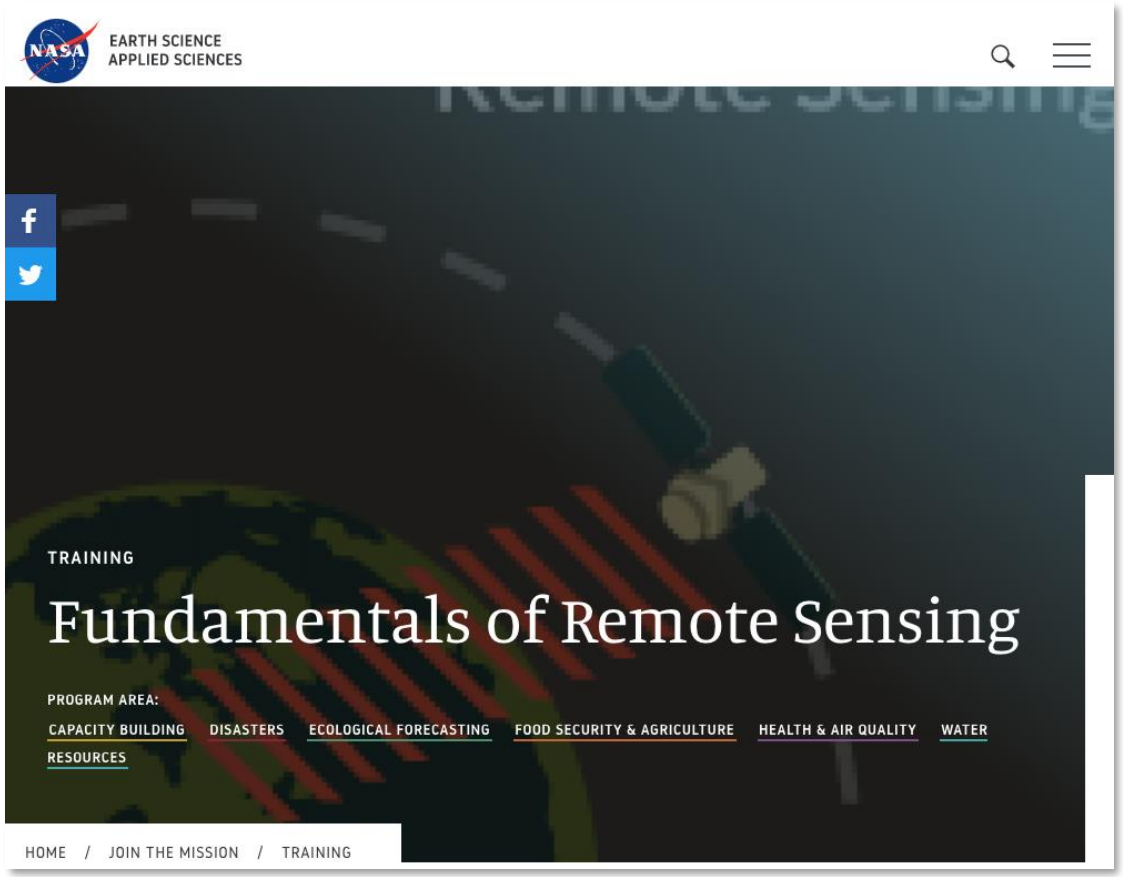
- For additional questions please email:
  - Juan L. Torres-Pérez (juan.l.torresperez@nasa.gov)
  - Amber McCullum (amberjean.mccullum@nasa.gov)
  - Britnay Beaudry (britnay.beaudry@nasa.gov)
  - Sativa Cruz (sativa.cruz@nasa.gov)



Prerequisites

- Prerequisites:
  - Fundamentals of Remote Sensing
  - Hyperspectral Data for Land and Coastal Systems
    - or equivalent experience

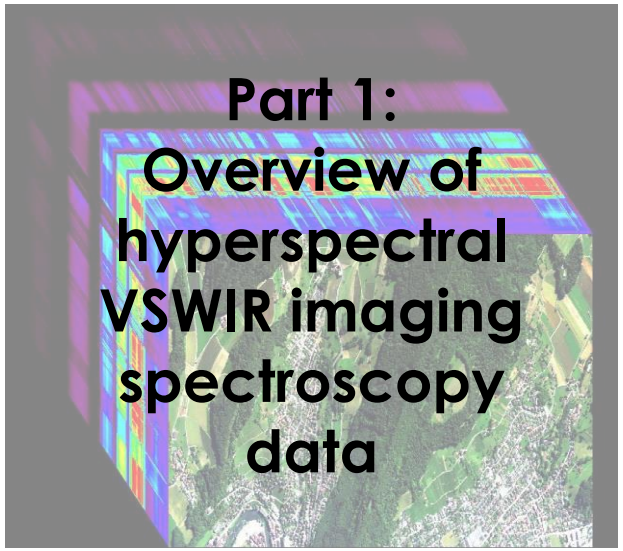


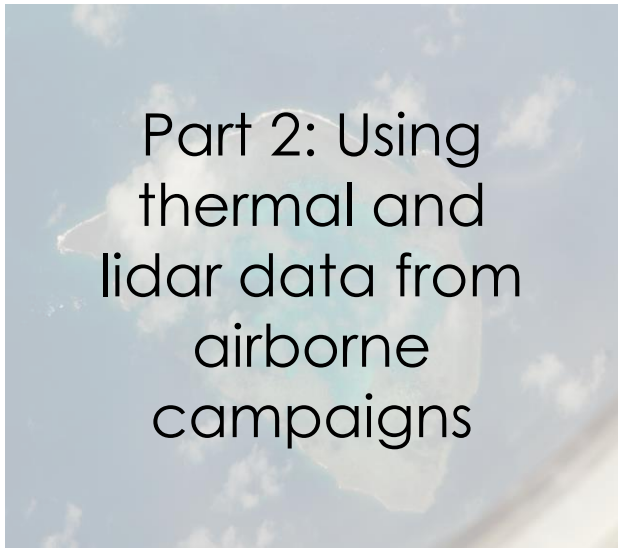


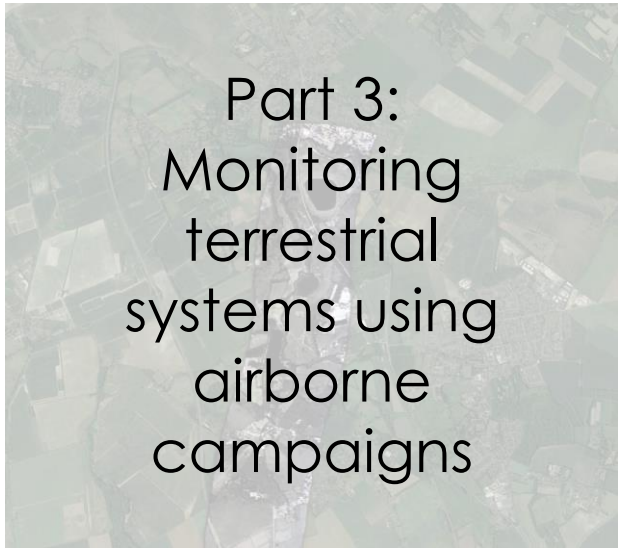
Homework and Certificates

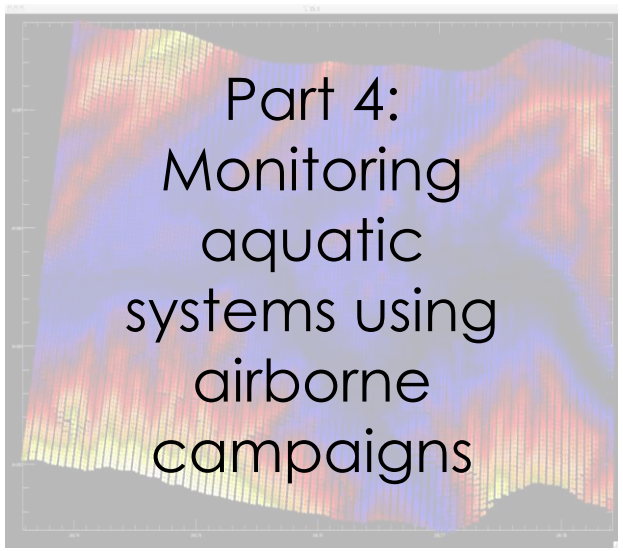
- **Homework:**
  - One homework assignment (available at the end of session four of this webinar series)
  - Answers must be submitted via Google Forms
  - **HW deadline: April 19th**
- **Certificate of Completion:**
  - Attend all four live webinars
  - Complete the homework assignment by the deadline (access from ARSET website)
  - You will receive certificates approximately two months after the completion of the course from: marines.martins@ssaihq.com

Course Outline





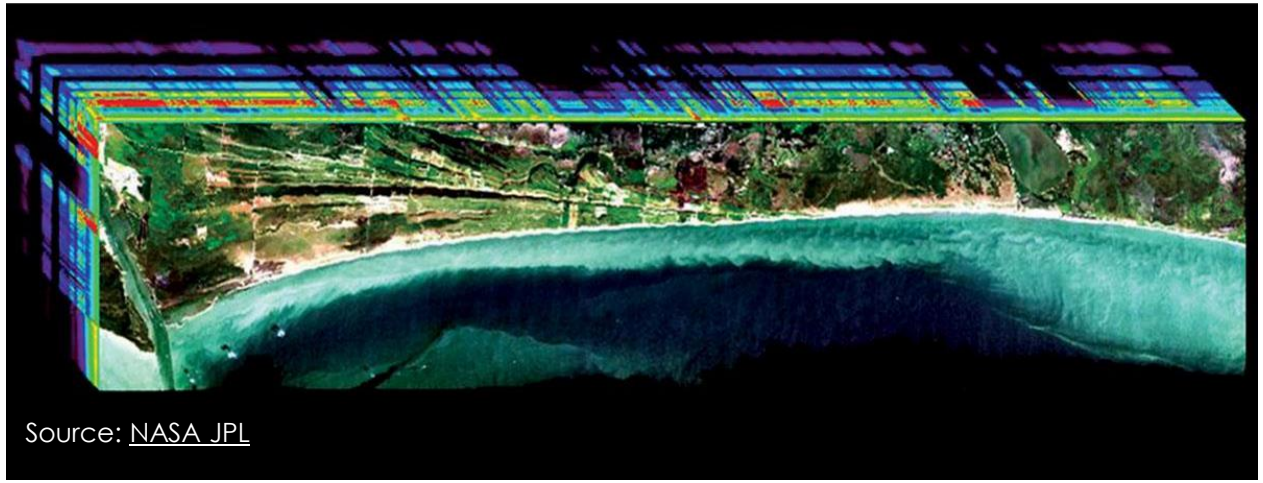




Learning Objectives

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

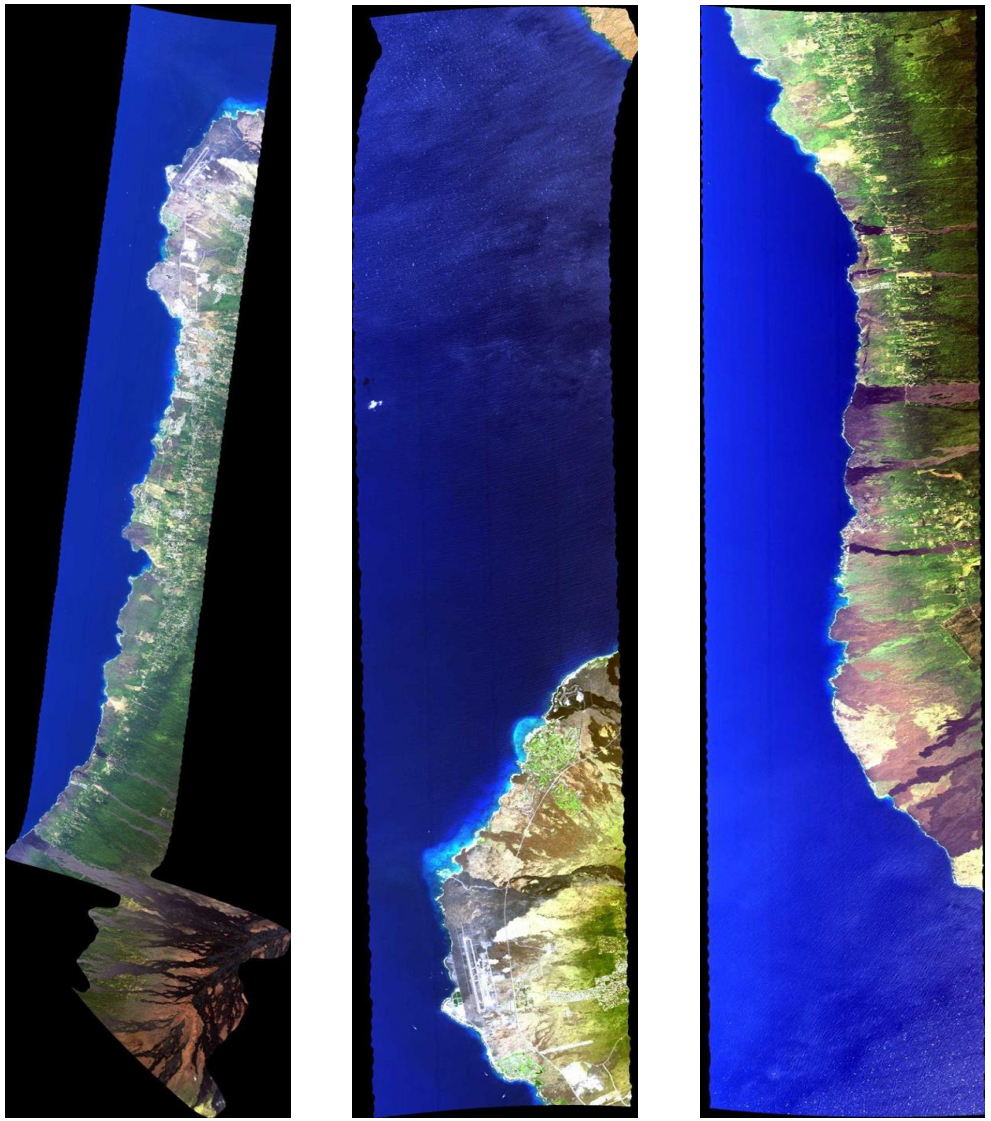
- Understand the applications of hyperspectral data, multispectral data, and LiDAR data for biodiversity monitoring and analysis
- Compare case studies that have used these datasets in preparation for upcoming NASA satellite missions and airborne campaigns



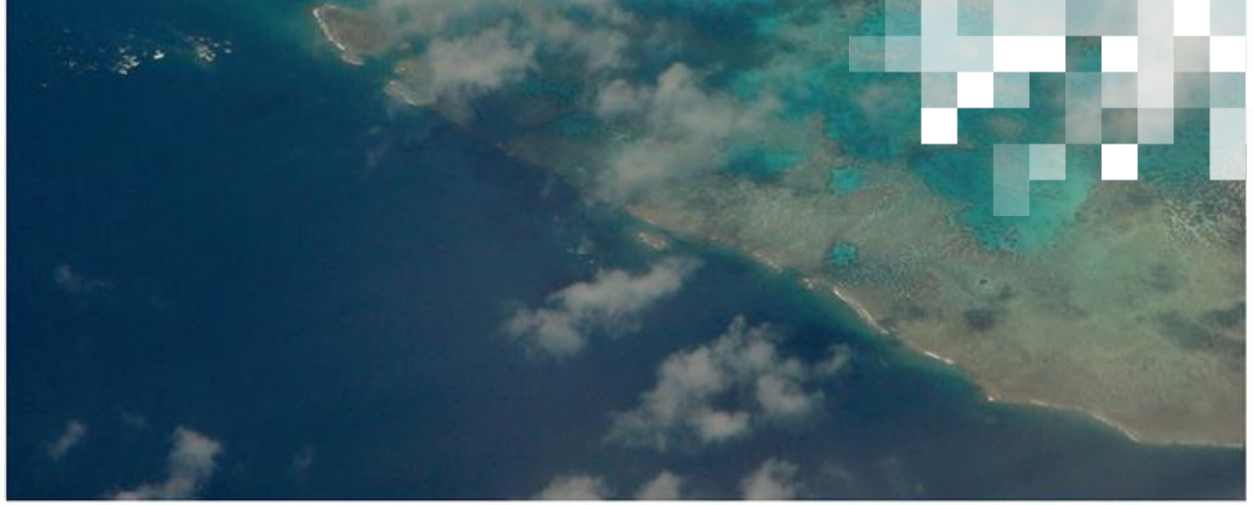
Source: NASA JPL

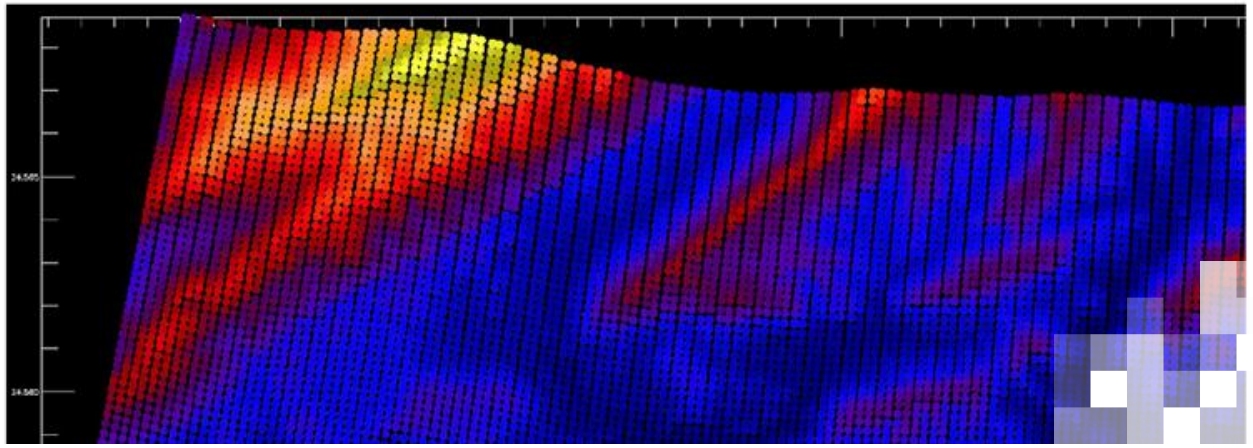
Part 1 Agenda

- Overview of hyperspectral visible to Shortwave Infrared (VSWIR) imaging spectroscopy data
- Highlight of hyperspectral instruments for measuring and monitoring terrestrial and aquatic biodiversity, in particular AVIRIS-NG and PRISM
- Highlight upcoming mission development such as the Surface Geology and Biology (SBG) mission and the Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission
- Q&A Session

