

1<sup>st</sup> INIOAS Training Course on Ocean Remote Sensing, 2023



17-21 Jun 2023 | Iranian National Institute for Oceanography and Atmospheric Science | Tehran, IRAN

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

# Fundamentals of Ocean Remote Sensing

**Masoud Moradi**

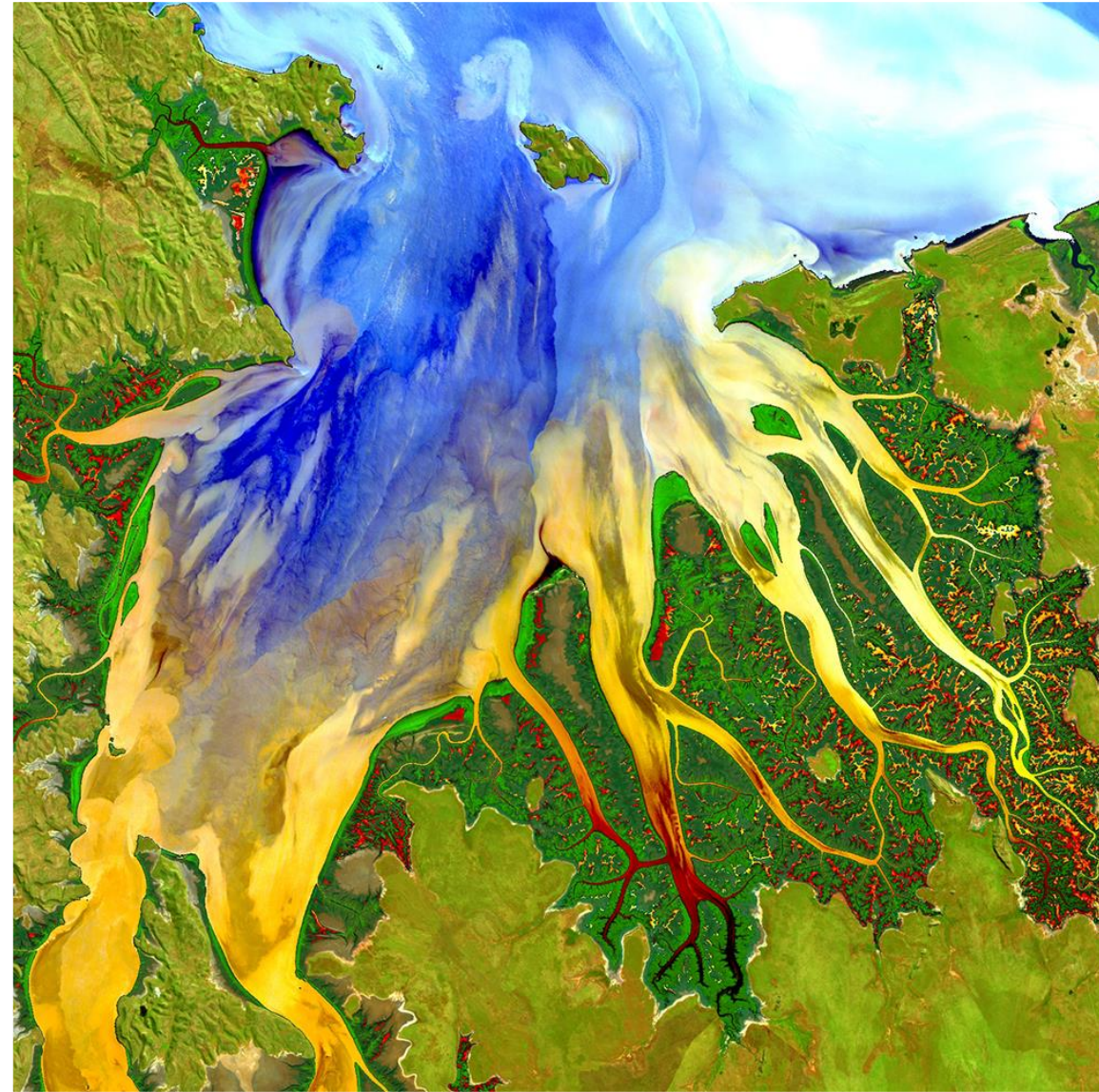
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<https://www.inio.ac.ir>

