National Aeronautics and Space Administration

Remote Sensing for Freshwater habitats

Amber McCullum & Juan Torres-Pérez

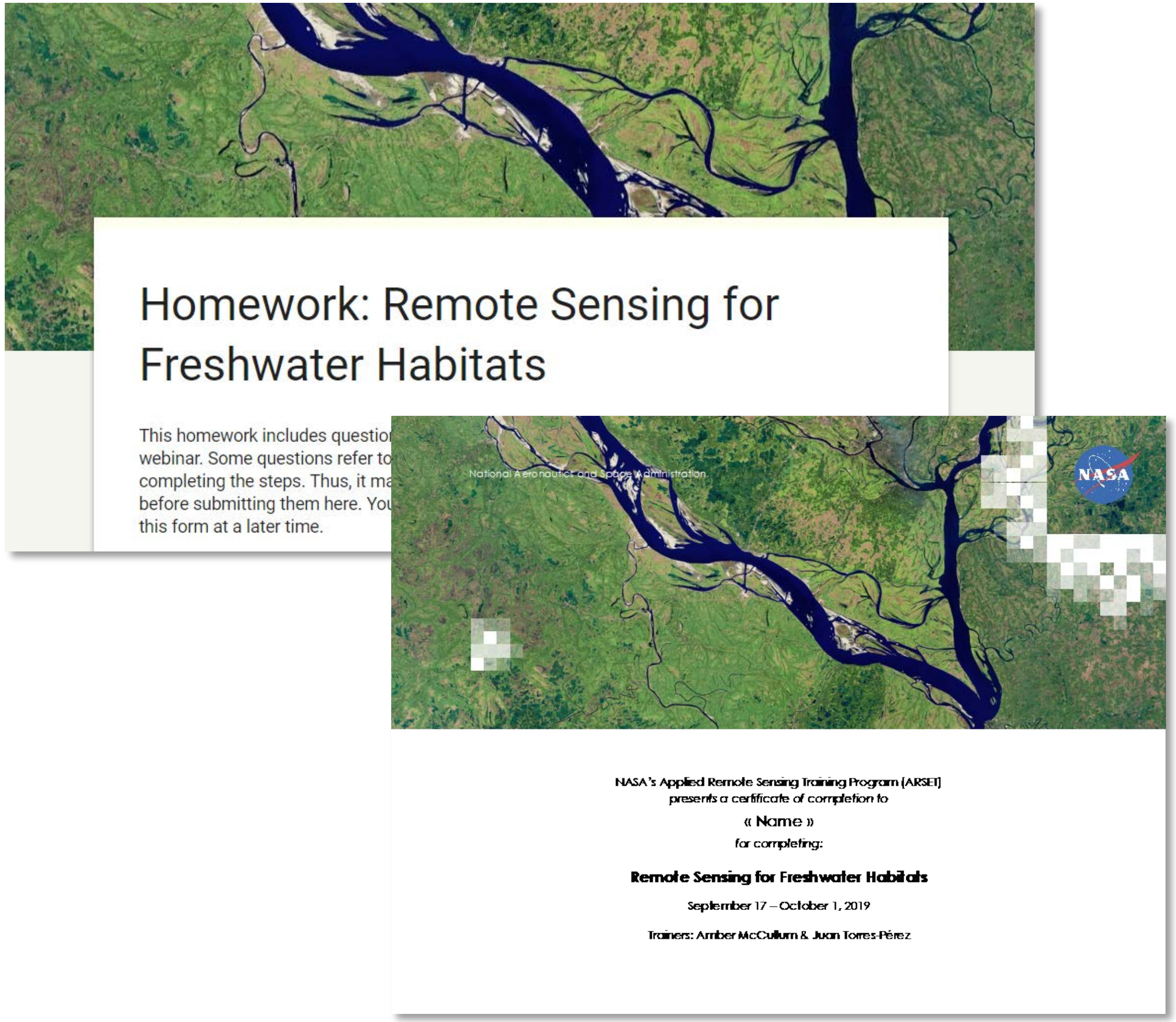
17 September – 1 October, 2019

Course Structure

- Three, 1-hour sessions on September 17, 24, and October 1
- The same content will be presented at two different times each day:
  - Session A: 10:00-11:00 EST (UTC-4)
  - Session B: 18:00-19:00 EST (UTC-4)
  - **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://arset.gsfc.nasa.gov/land/webinars/2019-freshwater**
- Q&A: Following each lecture and/or by email
  - amberjean.mccullum@nasa.gov
  - Or juan.l.torresperez@nasa.gov

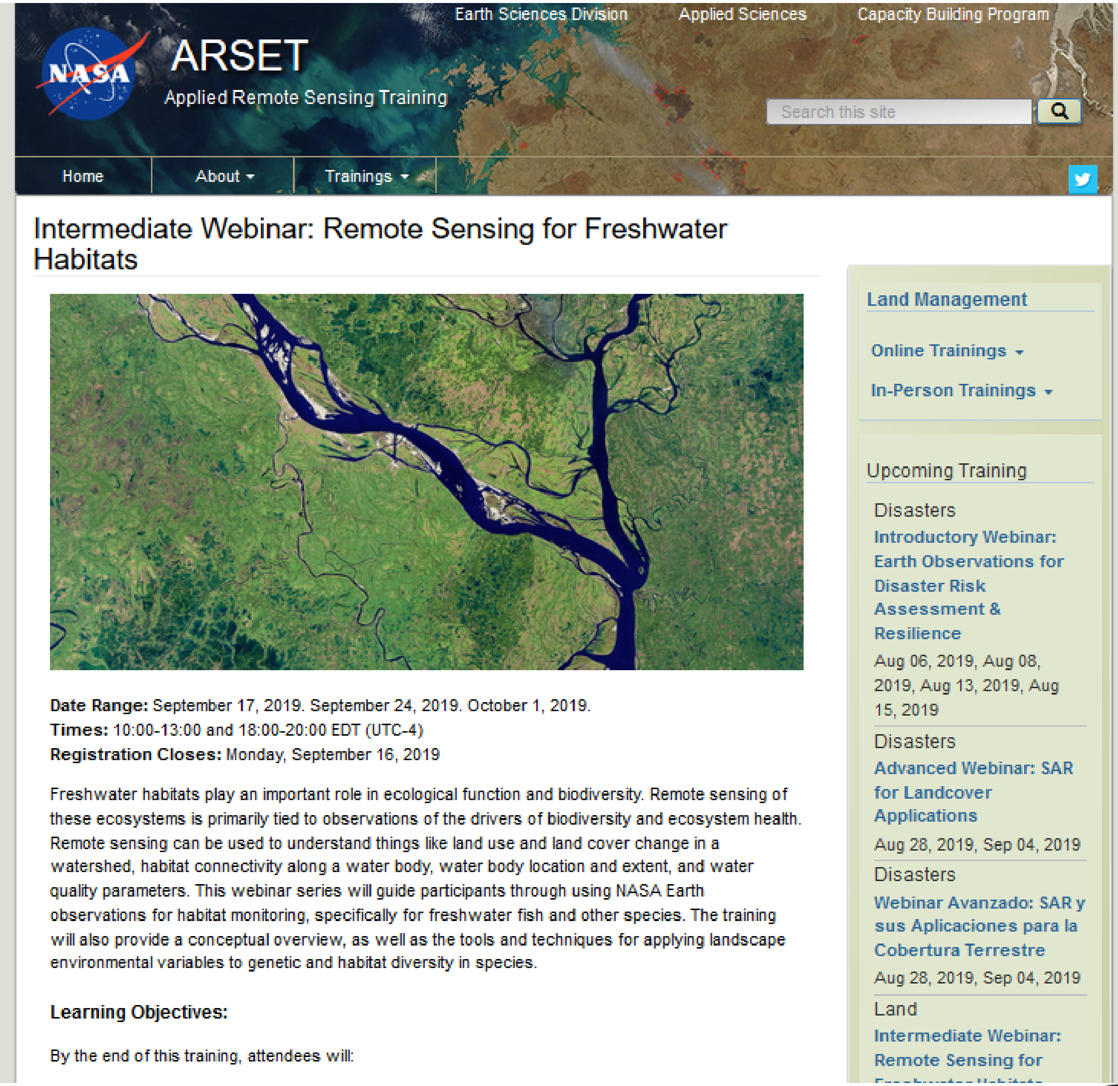
Homework and Certificates

- Homework
  - One homework assignment
  - Answers must be submitted via Google Forms
- Certificate of Completion:
  - Attend both live webinars
  - Complete the homework assignment by the deadline (access from ARSET website)
    - **HW Deadline: Tuesday Oct 15**
  - You will receive certificates approximately two months after the completion of the course from: marines.martins@ssaihq.com