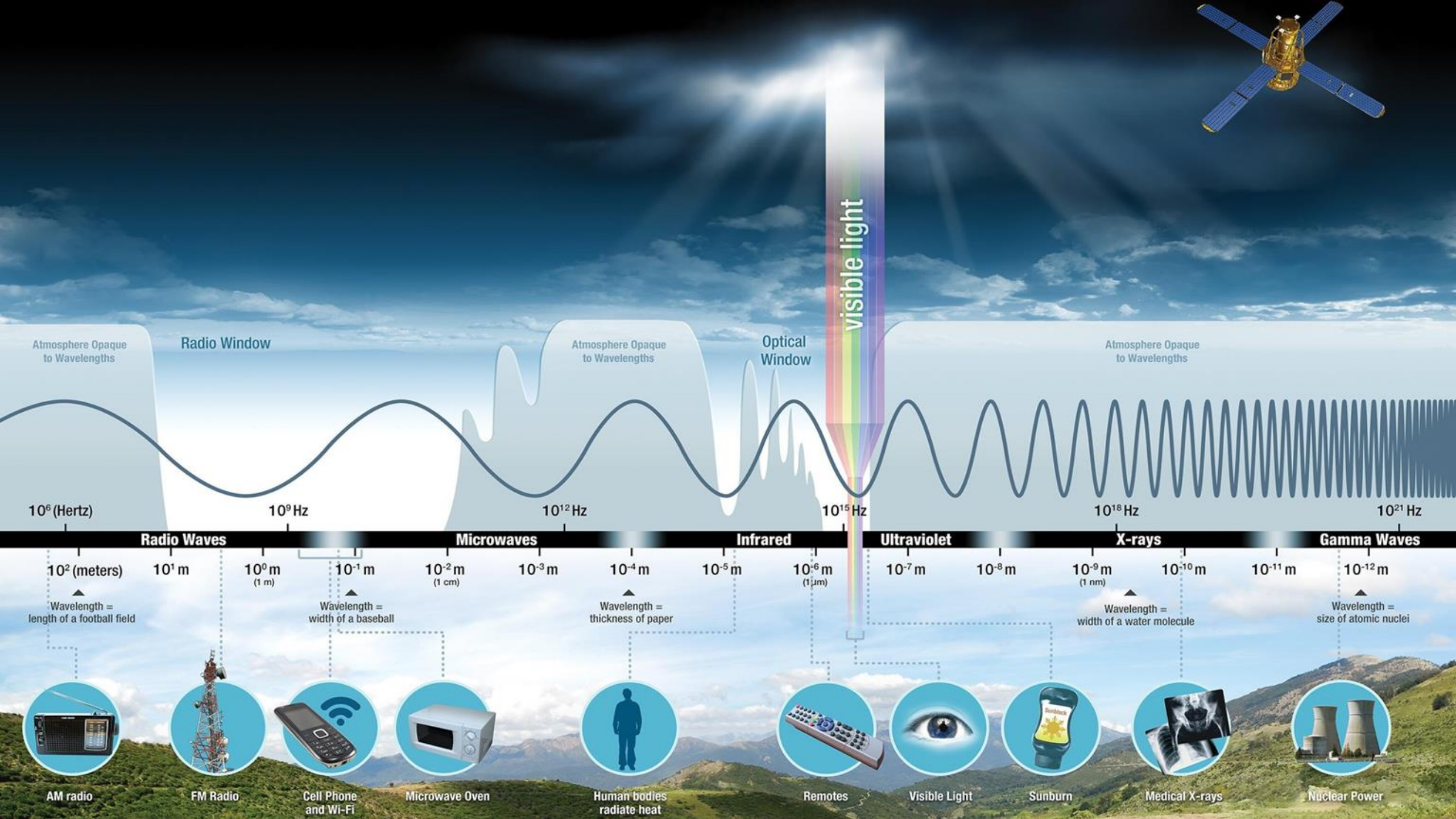


Source: NASA JPL



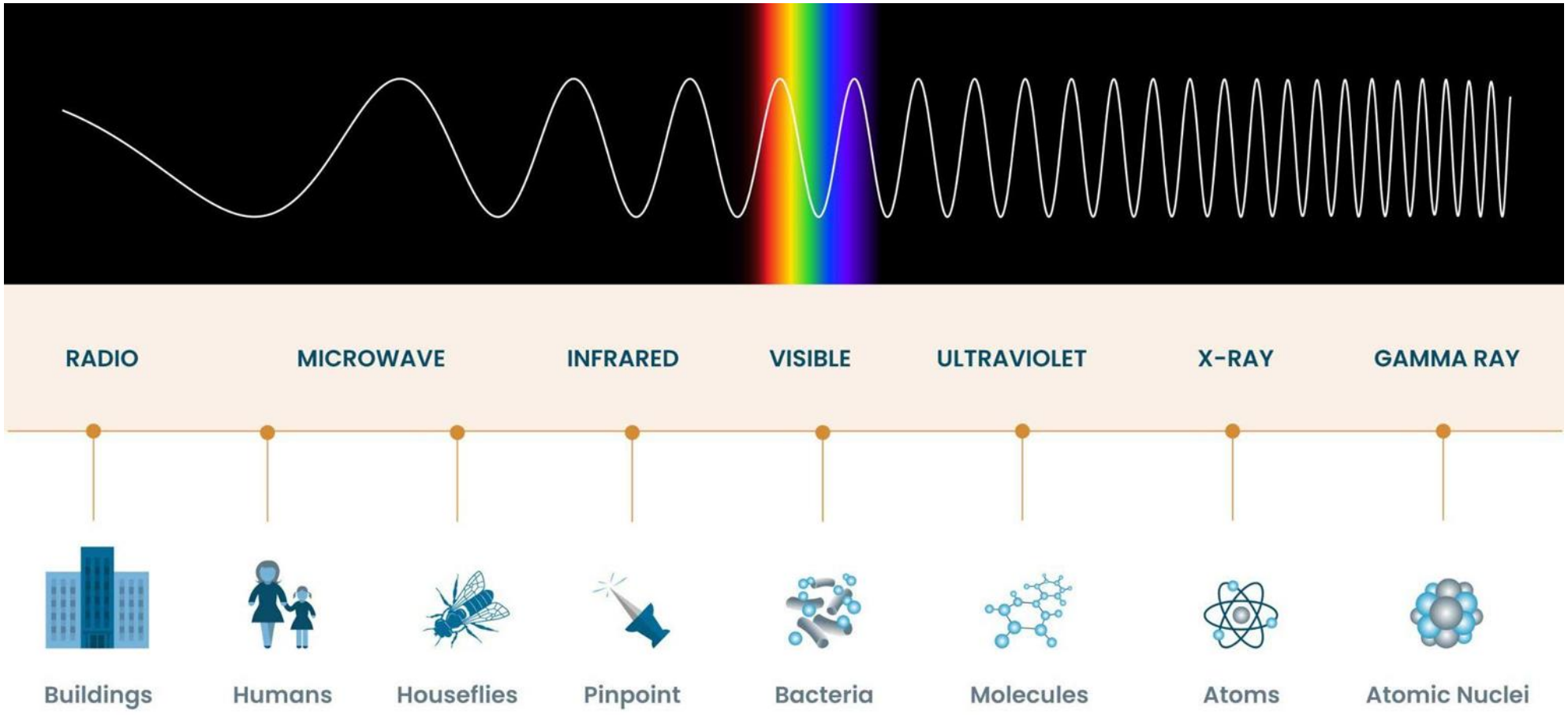


Overview of Hyperspectral Visible to Shortwave Infrared (VSWIR) imaging spectroscopy


Atmosphere Opaque to Wavelengths
Radio Window
Atmosphere Opaque to Wavelengths
Optical Window
visible light
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

Visible to Shortwave Infrared (VSWIR)

2500 nm - 380 nm



Source: NASA Hubble

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

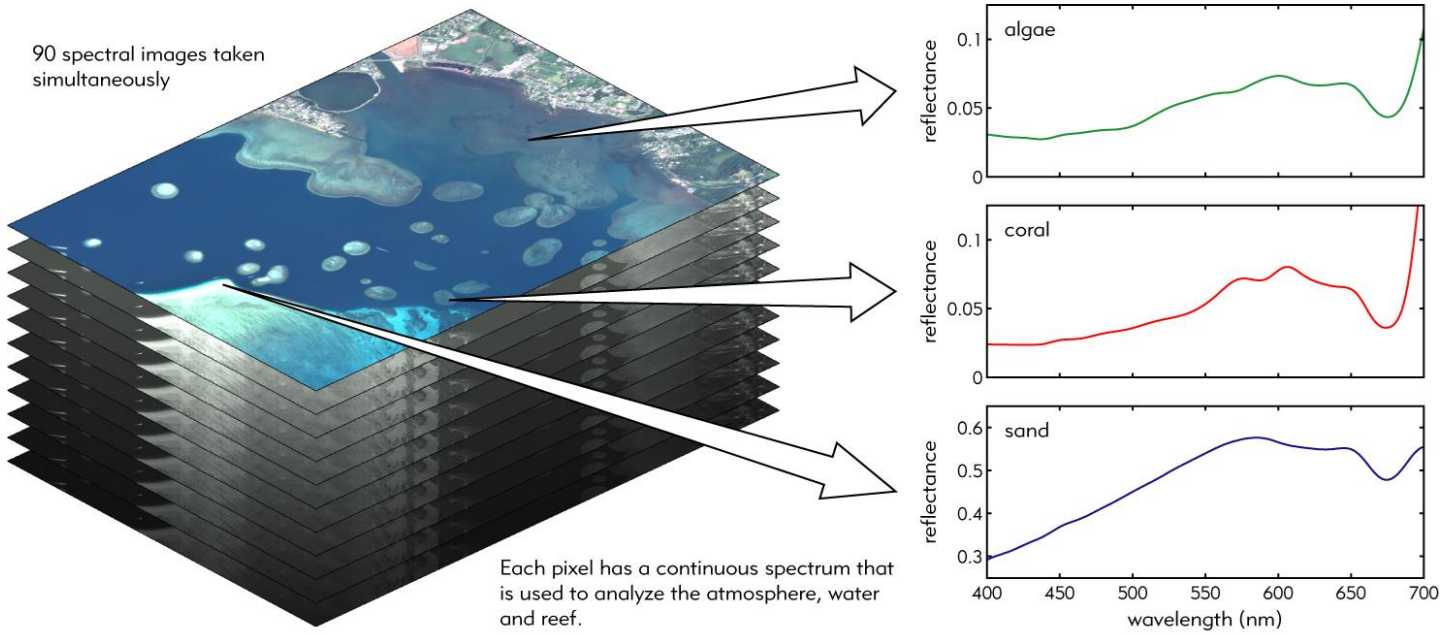
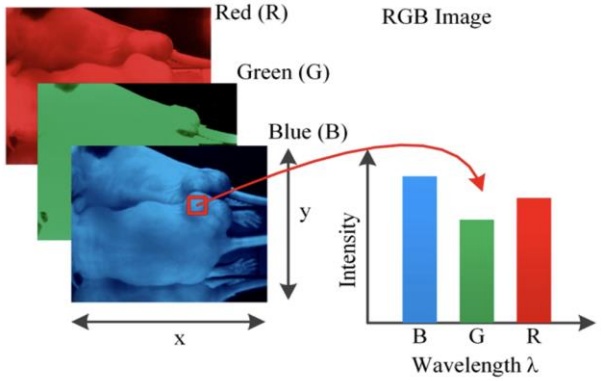


Image Credit: Eric Hochberg (CORAL PI)

