National Aeronautics and Space Administration

Integrating Remote Sensing into a Water Quality Monitoring Program

Sherry L. Palacios & Amita Mehta

5, 12, 19 June 2019

Training Objectives

Learn to:

- Understand which data products are used for water quality monitoring
- Follow rigorous practices for obtaining and processing aquatic remote sensing data
- Build skills in image processing for water quality monitoring for coastal and inland water bodies using NASA's SeaDAS image processing software

Prerequisites

- Fundamentals of Remote Sensing, Session 2C:
  - http://arset.gsfc.nasa.gov/webinars/fundamentals-remote-sensing
- Advanced Webinar: Processing Satellite Imagery for Monitoring Water Quality; Capacitación en Línea Avanzada: Procesamiento de Imágenes Satelitales para el Monitoreo de la Calidad del Agua
  - https://arset.gsfc.nasa.gov/water/webinars/wq-image-processing
- Download and install NASA's SeaDAS software. Ensure the software is working:
  - https://seadas.gsfc.nasa.gov/

Training Outline

June 5

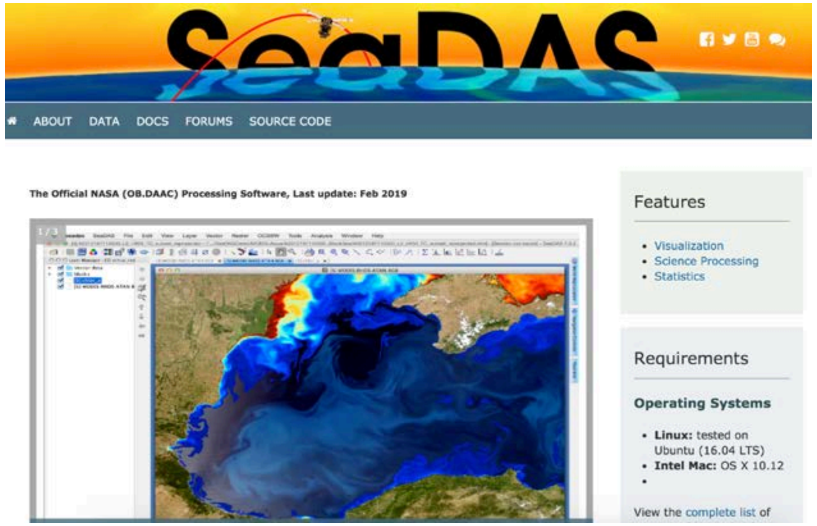
Water Quality in the Coastal Zone

June 12

Water Quality of Larger Inland Water Bodies

June 19

Aquatic Remote Sensing Skill Development and Best Practices

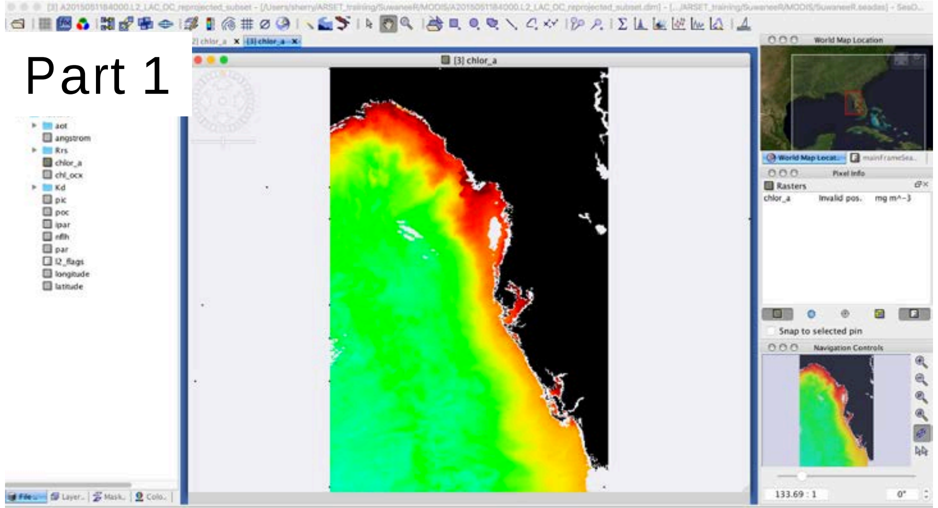


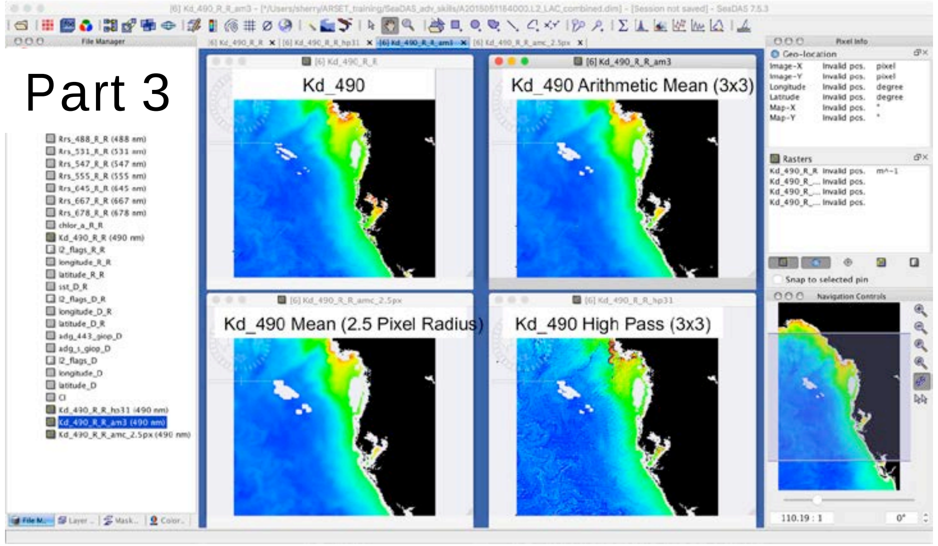
Outline for Part 1

- About ARSET
- Remote Sensing of Water Quality (WQ)
- Aquatic Remote Sensing Overview
- Examples of WQ Monitoring Programs
- Demonstration of MODIS & Landsat 8 OLI Image Data Access
  - OceanColor: https://oceancolor.gsfc.nasa.gov/
  - EarthExplorer: https://earthexplorer.usgs.gov/
- Exercise: Basic Skills in SeaDAS

Homework & Certificates

- Homework:
  - 3 homework assignments
  - Answers to homework from Parts 1 & 3 must be submitted via Google Forms
  - There is no form to complete for Part 2 homework
- Certificate of Completion
  - Attend all live webinars
  - Complete the homework assignments by June 21
- You will receive certificates approximately 2 months after the completion of the course from: marines.martins@ssaihq.com





About ARSET

NASA's Applied Remote Sensing Training Program (ARSET)

http://arset.gsfc.nasa.gov/

- 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
- Training topics focus on:
  - air quality
  - disasters
  - land
  - water

Helping Professionals Solve Problems Including…

ARSET Team Members

Program Support
- Ana Prados, Program Manager (GSFC)
- David Barbado, Spanish Translator (GSFC)
- Brock Blevins, Training Coordinator (GSFC)
- Annelise Carleton-Hug, Program Evaluator (Consultant)
- Elizabeth Hook, Technical Writer/Editor (GSFC)
- Selwyn Hudson-Odoi, Training Coordinator (GSFC)
- Marines Martins, Project Support (GSFC)
- Stephanie Uz, Program Support (GSFC)

Disasters & Water Resources
- Sean McCartney, Instructor (GSFC)
- Amita Mehta, Instructor (GSFC)
- Sherry Palacios, Instructor (ARC)
- Erika Podest, Instructor (JPL)

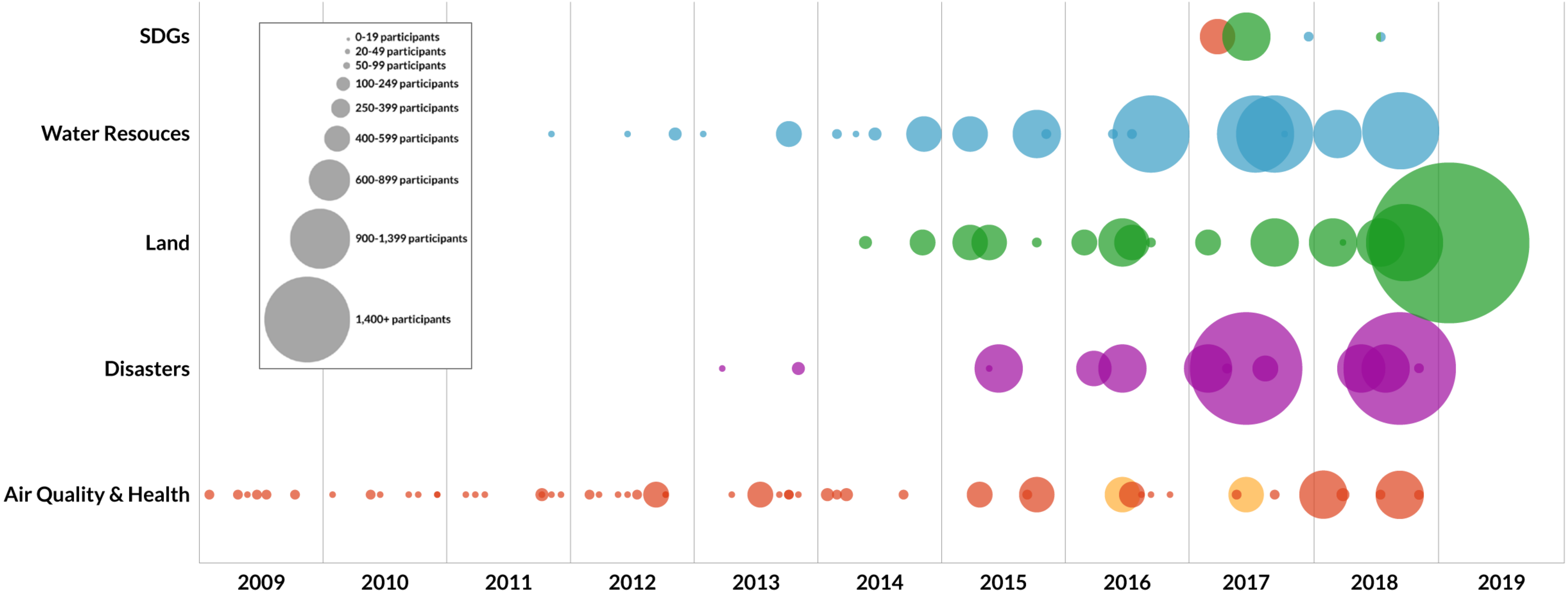
Land & Wildfires
- Cynthia Schmidt, Lead (ARC)
- Amber Jean McCullum, Instructor (ARC)

Health & Air Quality
- Pawan Gupta, Lead (MSFC)
- Melanie Cook, Instructor (GSFC)

Acknowledgement: We wish to thank Nancy Searby for her continued support

ARSET Trainings

110+ trainings 19,400+ participants 160+ countries 5,000+ organizations



* size of circle corresponds to number of participants

ARSET Water Quality Trainings

https://arset.gsfc.nasa.gov/water/

- Advanced Webinar: Processing Satellite Imagery for Monitoring Water Quality
  - https://arset.gsfc.nasa.gov/water/webinars/wq-image-processing