# 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

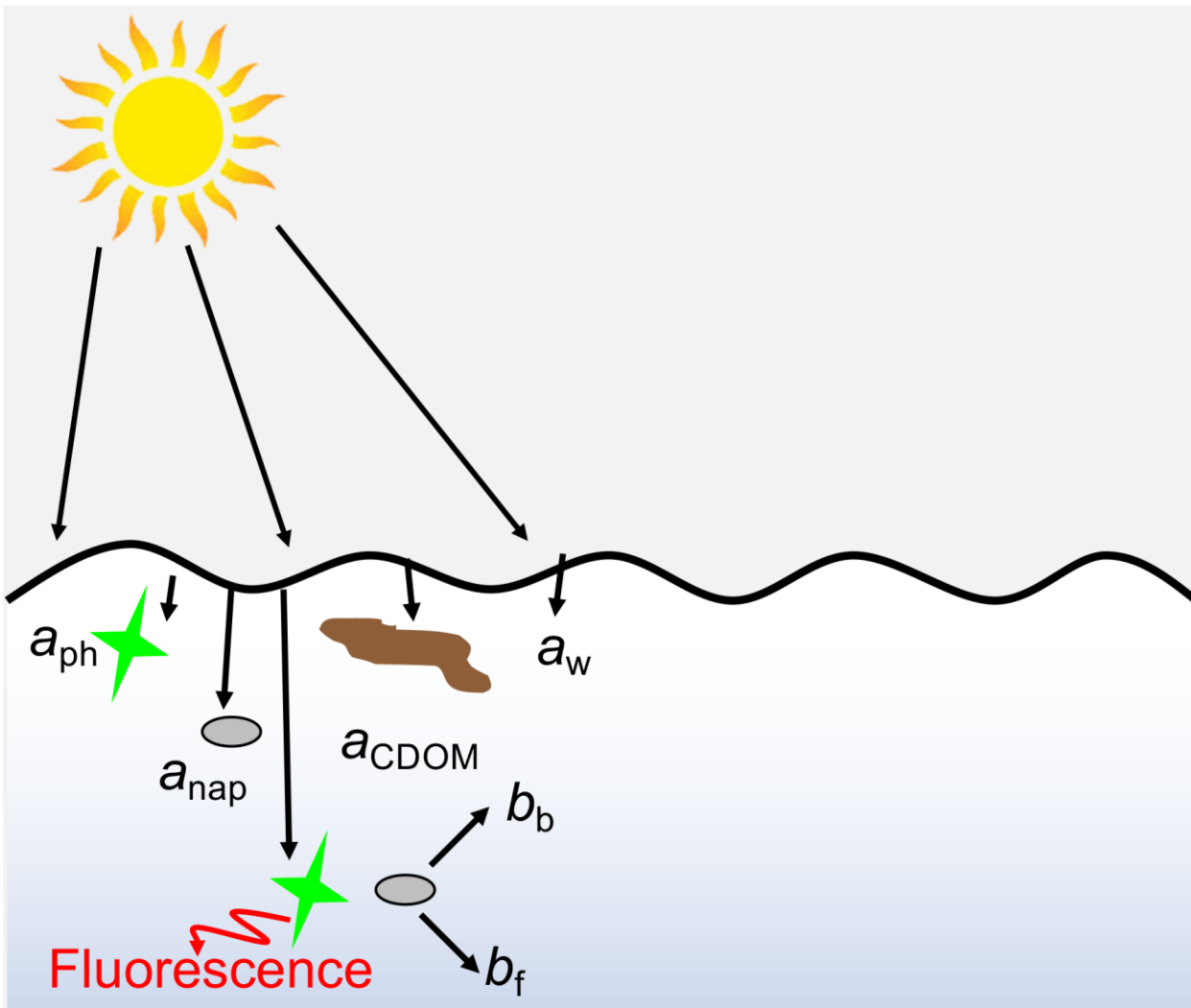
- Synoptic coverage
- Temporal frequency needed to capture dynamic aquatic processes
- Observations of remote ocean locations, infrequently accessed by sea-based platforms
- Historical data for studies of trends

## 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

# Light and Water

## How Light Interacts with Water



Defining Remote Sensing Reflectance ( $R_{rs}$ ) – or ‘Ocean Color’

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

*Inherent Optical Properties*

$a$  = absorption by...

phytoplankton (ph)

non-algal particles (nap)