Multispectral vs. Hyperspectral Data

Multispectral



Hyperspectral

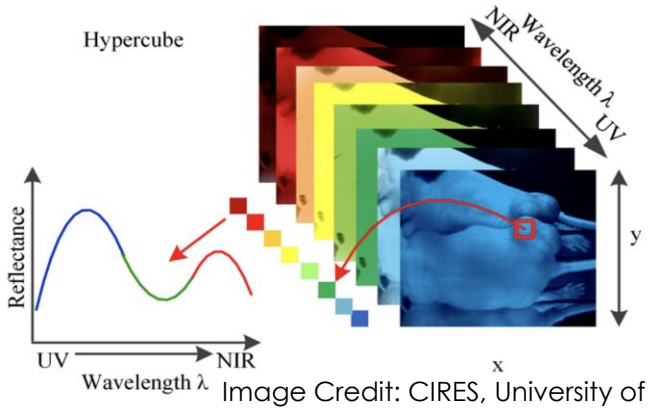


Image Credit: CIRES, University of Colorado

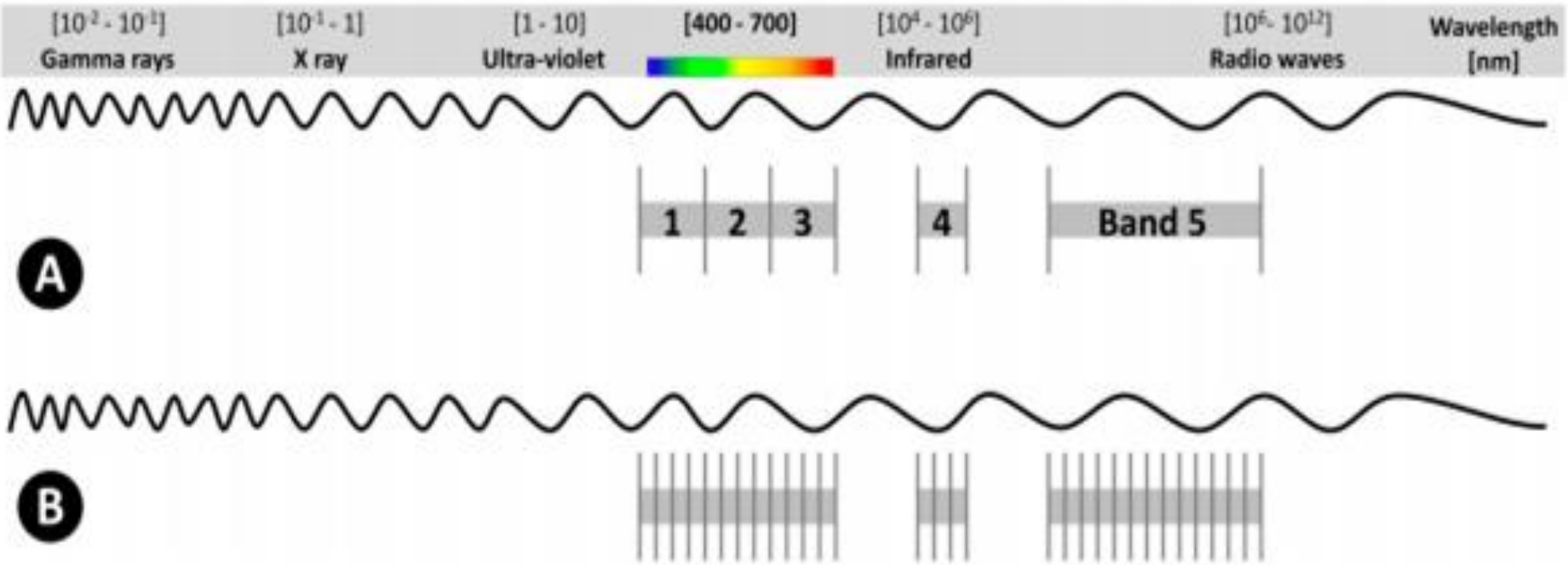
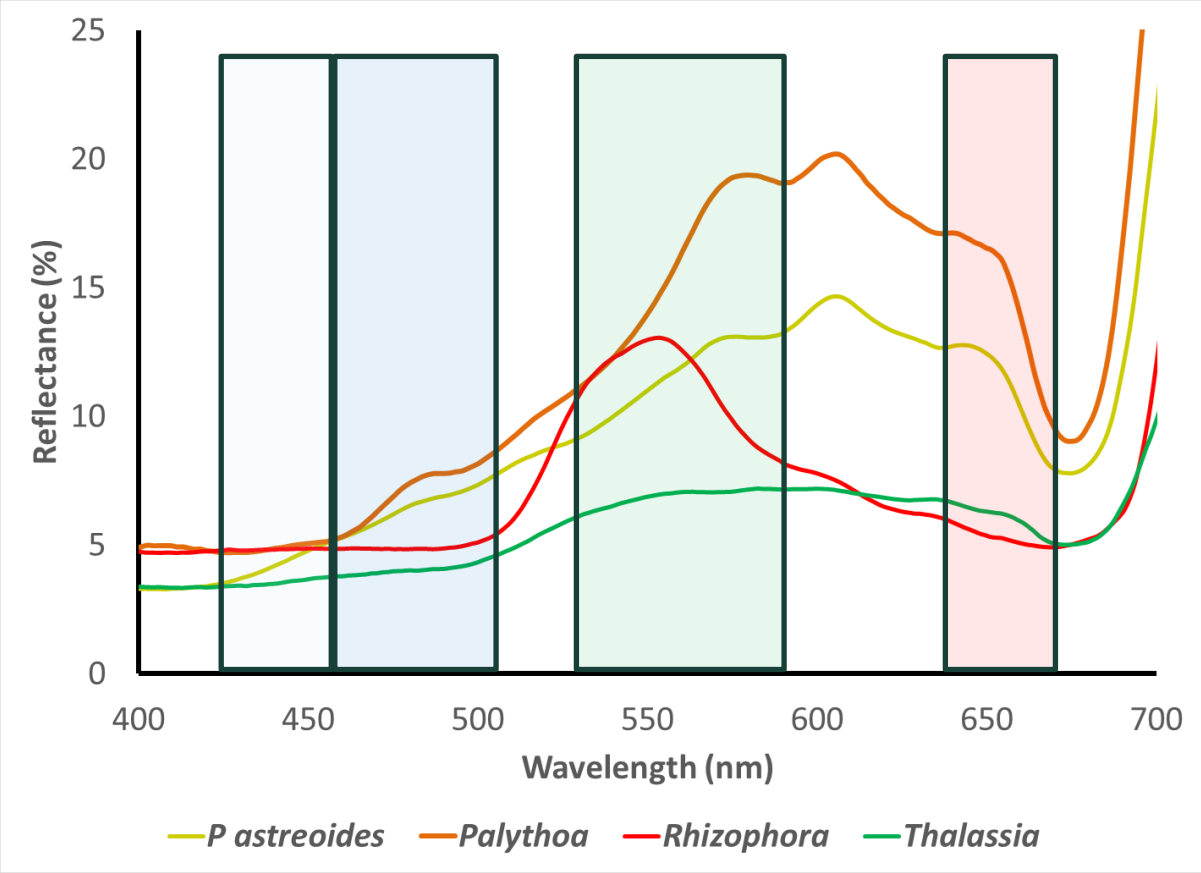
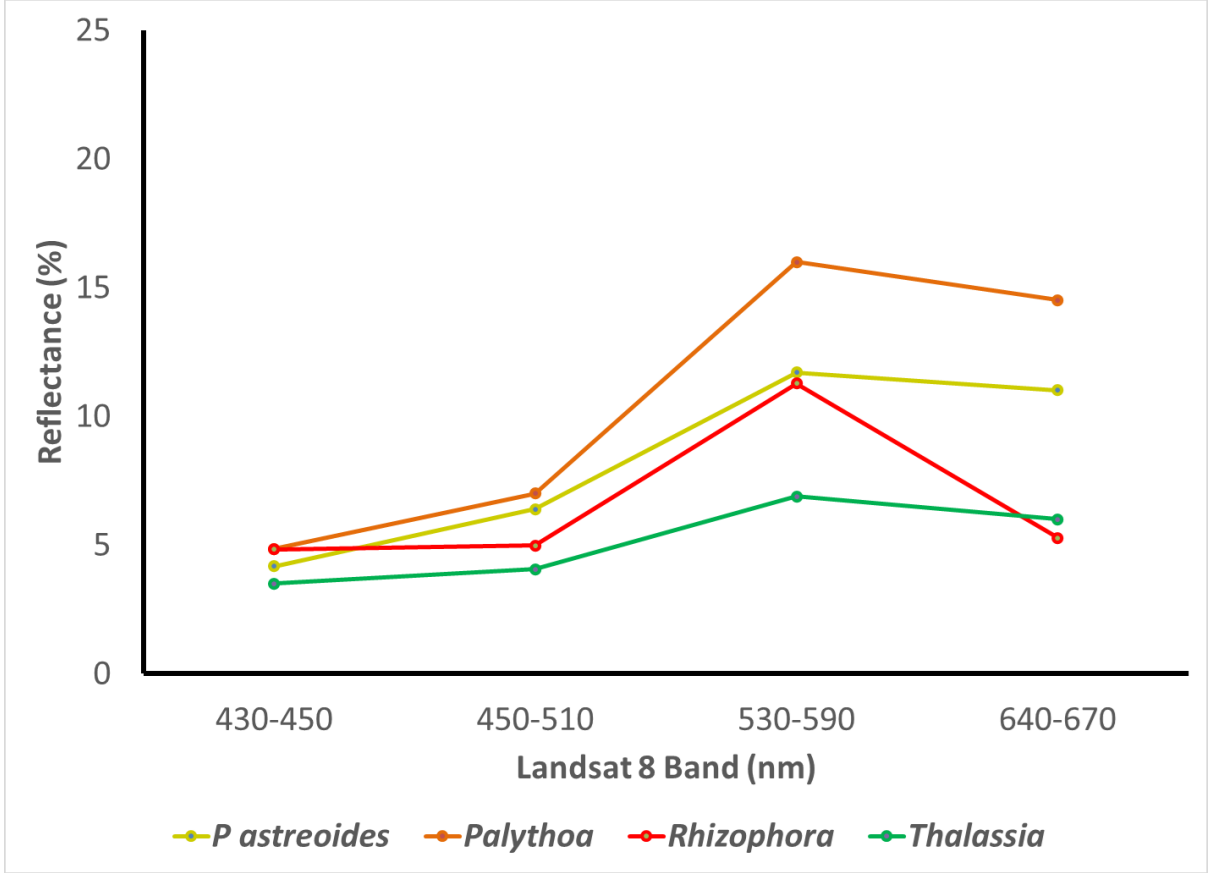


Image Credit: Adao, et al., 2017

Spectral Comparison of Different Coastal Marine Components (Hyperspectral vs. Multispectral)





Torres-Pérez (Unpublished)

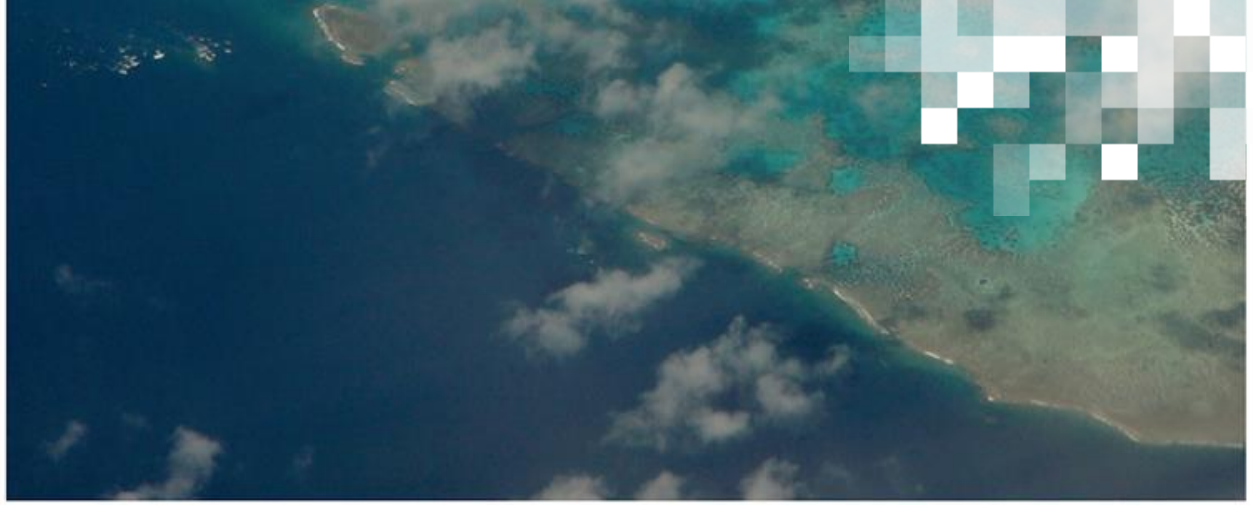
NASA Hyperspectral Imagers

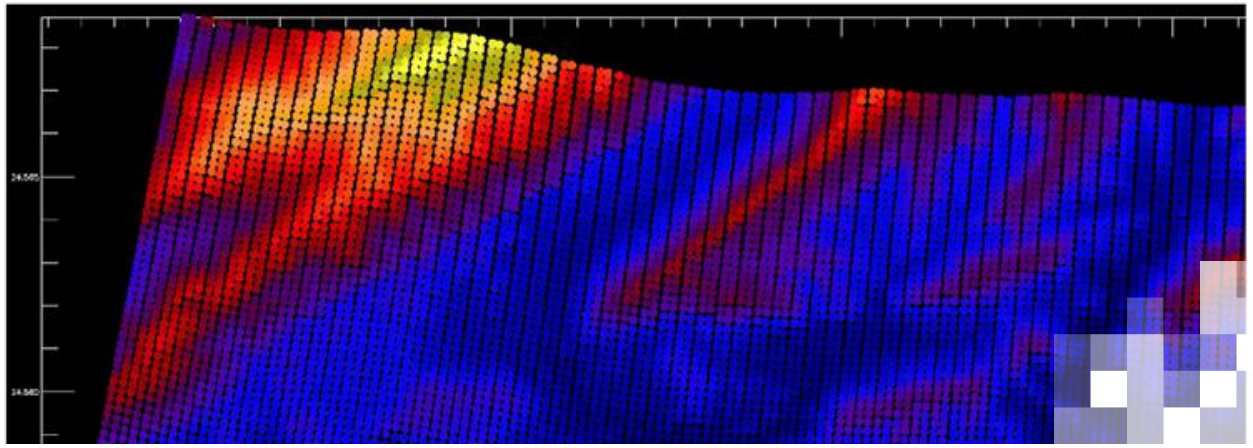
Satellite/Space-Based

- 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

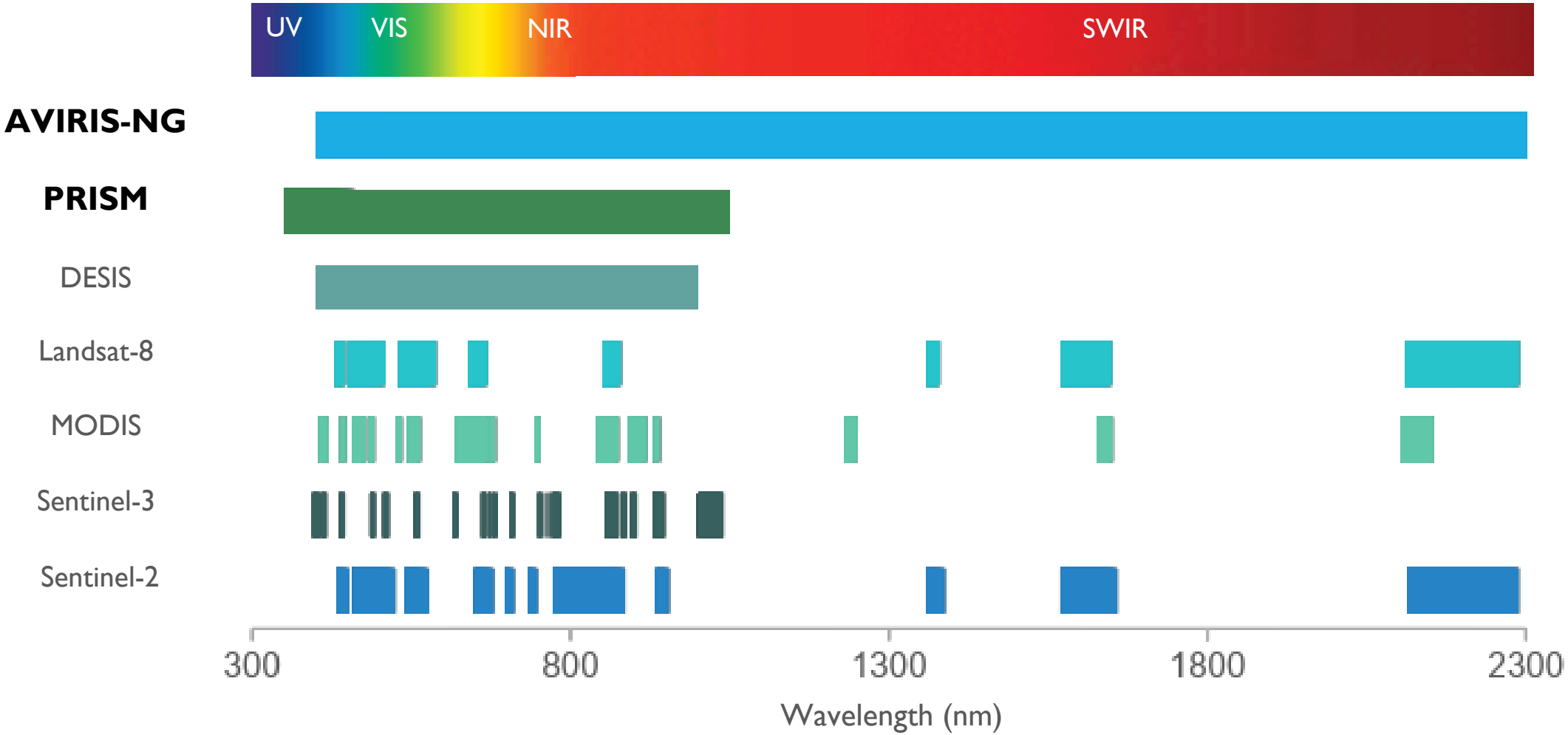
Airborne

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





Applications and Sources of Airborne VSWIR data



Adapted from: Wilson, A., Hestir, E., Slingsby, J., Cardoso, A. (2022). Biodiversity Survey of the Cape (BioSCape).

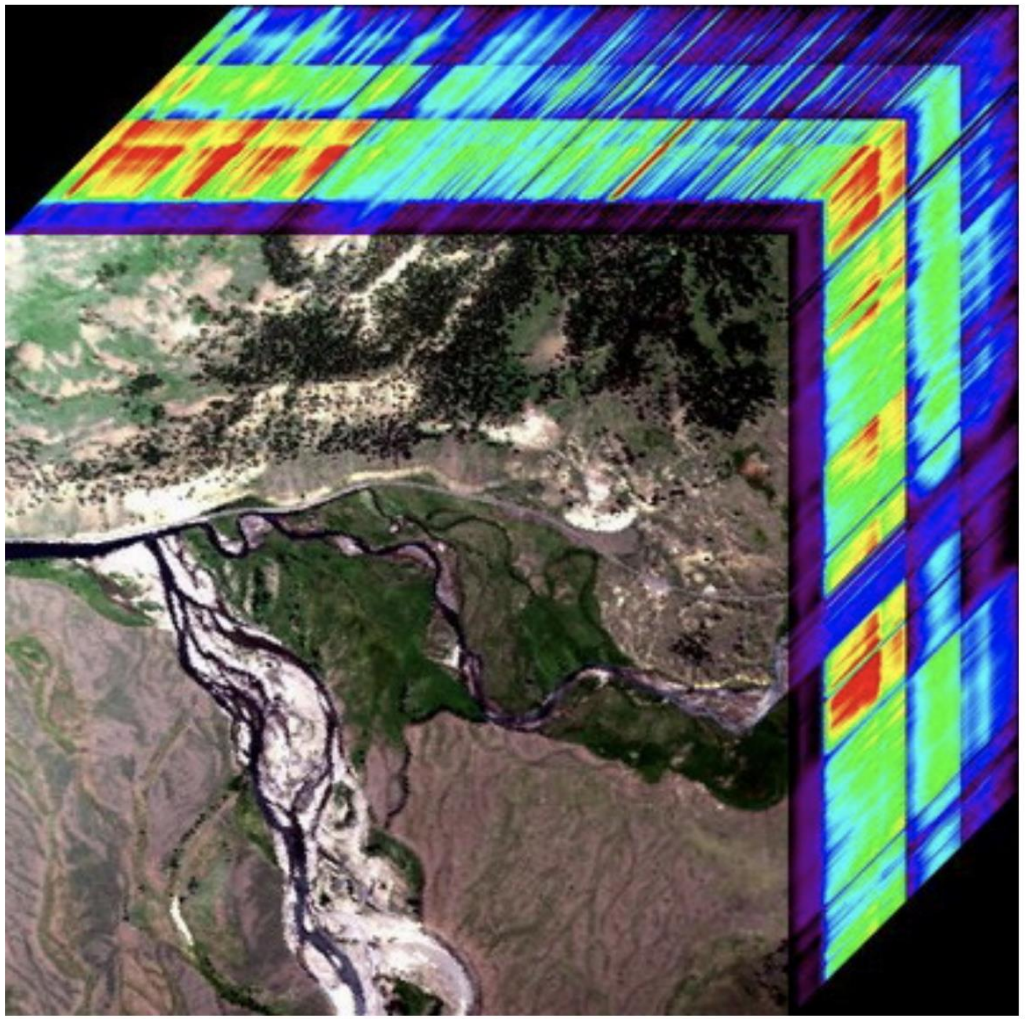
Applications of airborne VSWIR data

- Hyperspectral visible to shortwave infrared imaging spectroscopy data can be used to monitor and measure a wide array of environmental parameters such as climate variability, land cover distribution, seasonal cycles, and much more.
- Common sources of this data include AVIRIS-NG and PRISM