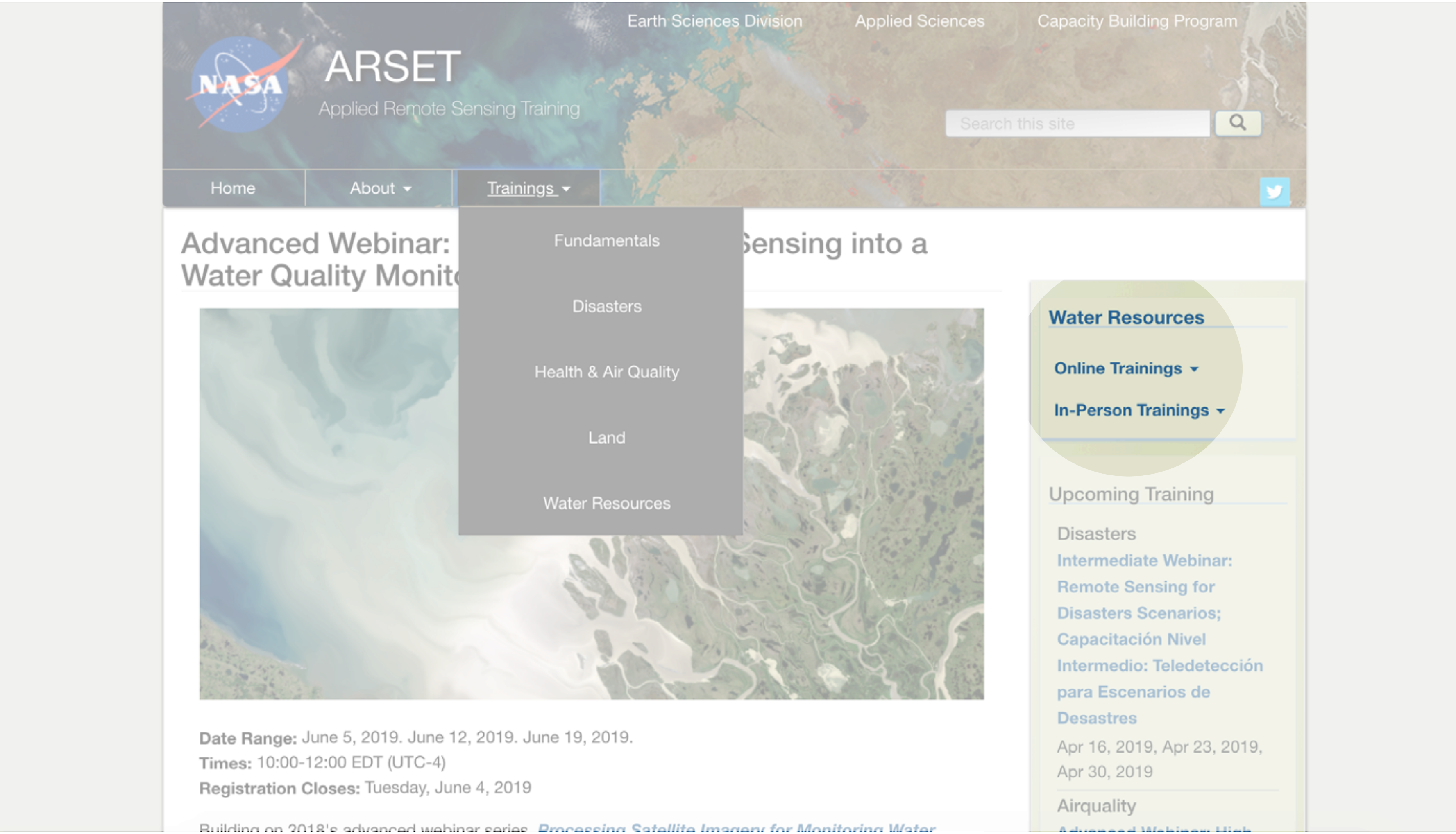
- Introduction to Remote Sensing of Harmful Algal Blooms:
  - https://arset.gsfc.nasa.gov/water/webinars/HABs17

- Introduction to Remote Sensing for Coastal & Ocean Applications:
  - https://arset.gsfc.nasa.gov/land/webinars/coastal-oceans-2016

- Water Quality Monitoring Using Remote Sensing Measurements:
  - https://arset.gsfc.nasa.gov/water/water-quality-2014

Learn More About ARSET

https://arset.gsfc.nasa.gov/



Remote Sensing of Water Quality

What Do We Mean by 'Water Quality'?

Water quality describes the condition of the water, including chemical, physical, and biological characteristics, usually with respect to its suitability for a particular purpose such as ecosystem function or human health

Examples of Some *In Situ* Water Quality Observations

- Water Temperature
- Salinity
- Dissolved Oxygen
- Alkalinity
- pH
- Color
- Nutrients (E.G., Nitrogen)
- Tests for Specific Pollutants (e.g., Industrial Organic Compounds)
- Heavy Metals
- Colored Dissolved Organic Matter
- Suspended Solids - Turbidity
- Bacteria (e.g., E. Coli)
- Water Clarity
- Cyanobacteria
- Pathogens and Pathogen Indicators
- Algae-Produced Toxins
- Plastic Microbeads
- Chlorophyll
- Chlorophyll Anomaly
- Algal Pigments

Water Quality Affects Water Optical Properties

Natural water contains material that is optically active. Remote sensing of this material may indicate the quality of the water.

Examples of two common constituents that influence water quality:

- Colored dissolved organic matter (CDOM) which is a mixture of organic compounds like lignins and tannins
- Suspended matter includes particles of clay, undissolved minerals, plankton, and algal blooms

Confluence of the Rio Negro and Rio Solimoes, Brazil, CDOM on the left, Sediments on the Right

Image Credit: Pant, A. A. (2014, October 21). Rivers that meet but do not mix. Retrieved from Awesci - Science Everyday website: http://awesci.com/rivers-that-meet-but-do-not-mix/

Some Water Quality Indicators Satellites Can Observe

- Turbidity and Sediments
- Colored Dissolved Organic Matter (CDOM)
- Sea Surface Temperature (SST)
- Chlorophyll-a (phytoplankton)
- Salinity
- Total Suspended Solids (TSS)
- Fluorescence Line Height
- Euphotic Depth
- Diffuse Attenuation of Light

Image Credit: A blackwater river meets the sea [Text.Article]. (2018, October 27). Retrieved from https://earthobservatory.nasa.gov/images/144147/a-blackwater-river-meets-the-sea

How *In Situ* and Satellite Observations Roughly Correspond

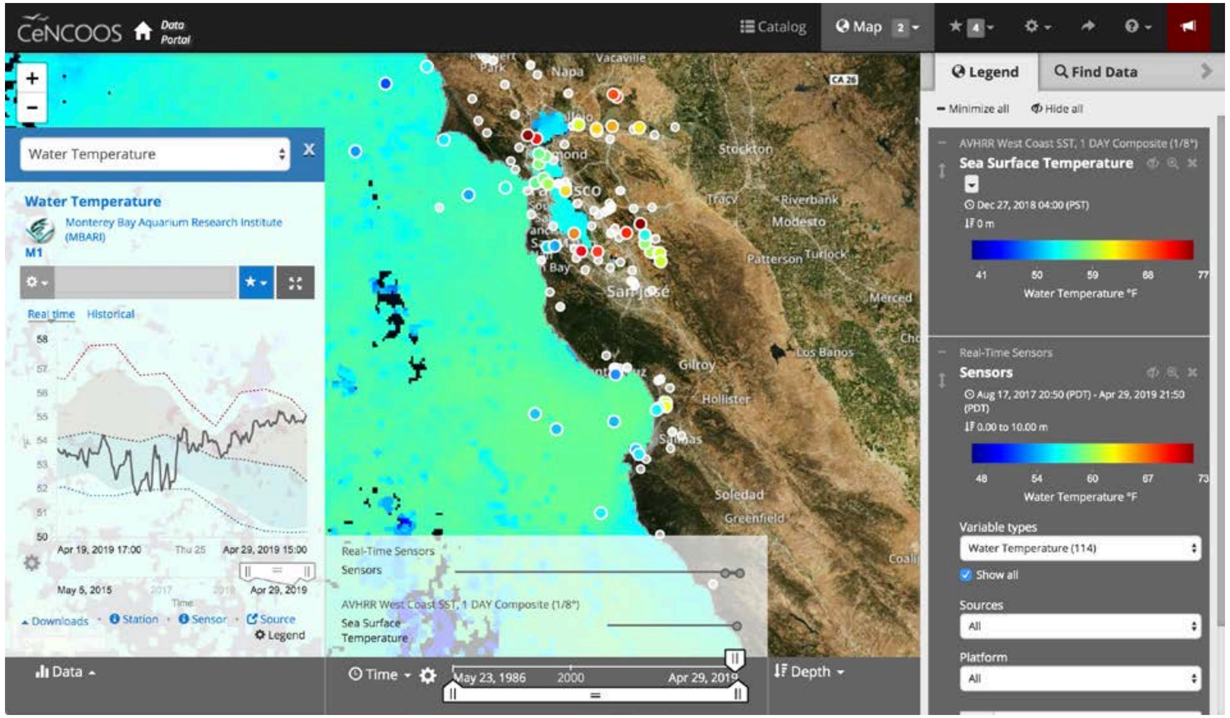
In Situ	Satellite
Water Temperature	Sea Surface Temperature (SST)
Colored Dissolved Organic Matter (CDOM)	Absorption by CDOM (a_{dg})
Suspended Solids – Turbidity	Diffuse attenuation of light at 490 nm (K_d)
Water Clarity	Chlorophyll-a, Normalized Fluorescence Line Height (nFLH)
Cyanobacteria	Cyanobacteria Index (CI)
Algal Pigments	Euphotic Zone Depth (Z_{eu}) Experimental Phytoplankton Functional Type Algorithms

Which Factors Influence Water Quality?

- Nutrient loading “eutrophication”
  - agricultural runoff
  - septic leaching
- Pollution
  - industrial point sources
  - deposition from the atmosphere
- Climate change
  - rising temperatures stimulate cyanobacterial blooms
  - ocean acidification from elevated CO2
- Food web changes
- Introduced species
- Changes in water flow
  - dams
  - natural events like hurricane, drought, or flood

Why Use Satellites?

- Regular and consistent observations over a large area
- Consistent revisit rate for well structured time series analyses
- Large number of data products available
- Complements *in situ* sampling
- Mostly free and open access



Sea Surface Temperature from the AVHRR Sensor

Image Credit: CeNCOOS Data Portal, https://data.cencoos.org/

Aquatic Remote Sensing Review

How Light Interacts with Water

Remote Sensing Reflectance (Rrs) or Ocean Color

$$\mathrm{Rrs}(\lambda, 0^+) \cong C \frac{b_b(\lambda)}{a(\lambda) + b_b(\lambda)} = \frac{L_w(\lambda)}{E_d(\lambda, 0^+)}$$

Inherent Optical Properties

- *a* = absorption by...
  - phytoplankton (ph)
  - non-algal particles (nap)
  - colored dissolved organic matter (CDOM)
  - water (w)
- *b* = scattering in forward (f) and backward (b) directions

Apparent Optical Properties

- L_w = water leaving radiance
- L_u = upwelling radiance
- E_d = downwelling irradiance
- R_{rs} = remote sensing (rs) reflectance

Inherent Optical Properties (IOPs) and the 'Color' of Water

- Light absorbed (a) is a combination of:
  - Phytoplankton (ph)
  - Non-Algal Particles (nap)
  - Water (w)
  - Colored Dissolved Organic Matter (CDOM)

$$a = a_{ph} + a_{nap} + a_{CDOM} + a_w$$

- Light scattered (b) is a combination of particles in forward (b_f) and backward (b_b) directions

$$b = b_f + b_b$$

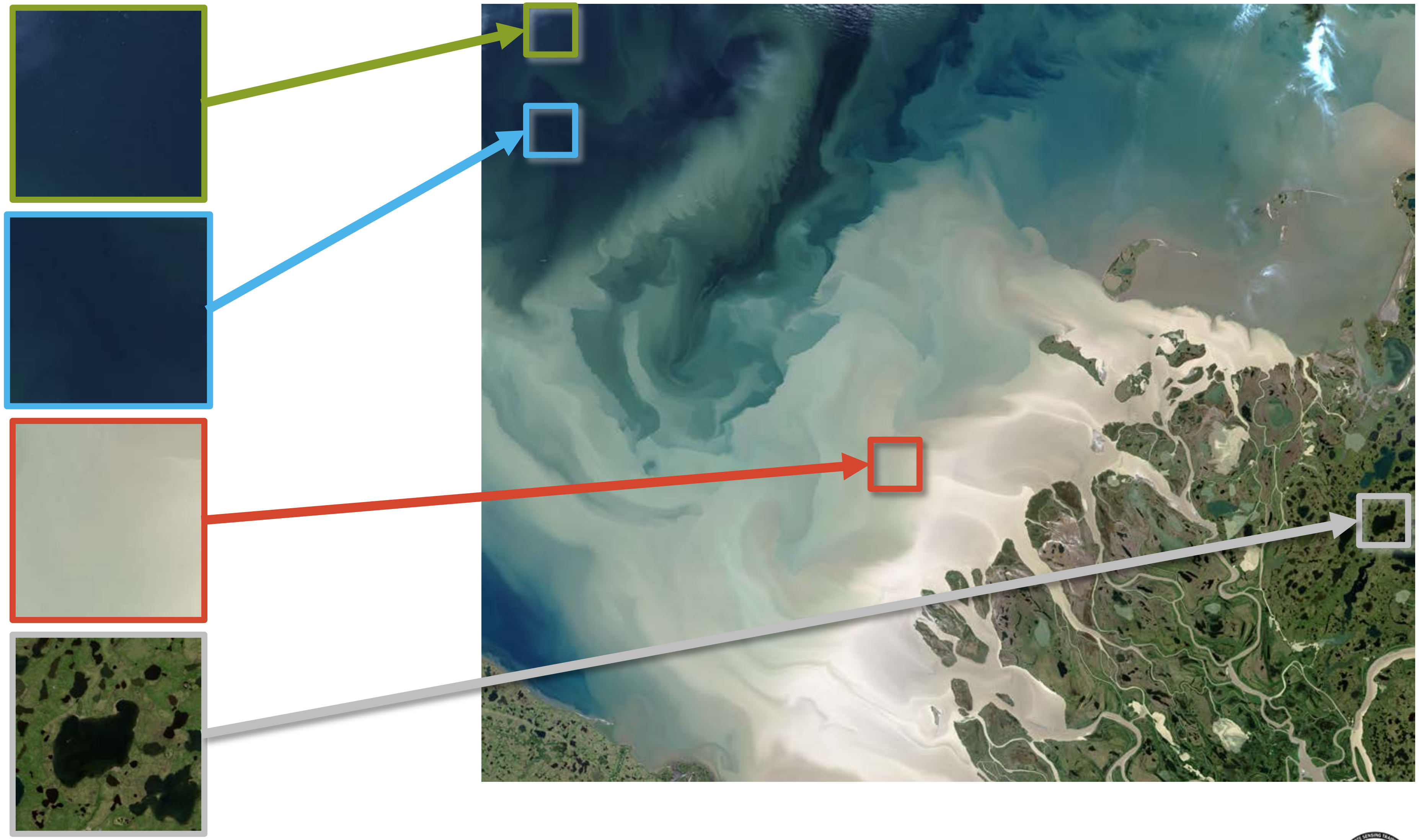
Inherent Optical Properties (IOPs) and the ‘Color’ of Water