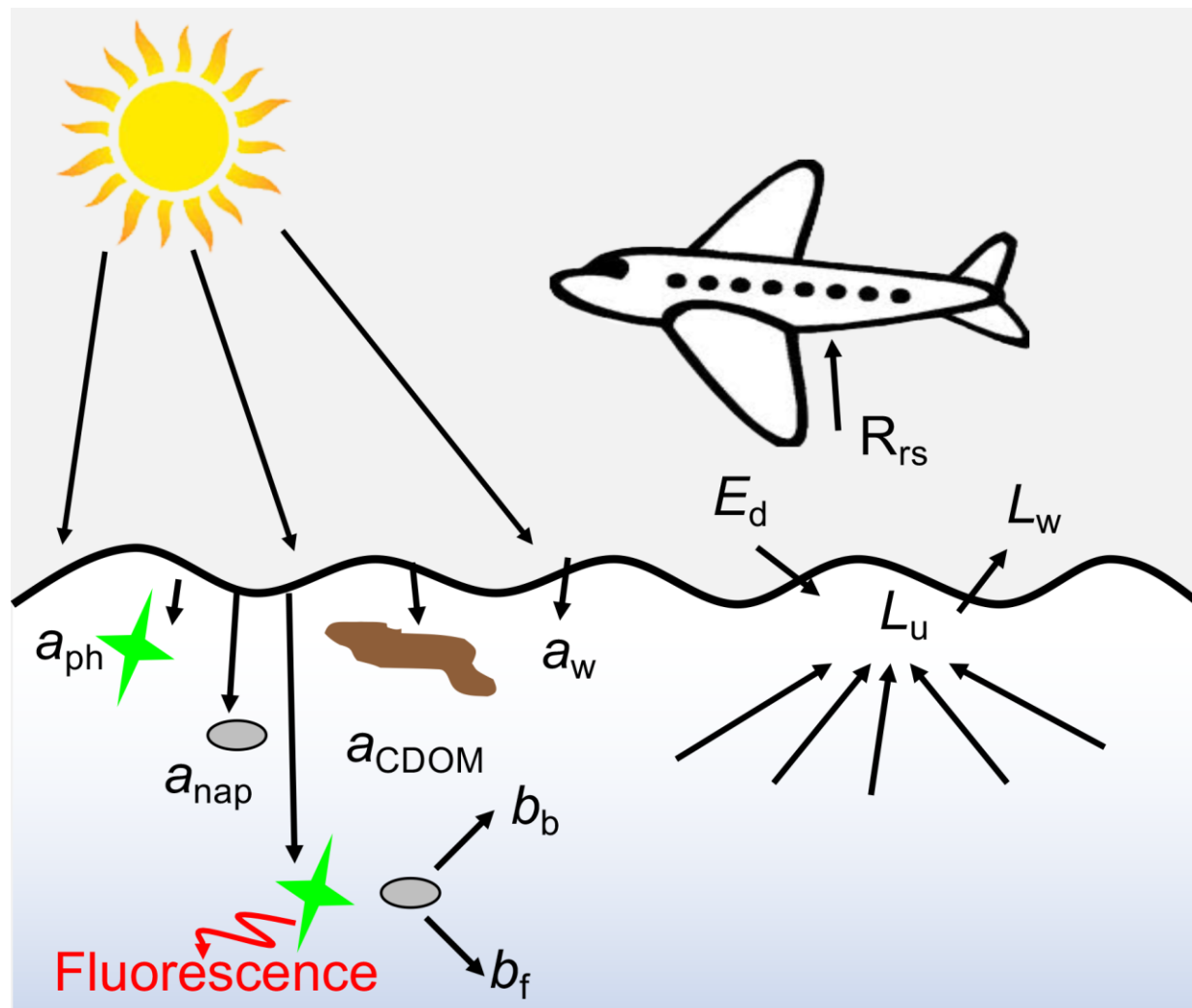
colored dissolved organic matter (CDOM)

water (w)

$b$  = scattering in forward (f) and backward (b) directions

# Light and Water

## How Light Interacts with Water



Defining Remote Sensing Reflectance ( $R_{rs}$ ) – or ‘Ocean Color’

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

*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

# Light and Water

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

Light absorption ( $a$ ) by phytoplankton (ph),  
non-algal particles (nap), water (w), and  
colored dissolved organic matter (CDOM)