Source: NASA JPL

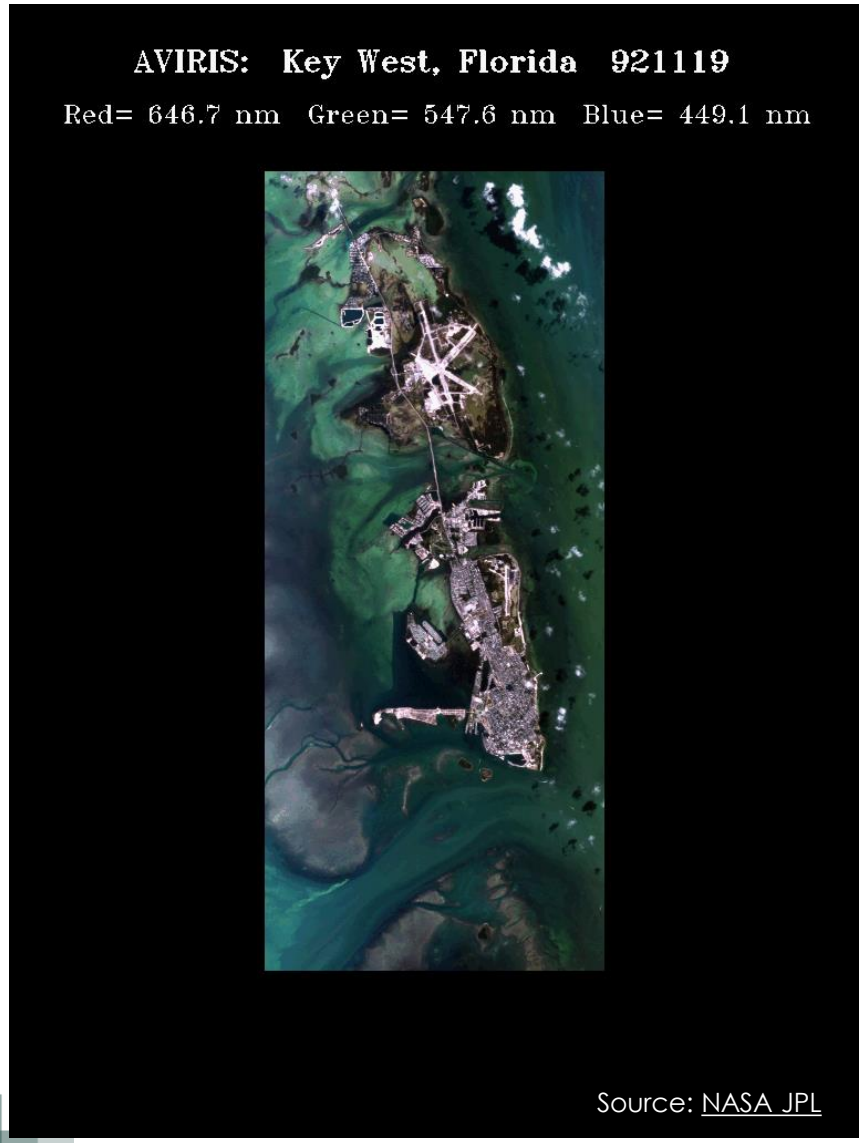
Airborne Visible/Infrared Imaging Spectrometer (AVIRIS)

- Objective: Identify, measure, and monitor constituents of Earth's surface and atmosphere based on molecular absorption and particle scattering signatures
- Sometimes referred to as AVIRIS-C "Classic"
- Flown in North America, Europe, portions of South America, and Argentina
- Flown on four aircraft platforms: NASA's ER-2 jet, Twin Otter International's Turboprop, Scaled Composites' Proteus, and NASA's WB-57
- Active since 1986



Source: Lu et al., 2020

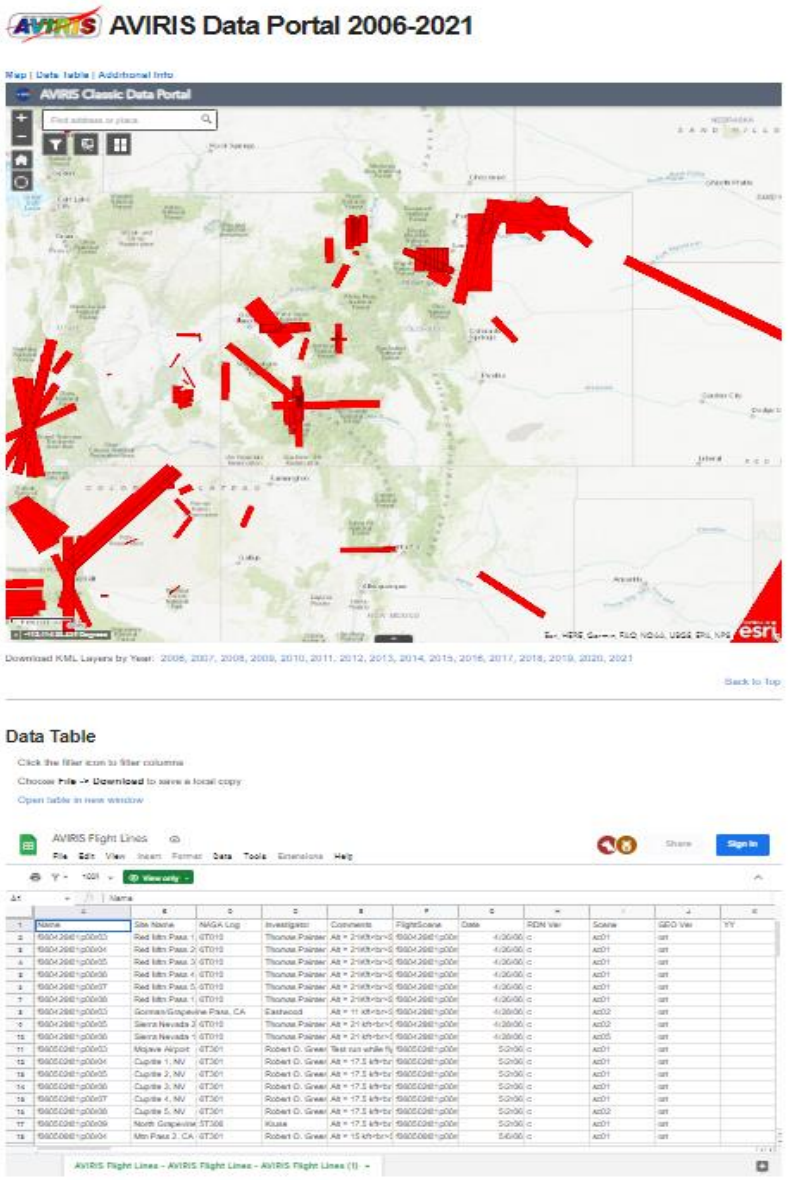
Airborne Visible/Infrared Imaging Spectrometer (AVIRIS)



Source: NASA JPL

- 224 continuous spectral bands
- Spectral coverage: 380 to 2500 nm
- Bandwidth: < 10 nm
- Pixel size based on altitude:
  - 20 km Above Ground Level (AGL) for 20 m pixel resolution
  - 4 km AGL for 4 m pixel resolution

Accessing and Using AVIRIS-C Data



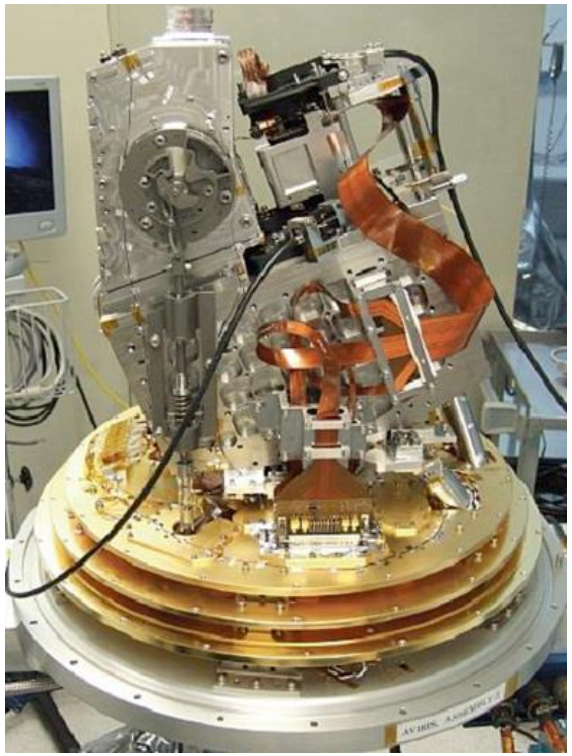
- 2006 - 2021 data is available to download from AVIRIS Data Portal
  - Many filtering options
  - Each flightline uses a specific base filename prefix
- To access pre-2006 data, users must fill out a request form
- Data types:
  - .KML
  - .JPEG
  - .dat
- Compatible ENVI, QGIS, ESRI products, etc.
- Preprocessing tutorial is provided

Previous AVIRIS Campaigns

2006-2021 Campaigns

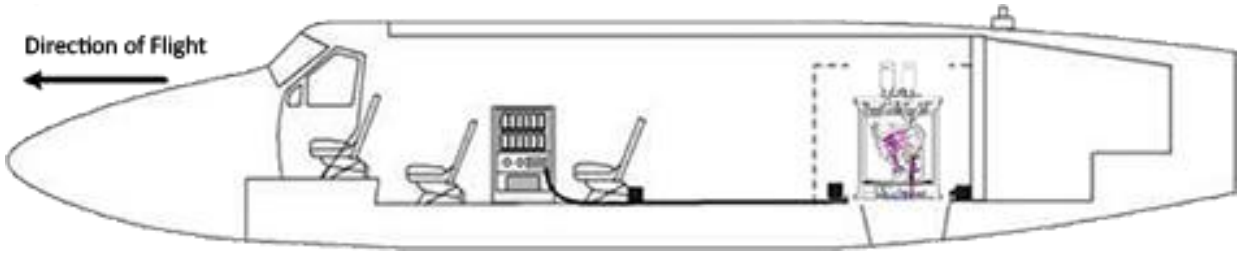
Airborne Visible InfraRed Imaging Spectrometer - Next Generation (AVIRIS-NG)

- Objective: To support NASA science and applications by measuring spectra as images that record the interaction of light with matter. These spectra are used to identify, measure, and monitor constituents of the Earth's surface and atmosphere.
- Flown on several aircraft platforms: NASA's ER-2 jet, the Twin Otter turboprop, B200 King Air, and NASA's Gulfstream III and V
- Flown in North America, Europe, and India
- Active since 2009



Source: NASA JPL

Airborne Visible InfraRed Imaging Spectrometer - Next Generation (AVIRIS-NG)



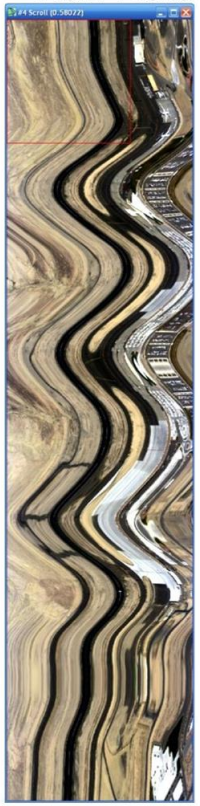
Source: NASA JPL

- 481 contiguous spectral bands
- Spectral coverage: 380 to 2510 nm
- Spectral resolution: 5 nm ± 0.5 nm
- Pixel size based on altitude:
  - 6,500 ft AGL for 2 m pixel resolution
  - 13,000 ft AGL for 4 m pixel resolution
  - 20,000 ft AGL for 6 m pixel resolution

AVIRIS-NG Data Products

Product Name	Product Description
L1B	Resampled calibrated data in units of spectral radiance as well as observational geometry and illumination parameters.
L2	Orthocorrected and atmospherically corrected reflectance data (32-bit floating point quantities from 0 to 1) as well as retrieved column water vapor and optical absorption paths for liquid H2O and ice.

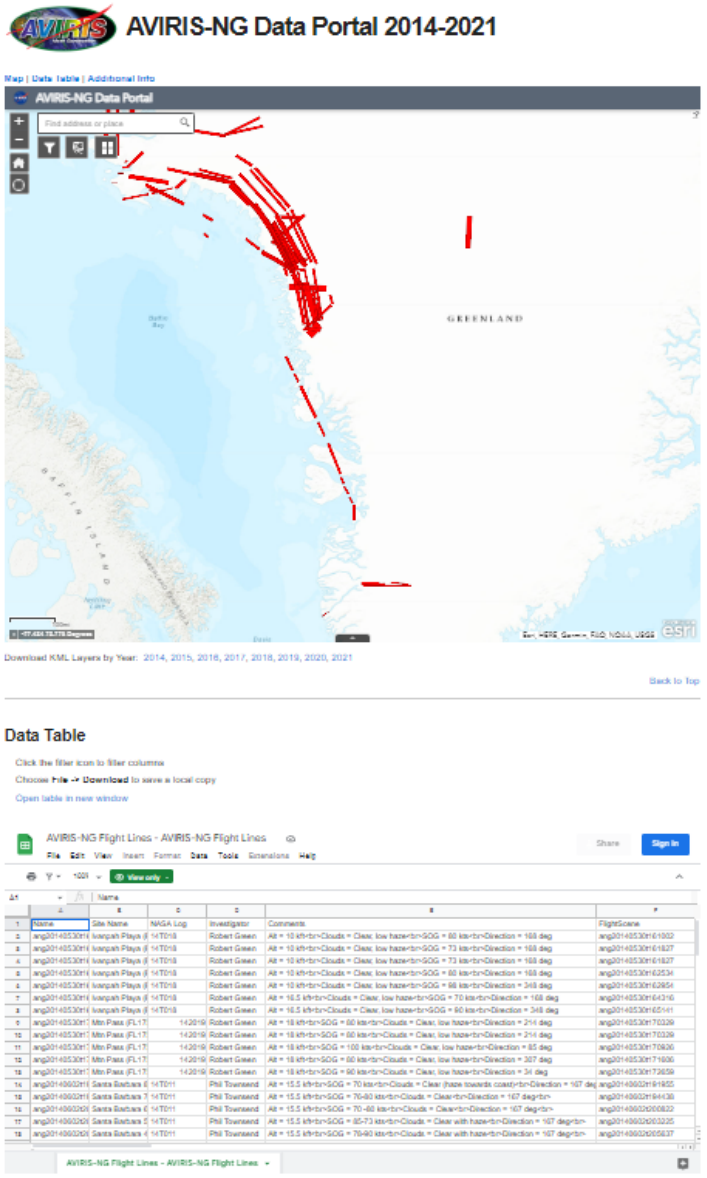
Raw Data



Successful Orthorectification

AVIRIS-NG Orthorectified

Accessing and Using AVIRIS-NG Data



- 2014 - 2021 data is available to download from [AVIRIS-NG Data Portal]
  - Many filtering options
  - Each flightline uses a specific base filename prefix
- Data types:
  - .KML
  - .JPEG
  - .dat
- Compatible ENVI, QGIS, ESRI products, etc.

Previous AVIRIS-NG Campaigns

2014-2021 Campaigns

Source: NASA JPL

Current and Upcoming AVIRIS and AVIRIS-NG Campaigns

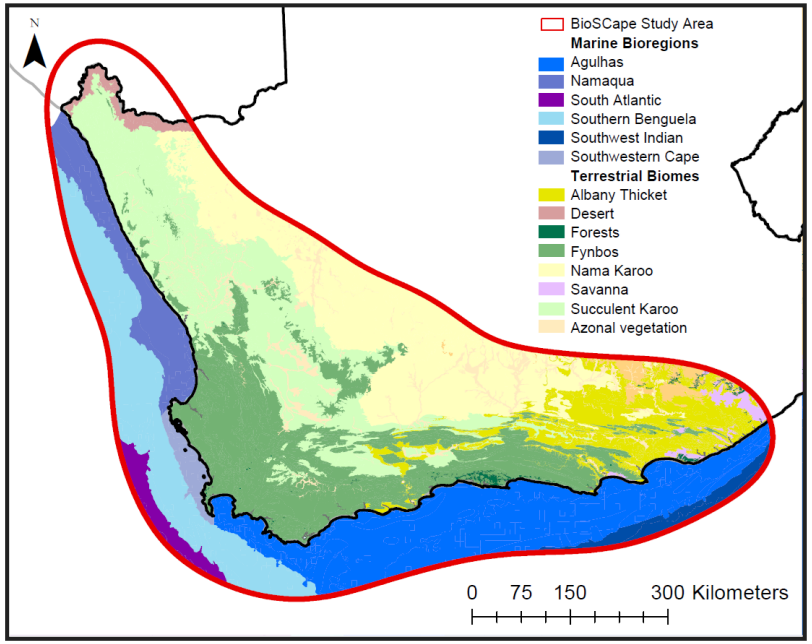
Campaign	Location	Timeframe	Aircraft	Sensor
Carbon Mapper	South America	2023 Jan-March	B200 King Air	AVIRIS-NG
SnowEx/ABoVE	Alaska	2023 April	B200 King Air	AVIRIS-NG
NASA STAQS	New York & Los Angeles	2023 June-Aug	LaRC G-III	AVIRIS-NG
AVIRIS-3 test flights	CONUS	2023 May	B200 King Air	AVIRIS-3
NASA BioSCAPE	South Africa	2023 Oct-Dec	LaRC G-III	AVIRIS-NG
NASA FireSense	Western US	2023 Sept	B200 King Air	AVIRIS-3
NASA WDTS	Western US	2023-2026 Summer	AFRC ER-2	AVIRIS Classic
USGS EMRI	Western US	2023-2026 Summer	AFRC ER-2	AVIRIS Classic

