1st INIOAS Training Course on Ocean Remote Sensing, 2023

INIOAS

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https://www.inio.ac.ir/ORSA

Fundamentals of Ocean Remote Sensing

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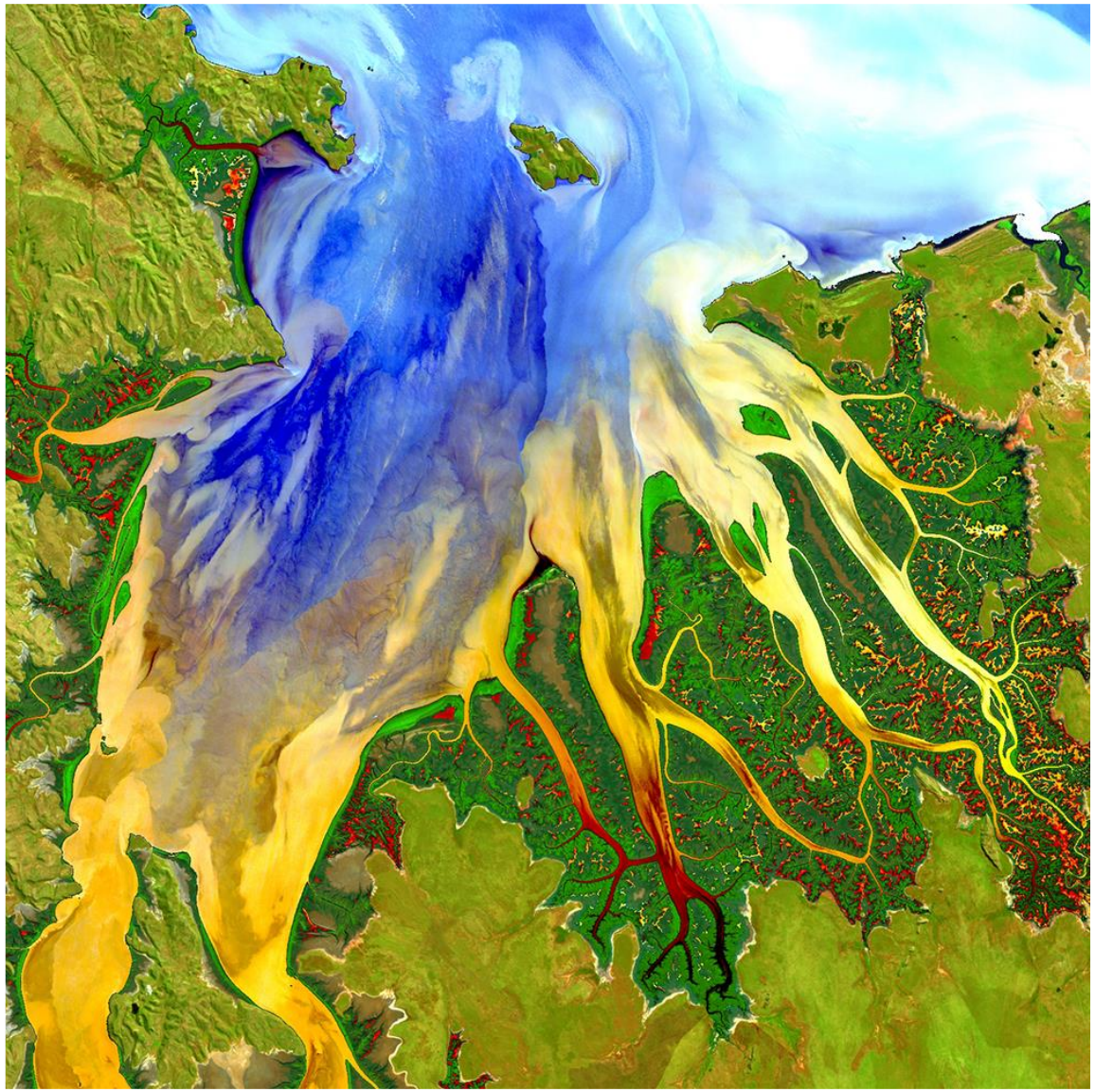
Objective

Provide an overview of aquatic optics, the remote sensing of water targets, and NASA Earth observation resources available for aquatic applications



Remote Sensing of Aquatic Environments

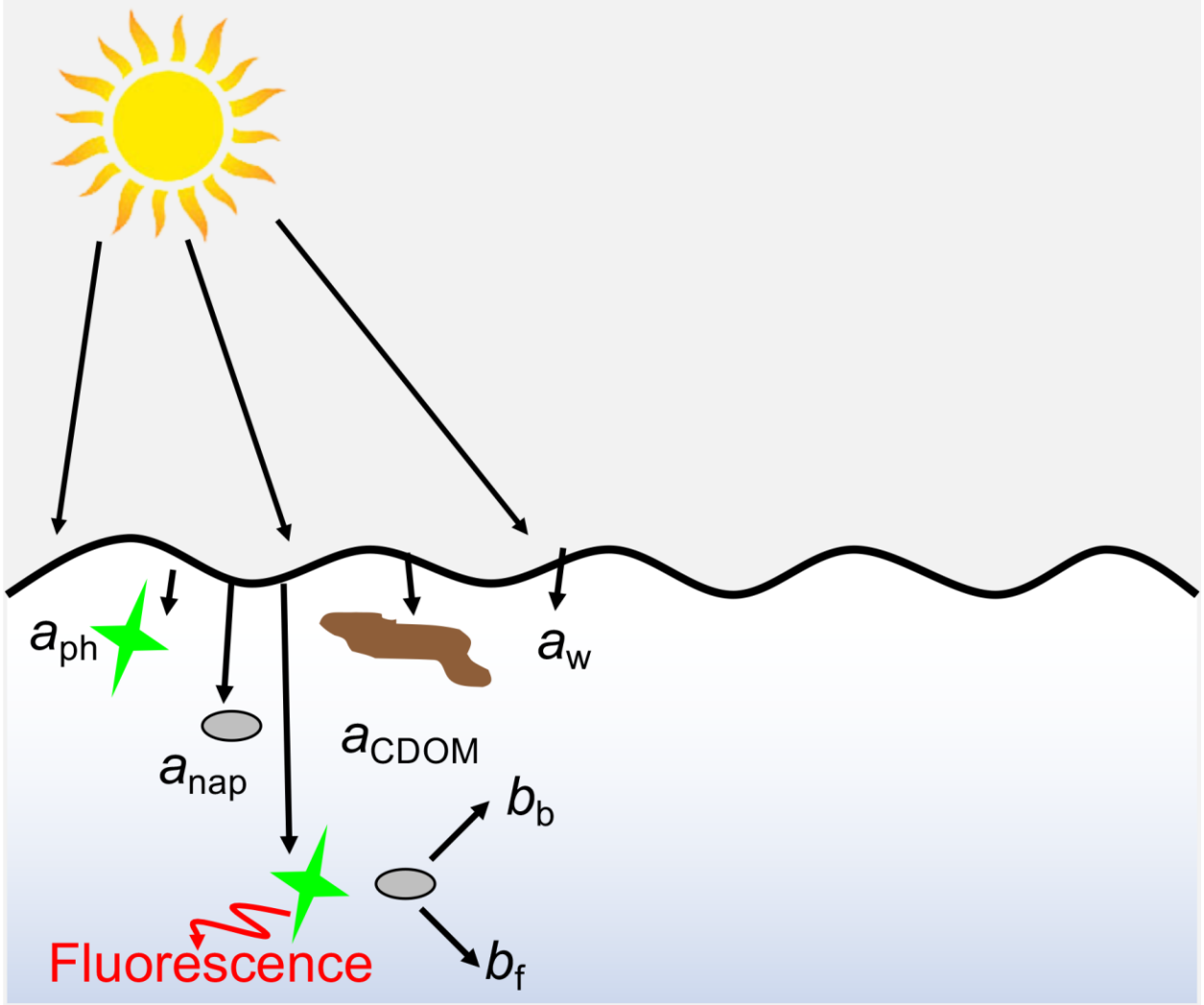
Advantages

- Synoptic coverage
- Temporal frequency needed to capture dynamic aquatic processes
- Observations of remote ocean locations, infrequently accessed by sea-based platforms
- Historical data for studies of trends

Disadvantages

- Optically complex conditions in aquatic environment
- Interference from the bottom
- Dynamic water quality changes
- Limited number of water quality parameters
- Collection of ground-truth data required

How Light Interacts with Water



Defining Remote Sensing Reflectance (Rrs) – or 'Ocean Color'

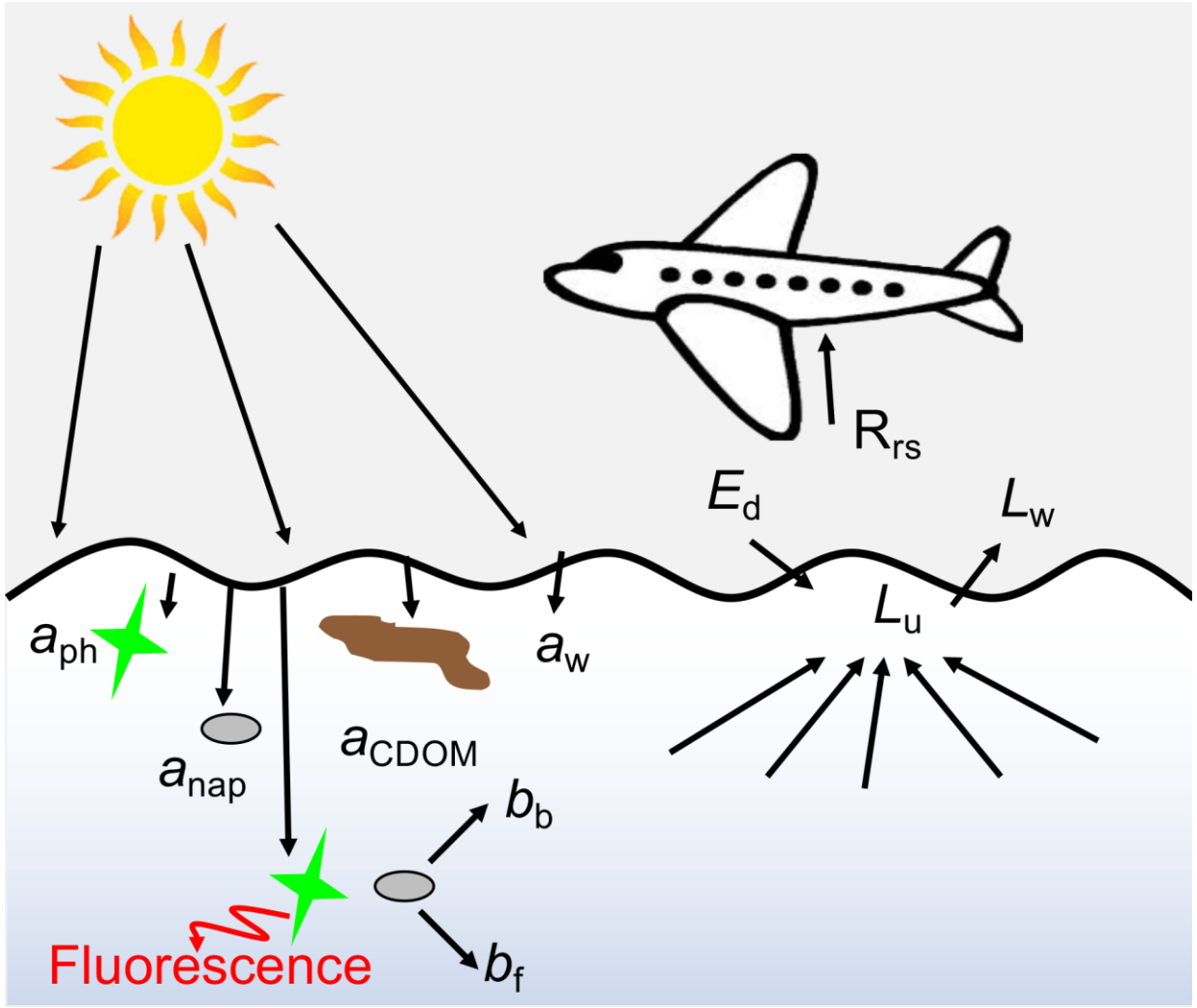
$$\mathrm{Rrs}(\lambda,0^+) \cong C\,\frac{b_b(\lambda)}{a(\lambda)+b_b(\lambda)}$$