Prerequisites and Course Materials

- Prerequisite
  - Please complete [Sessions 1 & 2A of Fundamentals of Remote Sensing](), or have equivalent experience
    - Attendees who do not have this knowledge may not follow the pace of the training
- Course Materials
  - Found here: [https://arset.gsfc.nasa.gov/land/webinars/2019-freshwater]()



NASA's Applied Remote Sensing Training Program (ARSET)

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

- Empowering the global community through remote sensing training
- Part of NASA's Applied Sciences Program
- 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

Topics for Trainings Include:

Course Outline

Session 1: Aquatic Remote Sensing

- Satellites and sensors
- Data limitations
- Combining multiple data types for freshwater habitat mapping
- Some case study examples

Session 2: Riverscape Analysis Project (RAP)

- Case studies
- RAP overview
- Data and analysis with RAP
- RAP demo

Session 3: Freshwater Health Index

- Freshwater health metrics overview
- FHI overview
- FHI demo

Session 1 Agenda

- Importance of freshwater systems
- Satellites and sensors for aquatic remote sensing
  - Advantages
  - Caveats/limitations
  - Combining multiple data types (in-situ, airborne, satellites)
- Case study examples
  - Lake Erie HAB Tracker
  - Riverscape Analysis Project (RAP)
  - Freshwater Health Index (FHI)

Image Credit: NASA Earth Observatory images by Joshua Stevens, using Landsat data from the U.S. Geological Survey

Why study inland waters?

- Provide water resources and food for millions of humans
- Habitat and ecosystem services
- Biodiversity and sustenance of thousands of species
- Important components of carbon and nutrient cycles
- Recreational value
- Mitigation of climate variability
- Irrigation
- Hydroelectric power
- Transportation corridors
- Flood control

Image Credit: myswitzerland.com

Factors That Affect Water Quality in Freshwater Ecosystems

- Climate-related
  - Extreme events (hurricanes, rainfall)
  - Temperature
  - Droughts
- Anthropogenic
  - Sedimentation
  - Eutrophication
  - Invasive/introduced species
  - Dumping of waste materials
    - Toxic waste
    - Organic
    - Inorganic

Image Credit: (Above) JL Torres-Pérez (NASA ARC). (Right) Tom Moore NOAA

Some Indicators for Evaluating Freshwater Ecosystems

- Ecosystem vitality – integrity and functioning of the ecosystem
  - Biodiversity
  - Water Quality/Quantity
  - Drainage Basin Condition
- Ecosystem Services – Resources or natural ecosystem processes that benefit humans. Also, benefits obtained from the regulation of ecosystem processes
  - Provisioning
  - Regulation and Support
  - Cultural/Social/Economical

Some Indicators for Evaluating Freshwater Ecosystems

Ecosystem Vitality

Major Indicator	Sub-Indicator	Local Datasets/Models	Global/Regional Datasets/Models
Water Quantity	Deviation from natural flow	River gauges, hydrological models [SWAT (USDA); GSFLOW (USGS)]	Global hydrological models [WaterGAP, etc]
	Groundwater storage	Monitoring wells	GRACE data
Water Quality	Water Quality Index (from TSS, TN, TP, etc)	Local stations, water quality models	Products ([Chl a], CDOM, TSS) derived from satellite imagery

Modified from: Freshwater Health Index

Some Indicators for Evaluating Freshwater Ecosystems

Ecosystem Vitality

Major Indicator	Sub-Indicator	Local Datasets/Models	Global/Regional Datasets/Models
Drainage Basin Condition	Extent of channel modification	Aerial photography, government agencies database	High resolution satellite imagery (Landsat, Sentinel); GRanD (Global Reservoir and Dam) database
	Land cover naturalness	Aerial photography; local surveys	Satellite products (MODIS, Landsat); Global Forest Change database; ESA Climate Change Initiative (CCI) land cover products
Biodiversity	Changes in number/size of particular species populations	Local surveys; citizen science	IUCN Red List, Endangered Species Act, Global Population Dynamics database, Global Invasive Species database

Modified from: Freshwater Health Index

Some Indicators for Evaluating Freshwater Ecosystems

Ecosystem Services

Major Indicator	Sub-Indicator	Local Datasets / Models	Global / Regional Datasets / Models
Provisioning	Water supply reliability	Local government regulations; water evaluation and planning (WEAP) model	Global hydrologic/land surface models; soil moisture and evapotranspiration models
	Biomass for consumption	Local data	Global carbon models Upcoming ESA Earth Explorer Biomass satellite (expected launch date: 2021)

Modified from: Freshwater Health Index

Some Indicators for Evaluating Freshwater Ecosystems

Ecosystem Services

Major Indicator	Sub-Indicator	Local Datasets/Models	Global/Regional Datasets/Models
Regulation & Support	Sediment regulation	Hydrological models, ecosystem services models (InVEST, etc)	High res imagery (Landsat, Sentinel), SAR surveys
	Water quality regulation	Local monitoring stations	Products ([Chl a], CDOM, TSS) derived from satellite imagery
	Flood regulation	Hydrological and hydraulic models	NRT Global Flood mapping, global flood risk models
	Disease regulation	Local monitoring	Global Infectious Disease and Epidemiology Network (GIDEON)
Cultural	Conservation / Cultural Heritage sites	Local government regulations	World Database on Protected Areas
	Recreation	Local surveys; aerial photography	Social media sites

Modified from: Freshwater Health Index

Using Earth Observations for Studying Freshwater Systems

Satellite Missions Available 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)

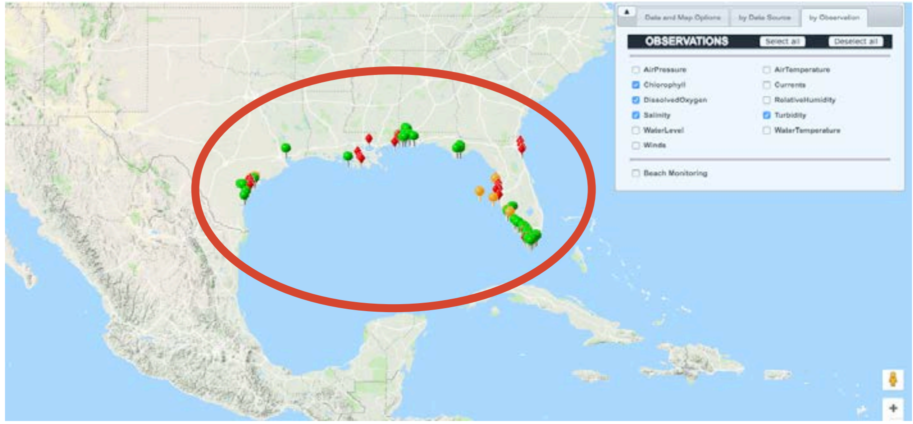
Satellites and Sensors for Monitoring Water Quality

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

Advantages of Satellite Observations

- Available for large regions
  - only source of global information for some parameters
- Long time series and data continuity
  - tracks progress
  - establishes baselines and trends
- Consistency and comparability
  - among multiple countries
- Diversity of measurements
  - many different physical parameters
- Complements traditional statistical methods
  - cross-check with in situ data
- Mostly free and open access

Limited Water Sampling Locations



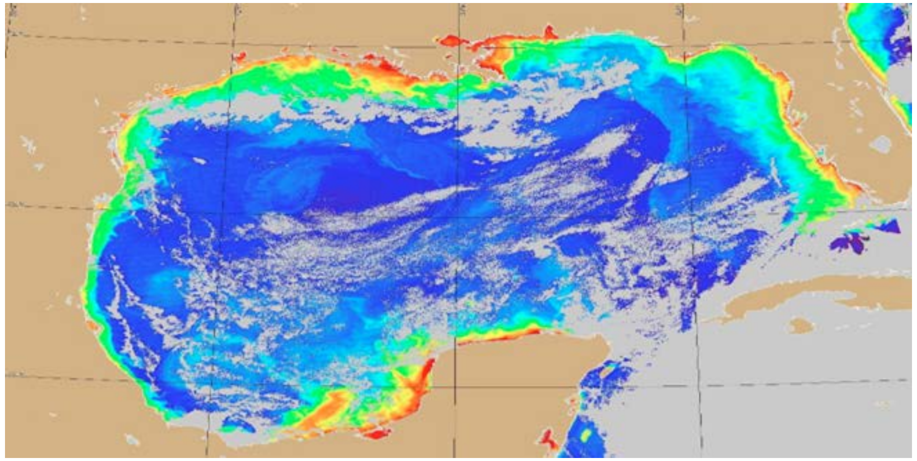


Image Credit (top) http://data.gcoos.org; (bottom) 2013 MODIS Aqua image showing elevated chlorophyll-a levels