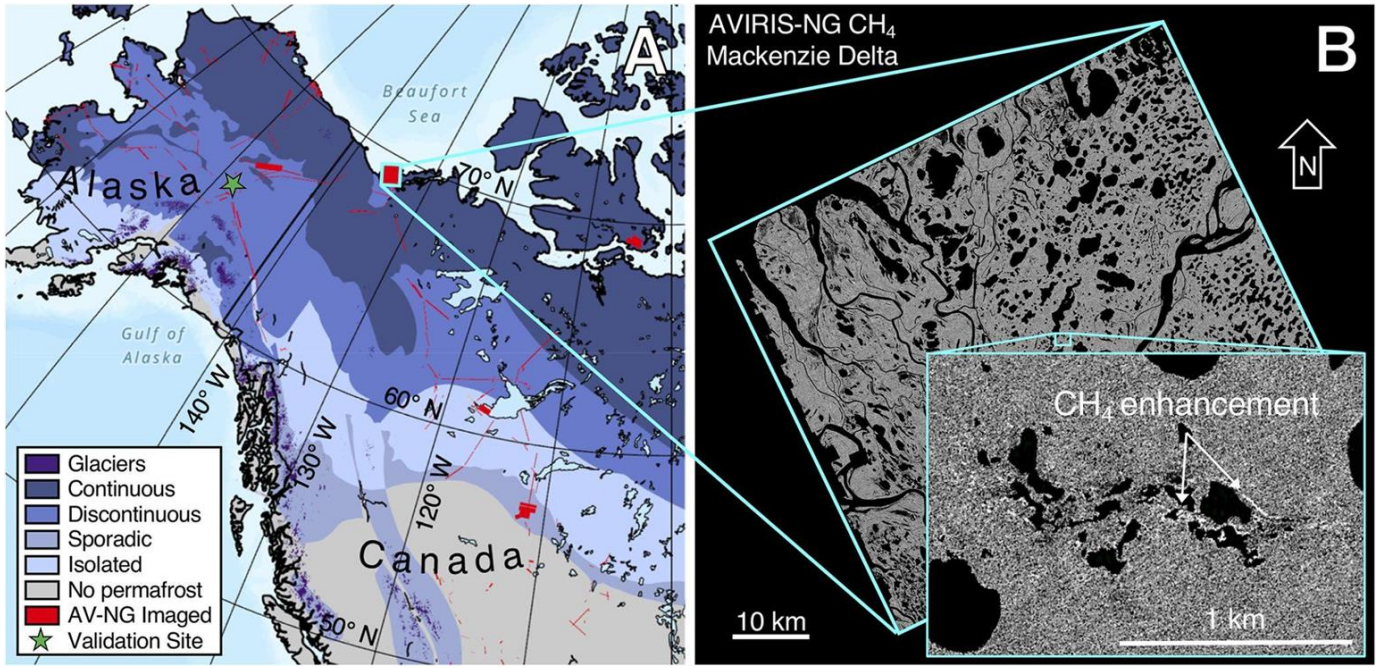
Source: NASA JPL

AVIRIS-NG Biodiversity Applications

BIOSCAPE
Biodiversity Survey of the Cape

ABoVE
ARCTIC – BOREAL VULNERABILITY EXPERIMENT

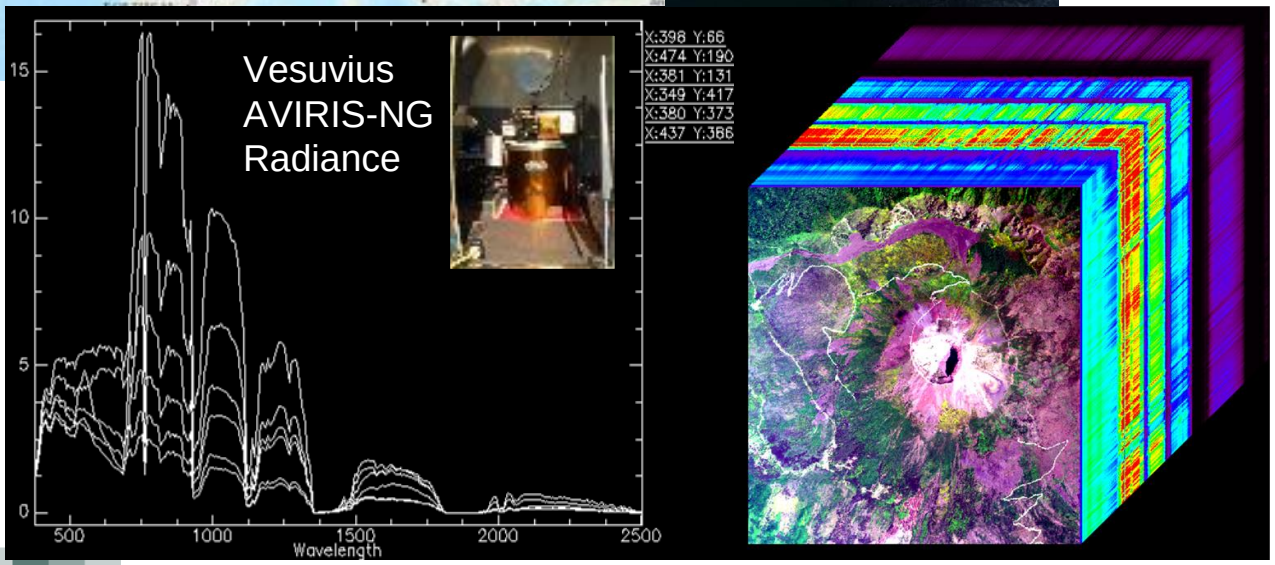


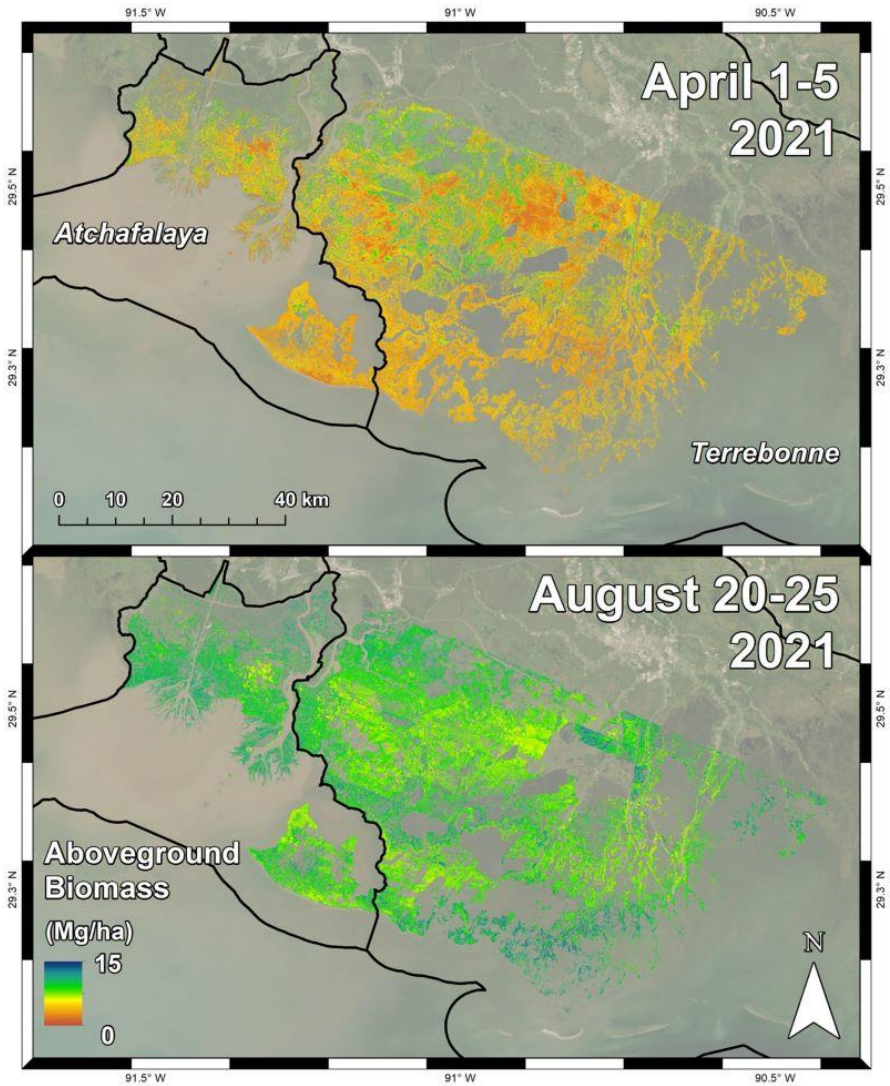


AVIRIS-NG ABoVE survey and a regional mapping example. Source: Elder, et al., 2020.

AVIRIS-NG Biodiversity Applications

Delta-X

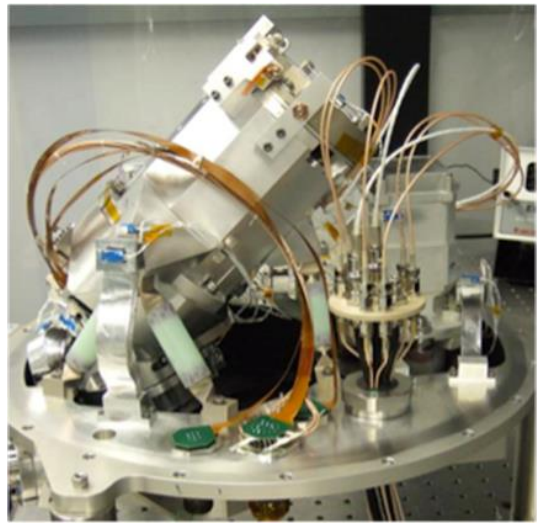




Herbaceous aboveground biomass in coastal Louisiana. Source: Jensen, et al., 2022.

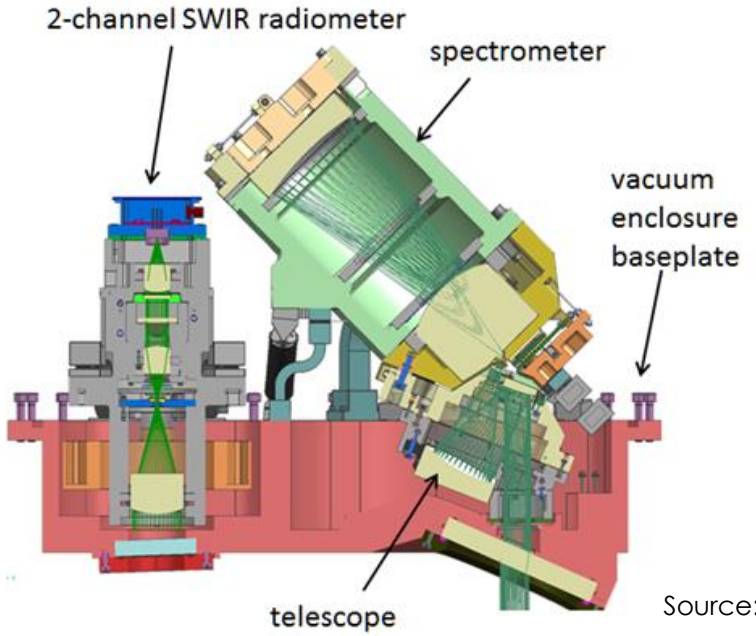
Portable Remote Imaging SpectroMeter (PRISM)

- Application: To serve as a UV-NIR (350 nm to 1050 nm) Coastal Ocean Science Instrument.
- Flown on four aircraft platforms: NASA's ER-2 jet, Twin Otter aircraft, Gulfstream GIII and GV
- Flown in Western United States, South America, and the Southern Ocean
- Active since 2012



Source: NASA JPL

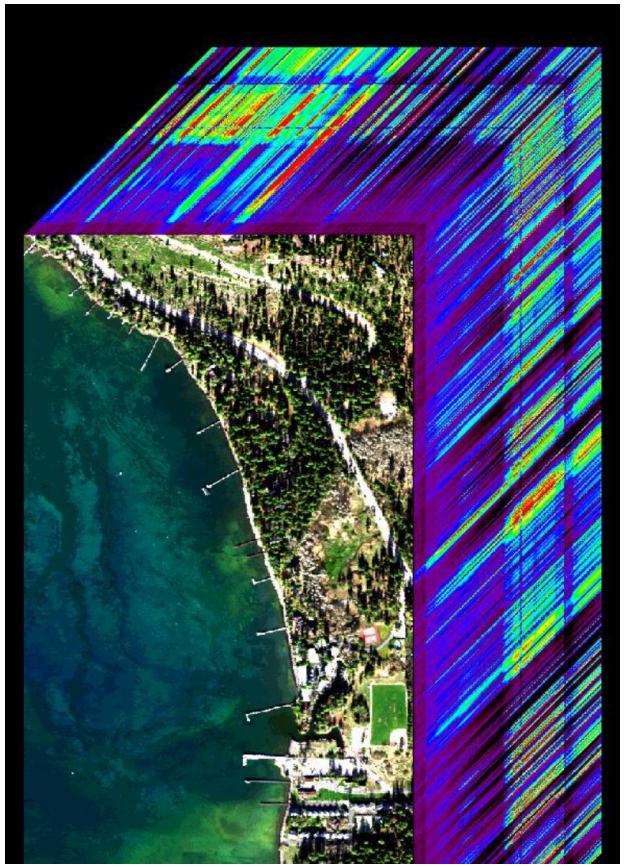
Portable Remote Imaging SpectroMeter (PRISM)



Source: NASA JPL

- Pushbroom imaging spectrometer with 246 contiguous spectral bands
- Spectral coverage: 350 -1050 nm
- Spectral resolution: 3.5 nm
- Two short wave infrared (SWIR) bands at 1240 and 1610 nm
  - Bandwidth: 22 nm and 56 nm
- The spatial resolution depends on the altitude and plane speed but ranges from 0.3 to 16 m.

PRISM Data Products



Product Name	Product Description
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L2	Orthocorrected and atmospherically corrected reflectance data (32-bit floating point quantities from 0 to 1) as well as retrieved column water vapor and optical absorption paths for liquid H2O and ice.

L1B Data Products

Grass Line, FL - View quicklook | Download data (4.5 GB)

Island Line, FL - View quicklook | Download data (4 GB)

Elkhorn, CA - View quicklook | Download data (9 GB)

Elkhorn, CA - View quicklook | Download data (10 GB)

Elkhorn, CA - View quicklook | Download data (10 GB)

L2 Data Products

Grass Line, FL - View quicklook | Download data (4.8 GB)

Island Line, FL - View quicklook | Download data (4.1 GB)

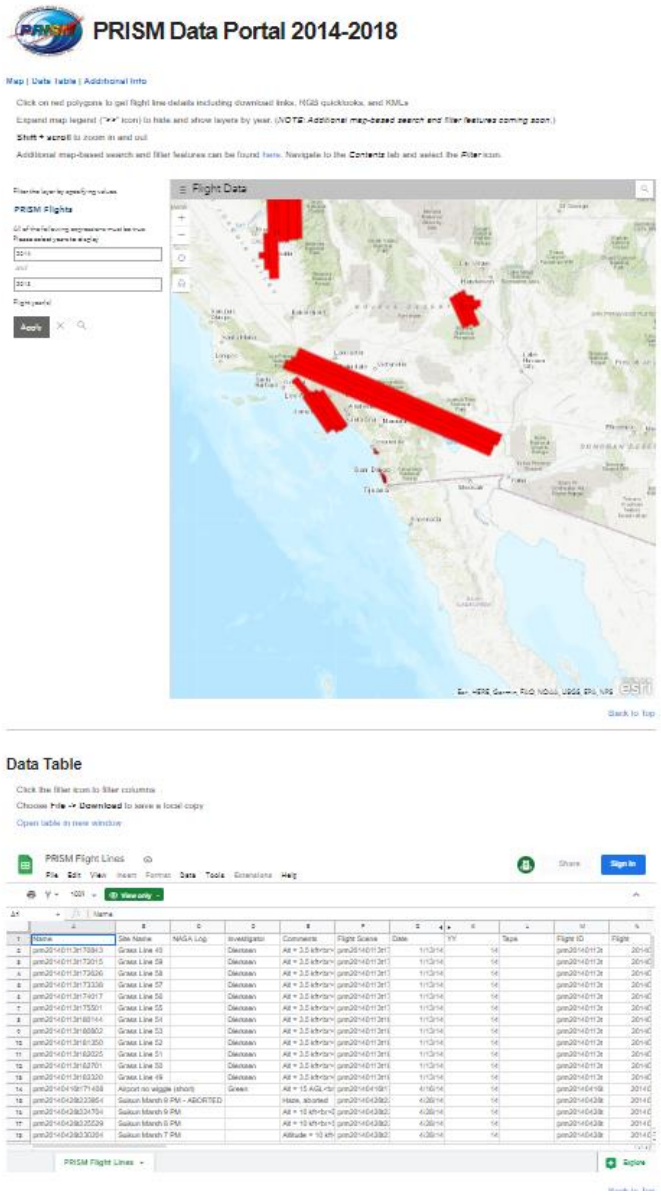
Elkhorn, CA - View quicklook | Download data (7.4 GB)

Elkhorn, CA - View quicklook | Download data (8.2 GB)

Elkhorn, CA - View quicklook | Download data (8.1 GB)

Source: NASA JPL

Accessing and Using PRISM Data



- 2014 - 2018 data is available to download from [PRISM Data Portal]
  - Many filtering options
  - Each flightline uses a specific base filename prefix
- Data types:
  - .KML
  - .JPEG
  - .dat
- Compatible ENVI, QGIS, ESRI products, etc.