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

How Light Interacts with Water



Defining Remote Sensing Reflectance (Rrs) – or 'Ocean Color'

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

Inherent Optical Properties
a = absorption
b = scattering

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 absorption (*a*) by photoplankton (ph),

non-algal particles (nap), water (w), and

colored dissolved organic matter (CDOM)

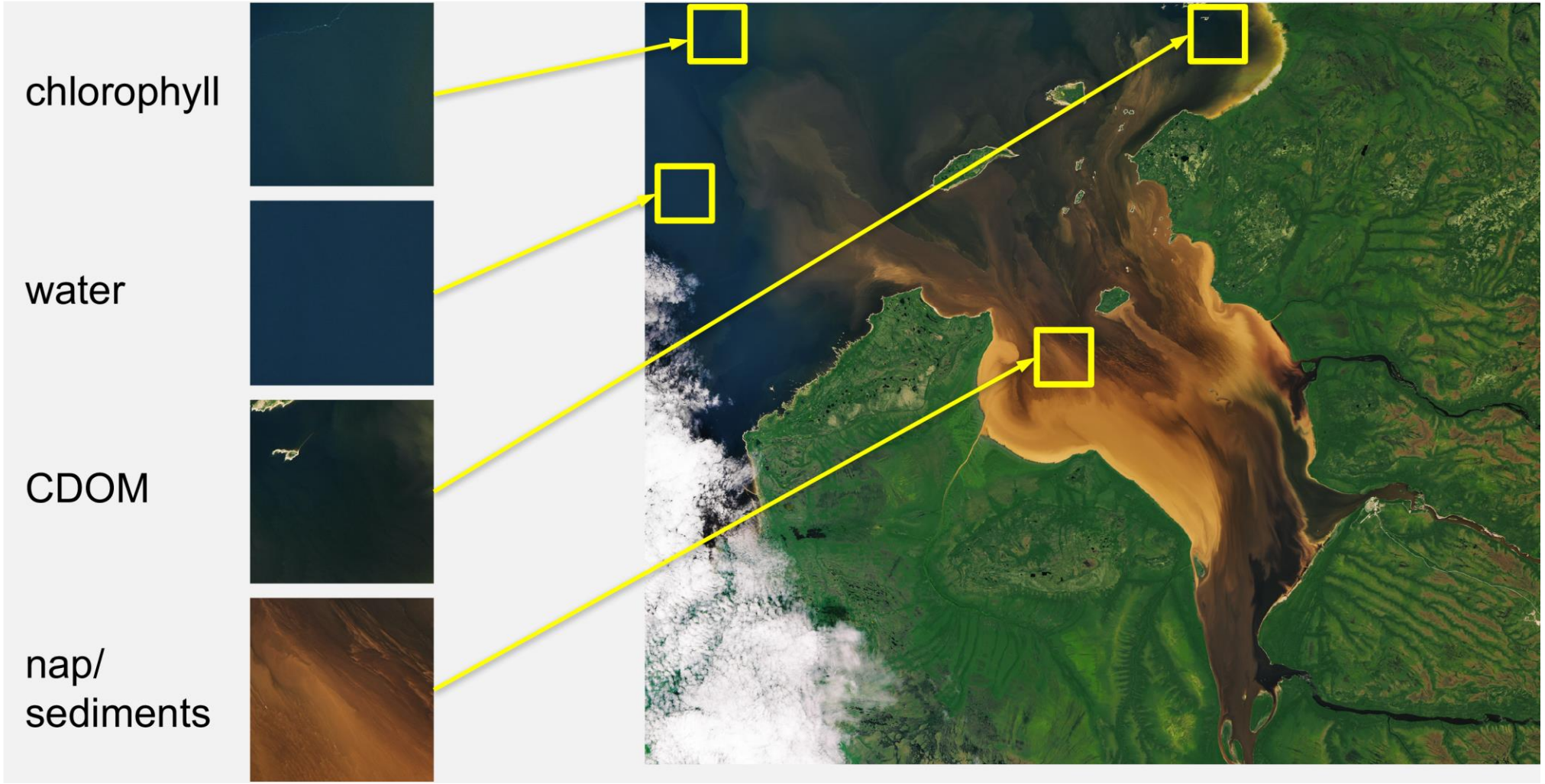
$a = a\text{ph} + anap + aCDOM + aw$

Light scattering (*b*) by particles in forward (*b*f)