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

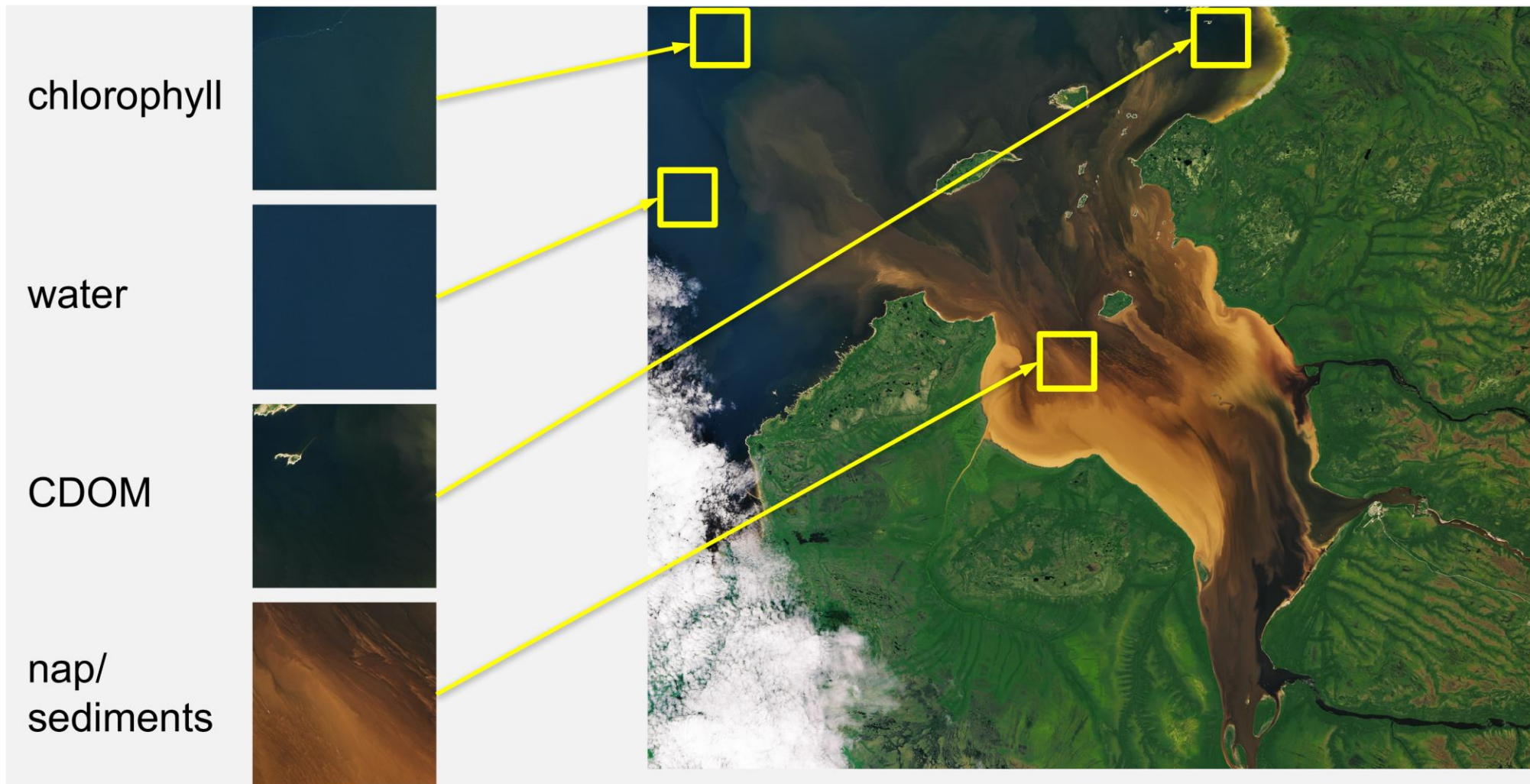
Light scattering ( $b$ ) by particles in forward ( $b_f$ )  
and backward ( $b_b$ ) direction