Chlorophyll

Water

Nap/
Sediments

CDOM



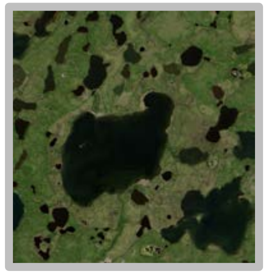
Inherent Optical Properties (IOPs) and the 'Color' of Water

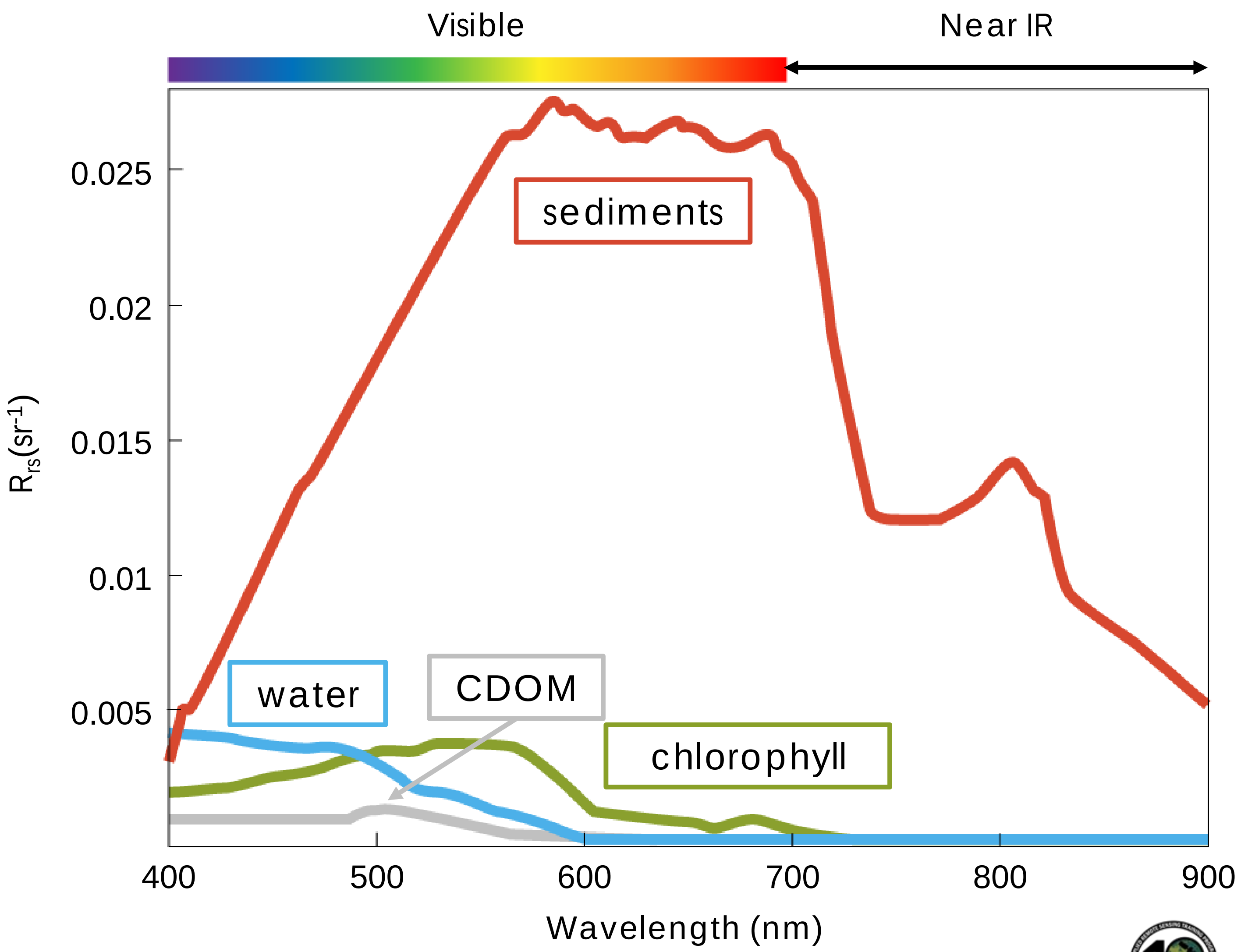
Chlorophyll

Water

Nap/
Sediments

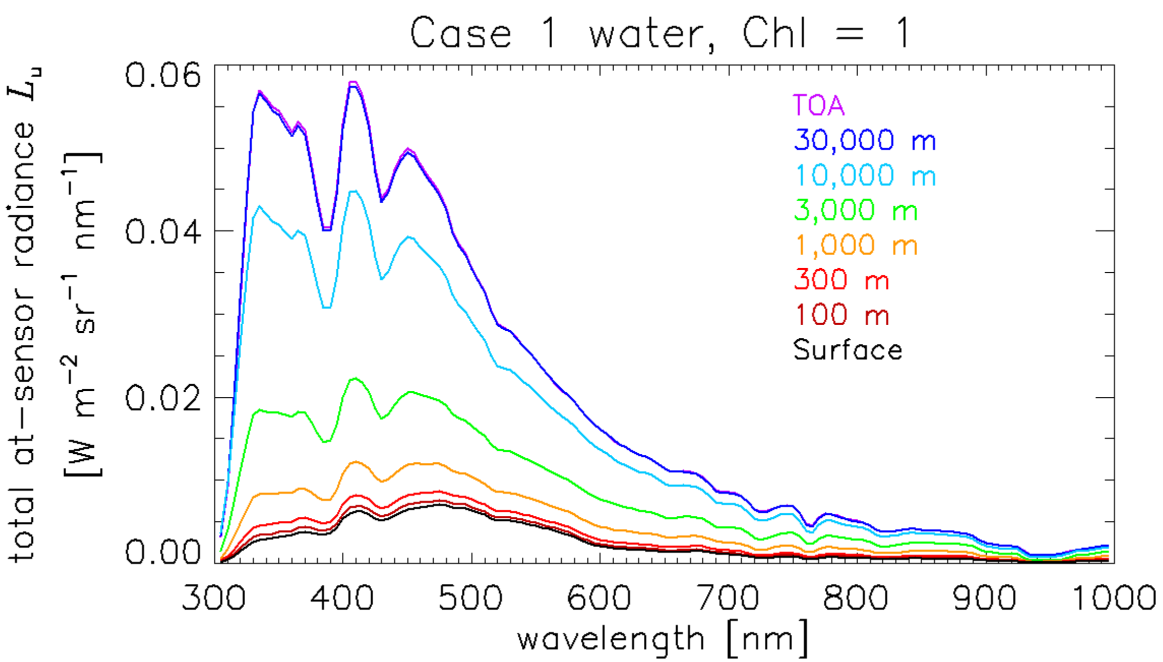
CDOM





Atmospheric Correction for Water Quality Monitoring

- Satellite sensors measure top-of-atmosphere (TOA) radiances
- The TOA radiances result from a combination of surface and atmospheric conditions, including effects of water vapor, relative humidity, gases, aerosol particle type and size distribution, aerosol hygroscopy
- The effect of sky radiance can be seen in at-sensor radiance spectra modeled for different altitudes

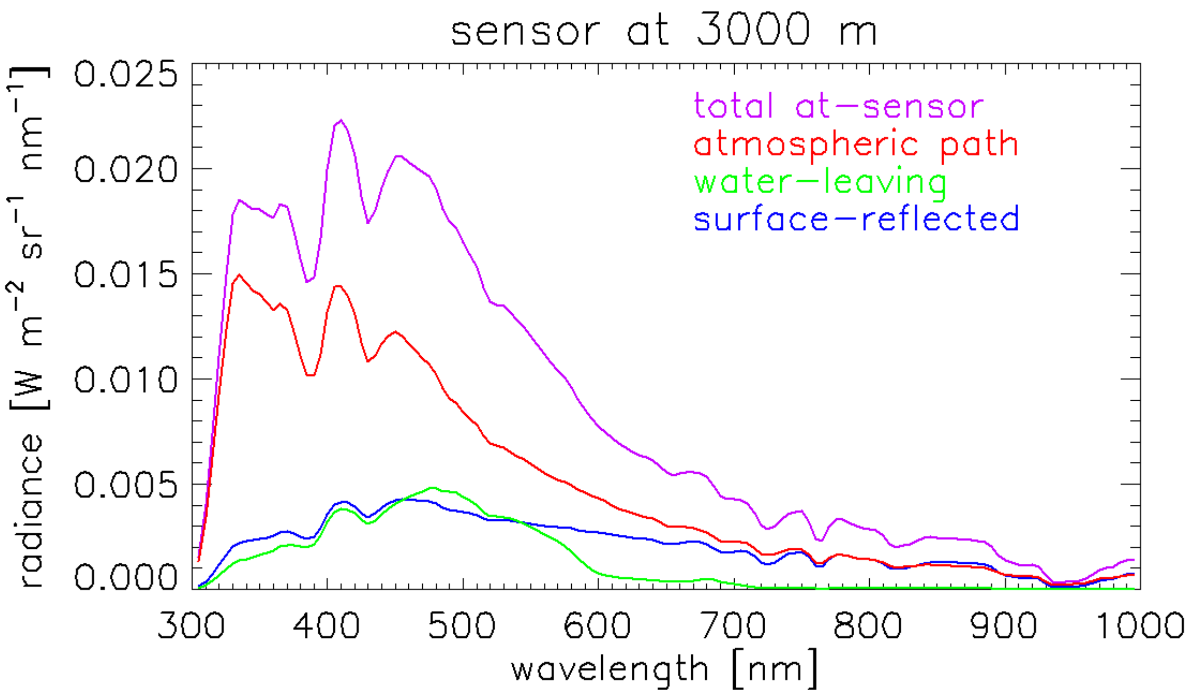


Examples of at-sensor radiance spectra for different sensor altitudes, assuming the same surface reflectance

Image Credit: Ocean Optics Web Book

Atmospheric Correction for Water Quality Monitoring

- The goal is to subtract the atmospheric path and surface-reflected spectra from the total at-sensor spectrum to arrive at the water-leaving radiance spectrum
- Requires radiative transfer modeling along with atmospheric conditions, clouds, and aerosol information
- Various techniques exist for atmospheric correction (e.g., 6S, ACOLITE, ATREM, FLAASH)

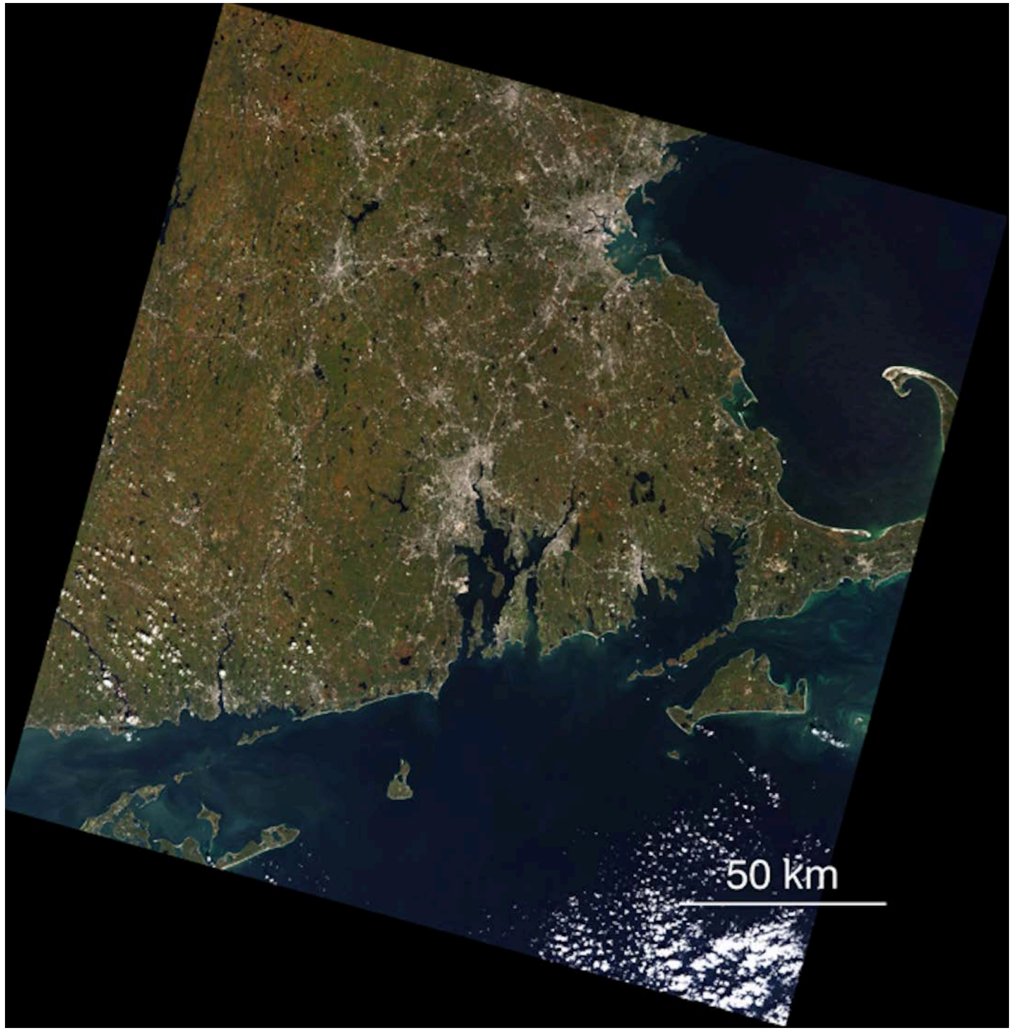


Atmospheric Correction

“Top of Atmosphere”