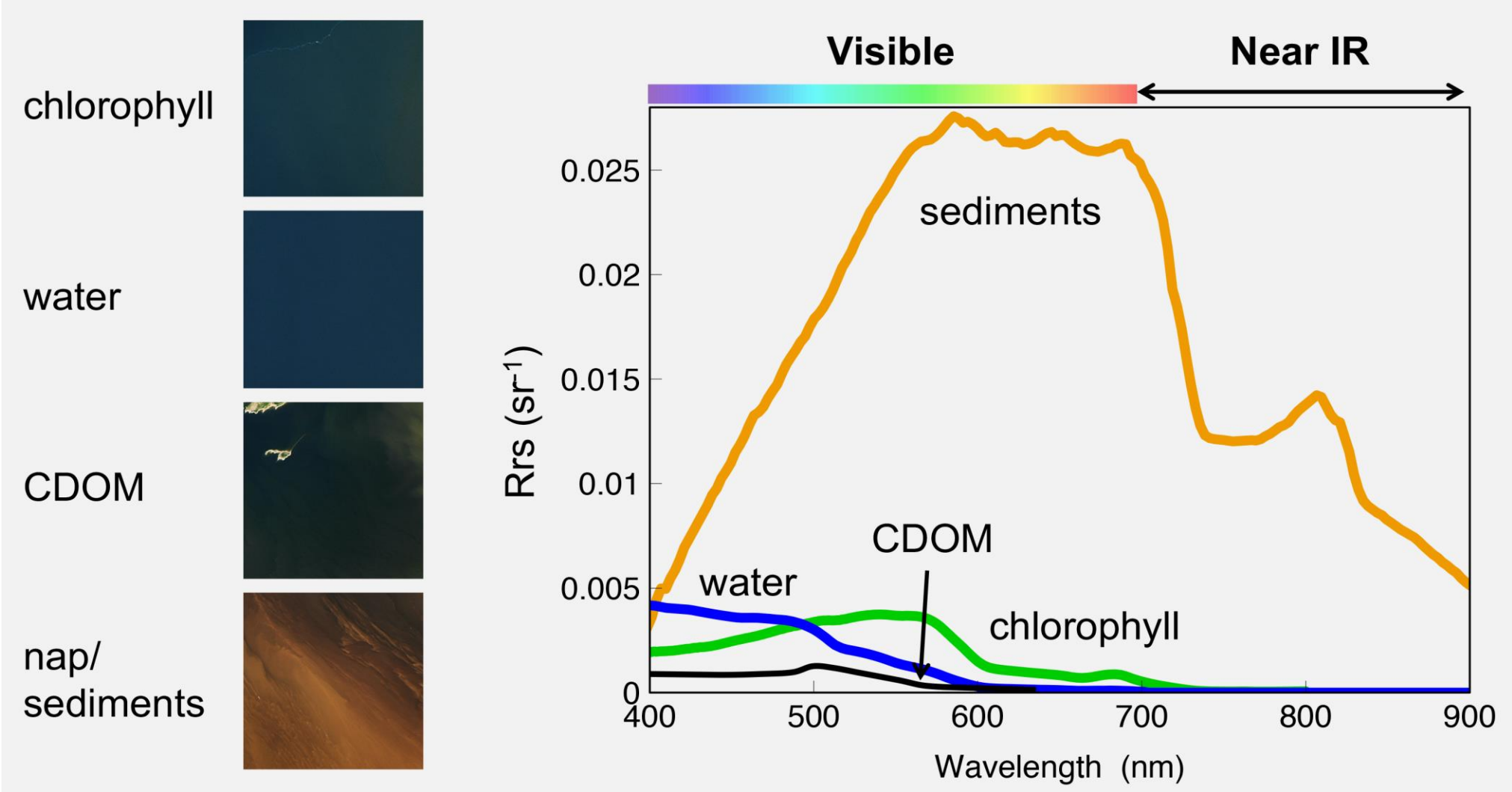
and backward (*b*b) direction

$b = b\text{f} + b\text{b}$

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

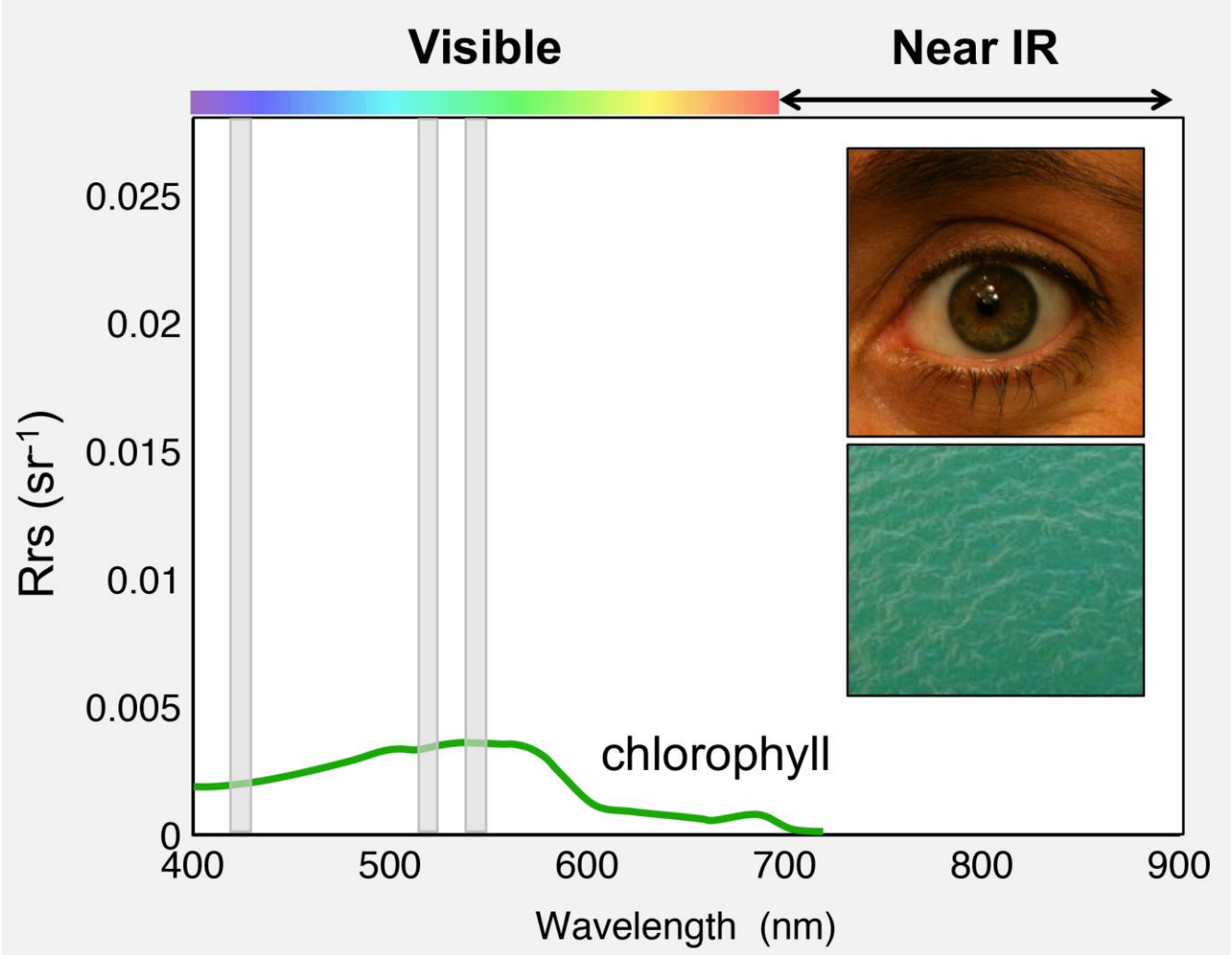


Inherent Optical Properties (IOPs) and the 'Color' of Water



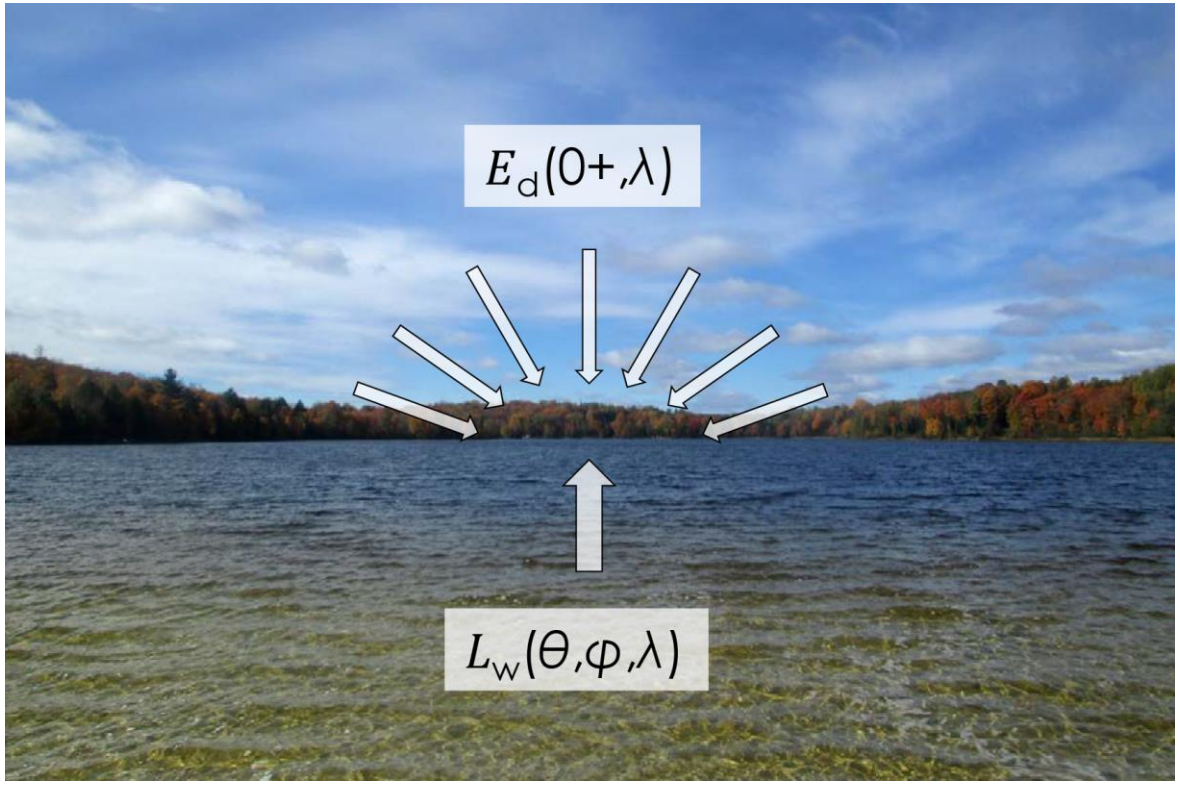
Inherent Optical Properties (IOPs) and the 'Color' of Water

- The typical human eye has color detecting receptors that sense light at:
  - 420-440 nm 'blue'
  - 534-555 nm 'green'
  - 564-580 nm 'red'
- Water with high chlorophyll content looks green because it reflects strongly in the green part of the spectrum



Apparent Optical Properties (AOPs) and the 'Color' of Water

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



- R_{rs} (θ,φ,λ): remote sensing reflectance
- L_w(θ,φ,λ): water leaving radiance
- E_d(0+,λ): downwelling irradiance
- θ: solar zenith angle
- φ: solar azimuth angle
- λ: wavelength

Calculation of the remote sensing reflectance of waterbodies. This equation relates the ratio of the water leaving radiance and the downwelling irradiance (*L*w (θ,φ,λ) and *E*d (0+,λ)) to the remote sensing reflectance (*R*rs(θ,φ,λ)).

Apparent Optical Properties (AOPs) and the 'Color' of Water

- What is the color and brightness of the ocean?
- How does sunlight penetrate the ocean?
- How does the angular distribution of light vary in the ocean?

• Depend on the directional structure of the ambient light field (i.e., on the radiance)

• Depend on the absorption and scattering properties of the water body (via the radiance)

• Display enough regular features and stability to be useful for describing a water body

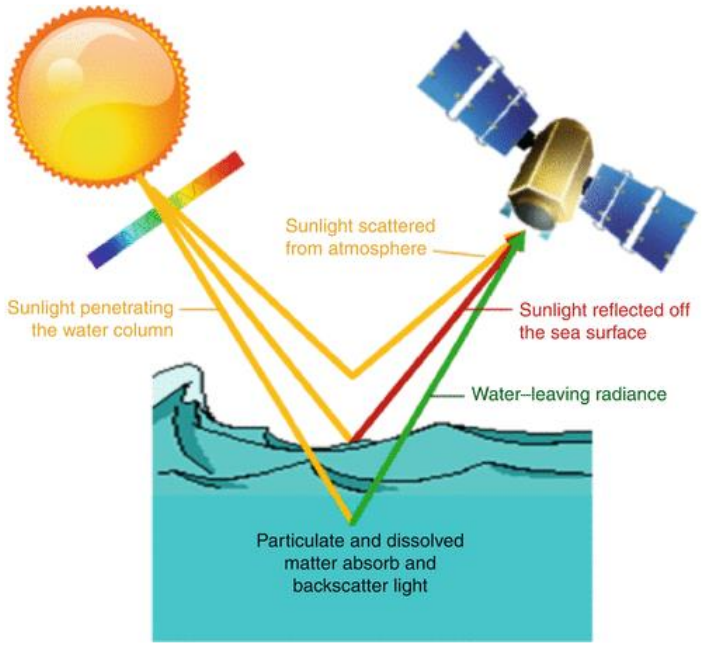
A good AOP depends weakly on the external environment (sky condition, surface waves) and strongly on the water IOPs

RADIATIVE TRANSFER EQUATION
RELATES THE IOPs TO THE AOPs

Remote Sensing of Water Bodies

Reflected Solar Radiation (~color of water)

- Measured by satellite sensors
- Used to derive the properties of optically active water constituents

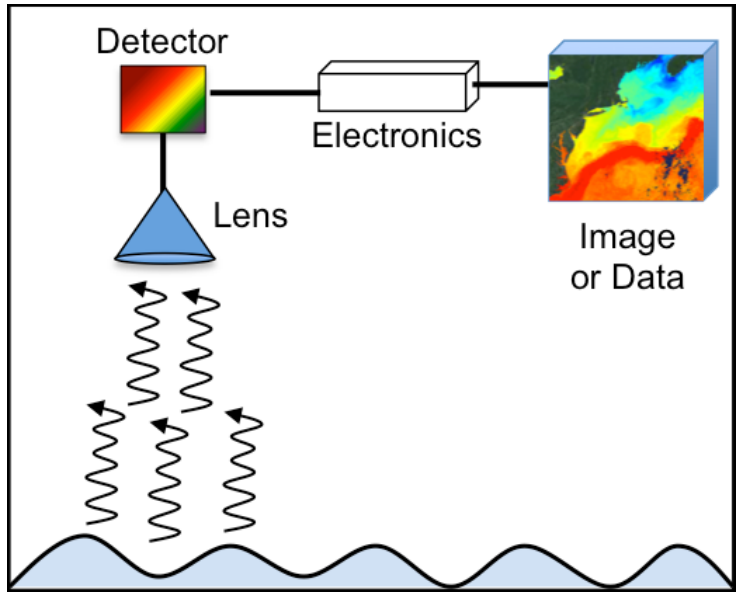


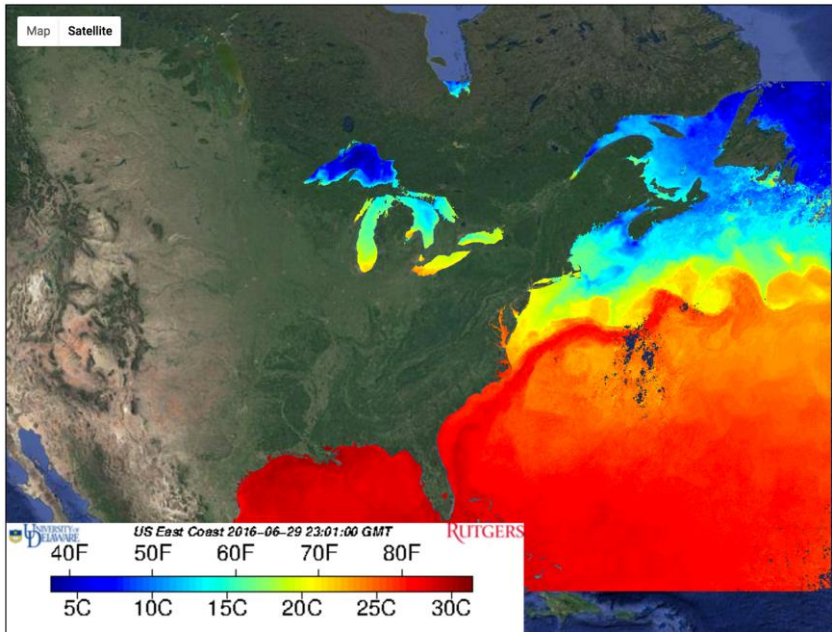
- Suspended Sediments
- Algae
- Colored Dissolved Organic Matter
- Detrital Organic Matter
- Submerged or floating vegetation
- Oil