$$b = b_f + b_b$$



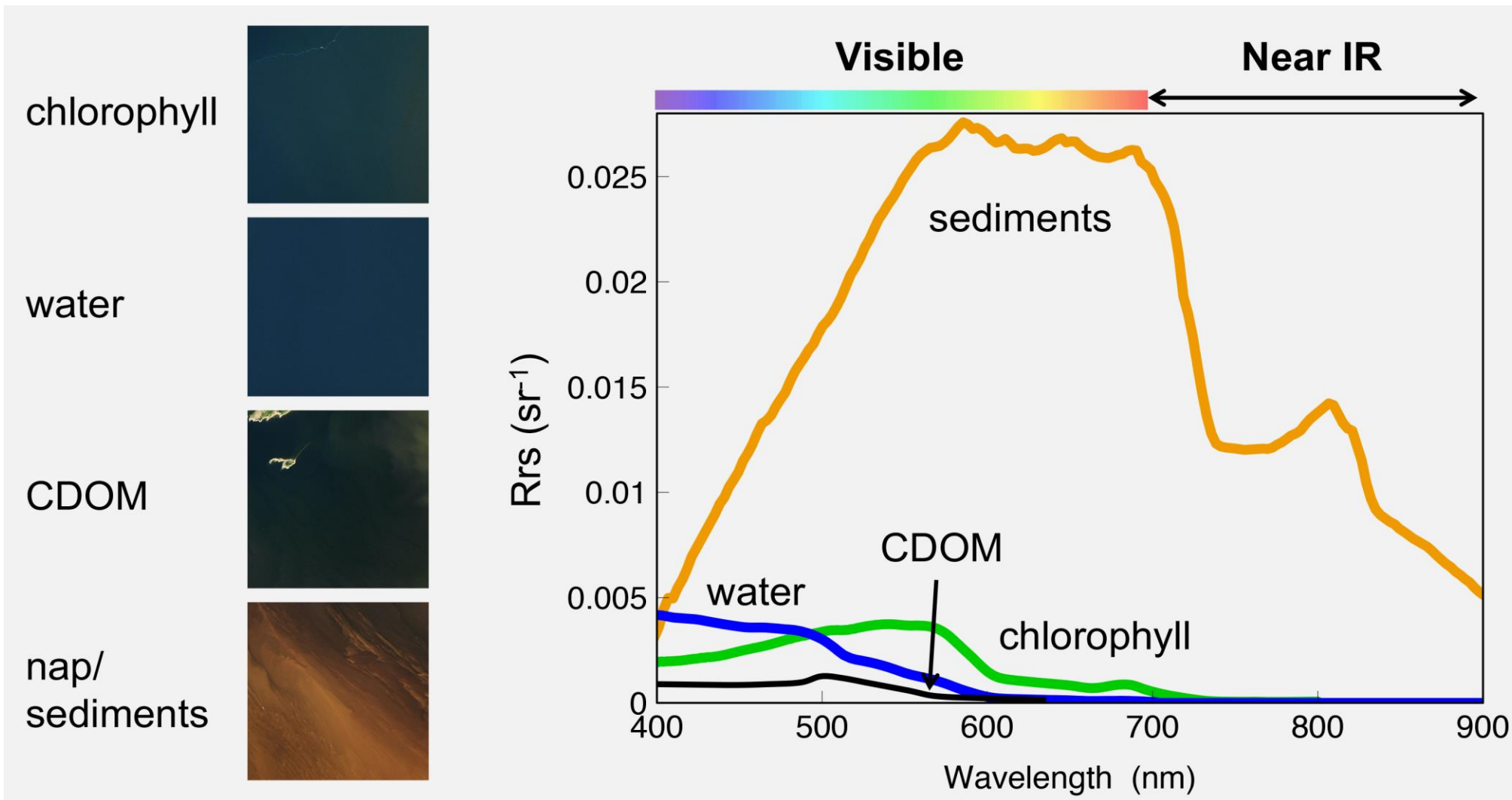
# Light and Water

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



# Light and Water

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

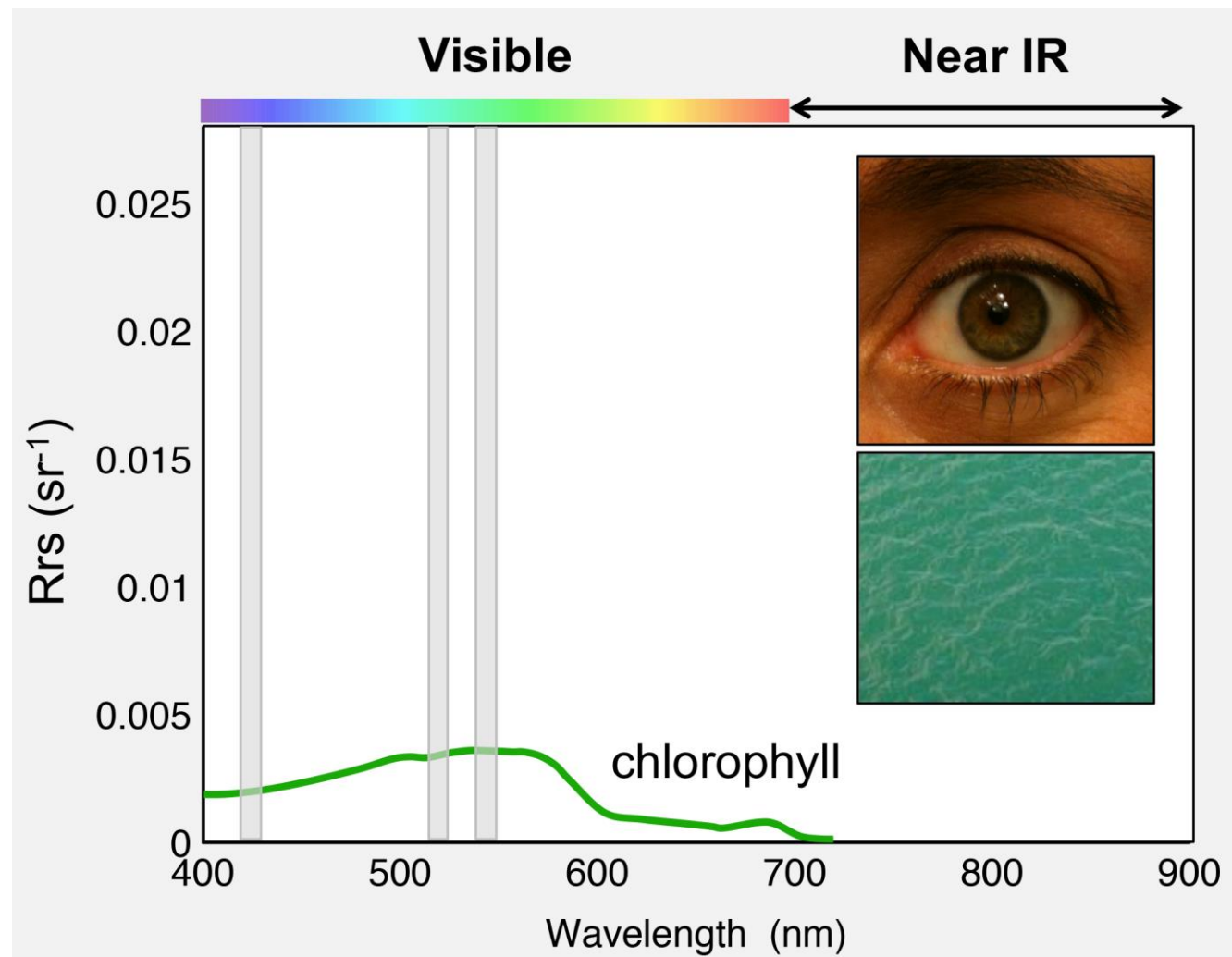




# Light and Water

## 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



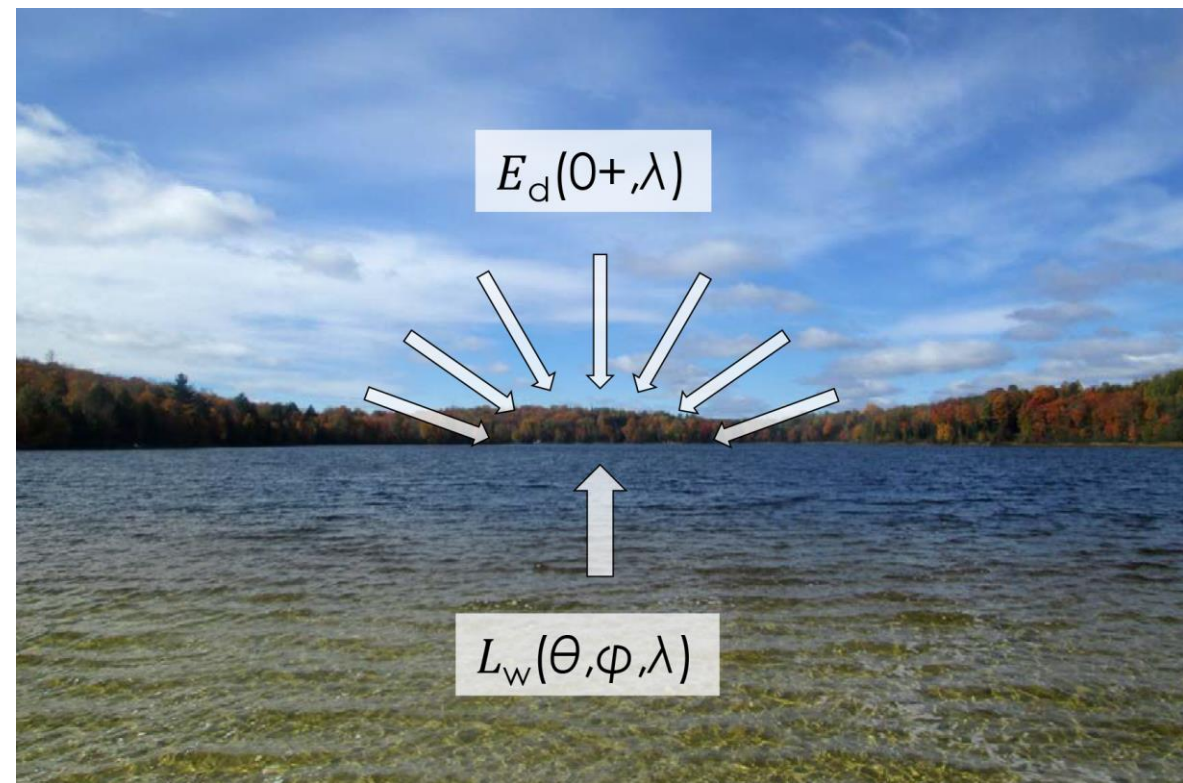
# Light and Water

## Apparent Optical Properties (AOPs) and the ‘Color’ of Water

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

- $R_{rs}(\theta, \phi, \lambda)$ : remote sensing reflectance
- $L_w(\theta, \phi, \lambda)$ : water leaving radiance
- $E_d(0^+, \lambda)$ : downwelling irradiance
- $\theta$ : solar zenith angle
- $\phi$ : solar azimuth angle
- $\lambda$ : wavelength

Calculation of the remote sensing reflectance of waterbodies. This equation relates the ratio of the water leaving radiance and the downwelling irradiance ( $L_w(\theta, \phi, \lambda)$  and  $E_d(0^+, \lambda)$ ) to the remote sensing reflectance ( $R_{rs}(\theta, \phi, \lambda)$ ).