Moderate Spatial Resolution and Characterizing Riverine Basins

- Landsat data (30 m) – classify open water and vegetated areas to delineate main and side channels of river flow [1,2]
- Combined with DEM data – extract drainage channels and floodplains
  - Disasters – Study river flood events
  - Ecology – Predict the importance of landscape features on ecologically and economically important fish species such as salmon (i.e., Riverscape Analysis Project (RAP))

Landsat 5 TM images showing the Great Mississippi Flood of 1993 (Images: GSFC)

See final slide for references

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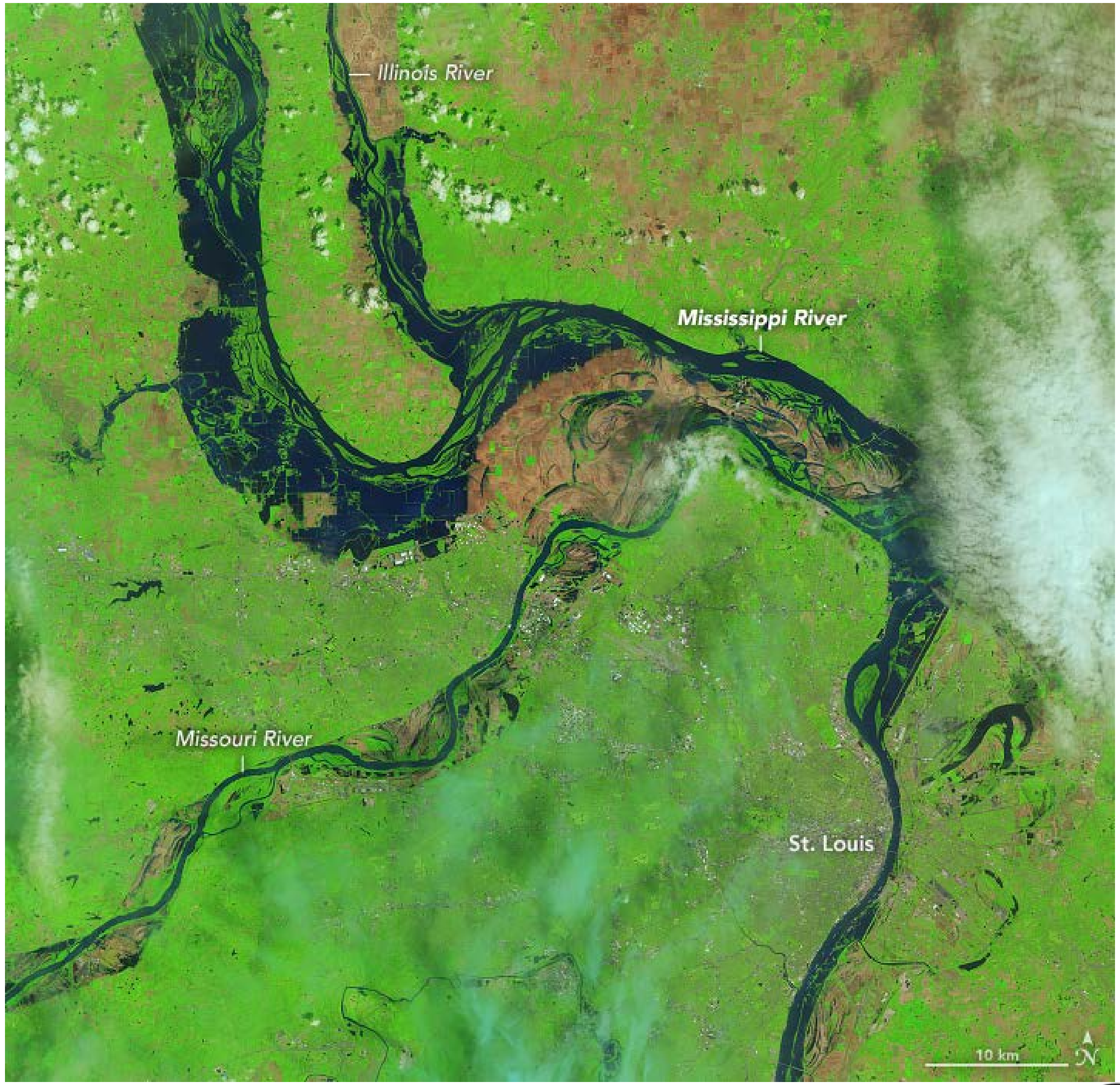
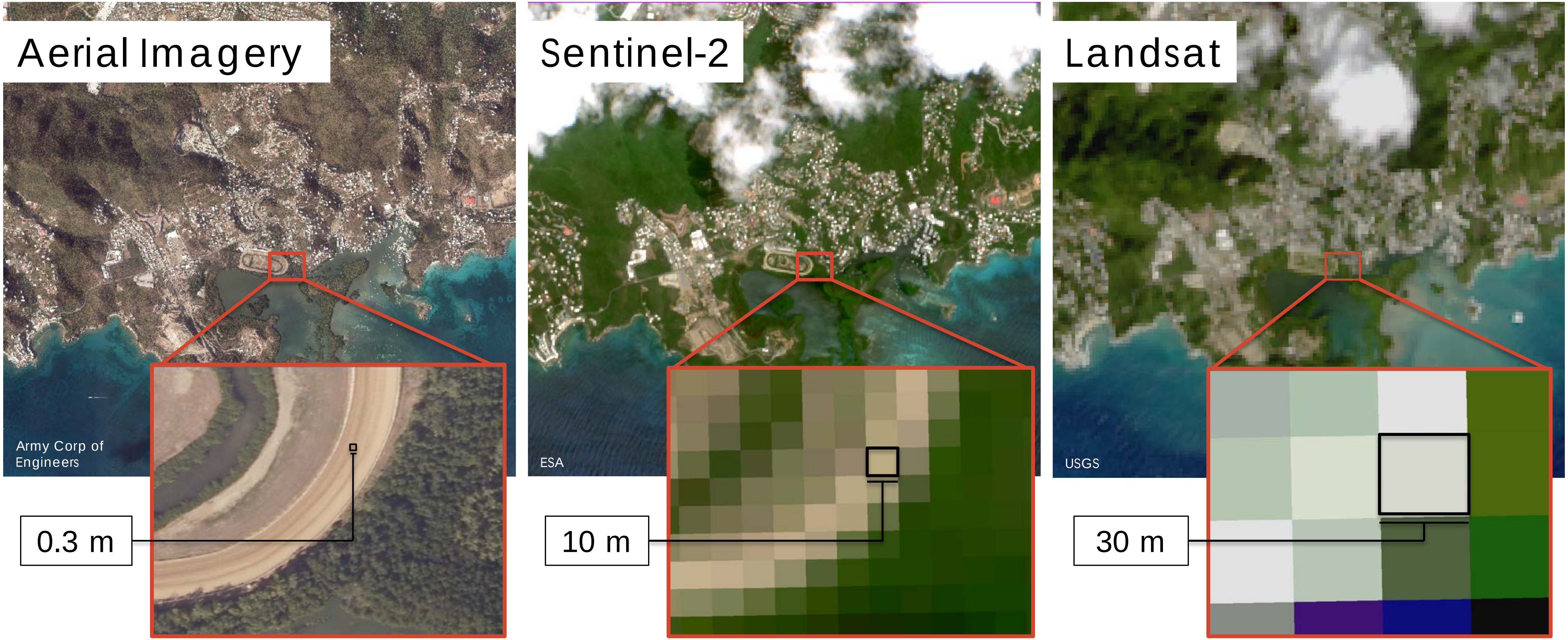


Landsat 8 (OLI) Image of Mississippi River Flooding (6/5/2018 compared to 5/7/2019)
See last slide for references

Limitations of Using Satellite Imagery



Courtesy of NASA DEVELOP

Limitations of Using Satellite Imagery

- Even Landsat (30 m) resolution might be too coarse for narrow rivers or creek systems
- May need even higher spatial resolution from either airborne (or drone) platforms (cm-m scale) or commercial satellites (Digital Globe, Planet, etc.) that have a spatial resolution of <5 m
- Information on pixels close to river borders might be "contaminated" with information from land
- Cloud cover

Region of Paysandú (Uruguay River)
Left: Planet's Digital Scope (4 m)
Above: Landsat (30 m)