Remote Sensing of Water Bodies

Emitted Thermal Radiation

Used to derive the surface temperature of water bodies





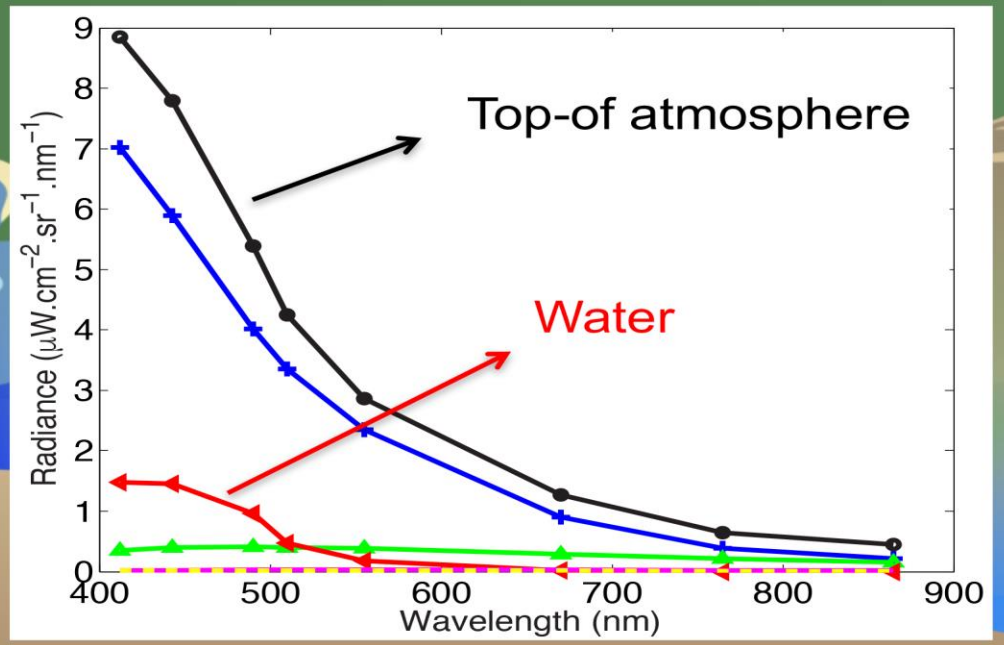
Remote Sensing of Water Bodies

Atmospheric Correction

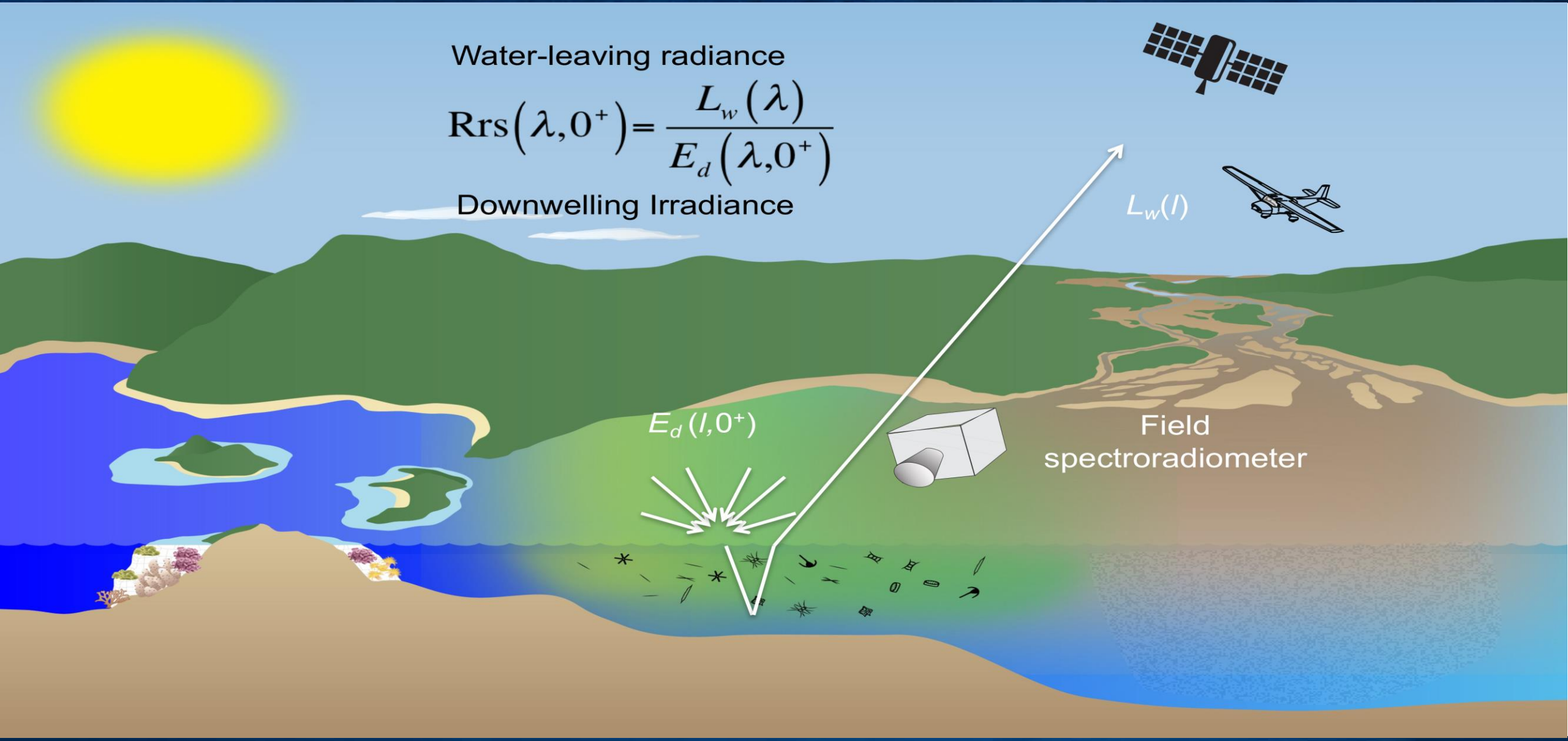
$$L_t(\lambda) = L_r(\lambda) + L_a(\lambda) + L_{ra}(\lambda) + T(\lambda,\theta)L_g(\lambda) + t(\lambda,\theta)L_{wc}(\lambda) + t(\lambda,\theta)L_w(\lambda)$$

>90%

<10%



Remote Sensing of Water Bodies



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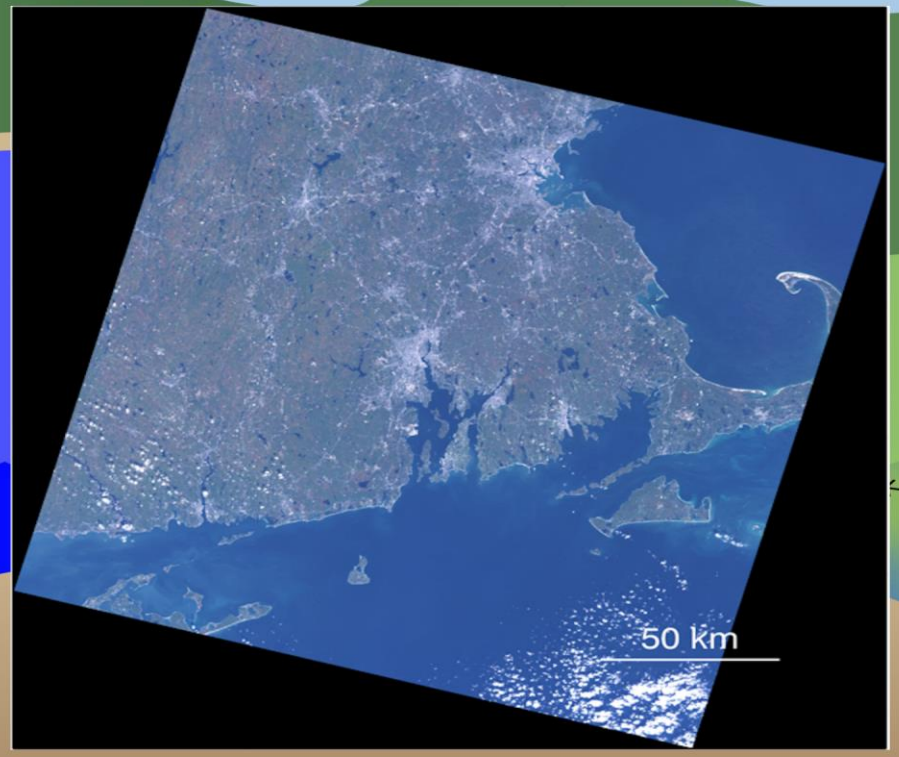
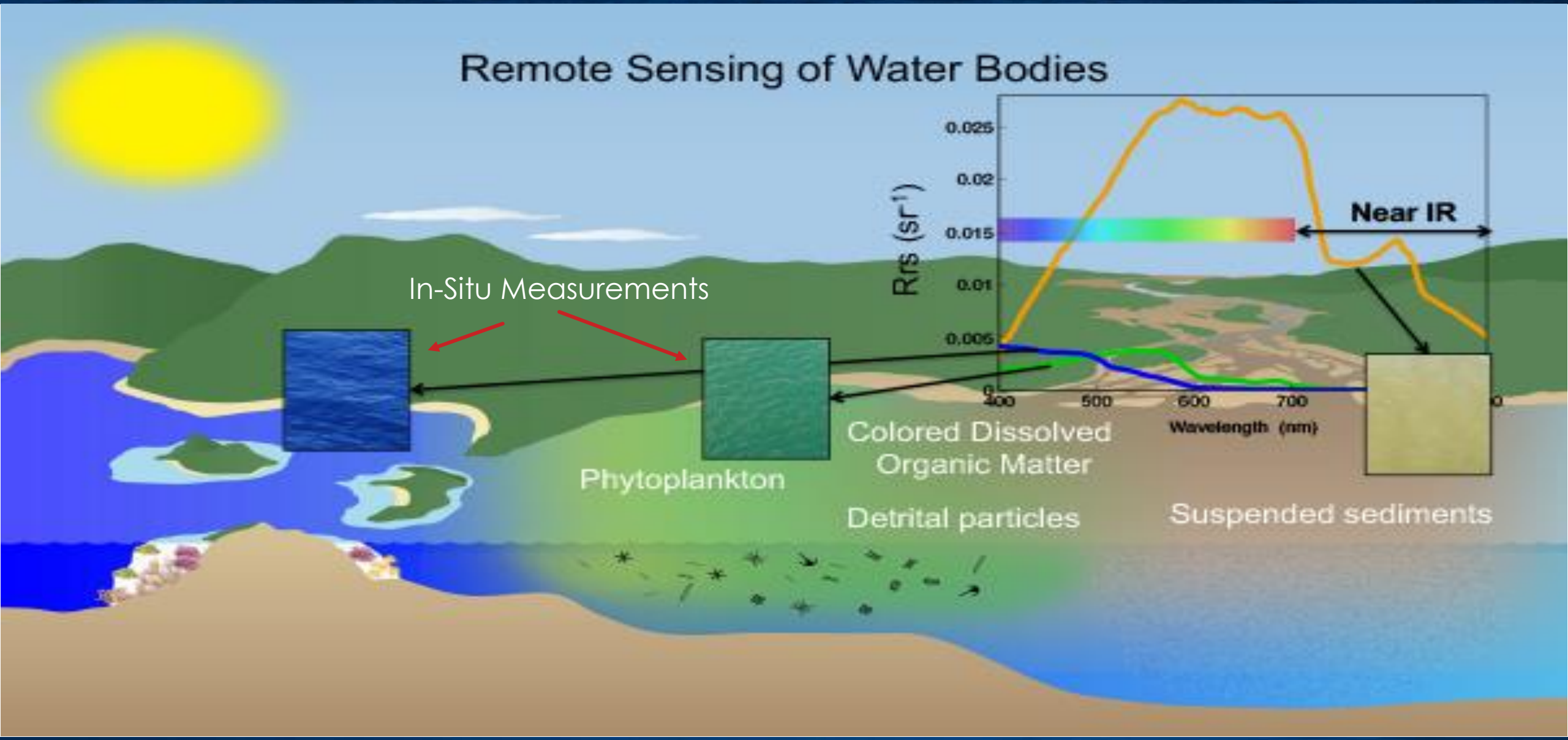