Atmospheric correction

“Surface Reflectance”



Data Processing Levels

L0: Raw instrument data

L1: Geolocated and calibrated

L2: Products derived from L1B

L3: Gridded and quality controlled

L4: Model output: derived variables

Data Processing Levels

Greater Skill Needed

Less Skill Needed

Processing Level	Description
Level 0	Reconstructed, unprocessed instrument and payload data at full resolution, with any and all communications artifacts (e.g., synchronization frames, communications headers, duplicate data) removed.
Level 1A	Reconstructed, unprocessed instrument data at full resolution, time-referenced, and annotated with ancillary information, including radiometric and geometric calibration coefficients and georeferencing parameters (e.g., platform ephemeris) computed and appended but not applied to Level 0 data.
Level 1B	Level 1A data that have been processed to sensor units (not all instruments have Level 1B source data).
Level 2	Derived geophysical variables at the same resolution and location as Level 1 source data. Data are atmospherically corrected prior to deriving these geophysical variables.
Level 3	Variables mapped on uniform space-time grid scales, usually with some completeness and consistency.
Level 4	Model output or results from analyses of lower-level data (e.g., variables derived from multiple measurements).

Satellites & Sensors for Water Quality Monitoring

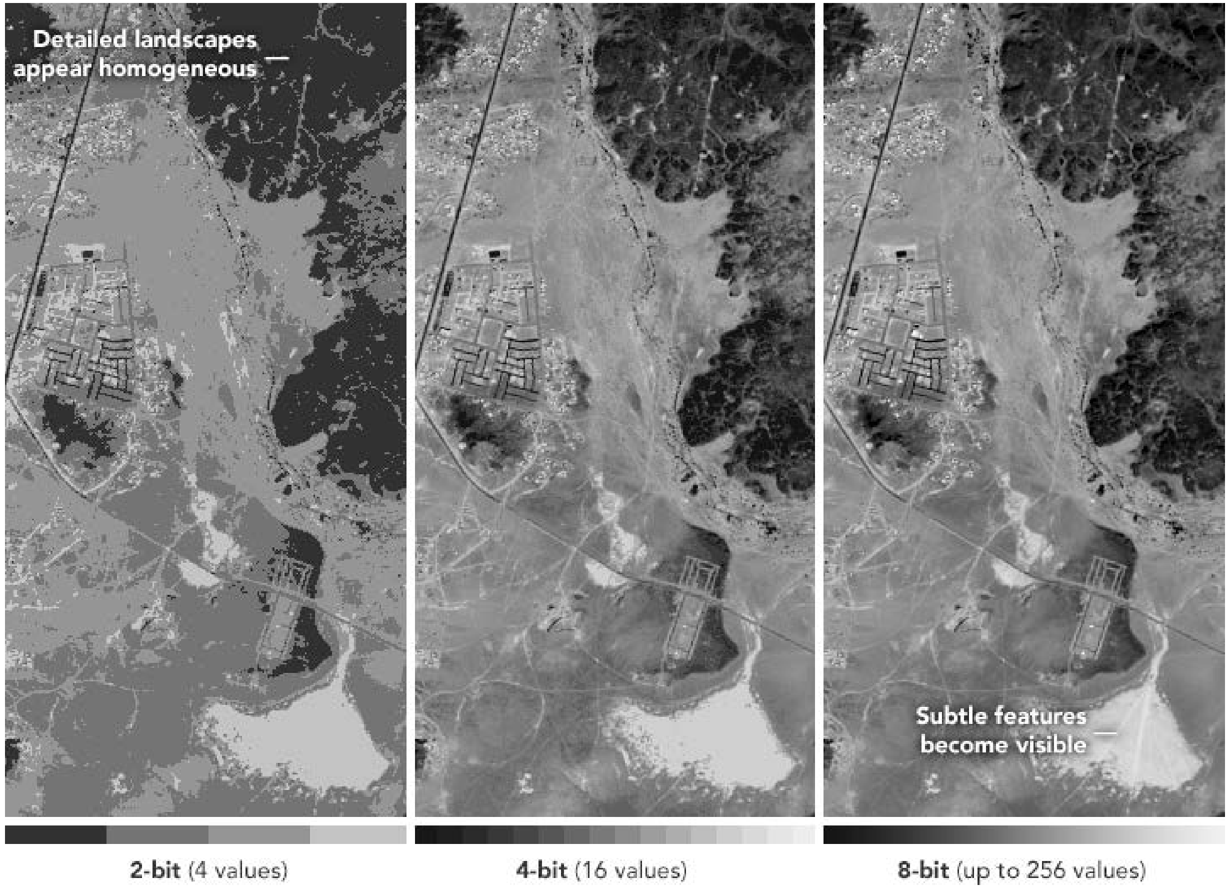
Satellites	Sensors	Resolution
Landsat 7	Enhanced Thematic Mapper (ETM+)	185 km swath; 15 m, 30 m, 60 m; 16 day revisit
Landsat 8	Operational Land Imager (OLI)	185 km swath; 15 m, 30 m, 60 m; 16 day revisit
Terra & Aqua	MODerate Resolution Imaging Spectroradiometer (MODIS)	2330 km swath; 250 m, 500 m, 1 km; 1-2 day revisit
Suomi NPP	Visible Infrared Imaging Radiometer Suite (VIIRS)	3040 km swath; 375 m – 750 m; 1-2 day revisit
Sentinel 2A and 2B	Multi Spectral Imager (MSI)	290 km swath; 10 m, 20 m, 60 m; 5 day revisit
Sentinel 3A	Ocean and Land Color Instrument (OLCI)	1270 km swath; 300 m; 27 day revisit

Current Satellite Missions for Water Quality Monitoring

- Landsat 7 (4/15/1999 – present)
- Landsat 8 (2/1/2013 – present)
- Terra (12/18/1999 – present)
- Aqua (5/4/2002 – present)
- Suomi National Polar Partnership (SNPP) (11/21/2011 – present)
- Sentinel-2A (6/23/2015 - present)
- Sentinel-2B (3/7/2017 – present)
- Sentinel-3A (2/16/2016 – present)

Radiometric Resolution & Signal to Noise Ratio (SNR)

- Radiometric resolution is the amount of information in a pixel
- Radiometric resolution is also dependent on the signal-to-noise ratio of the sensor
- In our tables, we use signal-to-noise (SNR) – the higher the SNR, the better for water



Landsat 7 ETM+ Resolution

Band	Spectral Range (µm)	Spatial Resolution (m)	SNR
1	0.45 – 0.515	30	32
2	0.525 – 0.605		35
3	0.63 – 0.69		26
4	0.775 – 0.90		32
5	1.55 – 1.75		25
7	2.08 – 2.35		17
8	0.52 – 0.9	15	15

Temporal Resolution 16 Days

Credit: eoPortal Directory

Landsat 8 OLI Resolution

Band	Spectral Range (µm)	Spatial Resolution (m)	SNR
1	0.433 – 0.453	30	238
2	0.450 – 0.515		364
3	0.525 – 0.60		302
4	0.630 – 0.680		227
5	0.845 – 0.885		204
6	2.10 – 2.30		265
7	0.500 – 0.680		334
8	2.08 – 2.35	15	149
9	1.36 – 1.39	30	165

Temporal Resolution 16 Days

MODIS Resolution

Band	Spectral Range (µm)	Spatial Resolution (m)	SNR
8	0.405-0.420	1000	880
9	0.438-0.448		838
10	0.483-0.493		802
11	0.526-0.536		752
12	0.546-0.556		750
13	0.662-0.672		910
14	0.673-0.683		1087
15	0.743-0.753		586

Temporal Resolution 1- 2 Days

VIIRS Resolution

Band	Spectral Range (µm)	Spatial Resolution (m)	SNR
M1	0.402-0.422	750	352
M2	0.436-0.454		380
M3	0.478-0.488		416
M4	0.545-0.565		362
M5	0.662-0.682		342
M6	0.739-0.745		199

Temporal Resolution 1- 2 Days

Credit: STAR JPSS

Sentinel-2A MSI Resolution

<table>
<tr><th>Band</th><th>Central Wavelength (nm)</th><th>Spatial Resolution (m)</th><th>SNR</th></tr>
<tr><td>1</td><td>442.7</td><td>60</td><td>129</td></tr>
<tr><td>2</td><td>492.4</td><td>10</td><td>154</td></tr>
<tr><td>3</td><td>559.8</td><td>10</td><td>168</td></tr>
<tr><td>4</td><td>664.6</td><td>10</td><td>142</td></tr>
<tr><td>5</td><td>704.1</td><td rowspan="2">20</td><td>117</td></tr>
<tr><td>6</td><td>740.5</td><td>89</td></tr>
</table>

<table>
<tr><th>Band</th><th>Central Wavelength (nm)</th><th>Spatial Resolution (m)</th><th>SNR</th></tr>
<tr><td>7</td><td>782.8</td><td>20</td><td>105</td></tr>
<tr><td>8</td><td>832.8</td><td>10</td><td>174</td></tr>
<tr><td>8a</td><td>864.7</td><td>20</td><td>72</td></tr>
<tr><td>9</td><td>945.1</td><td rowspan="2">60</td><td>114</td></tr>
<tr><td>10</td><td>1373.5</td><td>50</td></tr>
<tr><td>11</td><td>1613.7</td><td rowspan="2">20</td><td>100</td></tr>
<tr><td>12</td><td>2202.4</td><td>100</td></tr>
</table>

Temporal Resolution 5 – 7 Days

Sentinel-3 OLCI Resolution

Band	Central Wavelength (nm)	Spatial Resolution (m)	SNR
Oa1	400	300 & 1200	2420
Oa2	412.5		2398
Oa3	442.5		2161
Oa4	490		200
Oa5	510		1979
Oa6	560		1776
Oa7	620		1591
Oa8	665		1547
Oa9	673.75		1329
Oa10	681.25		1320
Oa11	708.75		1420

Band	Central Wavelength (nm)	Spatial Resolution (m)	SNR
Oa12	753.75	300 & 1200	1127
Oa13	761.25		502
Oa14	764.375		663
Oa15	767.5		558
Oa16	778.75		1514
Oa17	865		1243
Oa18	885		823
Oa19	900		691
Oa20	940		535
Oa21	1020		346