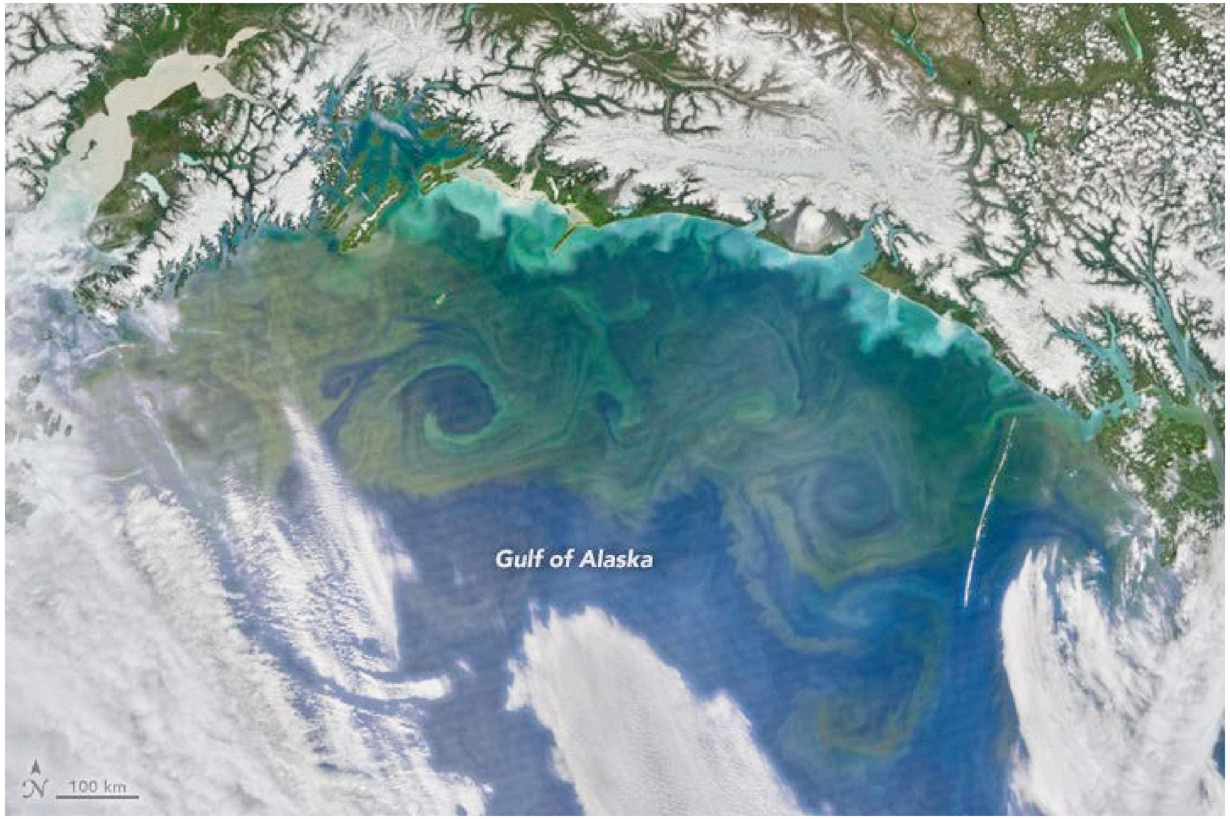
Considerations at the Time of Choosing Satellite Data

- Temporal resolution of data acquisition – Daily? Monthly?
- Spatial Resolution – depends on the satellite: meters to km
- Spectral Resolution – multispectral vs. hyperspectral
  – Where in the electromagnetic spectrum are the satellite bands? Visible, IR, SWIR
- Longevity of the Satellite Mission
  – Landsat has the longest record of satellite data (since 1970's)
- Geographical and Atmospheric Conditions at the Study Site
  – Tropical zones typically have more cloud cover year round
- Is the data freely available, or is there a cost associated with data acquisition?
- Are there any future missions being planned?
  – Surface Biology and Geology (SBG)
  – Plankton, Aerosol, Cloud, ocean Ecosystem (PACE)

Water Quality Indicators Observable from Satellites

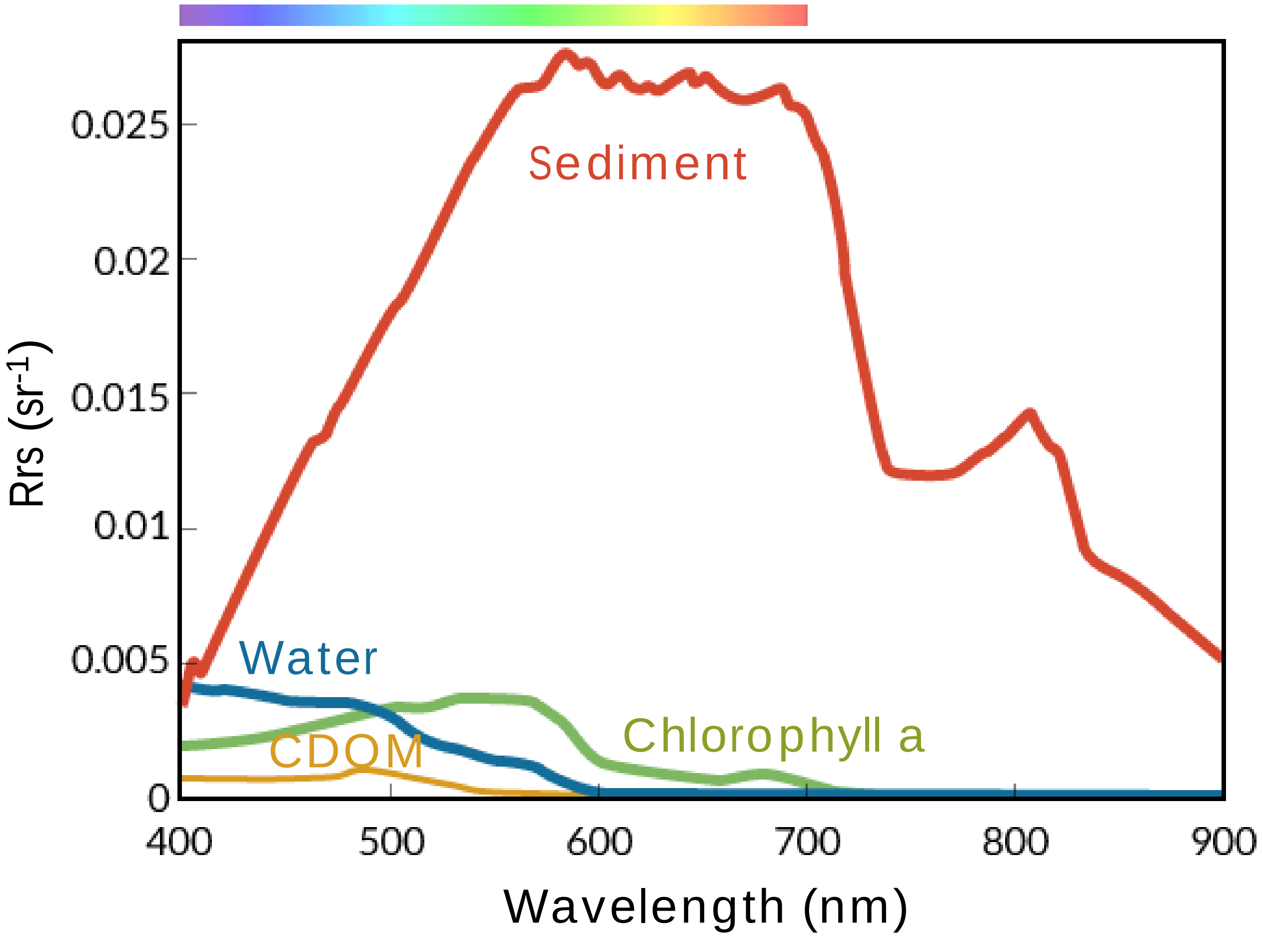
- Colored Dissolved Organic Matter (CDOM)
- Sea Surface Temperature (SST)
- Chlorophyll-a (phytoplankton)
- Salinity
- TSS (Total Suspended Solids) or Total Suspended Matter (TSM)
- Fluorescence Line Height
- Euphotic Depth

Phytoplankton Bloom in the Gulf of Alaska
SNPP-VIIRS June 9, 2016



In Situ Data Collection for Characterizing Water Bodies

- Water samples
  - Chl a
  - TSS/TSM
- Spectral
- Optical properties
  - Inherent Optical Properties (IOP)
  - Apparent Optical Properties(AOP)