Previous PRISM Campaigns

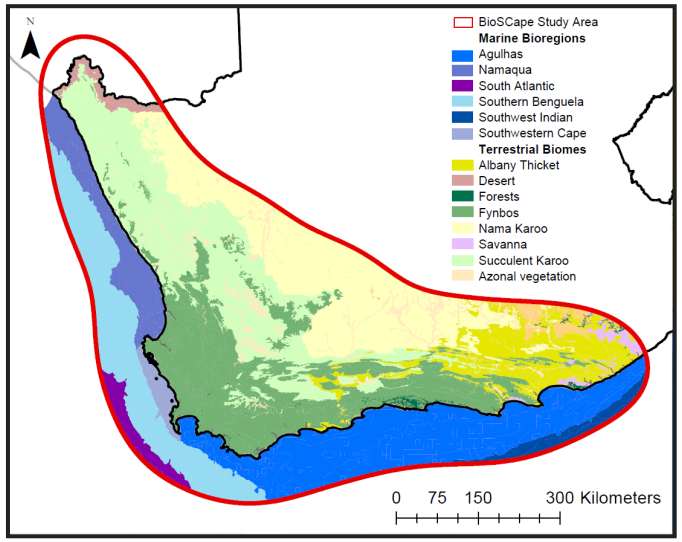
2012 - 2018 Campaigns

Source: NASA JPL

PRISM Biodiversity Applications

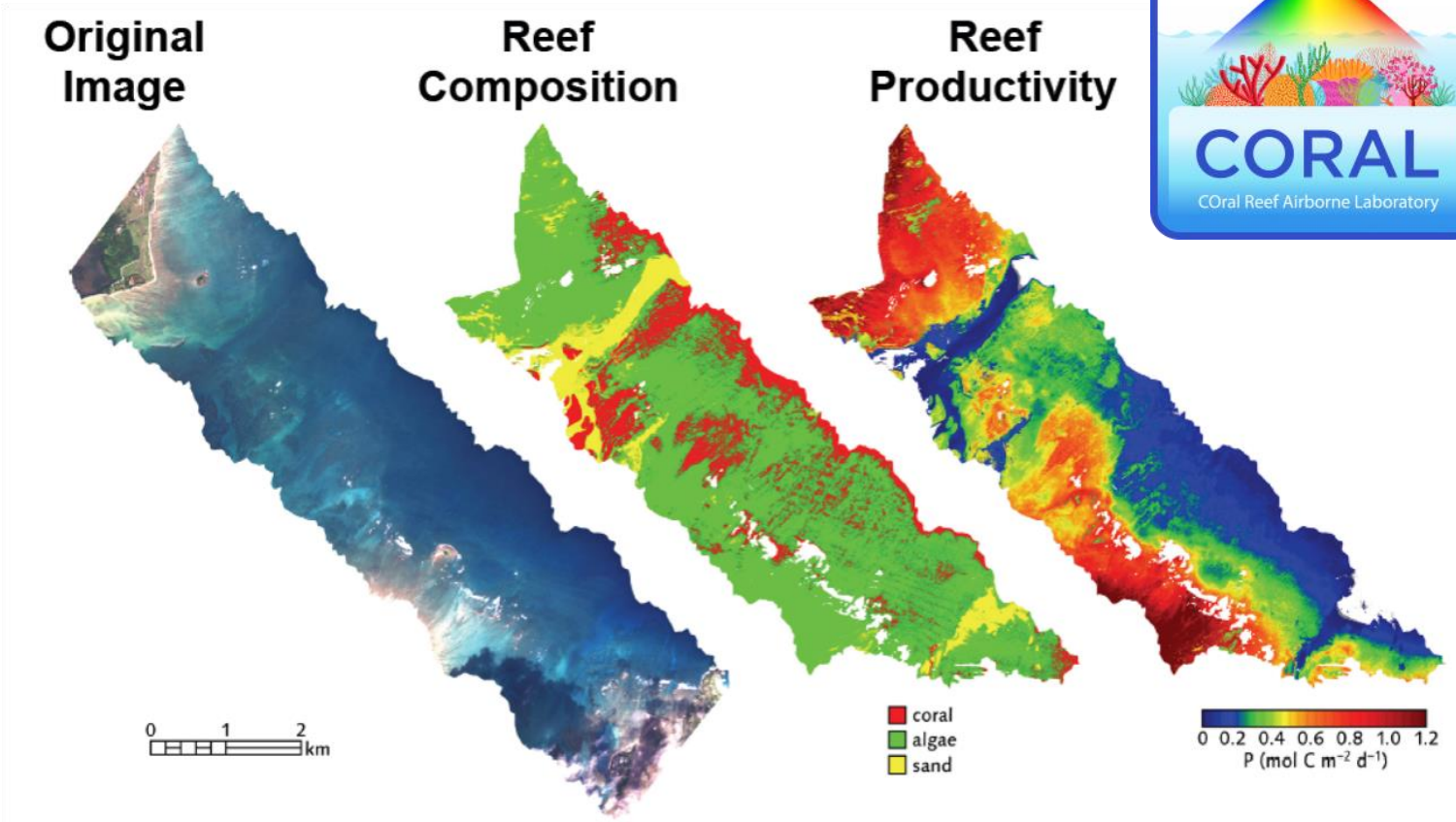
BIOSCAPE

Biodiversity Survey of the Cape



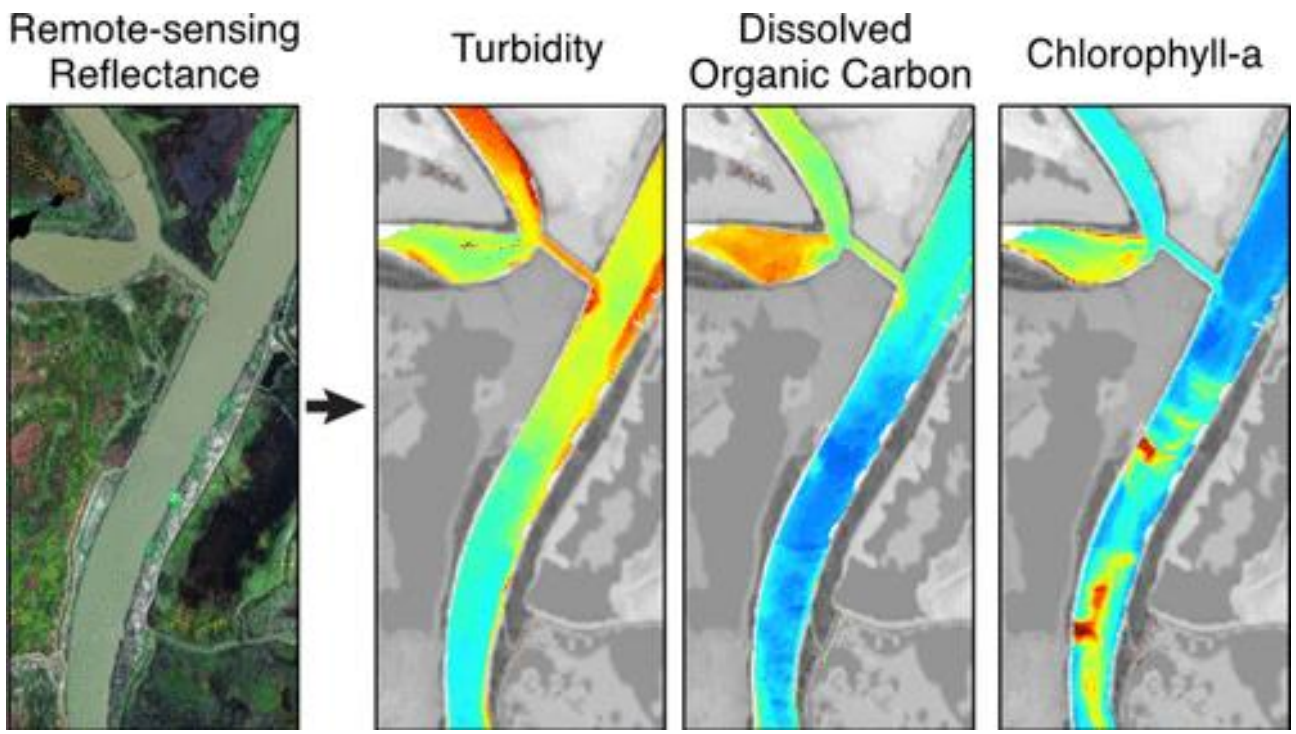
CORAL

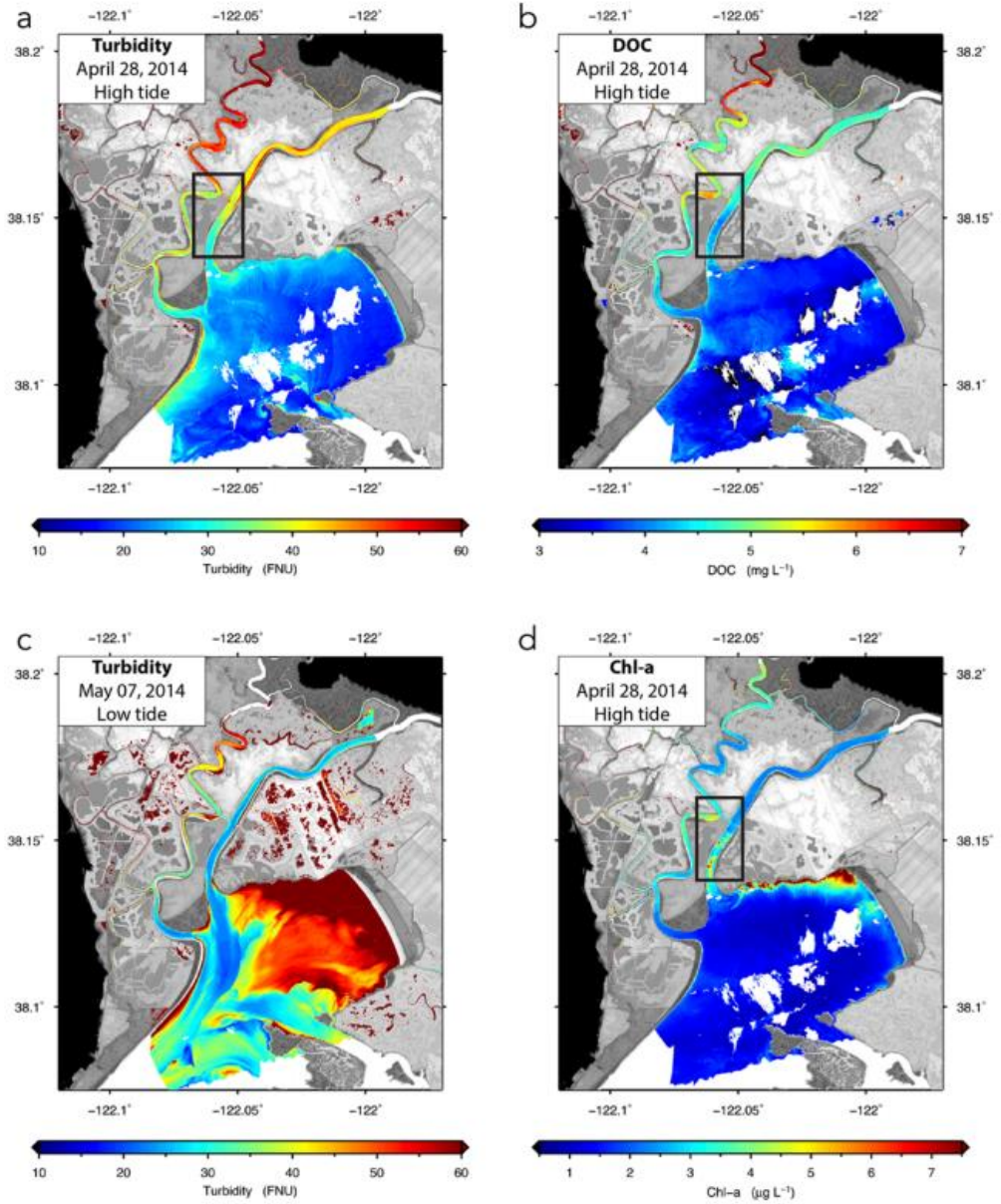
COral Reef Airborne Laboratory



Sourcet: BioSCape, Eric Hochberg (CORAL PI)

PRISM Biodiversity Applications





Above: Distributions of turbidity, dissolved organic carbon (DOC) and chlorophyll-a concentrations in the San Francisco Bay–Delta Estuary.

Right: Maps of turbidity, DOC, and chl-a in Suisun Bay (Grizzly Bay) and Suisun Marsh. Source: Fichot et al., 2016.

Comparing Airborne Systems: Specifications

AVIRIS-C

- Active since 1986
- 224 continuous spectral bands
- Spectral coverage: 380 to 2500 nm
- Spectral resolution: 10 nm
- Spatial resolution: 4 - 20 m

AVIRIS-NG

- Active since 2009
- 481 contiguous spectral bands
- Spectral coverage: 380 to 2510 nm
- Spectral resolution: 5 nm
- Spatial resolution: 2 - 6 m

PRISM

- Active since 2012
- 256 contiguous spectral bands and 2 SWIR bands: 1240 and 1610 nm
- Spectral coverage: 350 -1050 nm
- Spectral resolution: 3.5 nm
- Spatial resolution: 0.3 to 16 m

Comparing Airborne Systems: Access and Use

AVIRIS-C

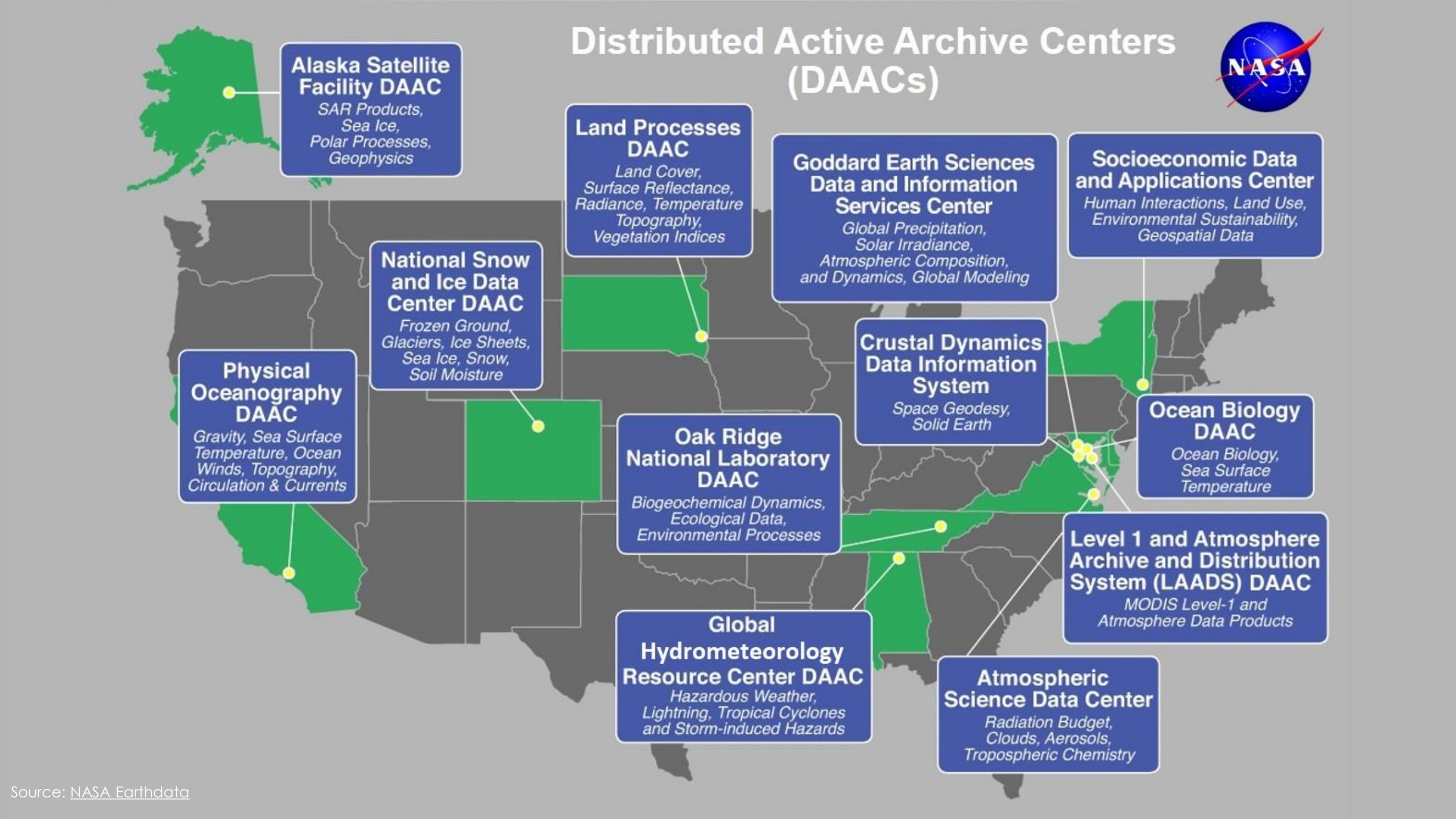
- Data Access:
  - Data portal
  - 2006 - 2021
  - Pre-2006 form
- Data products:
  - Up to Level 1B for 1993 to 2012
  - Up to Level 2 for data collected 2013 to present
- Data types:
  - .KML
  - .JPEG
  - .dat