Atmospheric correction

Remote Sensing of Water Bodies



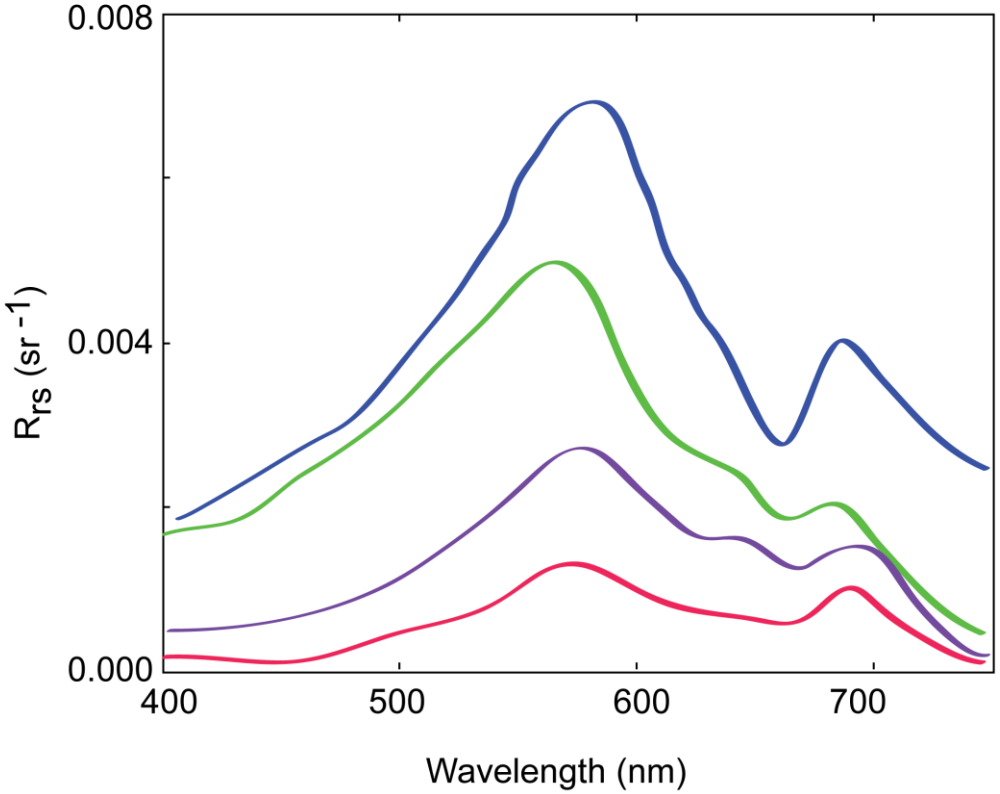
Remote Sensing of Water Bodies

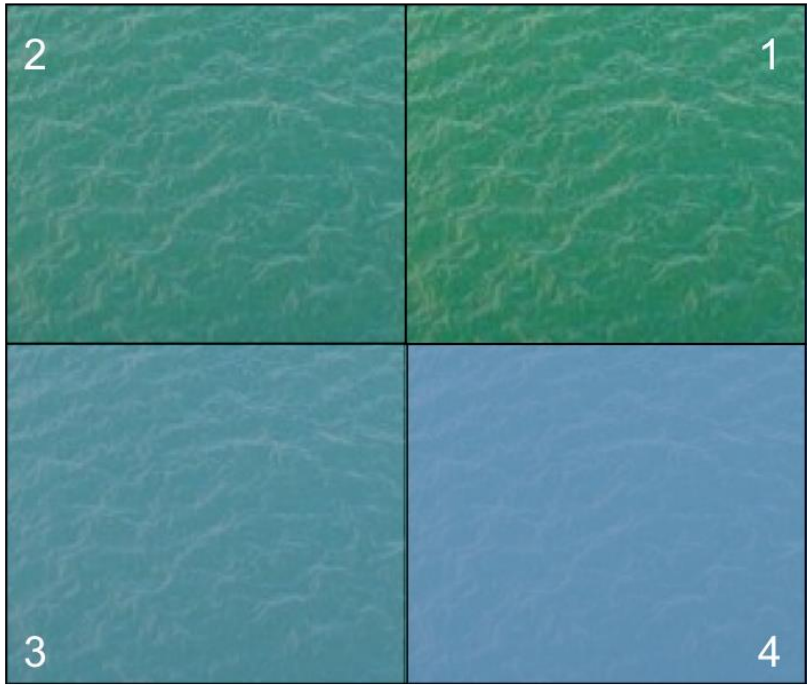
How *In Situ* and Satellite Observations Roughly Correspond

In Situ	Satellite
Water Temperature	Sea Surface Temperature (SST)
Colored Dissolved Organic Matter (CDOM)	Absorption by CDOM (adg_443_giop)
Suspended Solids – Turbidity	Diffuse attenuation of light at 490 nm (Kd_490)
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

Chlorophyll-a from Remote Sensing Reflectance (Rrs)

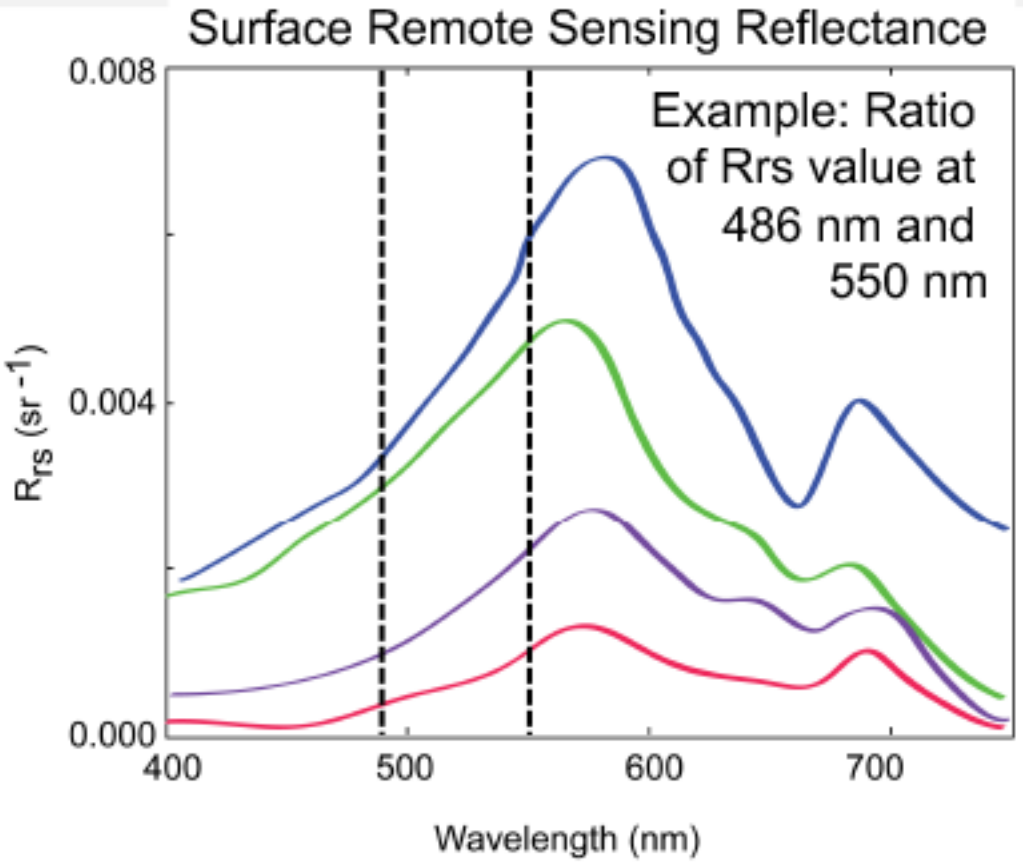
Rrs at Different Chlorophyll-a Concentrations