Temporal Resolution 27 Days

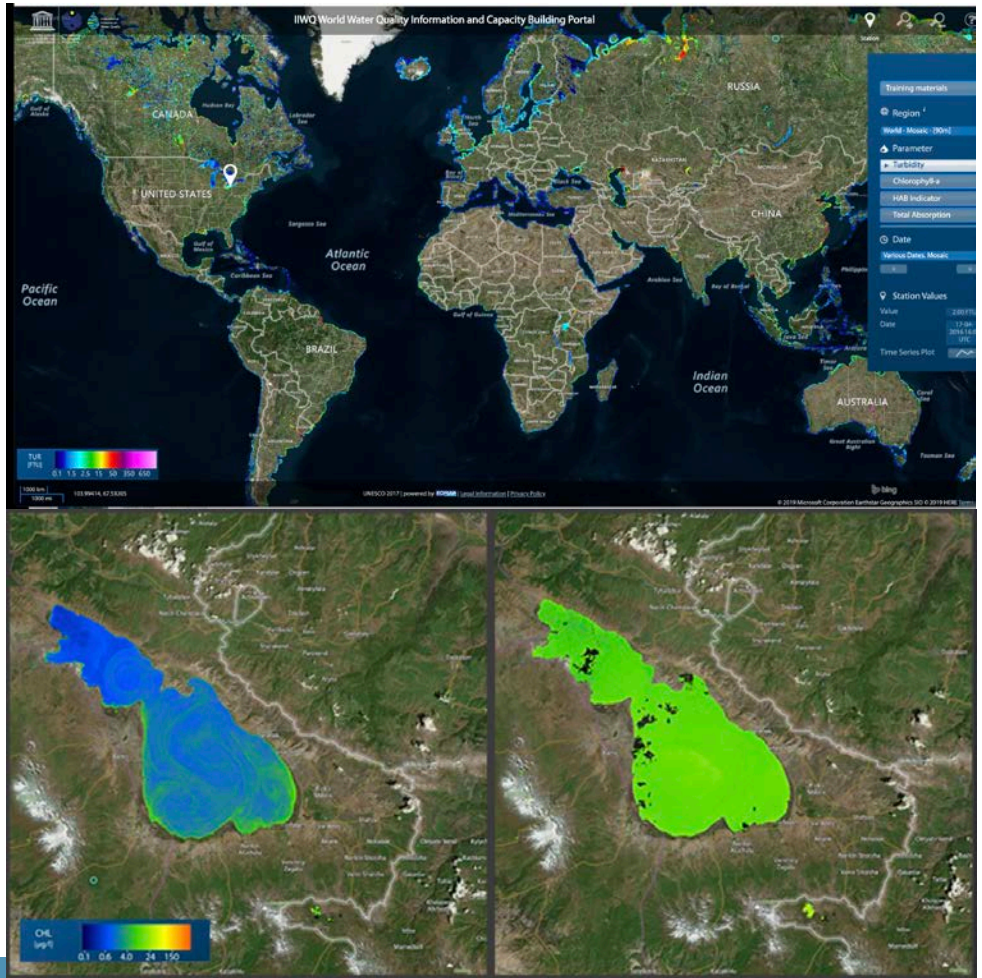
Examples of Water Quality Monitoring Programs

Water Quality Monitoring Program Examples

- UNESCO
  - Water Quality Information and Capacity Building Portal
- European Space Agency (ESA)
  - Earth Observation for Sustainable Development: Water Quality Monitoring
- Finnish Environment Institute
  - Monitoring Water Quality in Baltic Seas and Finnish Lakes
- UN-SPIDER Knowledge Portal
- Florida Fish & Wildlife Conservation Commission
  - Evaluating Suwannee River Discharge Effects on Water Quality in Big Bend Region

UNESCO Water Quality Information & Capacity Building Portal

http://www.worldwaterquality.org/

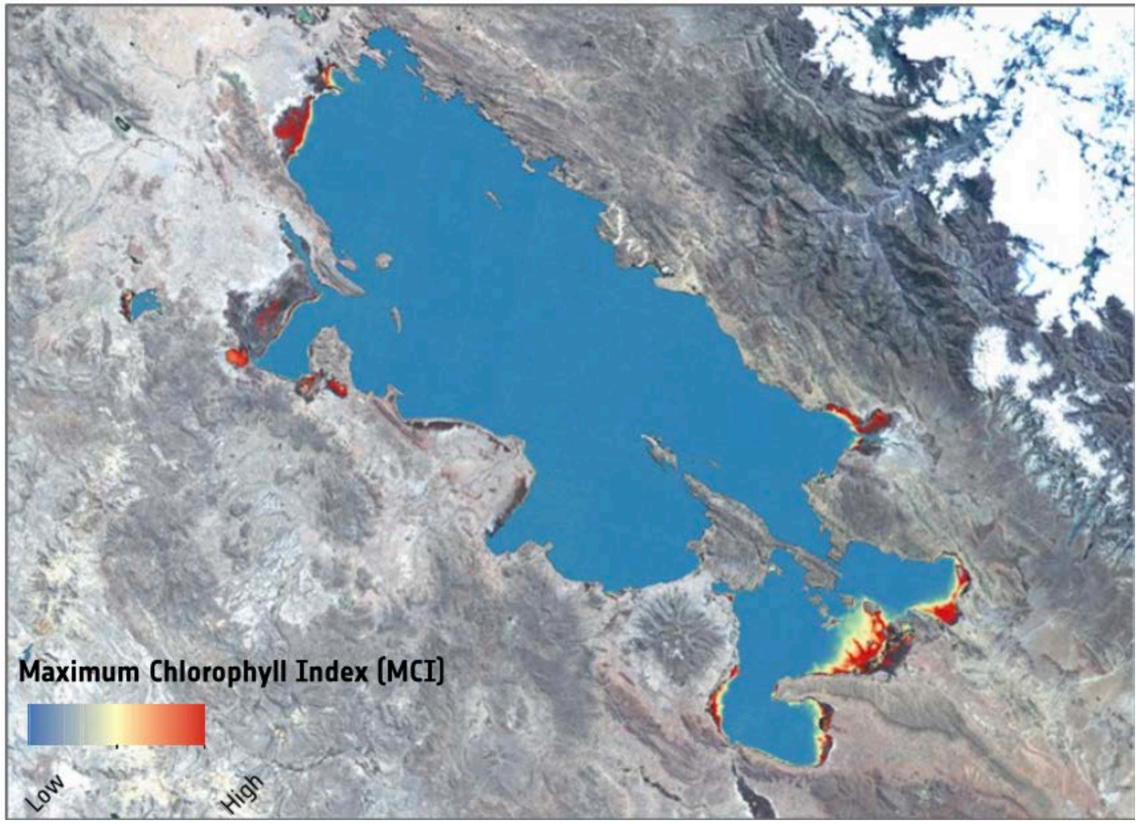


Chlorophyll-a levels in Lake Sevan on 26 August and 04 September 2016.
IIWQ World Water Quality Portal, UNESCO / EOMAP

- A portal based on optical data from Landsat and Sentinel-2 satellites, and a computational system, developed by EOMAP, Germany
- Provides Turbidity, Chlorophyll-a, HAB Indicator, Total Absorption, Surface Temperature

Earth Observation for Sustainable Development: WQ Monitoring

http://eo4sd-water.net/portfolio/product/water-quality-monitoring



Example of a chl map derived from satellite data in 10m resolution over Lake Titicaca on the border of Bolivia & Peru. © Copernicus Sentinel data/DHI GRAS

- Planned by European Space Agency
- Will Monitor Chlorophyll concentrations, Total Suspended Matter (TSM), and water temperature from satellite observations
- Will use Sentinel-2 MSI and Sentinel-3 OLCI data, and Landsat8 OLI data

Monitoring Water Quality in Baltic Seas and Finnish Lakes

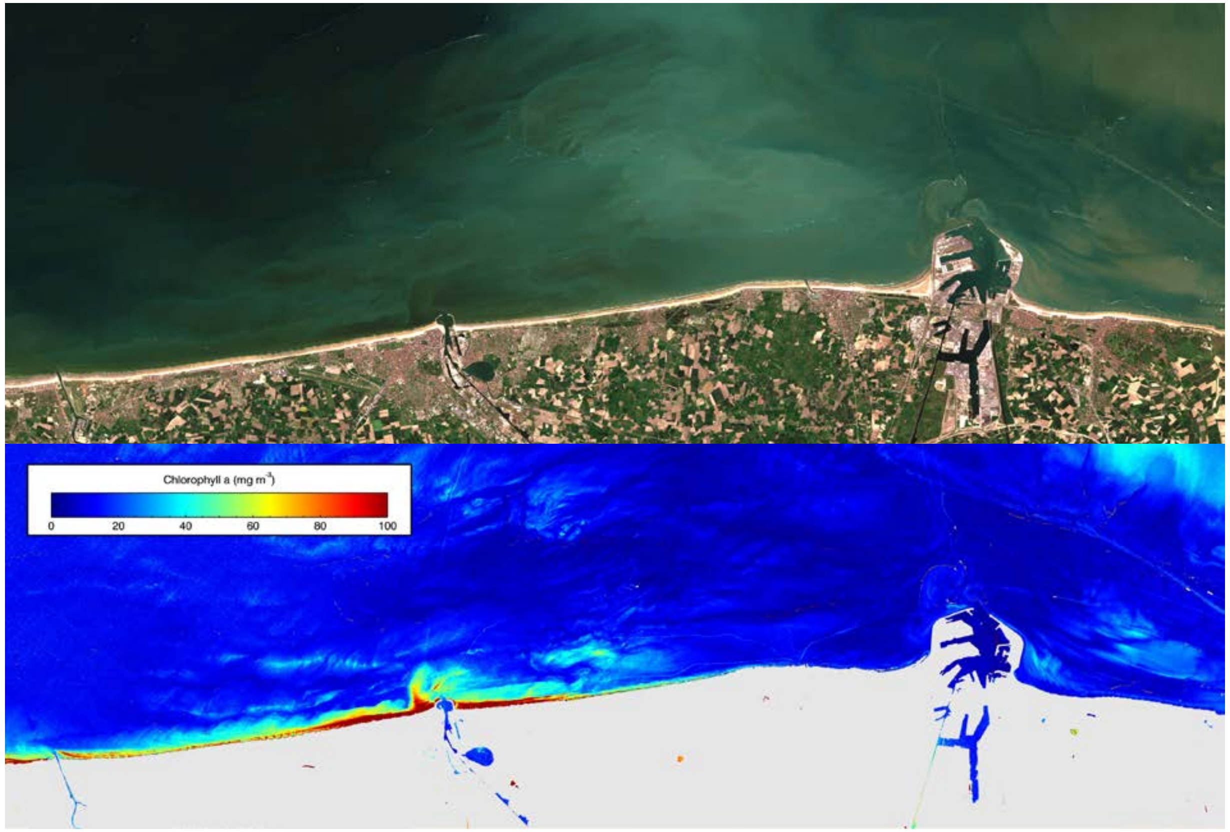
http://bit.ly/2LwYIhd

Sentinel-2 satellite image from 27/8/2016, the west coast of Finland. ESA Sentinel Program, processed by SKYE.

- A program by Finnish Environment Institute
- Utilization of data from Sentinel series of satellites and Landsat to monitor
  - chlorophyll a
  - Turbidity
  - Colored Dissolved Organic Matter (CDOM)
  - Secchi disk depth

UN-SPIDER Knowledge Portal

http://www.un-spider.org/links-and-resources/data-sources/daotm-water-quality



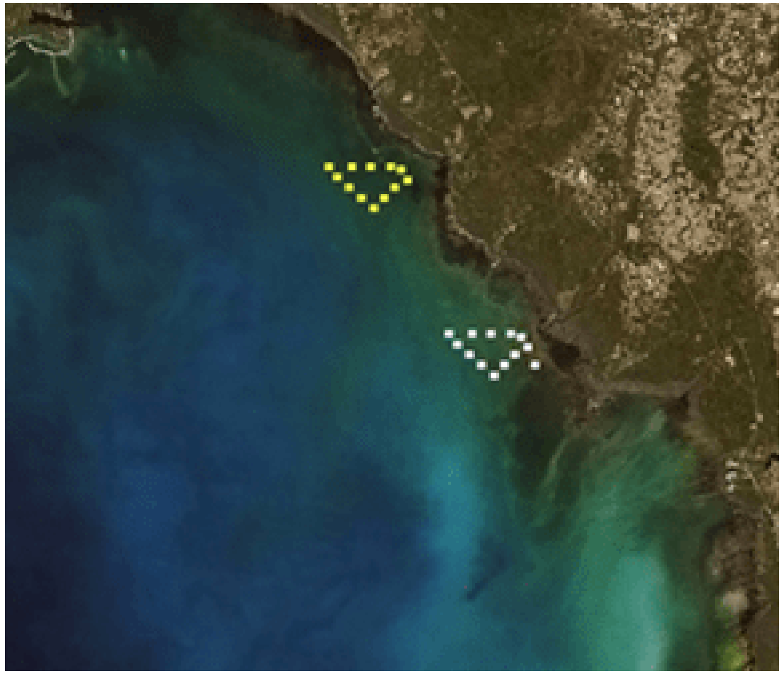
Algal bloom close to Belgium's coast. Captured by Sentinel-2A on 1 May 2016. Images contain modified Copernicus Sentinel data (2016) processed by RBINS

- Provides an overview of satellites, sensors, and spectral bands used for water quality monitoring

Evaluating Suwannee River Discharge Effects on Water Quality in Big Bend Region

- A study to link water quality to suitable habitat for seagrasses using in situ observations of nutrient load and other optical properties and remotely sensed imagery
- Build a regional algorithm for water quality parameters like water transparency, CDOM, chlorophyll, turbidity
- Relate historical seagrass distribution and abundance data to imagery-derived water quality parameters