AVIRIS-NG

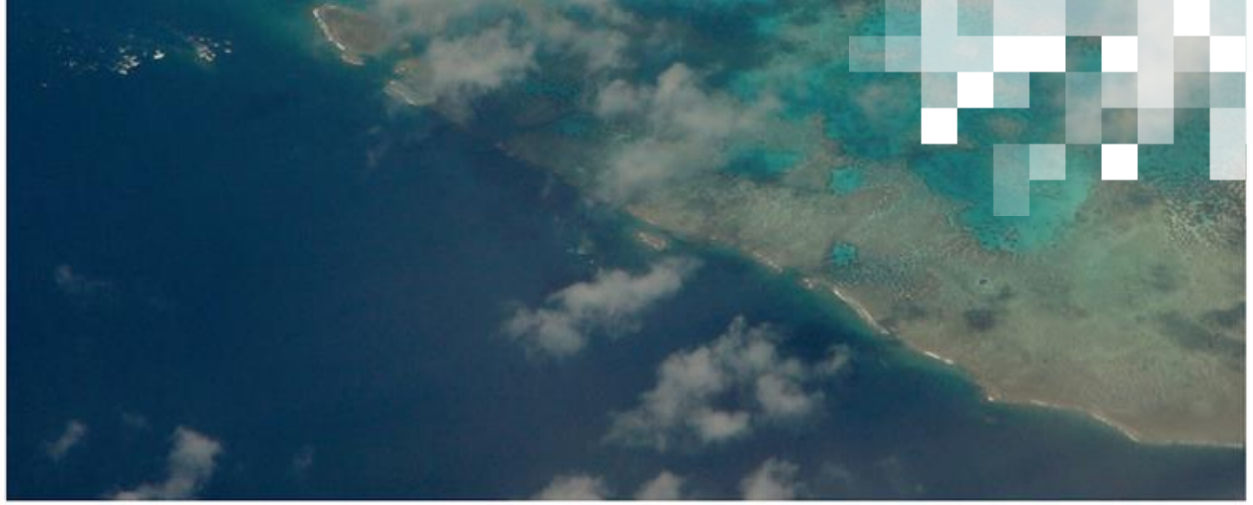
- Data Access:
  - Data portal
  - 2014 - 2021
- Data products: Level 1B and L2
- Data types:
  - .KML
  - .JPEG
  - .dat

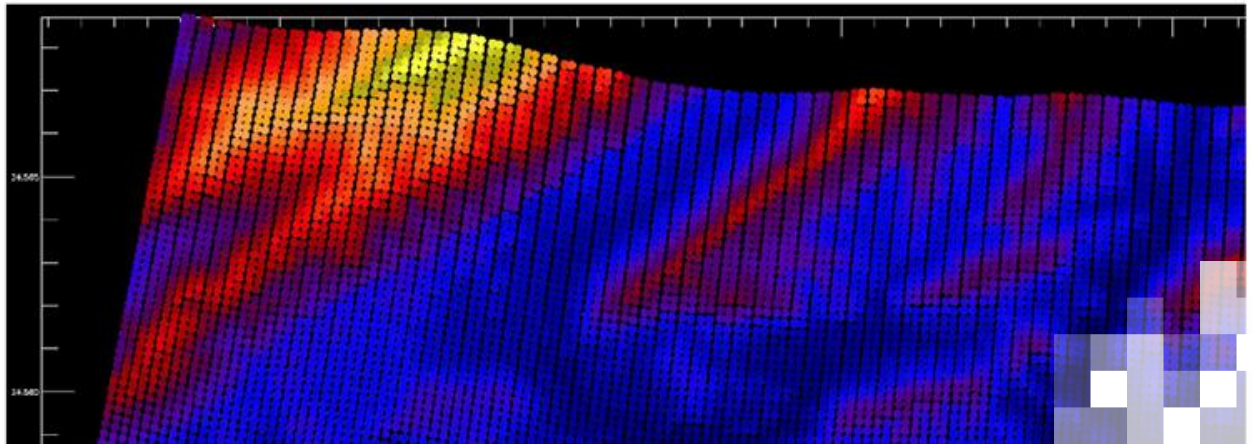
PRISM

- Data Access:
  - Data portal
  - 2014 - 2018
- Data products: Level 1B and L2
- Data types:
  - .KML
  - .JPEG
  - .dat



Source: NASA Earthdata



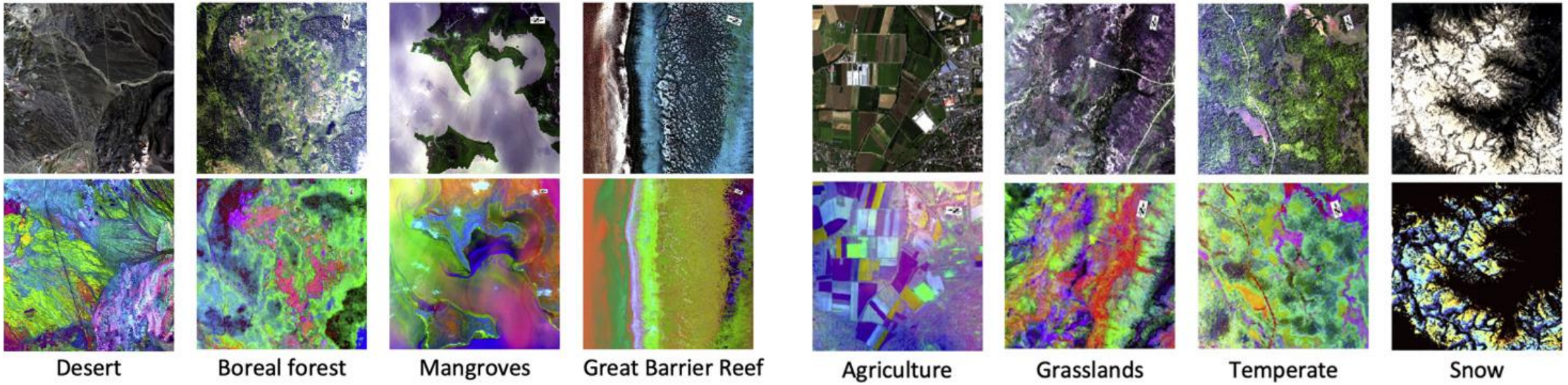


Upcoming Mission Highlights

Paving the Way for Future Missions

The design and data from these airborne instruments have been essential in the development of upcoming satellite missions and future science initiatives.

- Mission objectives and spectrometer specifications are based off of the successful implementation of previous airborne campaigns.



Imagery from HyTES, AVIRIS-NG, AVIRIS-C, and PRISM campaigns used for the development of NASA's SBG mission. Credit: Cawse-Nicholson, et al., 2021.

Upcoming NASA Hyperspectral Satellite Initiatives

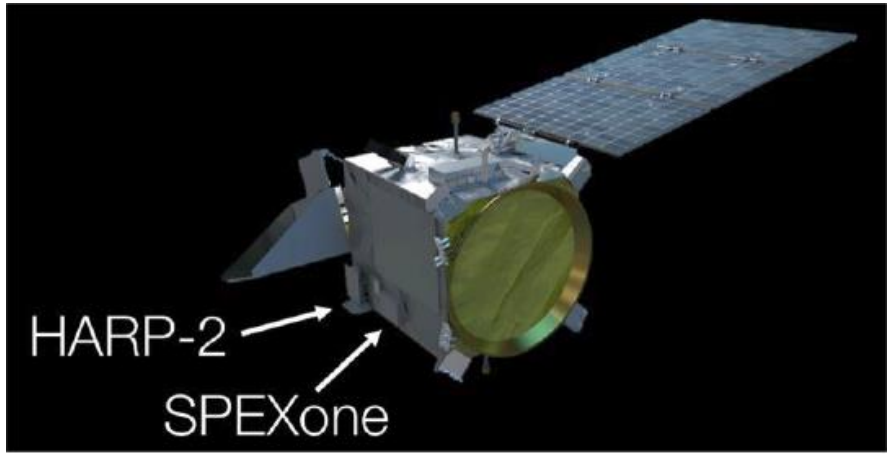
- **Plankton, Aerosol, Cloud, and Ocean Ecosystem (PACE)**
  - Observations of the global oceans, atmosphere, and terrestrial ecosystems
  - Ultraviolet through the visible and into the shortwave infrared region of the electromagnetic spectrum, specifically from 340-890 nm sampled at every 2.5 nm with 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

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

PACE is NASA's next great investment in hyperspectral earth imagery and multi-angle polarimetry.

- Launch Date: **Jan. 2024**
- 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-km2 at nadir
- Two Multi-Angle Polarimeters
  - **HARP-2**: Wide swath, hyper-angular, 4 bands across the VIS & NIR
  - **SPEXone**: Narrow swath, hyperspectral (UVNIR), 5 viewing angles



Extend key systematic **ocean** biological, ecological, & biogeochemical climate data records, as well as **cloud** & **aerosol climate data records**

Make **new global measurements of ocean color** that are essential for understanding the global carbon cycle & ocean ecosystem responses to a changing climate

Collect **global observations of aerosol & cloud properties**, focusing on reducing the largest uncertainties in climate & radiative forcing models of the Earth system

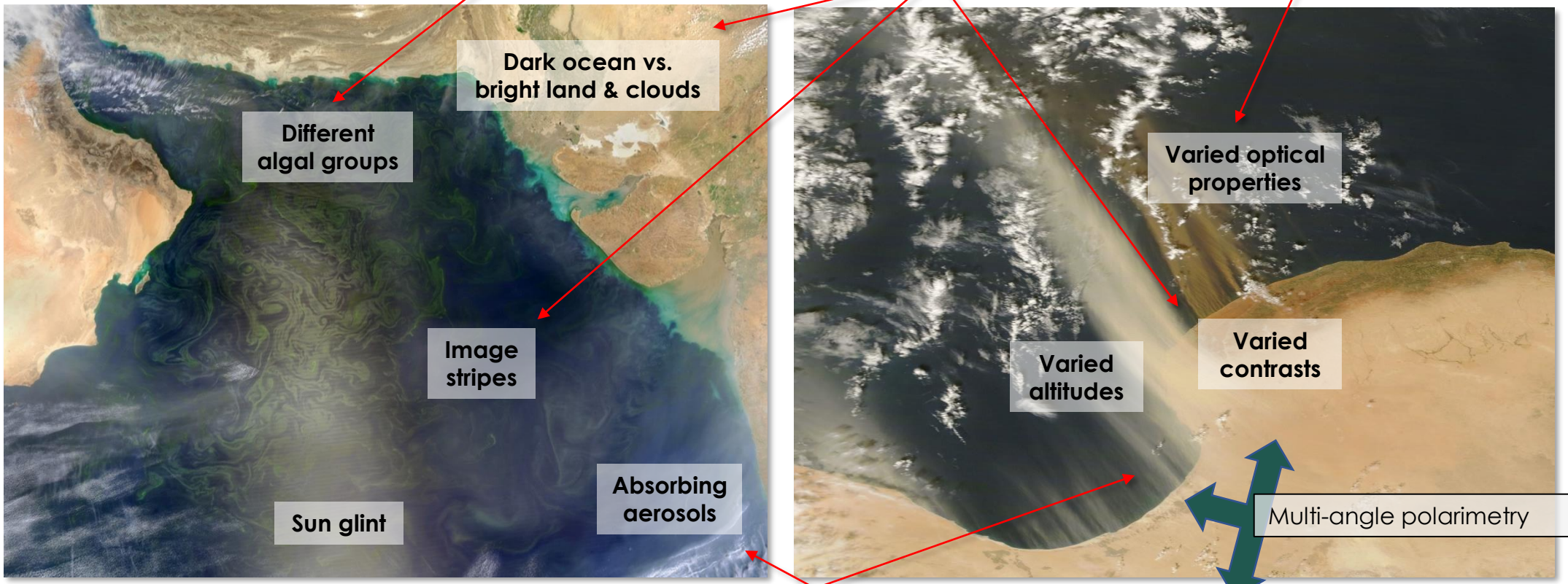
GSD of 1 ± 0.1 km² at nadir

Twice-monthly lunar calibration & onboard solar calibration (daily, monthly, dim)

Spectral range from 350-865 @ 5 nm

940, 1038, 1250, 1378, 1615, 2130, 2260 nm

Instrument performance requirements

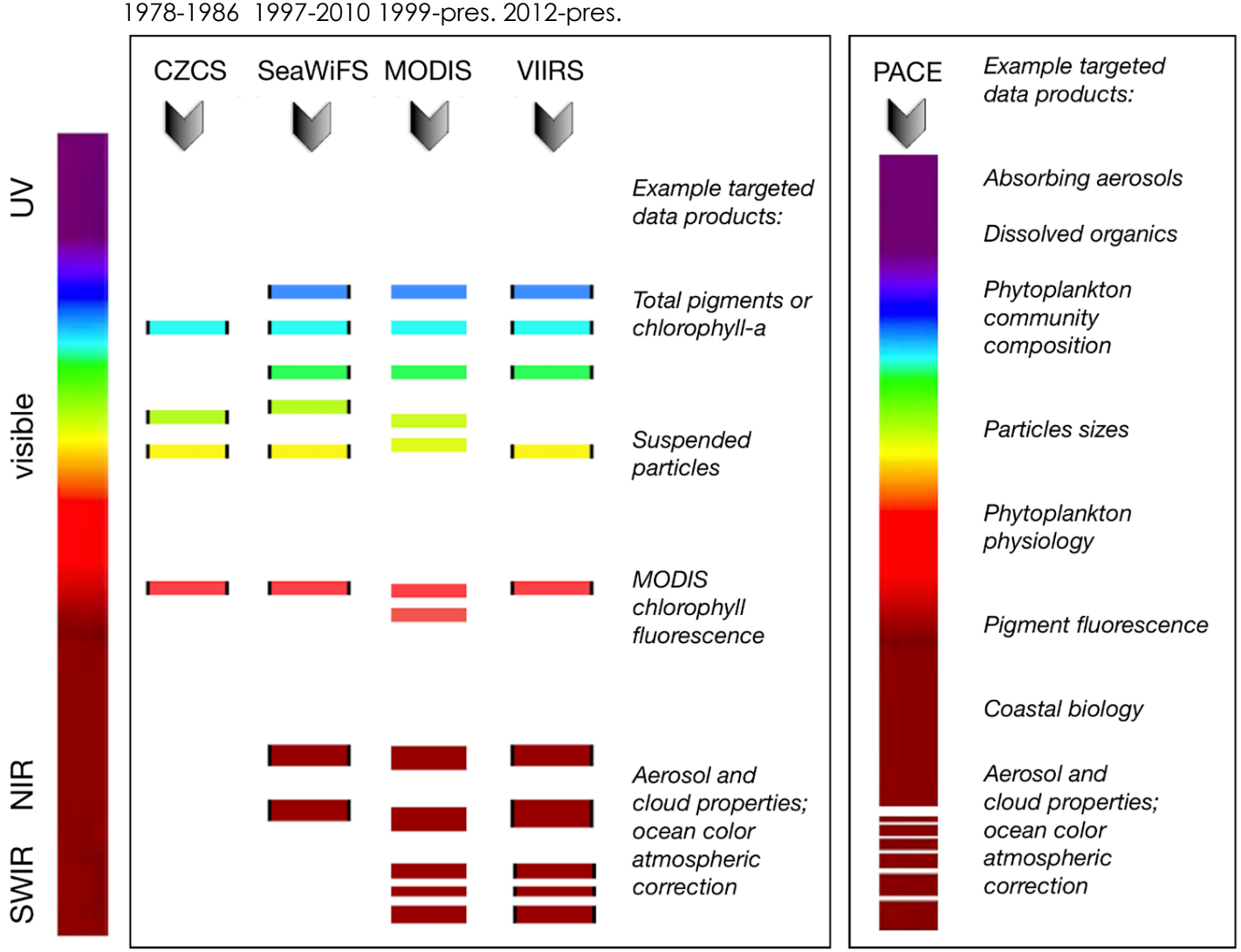


Tilt ± 20°

Spectral range goal of 320-865 @ 5 nm

Improve our understanding of how **aerosols influence ocean ecosystems & biogeochemical cycles** and how **ocean biological & photochemical processes affect the atmosphere**

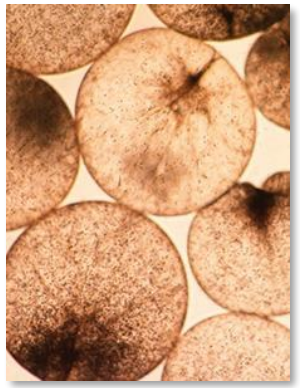
Moving from multi-spectral radiometry to spectroscopy