# Light and Water

## 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

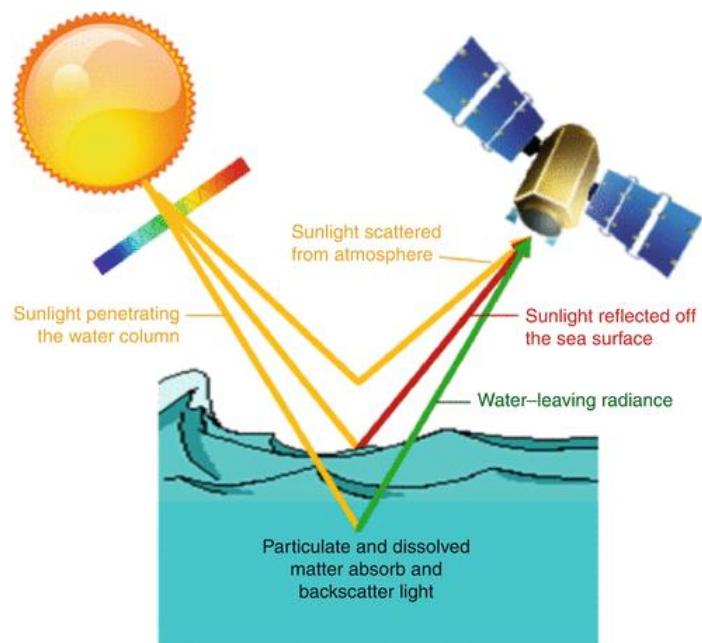
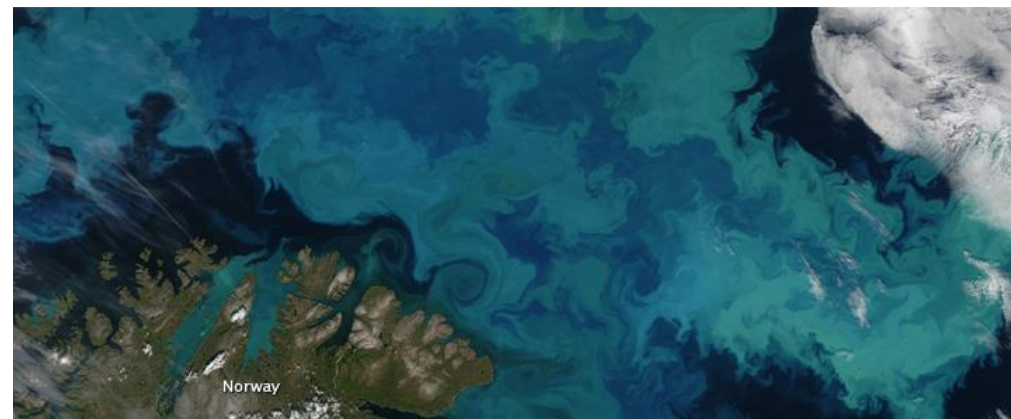
A good AOP depends weakly on the external environment (sky condition, surface waves) and strongly on the water IOPs