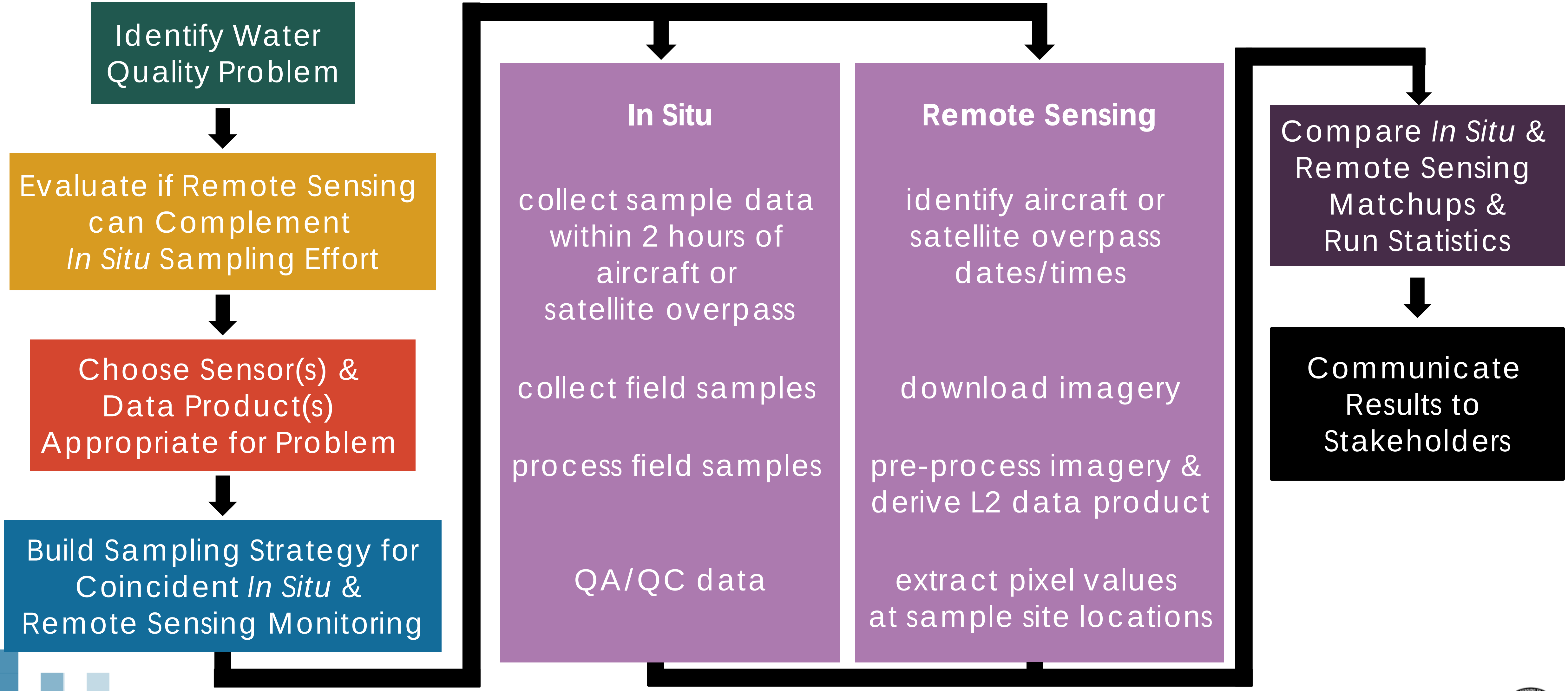
Florida Fish and Wildlife Conservation Commission



MODIS satellite image showing sampling sites near the mouths of the Suwannee (white) and Steinhatchee (yellow) rivers.

Credit: Florida Fish & Wildlife Conservation Commission

Water Quality Monitoring Program Workflow

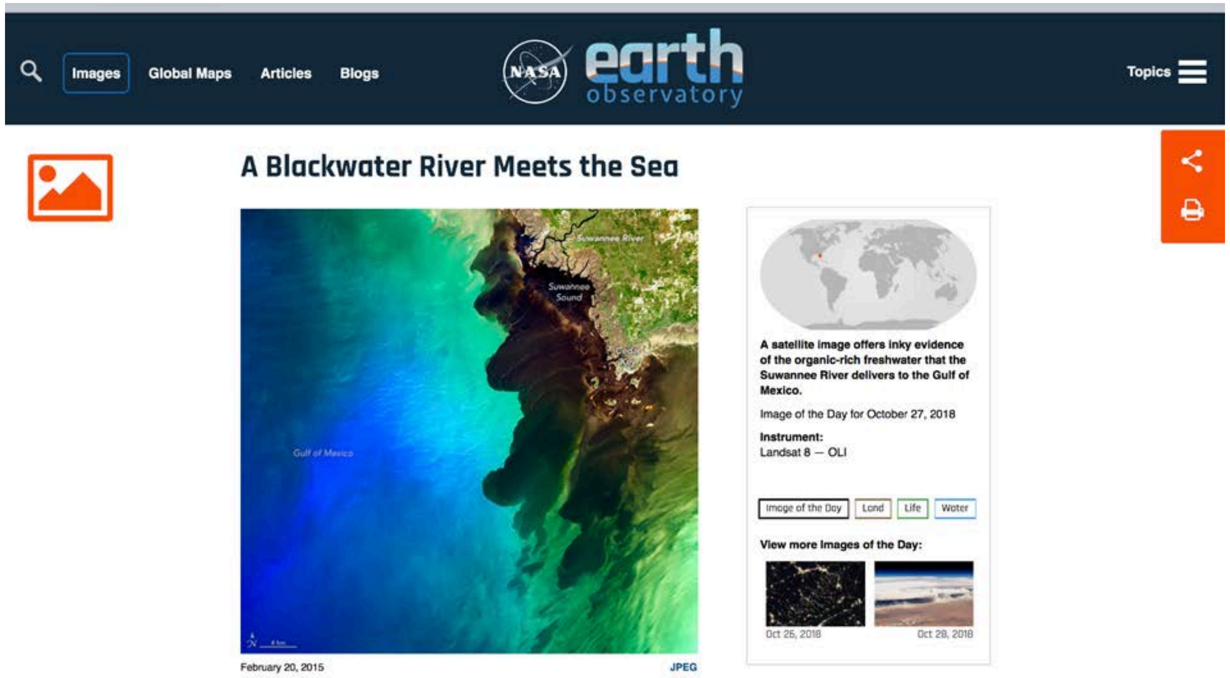


Exercise: Basic Skills in SeaDAS

Demonstration of MODIS & Landsat 8 OLI Image Data Access

NASA Earth Observatory - A Blackwater River Meets the Sea

- The Suwannee River, a naturally occurring "blackwater river", has its headwaters in boggy Okefenokee Swamp (Georgia, USA)
- It flows through Florida (USA) and drains into the Gulf of Mexico
- Its tannin- and lignin- rich water is dark brown from the colored dissolved organic matter
- When it meets the Gulf, the contrast in color is stark



Credit: Earth Observatory

Download Satellite Imagery

- **Location**: Western Florida, USA & Gulf of Mexico
- **Boundary Coordinates**:

29

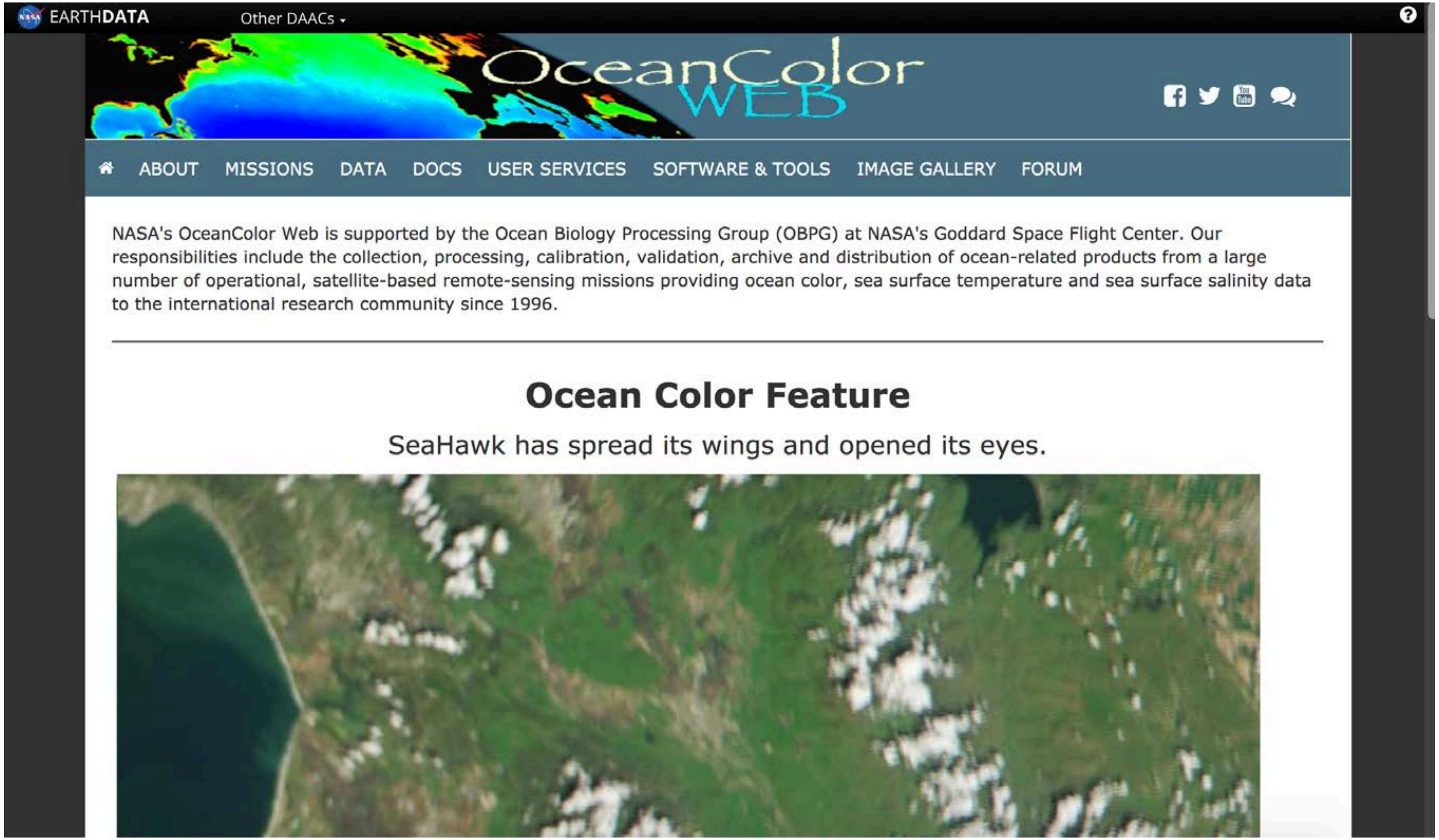
-84 81

25

- **Date**: 20 February 2015
- **Sensors**:
  - Aqua (MODIS)
  - Landsat 8 OLI

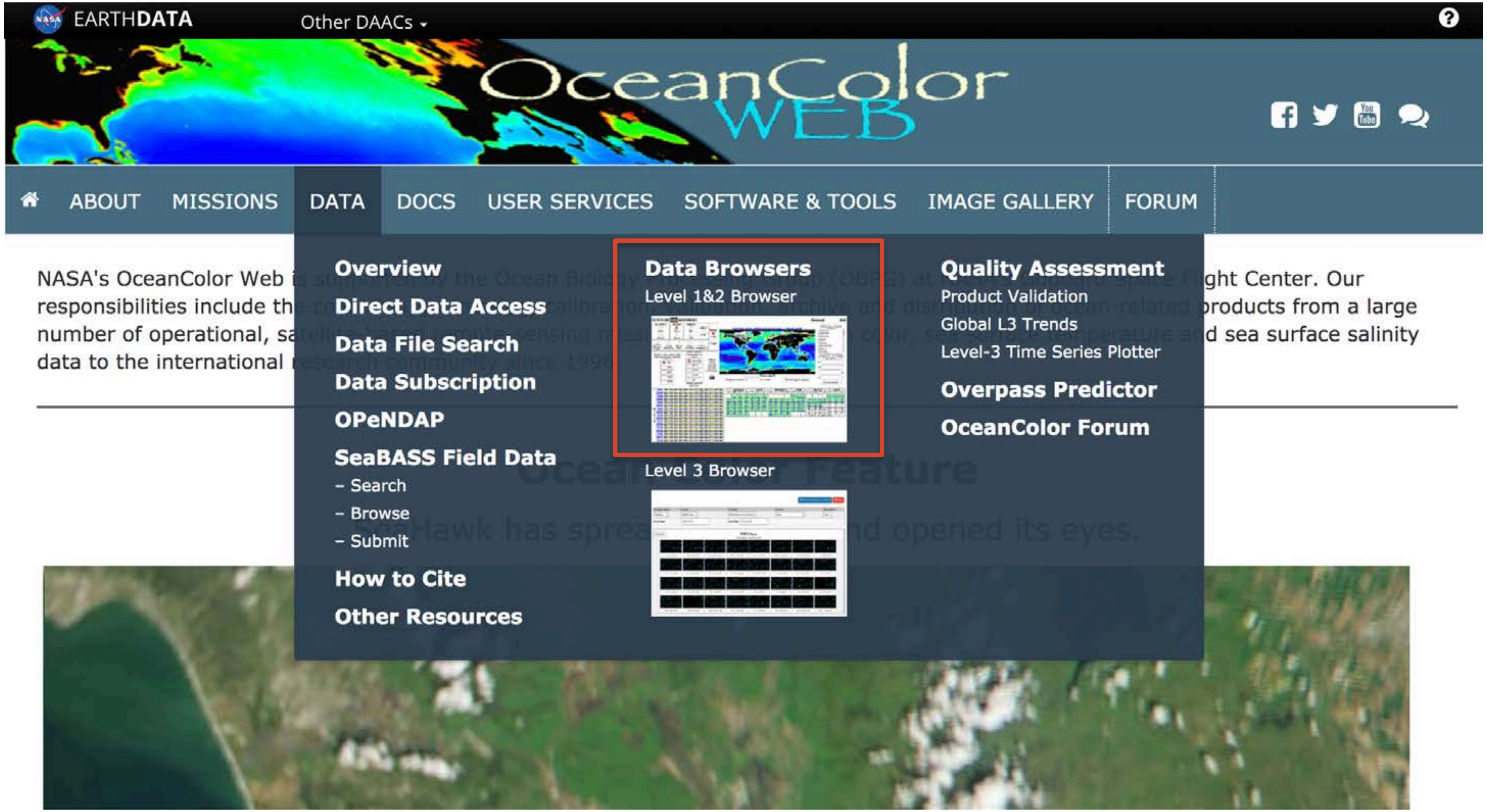
NASA OceanColor Web

https://oceancolor.gsfc.nasa.gov/



NASA OceanColor Web

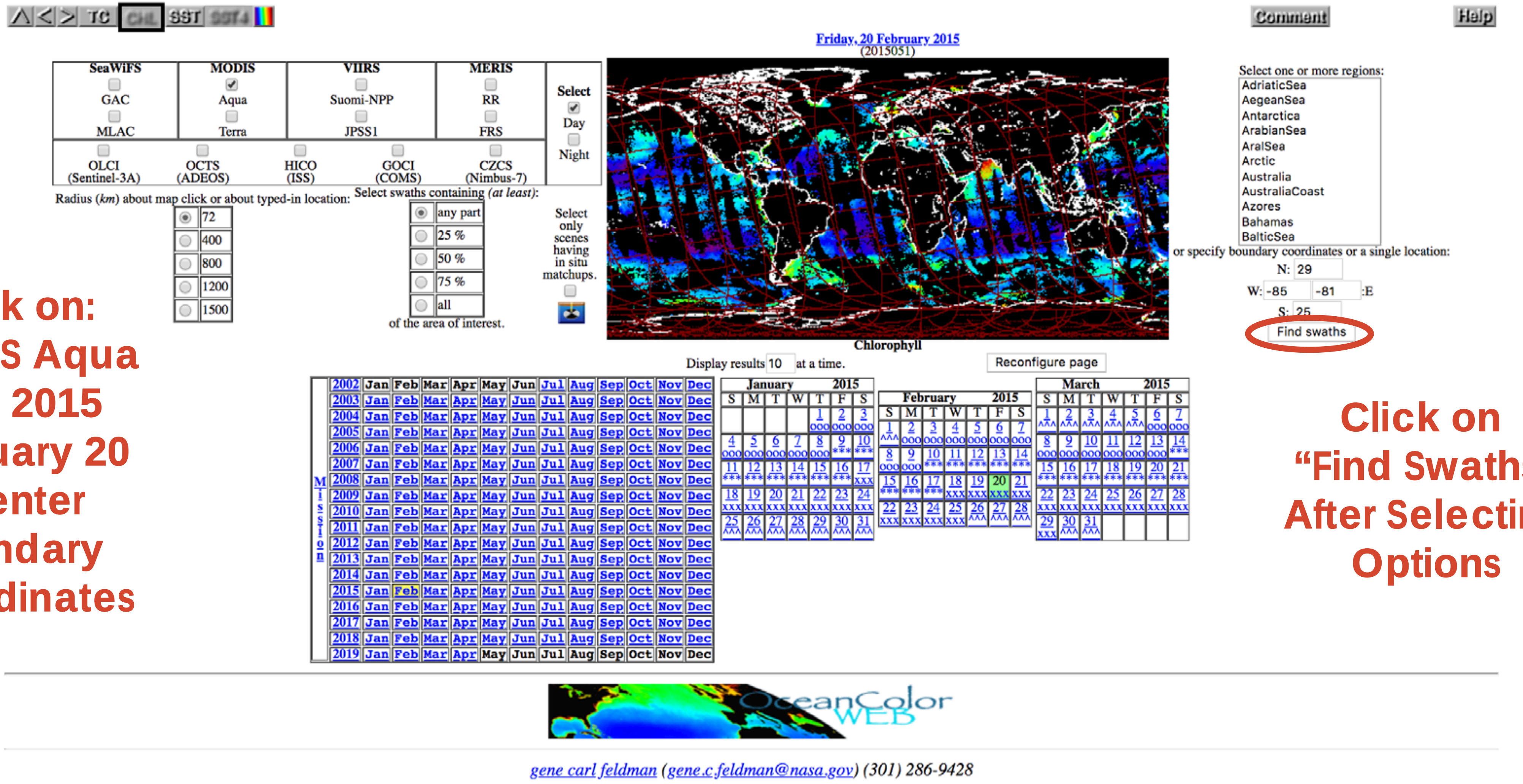
https://oceancolor.gsfc.nasa.gov/



NASA OBPG Level 1 & 2 Browser for MODIS Imagery

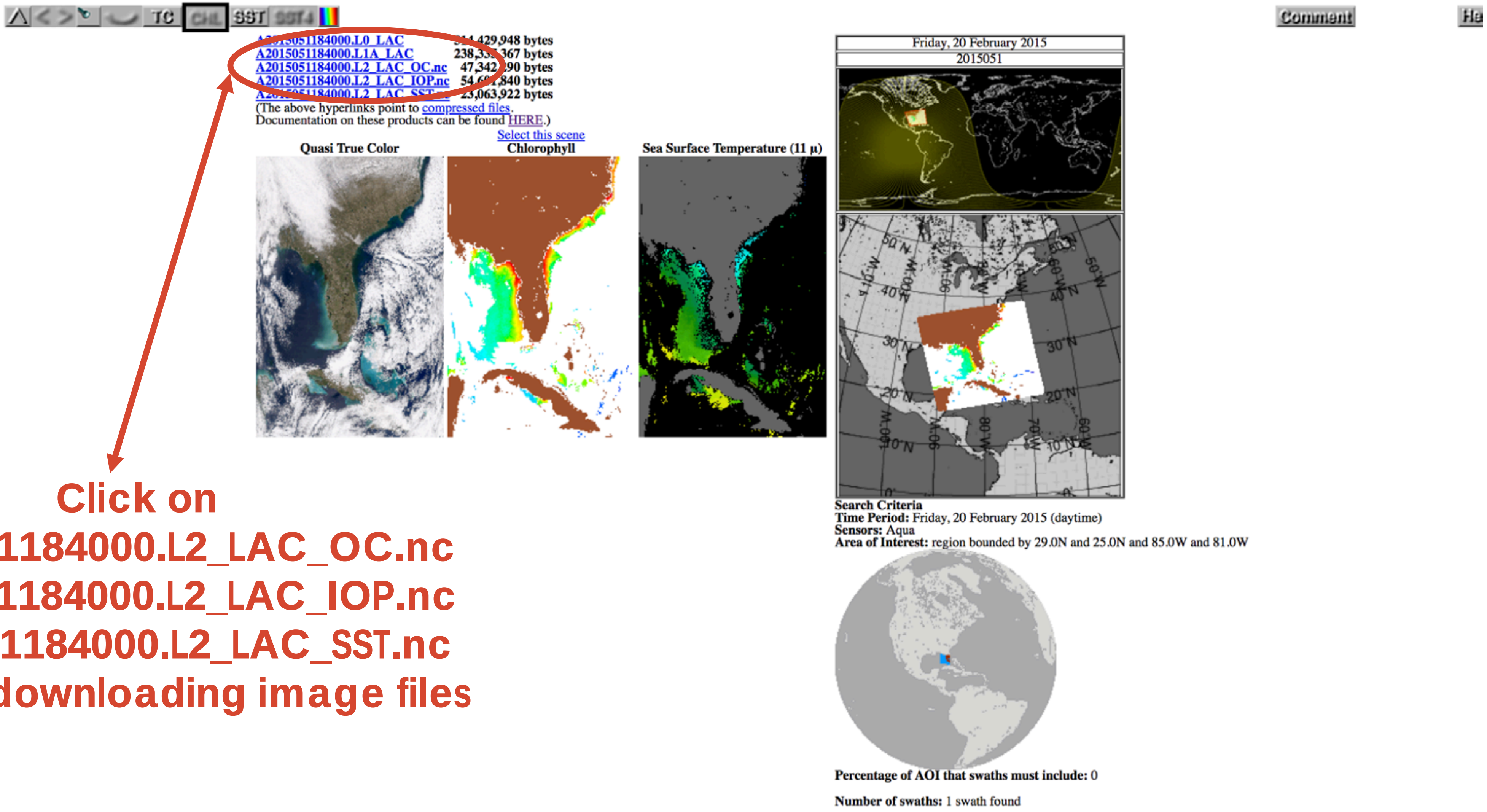
https://oceancolor.gsfc.nasa.gov/cgi/browse.pl?sen=am

Click on:
MODIS Aqua
Feb 2015
February 20
& enter
Boundary
Coordinates



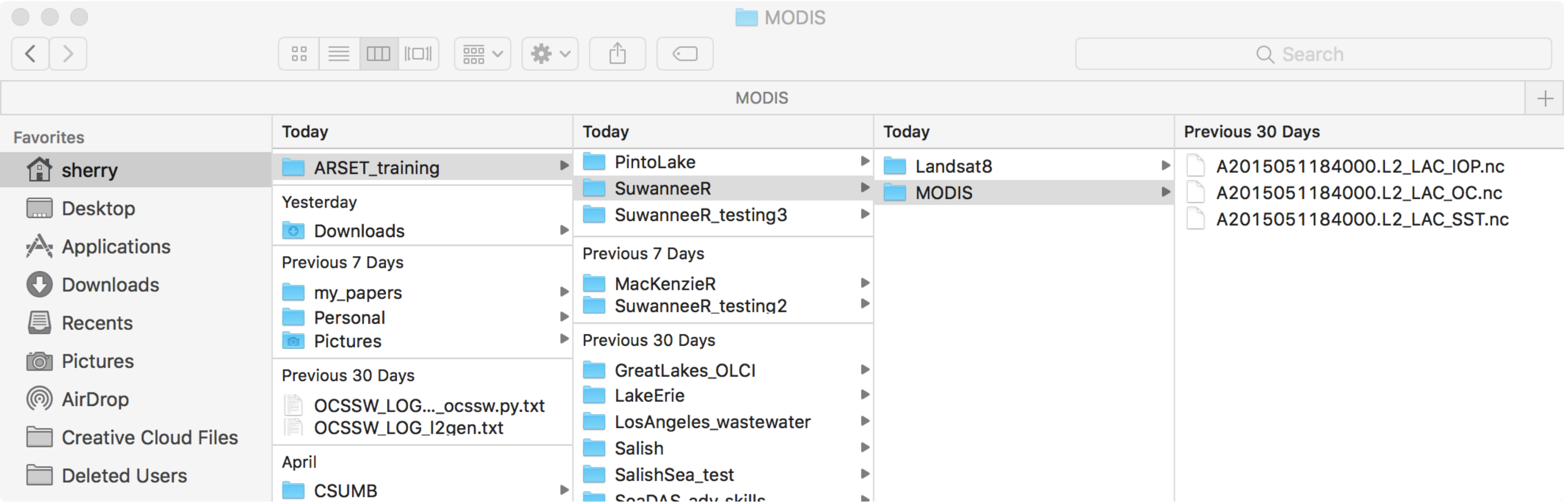
Click on
“Find Swaths”
After Selecting
Options

NASA OBPG Level 1 & 2 Browser Search Results



Click on
A2015051184000.L2_LAC_OC.nc
A2015051184000.L2_LAC_IOP.nc
A2015051184000.L2_LAC_SST.nc
to begin downloading image files