Example diatom

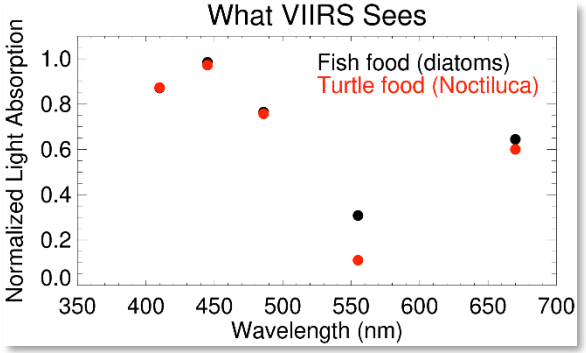
Linda Armbrecht, abc.com.au

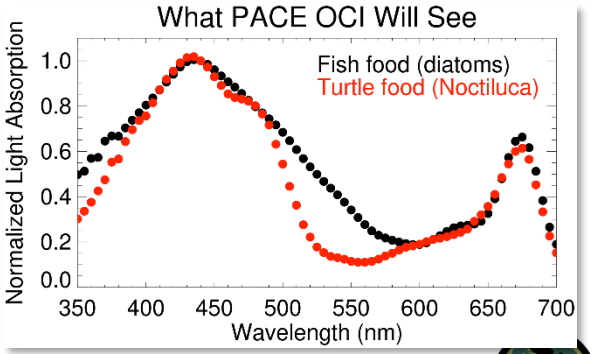
Example Noctiluca



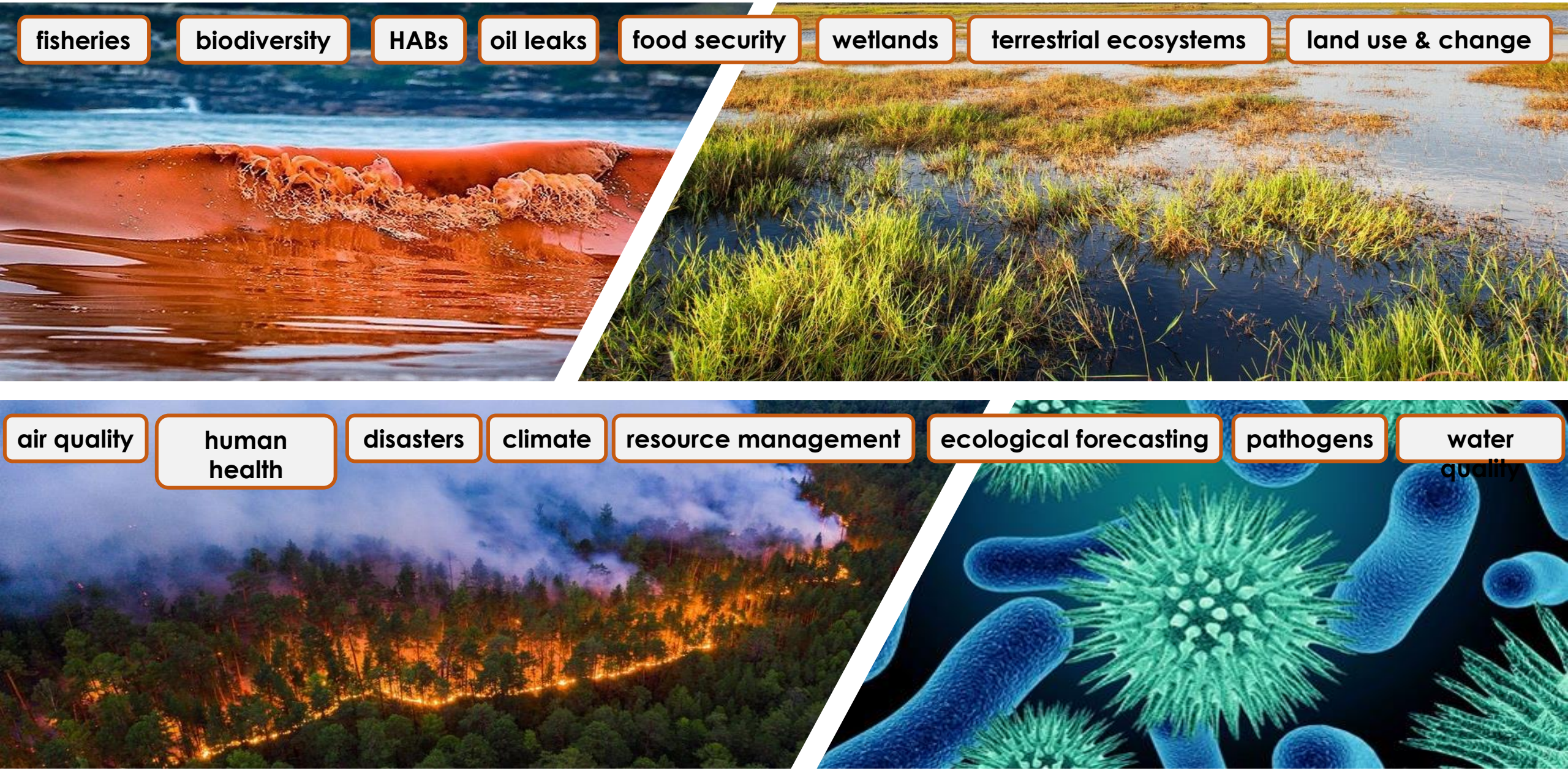
Joaquim Goes, LDEO

Signals from the ocean are small & differentiating between constituents requires additional information relative to what we have today





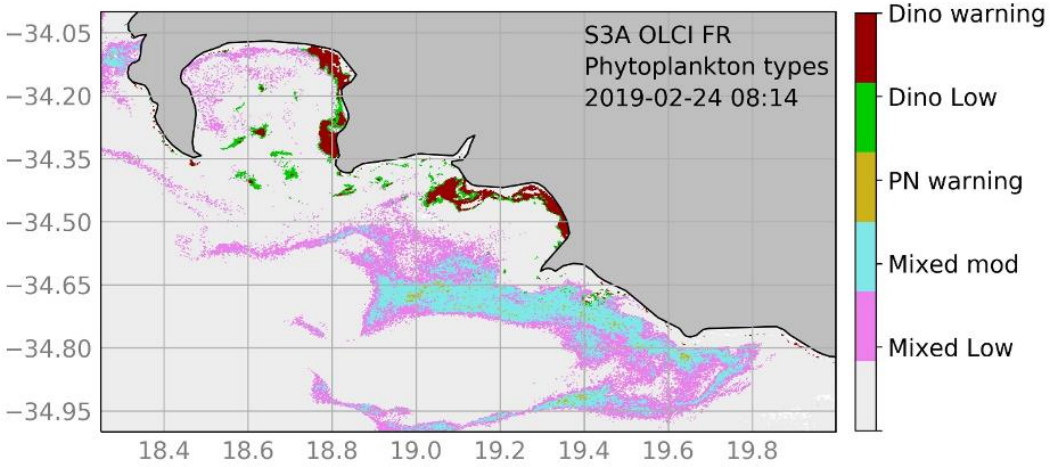
PACE: Interdisciplinary Applied Science Objectives

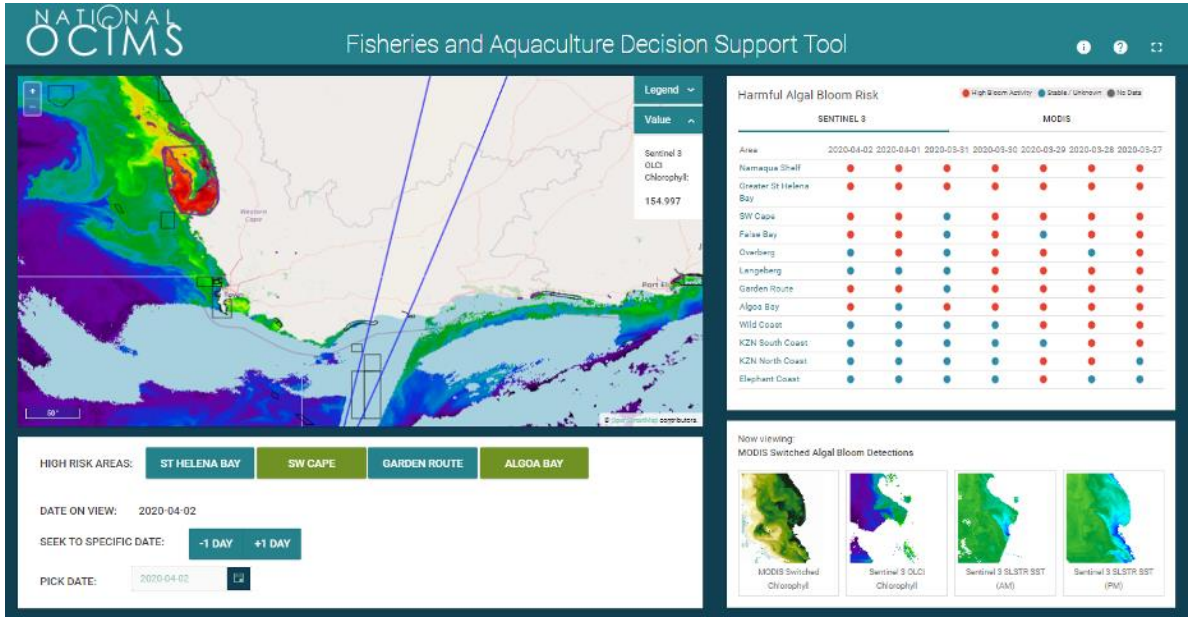


Informing Applications with PACE Data: Monitoring and Managing Marine Ecosystems

PACE will provide phytoplankton community composition data for understanding ocean ecosystems, which can benefit and/or inform:

- Fisheries and aquaculture
- Marine food webs
- Aquatic biodiversity
- Ecosystem health





Top: Existing phytoplankton type products for potential HAB detection in the southern Benguela will be improved by PACE. Middle: The National Oceans and Coastal Information Management System (OCIMS) Fisheries and Aquaculture Decision Support Tool will incorporate PCC from PACE. Left: HAB conditions discolor coastal waters. (Photo courtesy of Wolfgang Volgelbein, VIMS)

Informing Applications with PACE Data: Monitoring and Managing Terrestrial Ecosystems

PACE will provide data on surface vegetation, including surface reflectance, BRDF, and NDVI, which can benefit and/or inform:

- Wetland ecosystem health
- Forest health
- Agriculture
- Understanding impacts from land to coastal environments

Get Involved with PACE:
https://pace.oceansciences.org/app_involved.htm

PACE Applications Program

Air Quality

Water Resources

Disasters

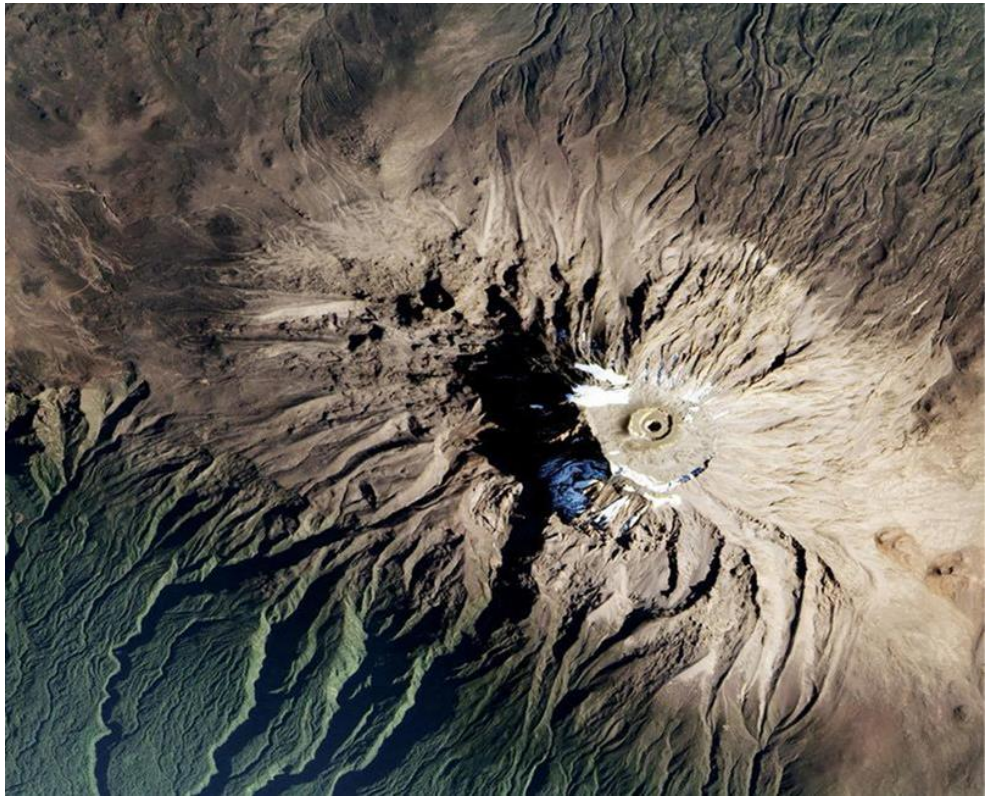
Ecological Forecasting

Climate

Surface Biology and Geology (SBG) Mission

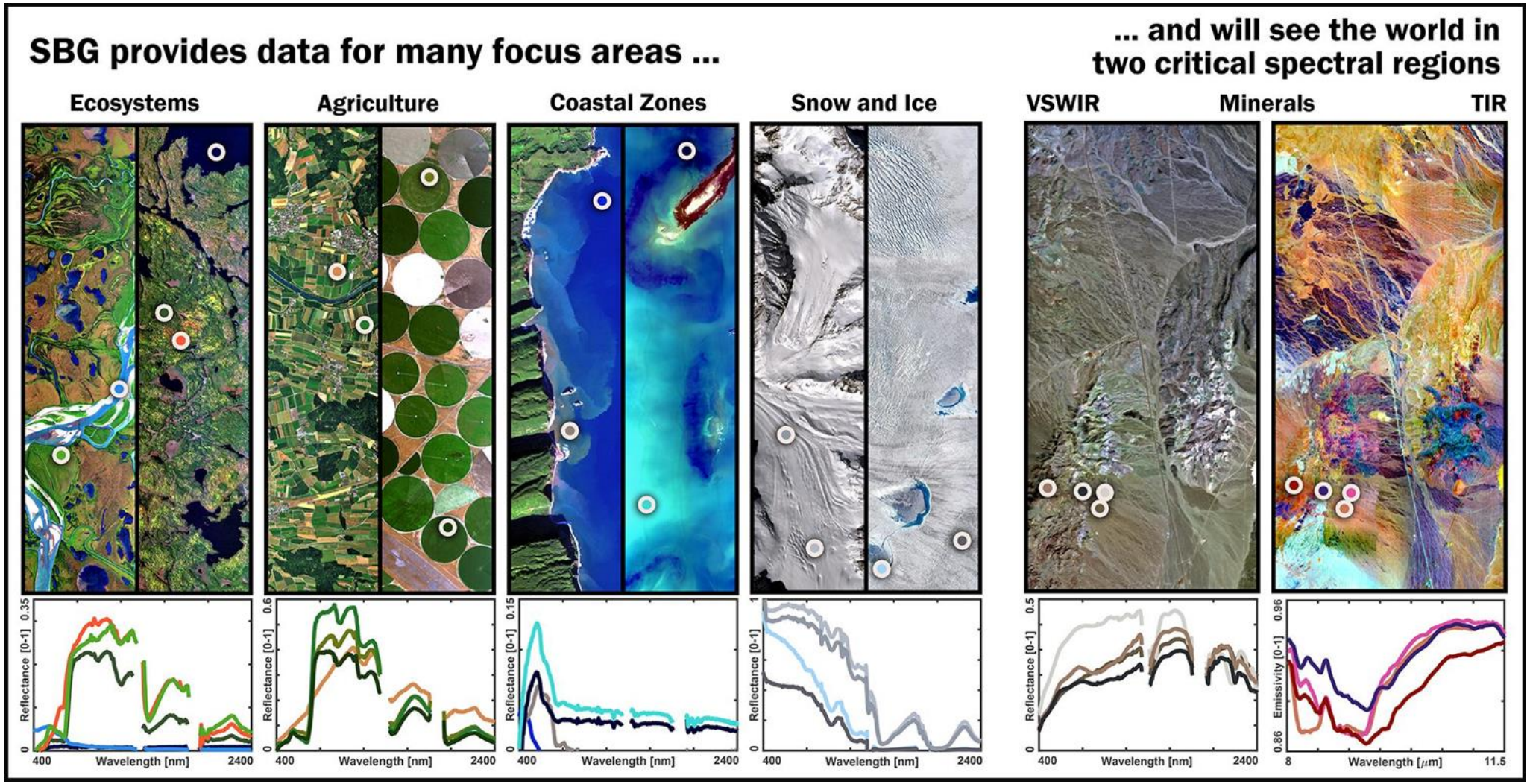
https://sbg.jpl.nasa.gov/

- 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- to 16-day revisit times
  - Thermal Bands:
    - Spectral Range: 8000 to 12000 or 3000 to 5000 nanometers
    - Spectral Resolution: Greater than 5 bands
    - Global with 1- to 70-day revisit times



Mount Kilimanjaro Image Credit: JPL SBG

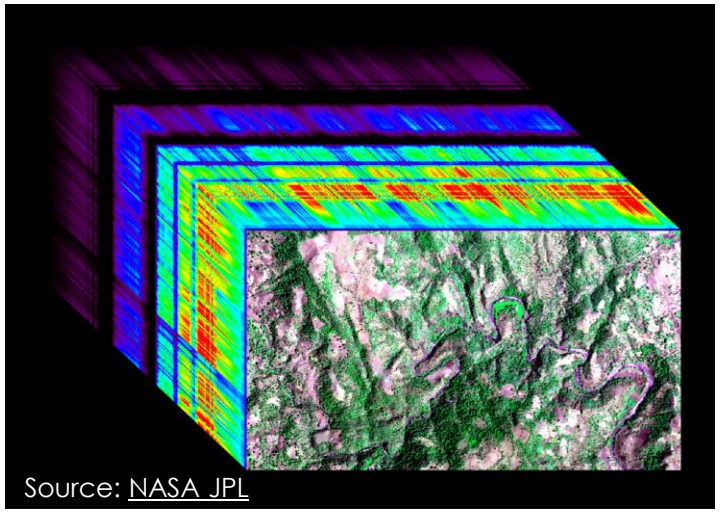
SBG Mission



SBG Potential Applications; Image Credit: JPL SBG

Summary

- Hyperspectral visible to short wave infrared (VSWIR) data refers to wavelengths within the visible and infrared portions of the electromagnetic spectrum (380- 2500 nm).
- The increased spectral resolution from hyperspectral data can provide users with additional data that multispectral data cannot measure.
- Airborne Visible/Infrared Imaging Spectrometer (AVIRIS), Airborne Visible InfraRed Imaging Spectrometer - Next Generation (AVIRIS-NG) and Portable Remote Imaging SpectroMeter (PRISM) airborne campaigns provide us with hyperspectral VSWIR data.
- Future hyperspectral missions include Airborne Visible InfraRed Imaging Spectrometer 3 (AVIRIS-3), Plankton, Aerosol, Cloud, and Ocean Ecosystem (PACE), and Surface Biology and Geology (SBG).


Source: NASA JPL

Resources

https://airbornescience.nasa.gov/

https://aviris.jpl.nasa.gov/

https://prism.jpl.nasa.gov/

https://www.bioscape.io/

https://airbornescience.jpl.nasa.gov/campaign/coral

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

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

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  - Sativa Cruz: sativa.cruz@nasa.gov

- Training Webpage: https://appliedsciences.nasa.gov/join-mission/training/english/arset-biodiversity-applications-airborne-imaging-systems

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

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