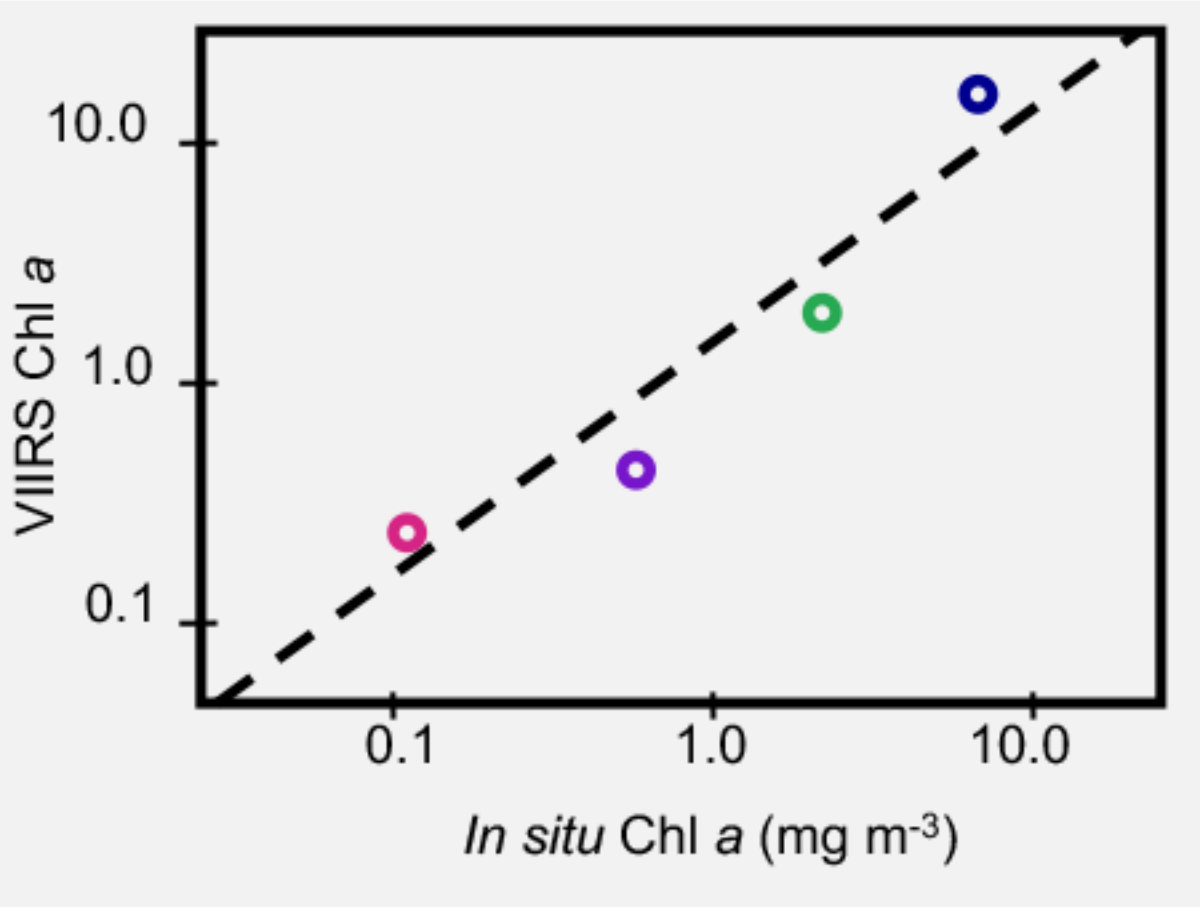




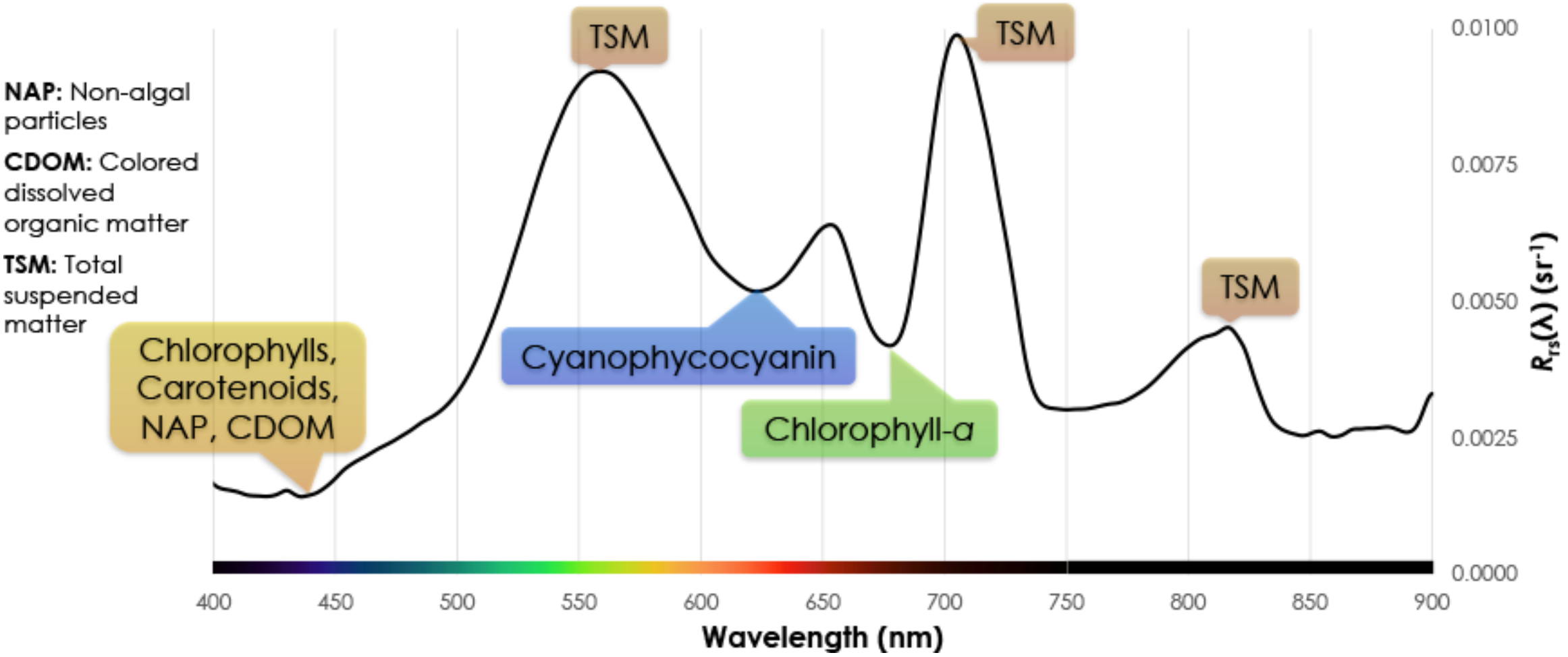
Chlorophyll-a Estimates

Estimations are a function of the ratios of Rrs values

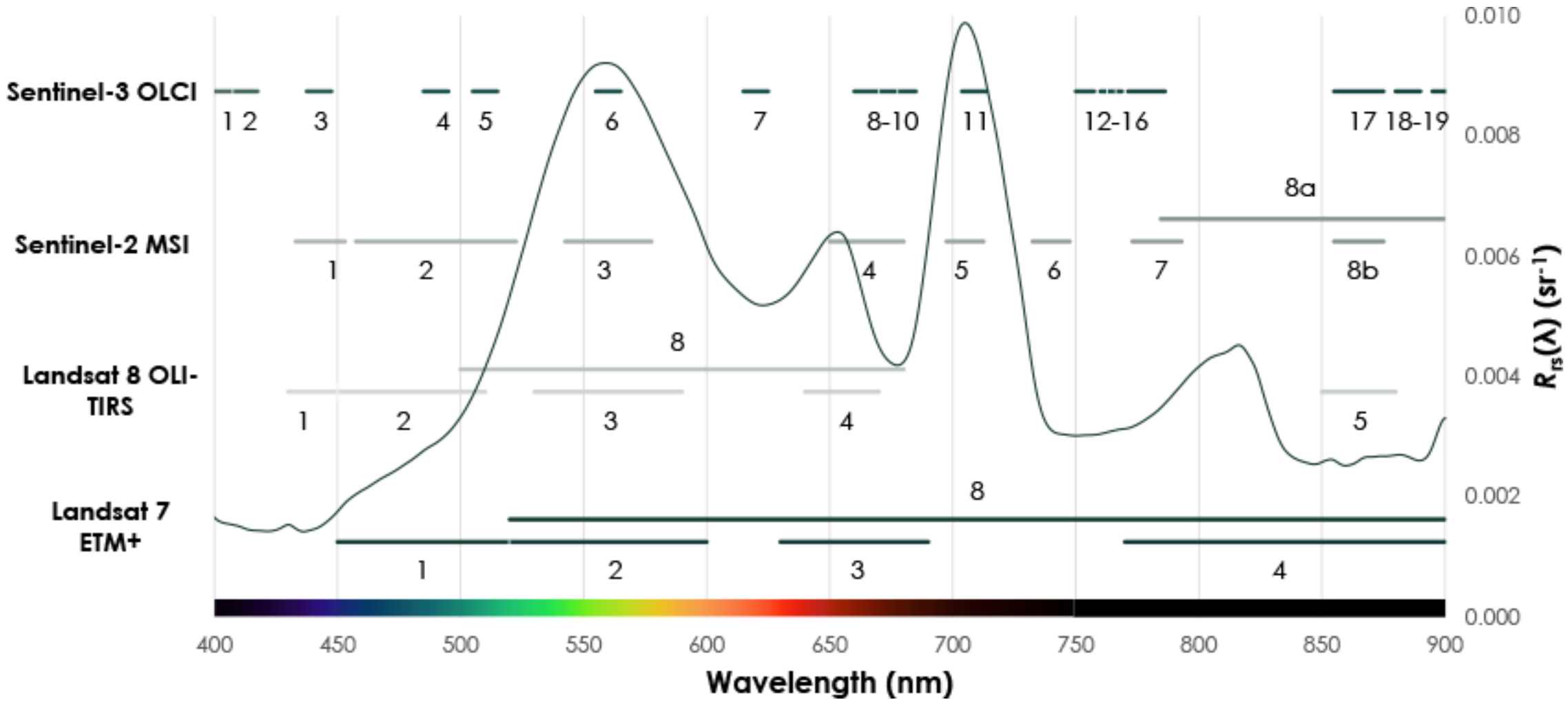




Remote Sensing of Water Bodies



Remote Sensing of Water Bodies



What Can We Observe from Space?

Observation	Application
Chlorophyll-a	Phytoplankton biomass, primary productivity, biogeochemical cycling
Water Turbidity	Water quality, human and ecosystem health
Colored Dissolved Organic Matter (CDOM)	Water quality, biogeochemical cycling, human and ecosystem health
Sea Surface Temperature (SST)	Currents, primary productivity, climate studies, biogeochemistry, temperature flux
Surface winds	Currents, mixing, air-sea flux of gases
Salinity	Mixing, air-sea flux of gases, geostrophic currents, salt flux

NASA Satellites & Sensors for Ocean and Coastal Systems

Satellite	Sensor	Parameter
Landsat Series (7/1972 - present)	• Thematic Mapper (TM) • Enhanced Thematic Mapper (ETM+) • Operational Land Imager (OLI)	• Spectral Reflectance
Terra (12/1999 - present)	Moderate Resolution Imaging Spectroradiometer (MODIS)	• Spectral Reflectance • Chlorophyll-a Concentration • Temperature • Colored Dissolved Organic Matter (CDOM) • Turbidity • Euphotic Depth
Aqua (5/2002 - present)		
Terra (12/1999 – present)	Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER)	• Spectral Reflectance • Temperature

NASA Satellites & Sensors for Ocean and Coastal Systems

Satellite	Sensor	Parameter
National Polar Partnership (NPP) (11/2011-present)	Visible Infrared Imaging Radiometer Suite (VIIRS)	• Spectral Reflectance • Chlorophyll Concentration
International Space Station	Hyperspectral Imager for the Coastal Ocean (HICO) (2009 – 2014)	• Spectral Radiance • Spectral Remote Sensing Reflectance
Plankton, Aerosols, Clouds, ocean Ecosystems (PACE) (proposed for 2022 or 2023)	Ocean Color Instrument	• Spectral Reflectance • Optional Polarimeter being considered

NASA Satellites & Sensors for Ocean and Coastal Systems

Landsat Satellites and Sensors

- Near-polar orbit
- 10 a.m. equator crossing time
- Global coverage
- July 1972 – present
- 16 day revisit time
    - Sensors:
    - MSS
    - TM
    - ETM+
    - OLI
    - TIRS

http://landsat.gsfc.nasa.gov/

Landsat-8 Operational Land Imager (OLI)