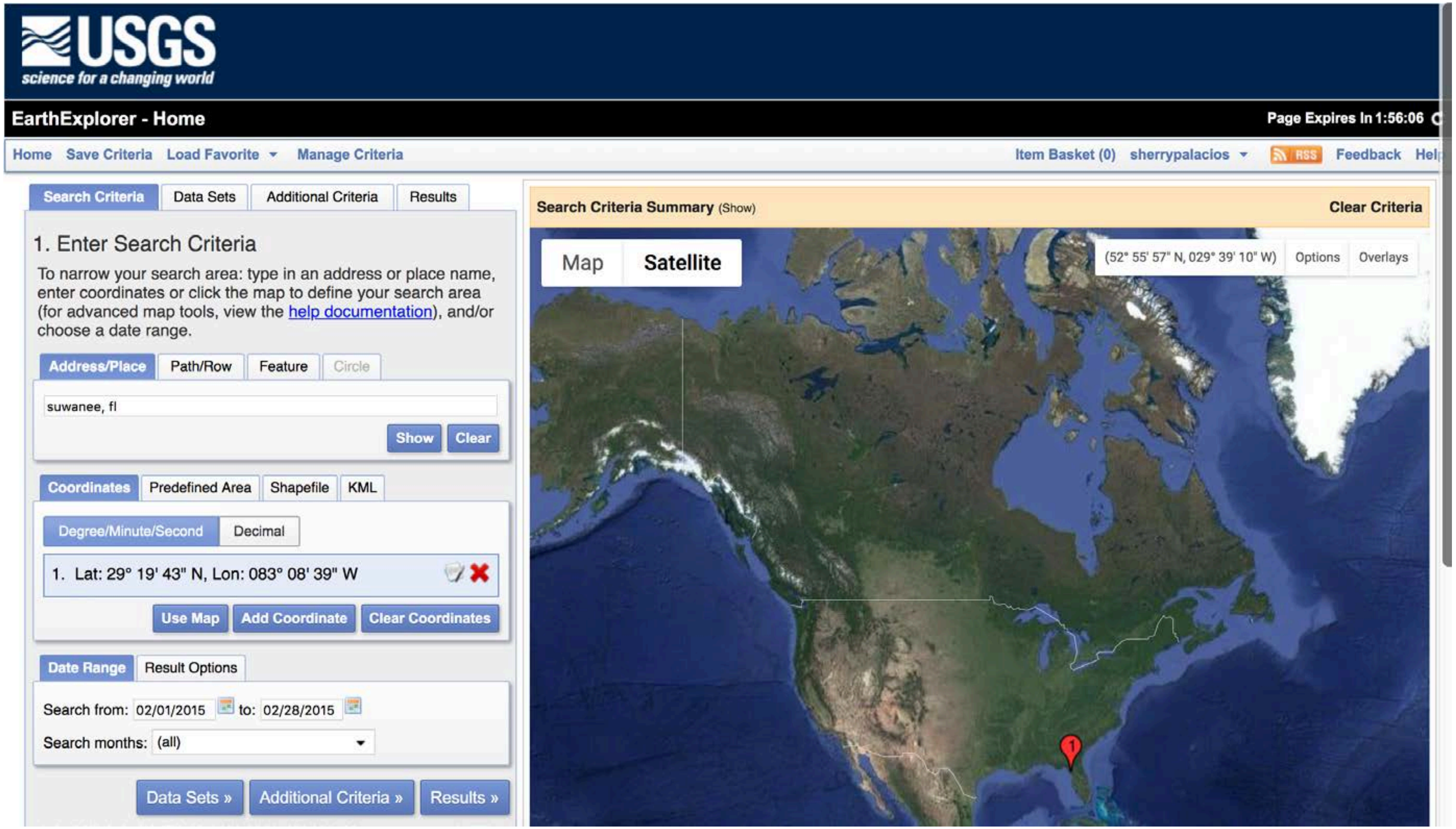
Save Files to a Meaningful Location



Find and Download the Landsat 8 OLI Imagery

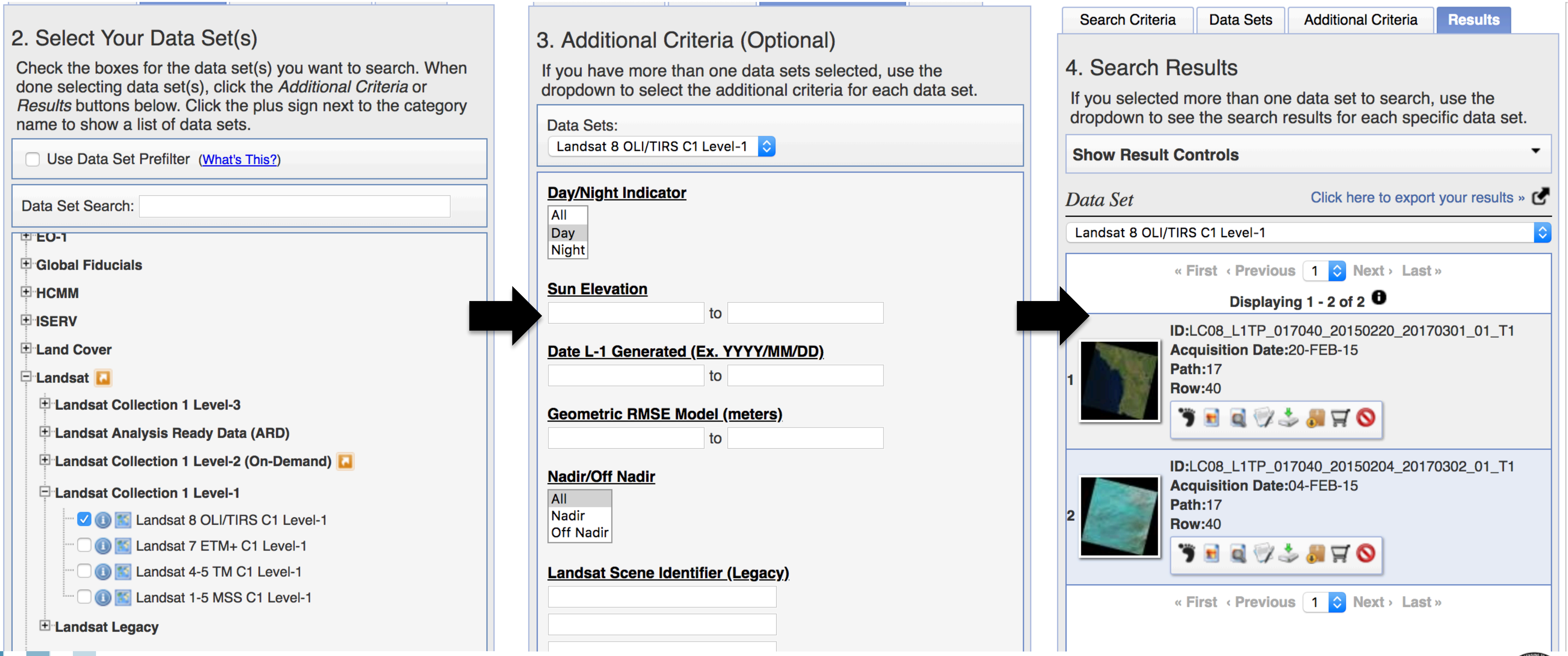
https://earthexplorer.usgs.gov/

Set up
a free
account
and
log in



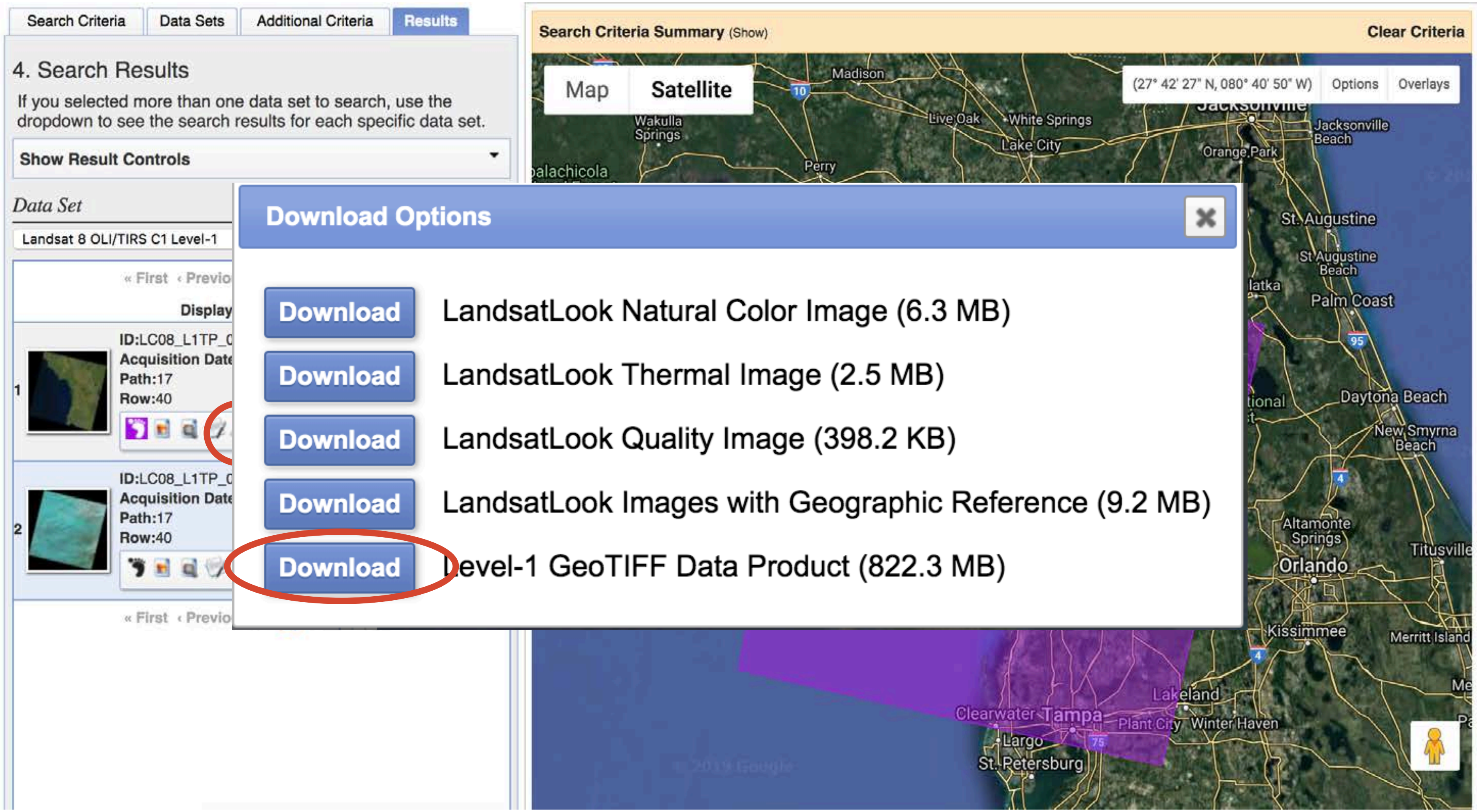
Find and Download Landsat 8 OLI Imagery

https://earthexplorer.usgs.gov/



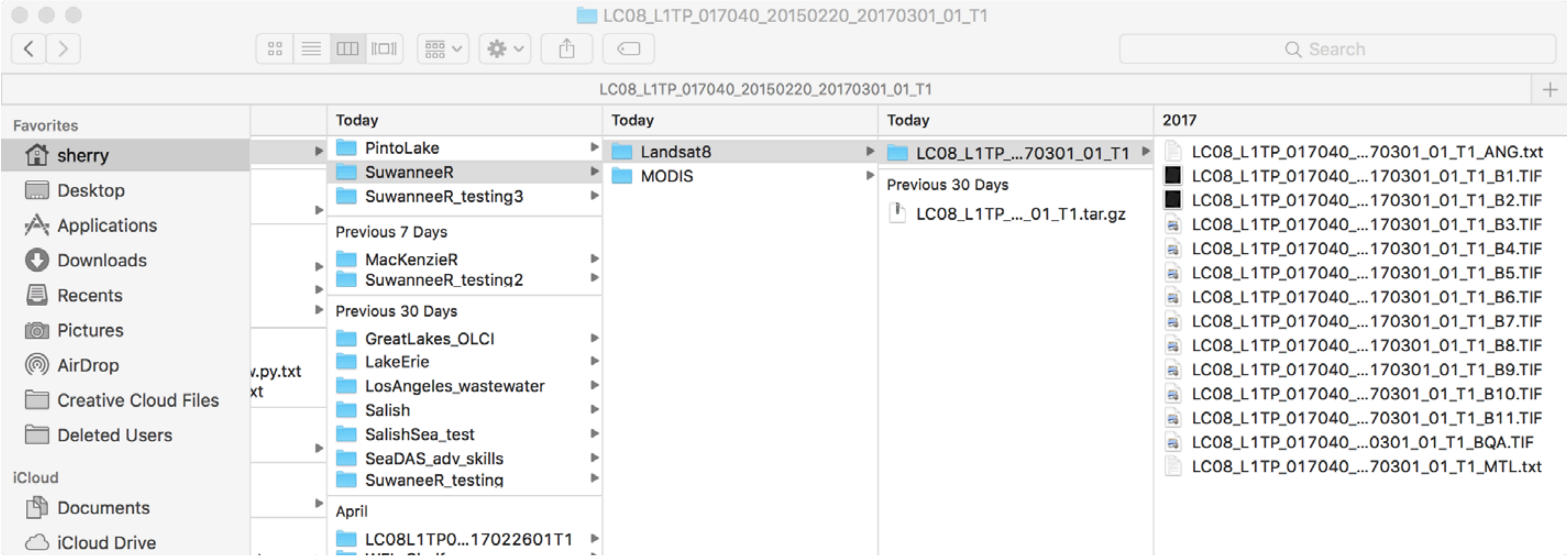
Find and Download Landsat 8 OLI Imagery

https://earthexplorer.usgs.gov/



Extract and Save Files to a Meaningful Location

(not too deep in your directory structure)



Exercise: Basic Skills in SeaDAS