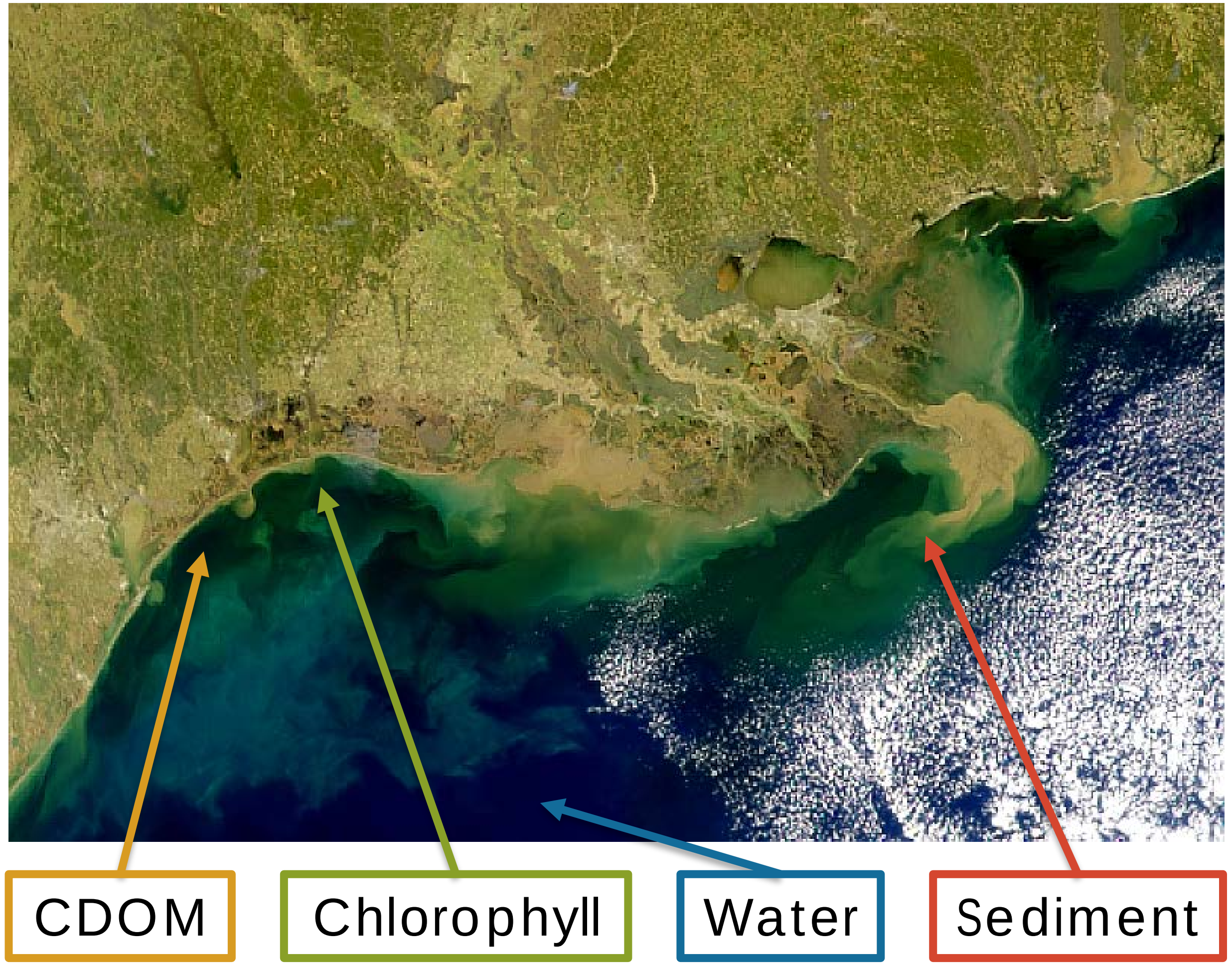


Inherent Optical Properties (IOPs) and the 'Color' of Water

Light absorption (a) by photoplankton (ph), sediment (s), water (w), and colored dissolved organic matter (CDOM)

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

Light scattering (b) by particles in forward (b_f) and backward (b_b) direction $b = b_f + b_b$



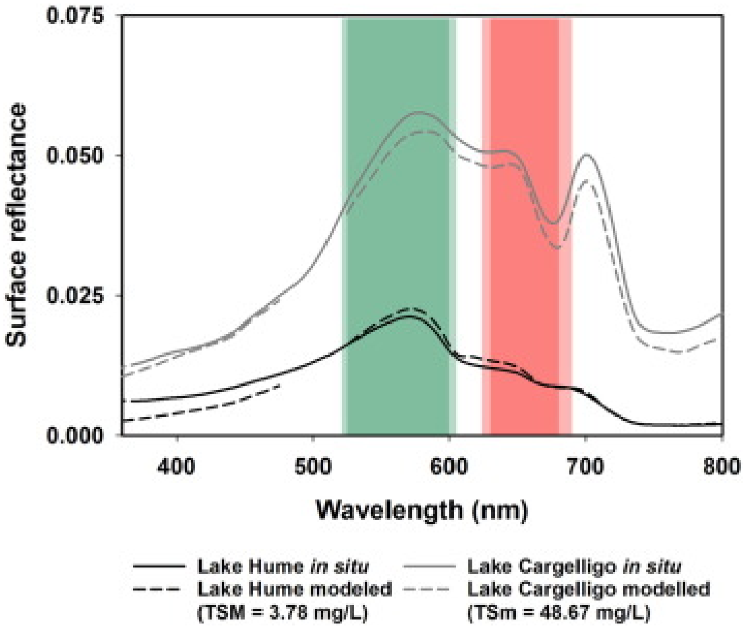
Some Focus Areas of Remote Sensing of Freshwater Systems in the Last Decade

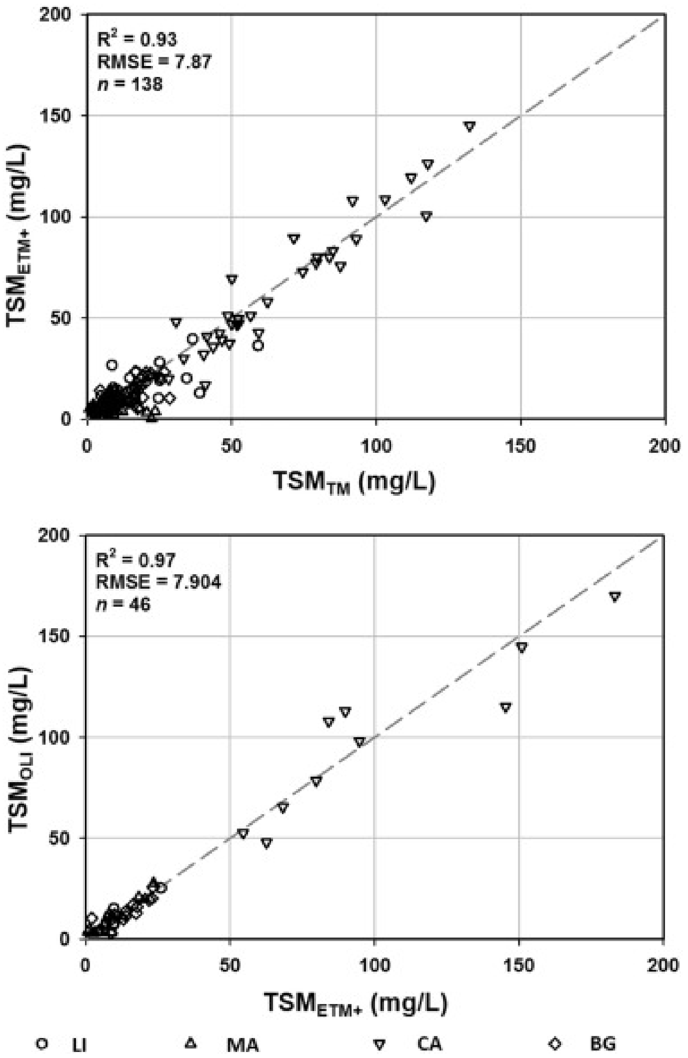
Focus Area	Sensor Type
Depth (and error) algorithms [3, 4]	Active (LiDAR)
Streambed or sediment size mapping [5, 6]	Passive (digital cameras)
Water surface extent and elevation [7]	Active (LiDAR)
Temporal and spatial variation in floodplain channels and water surface heights [8]	Active (SAR)
Bathymetry; water column characteristics [9, 10, 11]	Passive (Hyperspectral)
River complexity, fish habitat [1, 2]	Passive (Landsat)
Movement of fluvial debris [12]	Passive (drone)
Water quality (CDOM; Chl a; HABs) [13, 14, 15, 16]	Passive (Multispectral, Hyperspectral)
Estimation of water storage [17]	Passive (MODIS)
Submerged aquatic vegetation]18]	Passive (Hyperspectral)

See last slide for references

Progress on the Use of Several Sensor/Satellite Systems to Study Inland Waters

- Since the 1980's researchers have used Landsat to retrieve information from lakes:
  - Chl a and depth [19]
  - Total Suspended Matter – TSM [20]
  - Water transparency [21]
  - Cyanobacterial blooms [22]
  - CDOM [23, 16]