- Flying on-board Landsat 8 (Landsat Data Continuity Mission – LDCM) polar orbiting satellite
- Spatial Coverage & Resolution:
    - Global, Swath 185 km
    - Spatial Resolution: 15 m, 30 m
- Temporal Coverage & Resolution:
    - February 11, 2013 – present
    - 16 day revisit time
- Spectral Bands
    - 9 bands (major bands include blue-green,
    - red, near IR, shortwave and thermal IR, panchromatic)

http://landsat.usgs.gov/landsat8.php

Terra and Aqua

Terra

- Polar orbit, 10:30 a.m. equator crossing time
- Global Coverage
- December 18, 1999 – present
  - 1-2 observations per day
- Sensors:
  - ASTER, CERES, MISR, MODIS, MOPITT

http://terra.nasa.gov/

Aqua

- Polar orbit, 1:30 p.m. equator crossing time
- Global Coverage
- May 4, 2002 – present
  - 1-2 observations per day
- Sensors:
  - AIRS, AMSU, CERES, MODIS, AMSR-E

http://aqua.nasa.gov/

MODerate Resolution Imaging Spectroradiometer (MODIS)

- On board Terra and Aqua
- Designed for land, atmosphere, ocean, and cryosphere observations
- Spatial Coverage and Resolution:
  - Global, Swath: 2,330 km
- Spatial Resolution Varies: 250 m, 500 m,
  - 1 km
- Temporal Coverage and Resolution:
  - 2000 – present
  - 2 times per day

Spectral Bands

- 36 bands (red, blue, IR, NIR, MIR)
  - Bands 1-2: 250 m
  - Bands 3-7: 500 m
  - Bands 8-16: 1000 m

http://modis.gsfc.nasa.gov

NASA Satellites & Sensors for Ocean and Coastal Systems

National Polar Partnership (NPP)

- Polar orbit
- 1:30 p.m. equator crossing time
- Global coverage
- November 21, 2011 – present
- 1-2 observations per day
- Sensors:
  - VIIRS
  - ATMS
  - CrlS
  - OMPS
  - CERCES

http://www.nasa.gov/mission_pages/NPP

Visible Infrared Imaging Radiometer Suite (VIIRS)

• Flying on-board NPP, polar-orbiting satellite
• Designed to collect measurements of clouds, aerosols, ocean color, surface temperature, fires, and albedo
• Spatial Coverage and Resolution:
– Global, swath width: 3,040 km
– Spatial resolution: 375 m – 750 m
• Temporal Coverage
– October 2011 – present
– 2 times per day

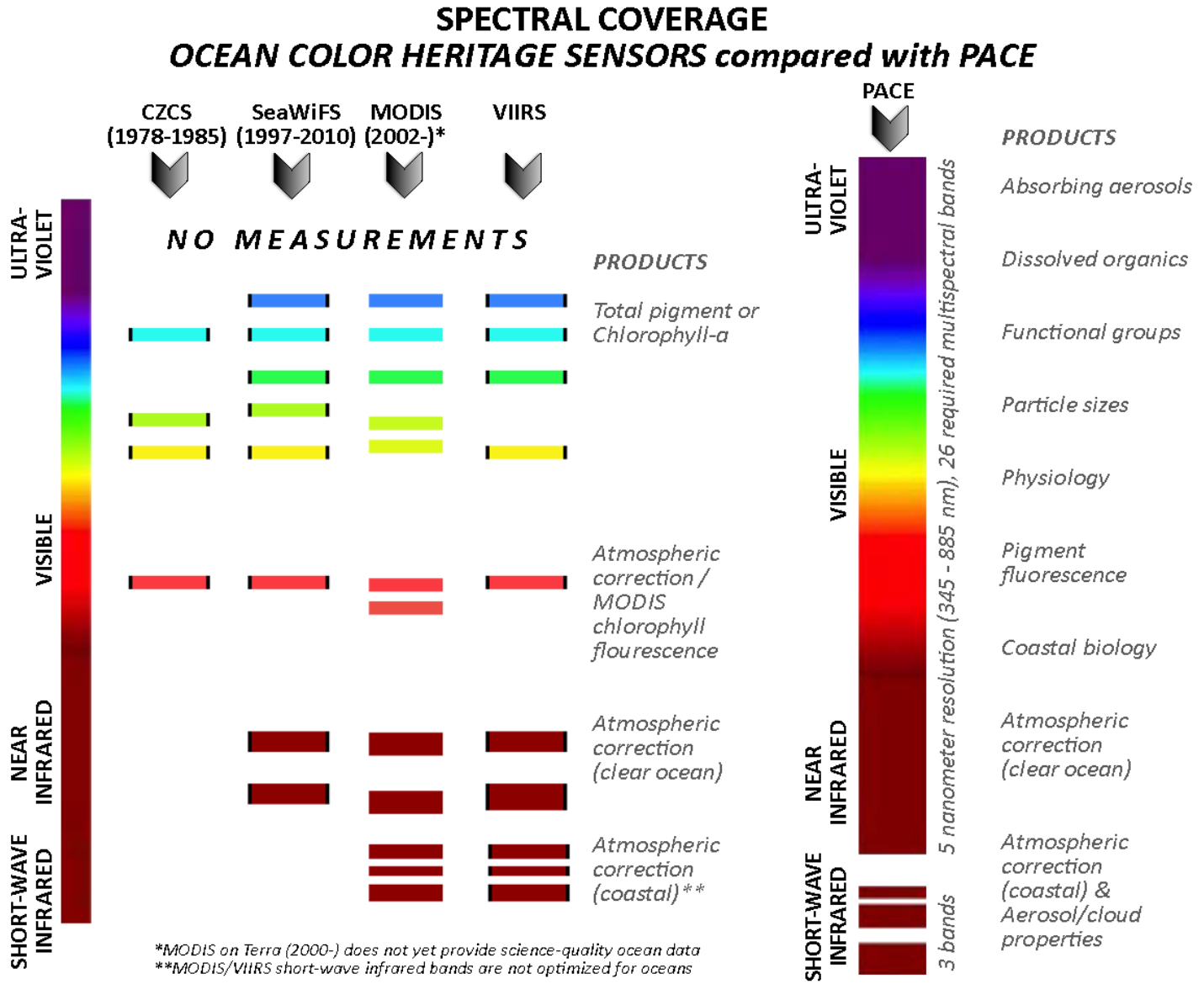
• Spectral Bands
– 15 bands (major bands include visible, red, blue, green, short, middle, and long-wave IR)
– Ocean Color Bands 1-7: 0.402 - 0.682 μm
– Sea Surface Temperature Bands 12-13: 3.660 - 4.128 μm

http://npp.gsfc.nasa.gov/viirs.html

Plankton, Aerosol, Clouds, Ocean Ecosystem (PACE)

- Polar orbiting, 2-day revisit
- High spectral resolution
- 1 km ground sample distance
- Optional polarimeter being considered for cloud and aerosol study and to aid in atmospheric correction
- Anticipated launch 2022

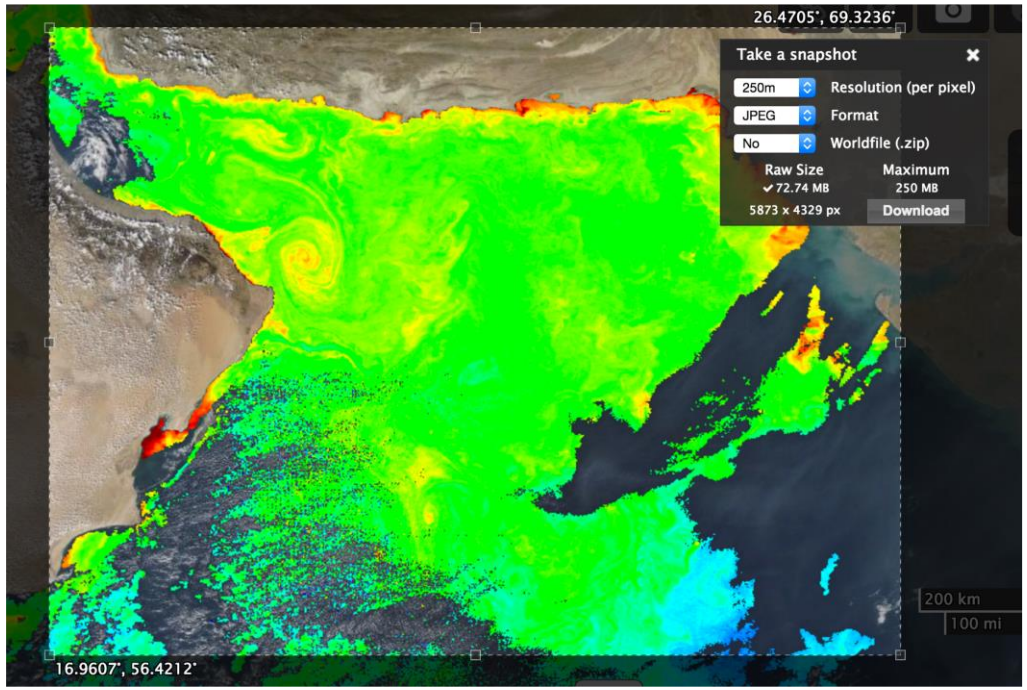
http://pace.gsfc.nasa.gov/



Accessing NASA Satellite Data

NASA Worldview

- Interactive web-based tool for browsing satellite imagery
- Imagery is generally available within four hours of observation
- Daily imagery from May 2012 to present
- Data can be downloaded
- Image output in JPEG, PNG, GeoTIFF, and KML formats



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

INIOAS Mapview

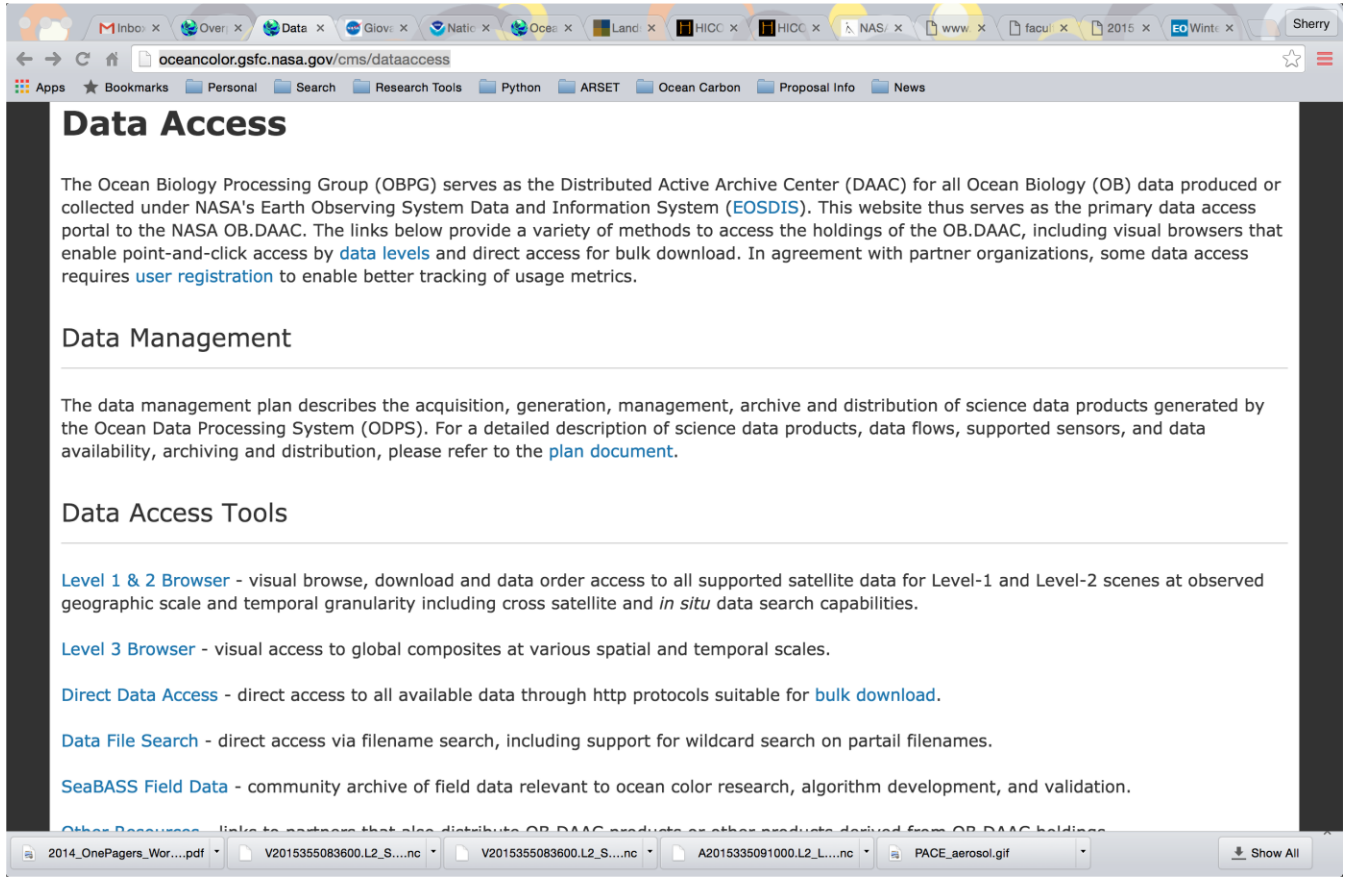
(Worldview Heritage)