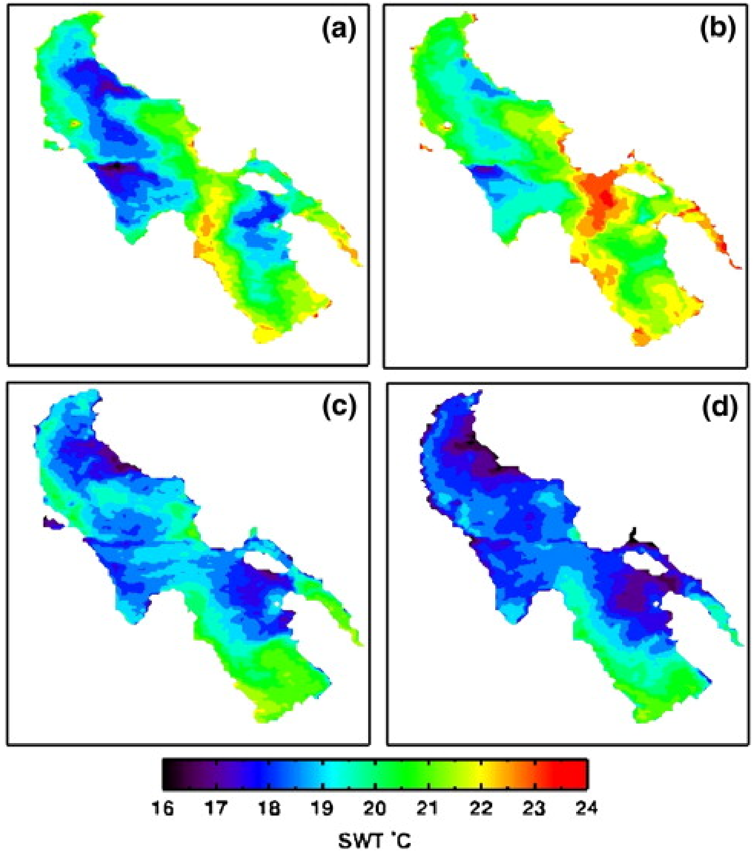




2015 – Special issue of RSE dedicated to remote sensing of inland waters – highly recommended!
https://www.sciencedirect.com/journal/remote-sensing-of-environment/vol/157

See last slide for references

Progress on the Use of Several Sensor/Satellite Systems to Study Inland Waters



MODIS-derived water surface temperature Great Salt Lake (UT)

- Other ocean color-intended sensors have been applied to lakes:
  - Coastal Zone Color Scanner (CZCS)
    - Chl a [24] and upwelling zones [25]
  - Sea-Viewing Wide Field-of-View Sensor (SeaWiFS)
    - Water clarity, Chl a [26, 27]; Dissolved Organic Carbon, suspended matter [28]
  - Moderate Resolution Imaging Spectroradiometer (MODIS)
    - Chl a [29]; TSM, turbidity [30, 31]; surface water temperature [32, 33]
  - MEdium Resolution Imaging Spectrometer (MERIS-ESA)
    - cyanoHABs [34]

Image Credit: Crosman and Horel (2009) RSE; See last slide for references

CDOM Detection

- Colored Dissolved Organic Matter (CDOM) is the optically-active part of dissolved organic matter (DOM)
  - CDOM – also known as yellow substance, chromophoric dissolved organic matter, humic color, and gelbstoff [35]
  - Occurs naturally, but can increased due to runoff, sewage discharges
  - Also as a result of extreme weather events (hurricanes)

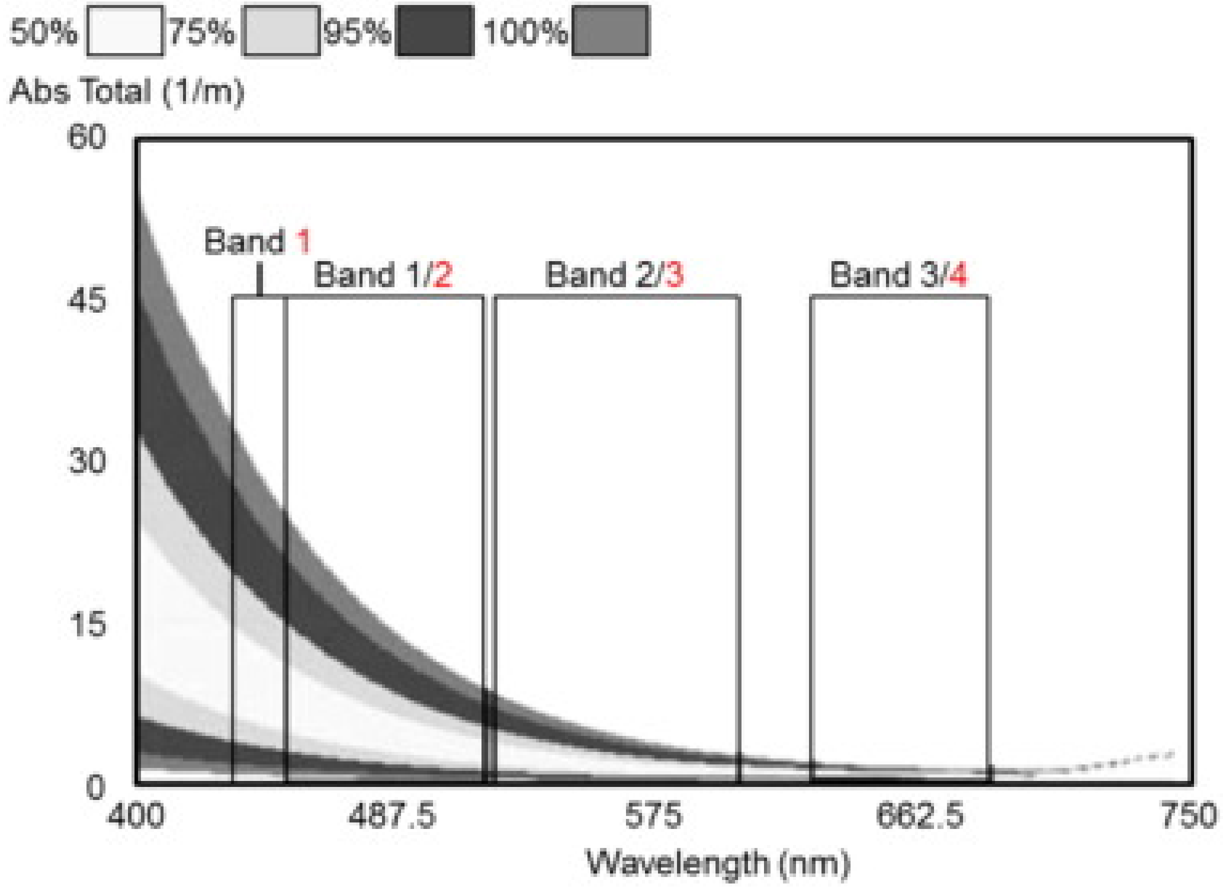


Image Credit: Slonecker et al 2016; See last slide for references

CDOM Detection

- DOM (and CDOM) results from decomposition of detritus and other organic materials
- Reduces light availability in the water column particularly in the blue region – affects photosynthesis
- Typically, bands combinations in the ~440 nm and >600 nm are used to quantify CDOM
  - The new “Coastal” band in L8 (Band 1) has proven to be very useful for CDOM detection

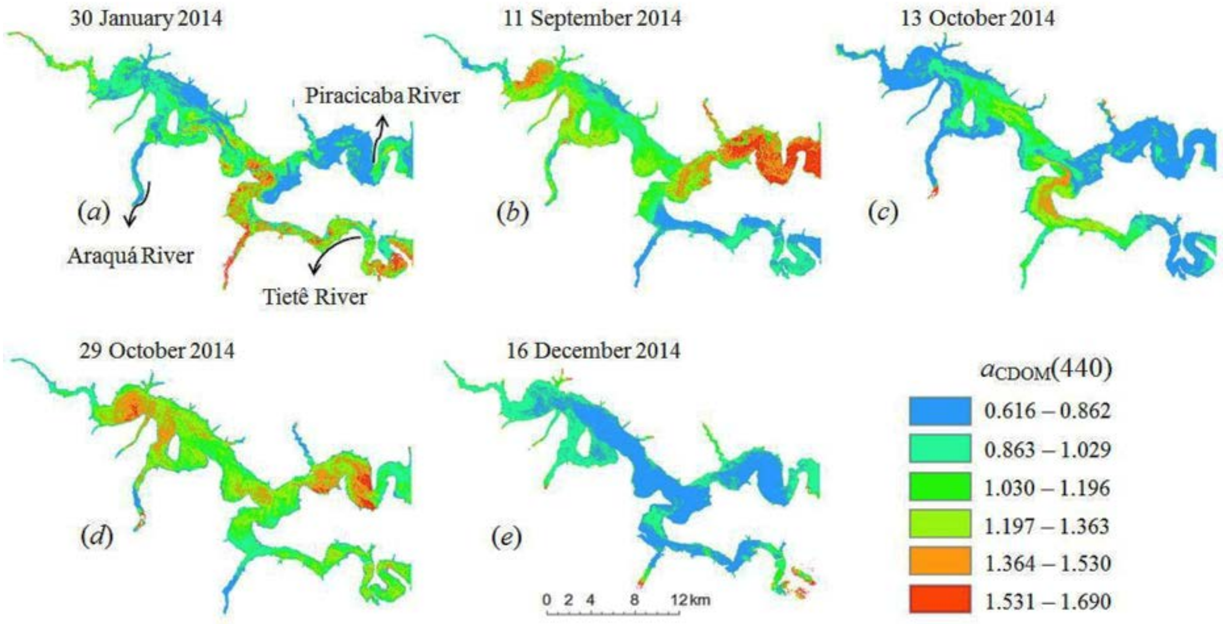
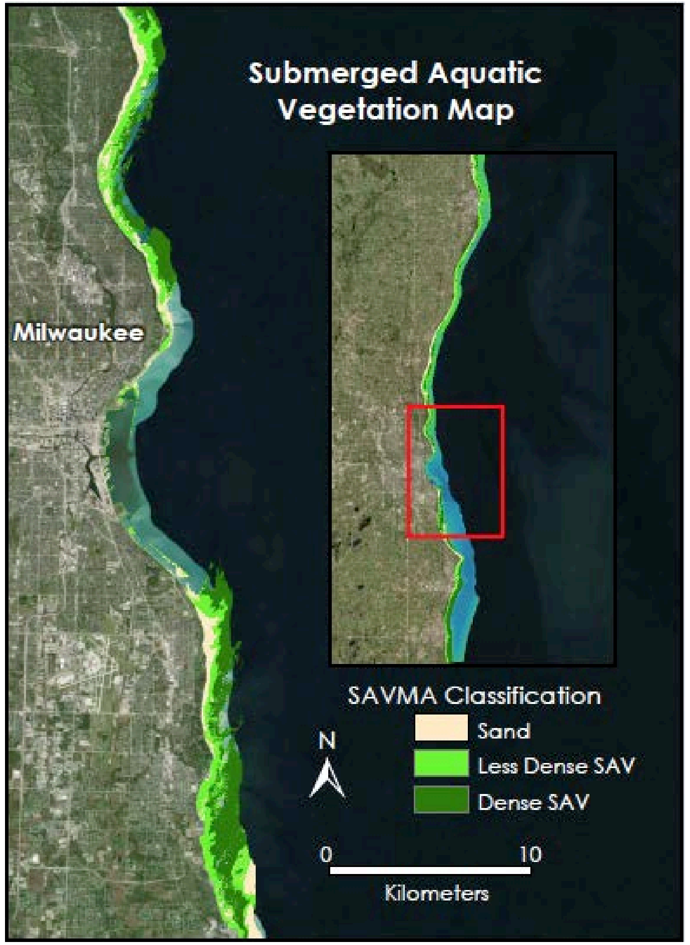


Image Credit: Alcantara and Bernardo (2016) AGU presentation. Downloaded from: landsat.gsfc.nasa.gov

SAV Detection in Freshwater Systems

- Brooks et al (2015) used the Landsat time-series to study the nuisance Cladophora on the Great Lakes
- A similar project was conducted at NASA DEVELOP to detect and map the displacement of Cladophora in Lake Michigan using Landsat 8 and MODIS data
- Off-the-shelf UAVs and digital cameras for Cladophora detection in rivers [36]
- Hypespectral data has also been used to quantify and map SAV in Italy [37]



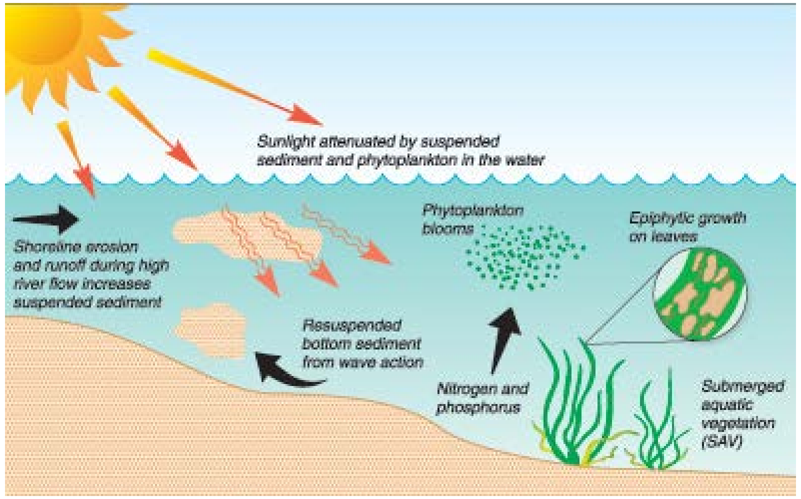


Image Credit: (Left) Lake Michigan *Cladophora* detection, NASA DEVELOP. (Top Right) USGS. (Bottom Right) *Cladophora* lining the shore of Lake Michigan, Credit: Ashley Spoljaric, USGS.

Chlorophyll and accessory pigments retrieval in inland waters

- One of the 1st attempts to retrieve accessory pigments (and PFT's) from airborne data was in lakes [38]
- Recently, hyperspectral airborne data has been used for phycocyanin (cyanoHABs) detection in lakes [39, 40, 15]

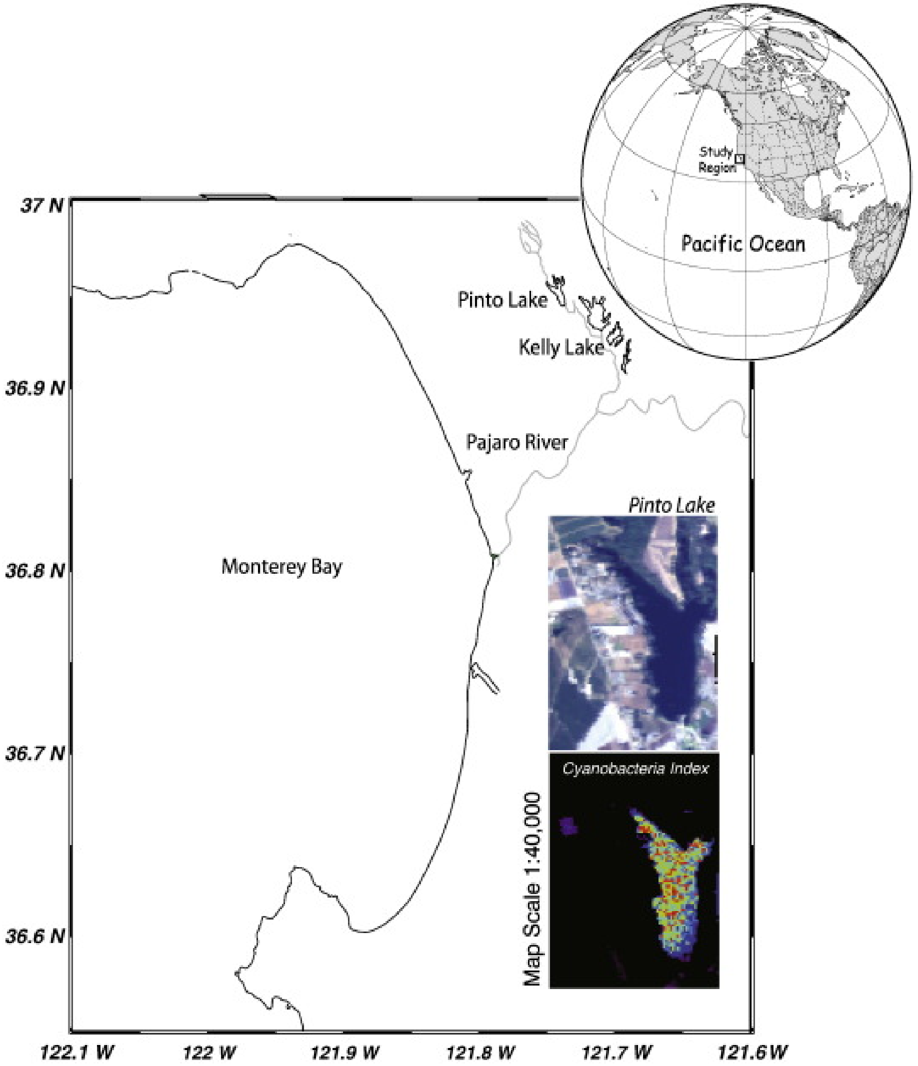


Image Credits: (Left) Algal bloom in Lake Erie; (Right) Kudela et al (2015) RSE ; Refer to last slide for references