https://www.inio.ac.ir/mapview

Accessing NASA Satellite Data

NASA OceanColor Web – Data Access

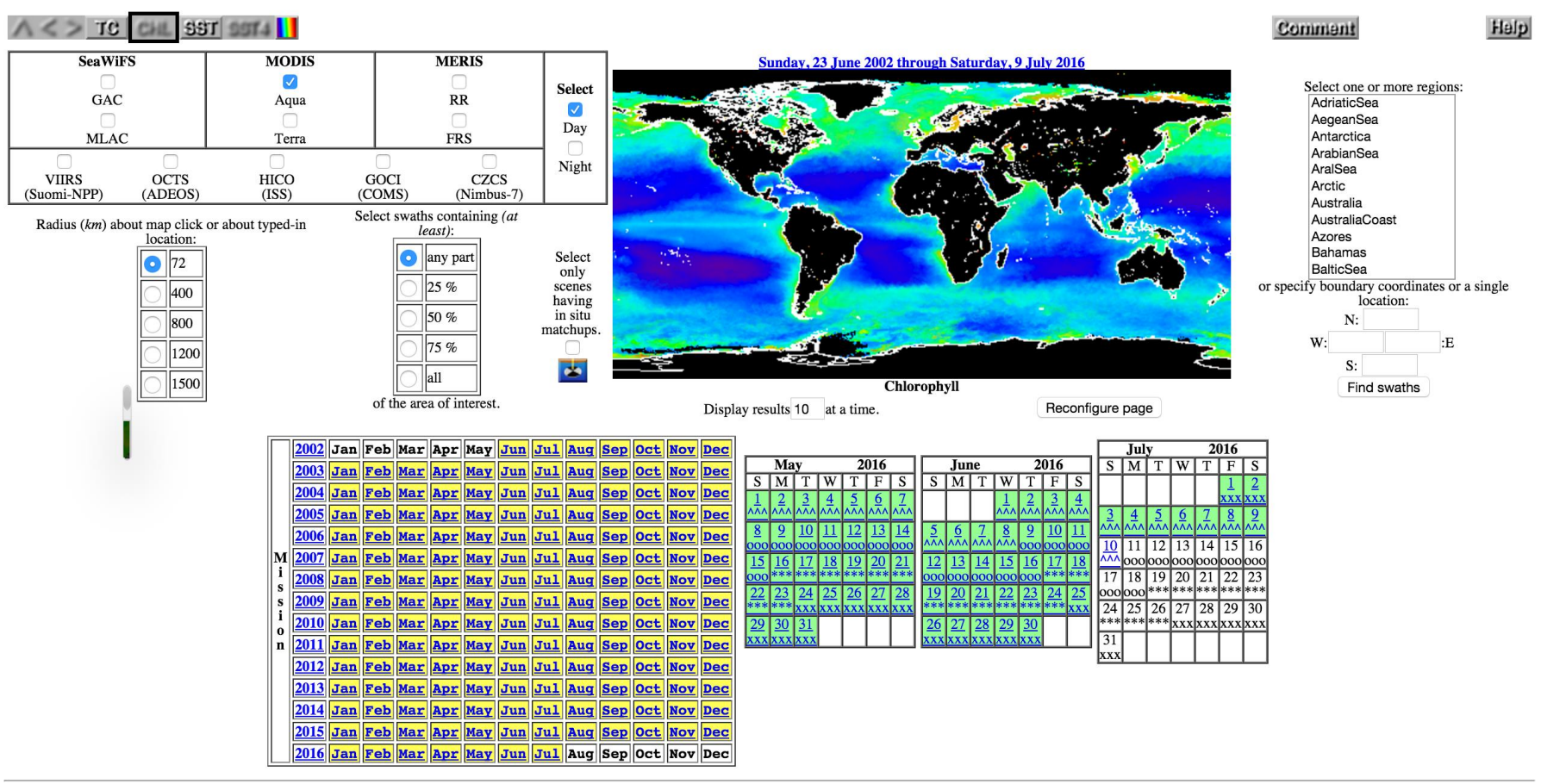
- Level 1 & 2 Browser
- Level 3 Browser
- Direct Data Access
- Data File Search
- SeaBASS Field Data



http://oceancolor.gsfc.nasa.gov/cms/dataaccess

NASA OceanColor Web – Level 1 & 2 Browser

http://oceancolor.gsfc.nasa.gov/cgi/browse.pl



Other Data Access Tools

- NOAA CoastWatch
  – http://coastwatch.noaa.gov/

- NASA Giovanni
  – http://giovanni.gsfc.nasa.gov/giovanni/

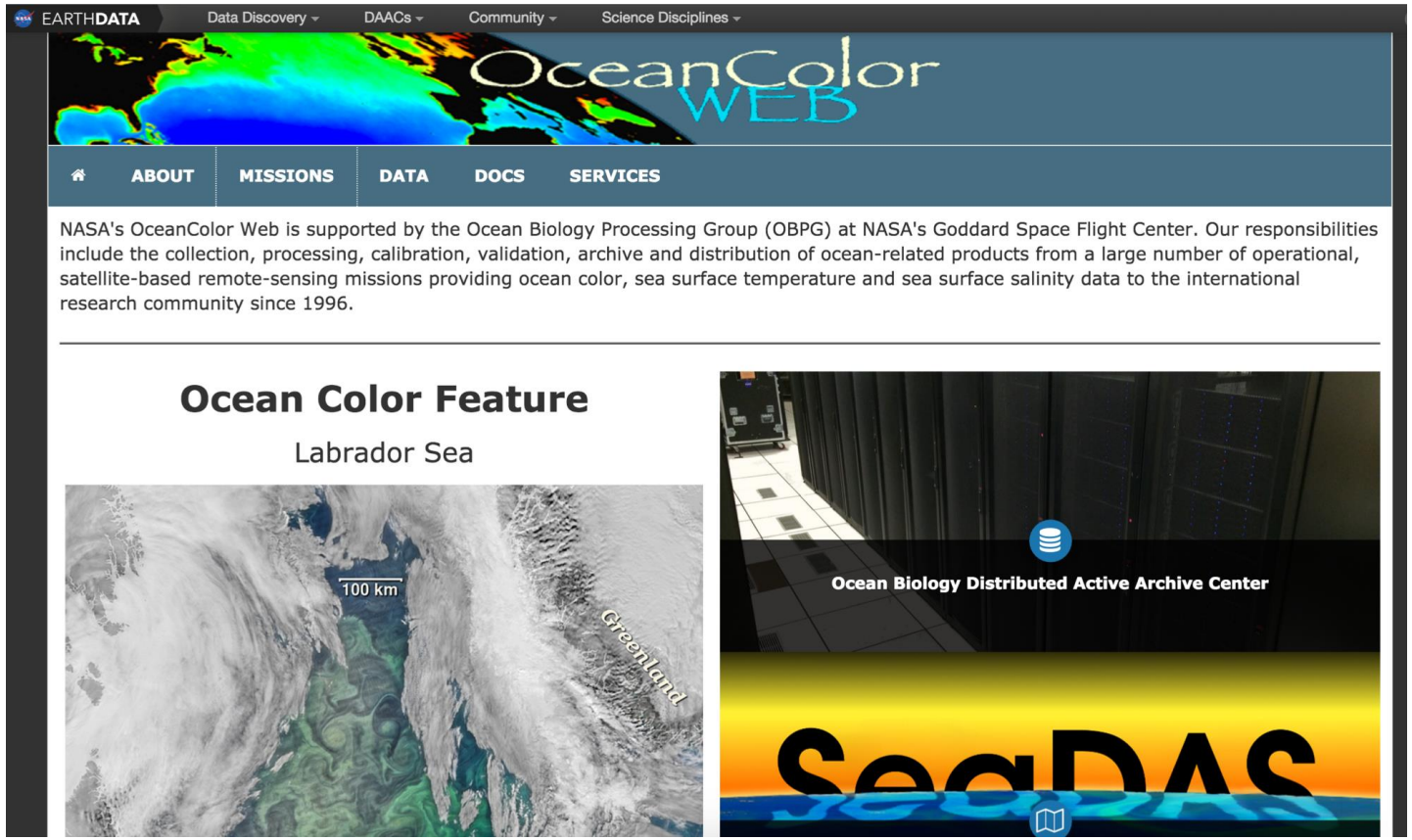
- USGS Earth Explorer
  – http://earthexplorer.usgs.gov/

- ESA Ocean Data Lab
  – http://ovl.oceandatalab.com

NASA OceanColor Web

• OceanColor Web is supported by the Ocean Biology Processing Group (OBPG) at NASA Goddard

• OBPG's duties include collection, processing, calibration, validation, archive, and distribution of ocean-related data products from a large number of satellite missions



SeaWiFS Data Analysis System (SeaDAS)

- Image analysis package for the processing, display, analysis, & quality control of ocean color data
- Originally developed for SeaWiFS, but supports most U.S. and international ocean color missions
- Online tutorials, help pages, and an active user community in the Ocean Color Forum
- Attentive & friendly support team based at NASA Goddard

http://seadas.gsfc.nasa.gov/

SNAP

The Sentinel Application Platform (SNAP) is a common architecture for all Sentinel Toolboxes. The software is developed by Brockmann Consult, Skywatch, Sensar and C-S.

The SNAP architecture is ideal for Earth observation (EO) processing and analysis due to the following technological innovations: *extensibility*, *portability*, *modular rich client platform*, *generic EO data abstraction*, *tiled memory management*, and a *graph processing framework*.

SNAP and the individual Sentinel Toolboxes support numerous sensors other than Sentinel sensors.

https://step.esa.int/main/download/snap-download/

Thank You