Bathymetry Estimations in Shallow Water Riverine Systems

- In clear shallow waters, the upwelling spectral radiance ($L_T\lambda$) depends mostly on the bottom-reflected radiance ($L_b\lambda$) and the absorption of pure water
- Legleiter et al 2009 – Optimal Band Ratio Analysis (OBRA) for bathymetry estimations in clear shallow rivers
  - Uses a 2-band ratio (586/614nm)
  - Based on Hydrolight simulations and field spectroscopy

Image Credit: NPS

Bathymetry Estimations in Shallow Water Riverine Systems

- In eutrophic systems the water column constituents (CDOM, sediments, Chl a) may make the bottom contribution negligible
- Pan et al (2015) – support vector regression (SVR) as an alternate method for clear and turbid waters as it uses the information in the whole spectrum and not just two bands

Image Credit: Sediment plume of the Río Grande de Manatí (PR) after a rain event. Photo: JL Torres-Pérez

Some Examples for Water Quality in Freshwater Ecosystems

Lake Erie HAB Tracker

https://www.glerl.noaa.gov/res/HABs_and_Hypoxia/habTracker.html

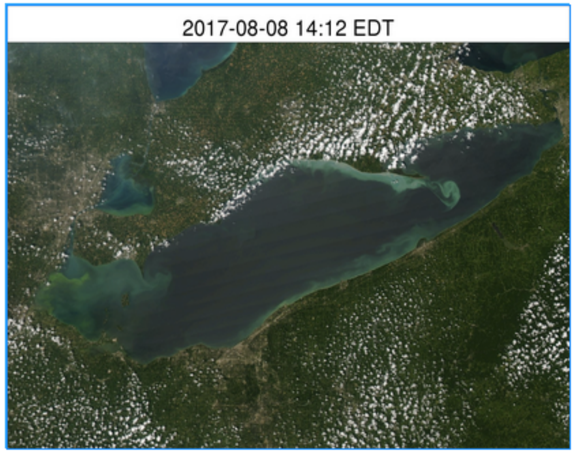
- A forecast model that uses MODIS data
- Incorporates weather and modeled water currents data
- Also, in situ water quality data
- Produces near real-time and 5-day HAB forecasts for cyanoHABs detection

Image Credits: NOAA GLERL

Latest satellite-derived data used by the HAB Tracker

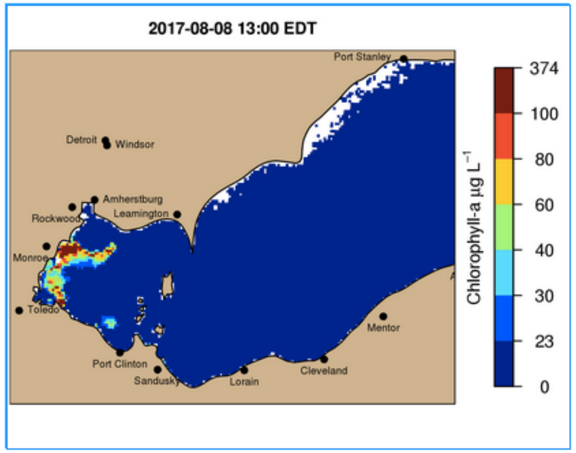
Sensors attached to satellites gather data, which is processed into the cyanobacterial index, an indicator of the abundance, or biomass, of the cyanobacteria associated with HABs. Processed satellite imagery is provided by the NOAA HAB Operational Forecasting System. The cyanobacterial index scale is converted to a cyanobacterial chlorophyll scale for use in the HAB Tracker, a similar indicator of cyanobacterial abundance.

True-color satellite image of Lake Erie



Latest usable (relatively cloud-free) satellite image of Lake Erie. For additional satellite imagery of Lake Erie, visit the NOAA Great Lakes CoastWatch webpage.

HABs extent analysis



Latest HAB extent analysis from valid satellite imagery above used to update the bloom location in the model.

The Riverscape Analysis Project (RAP)

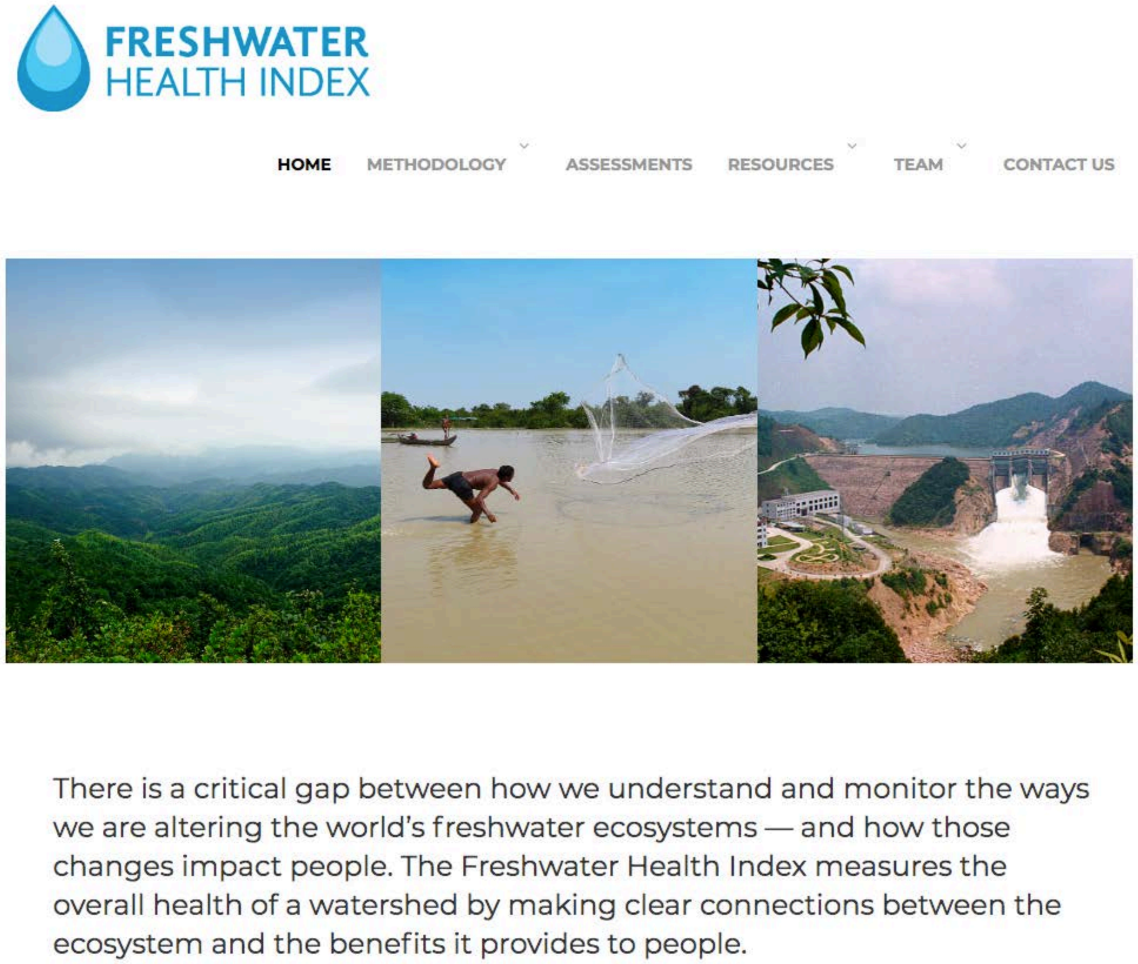
http://www.ntsg.umt.edu/rap/

- Univ Montana; Northwest Climate Science Center; funded by NASA
- Web-based GIS Decision Support System (DSS) for salmonid conservation
- Offers a number of tools, datasets, and educational resources for the conservation of salmonid populations along the North Pacific Rim river system under a climate change scenario
- Provides for downloading and extracting remote sensing data, habitat classification and vulnerability assessments, genetic and demographic data, and a citizen science sampling program.

Freshwater Health Index (FHI)

https://www.freshwaterhealthindex.org/

- Developed by Conservation International (CI)
- Is a web-based tool that measures system health by linking freshwater ecosystems with the benefit these provide to humans and the governance system in place
- Three main components:
  – Ecosystem vitality
  – Ecosystem services
  – Governance and Stakeholders



Contacts

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  - Juan Torres-Perez: juan.l.torresperez@nasa.gov
- General ARSET Inquiries
  - Ana Prados: aprados@umbc.edu
- ARSET Website:
  - http://arset.gsfc.nasa.gov

Thank You!

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