**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

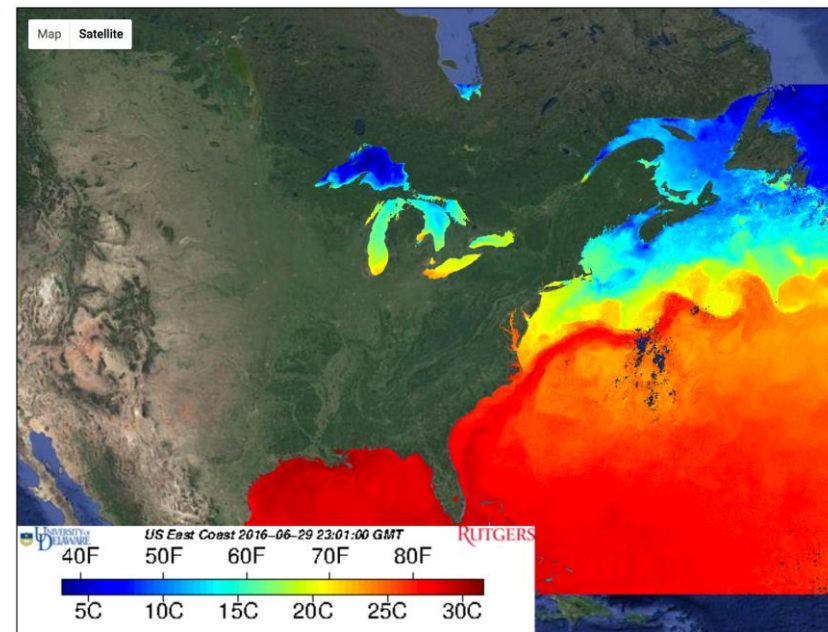
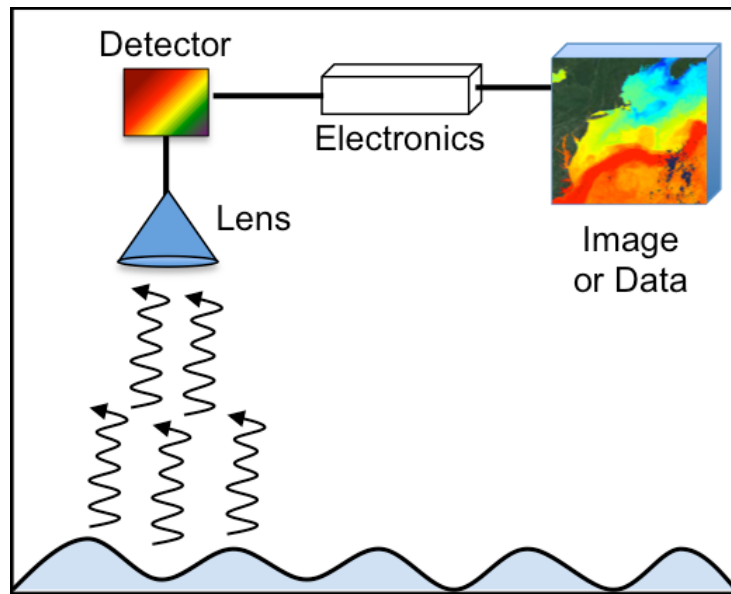


- Suspended Sediments
- Algae
- Colored Dissolved Organic Matter
- Detrital Organic Matter
- Submerged or floating vegetation
- Oil

# Remote Sensing of Water Bodies

## Emitted Thermal Radiation

Used to derive the surface temperature of water bodies



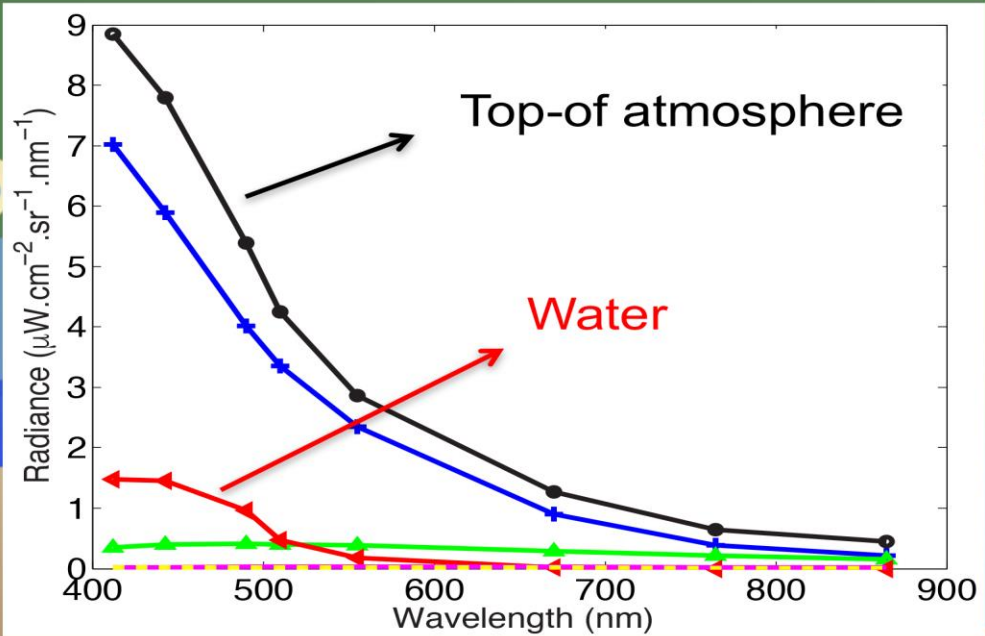
# Remote Sensing of Water Bodies

## 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%

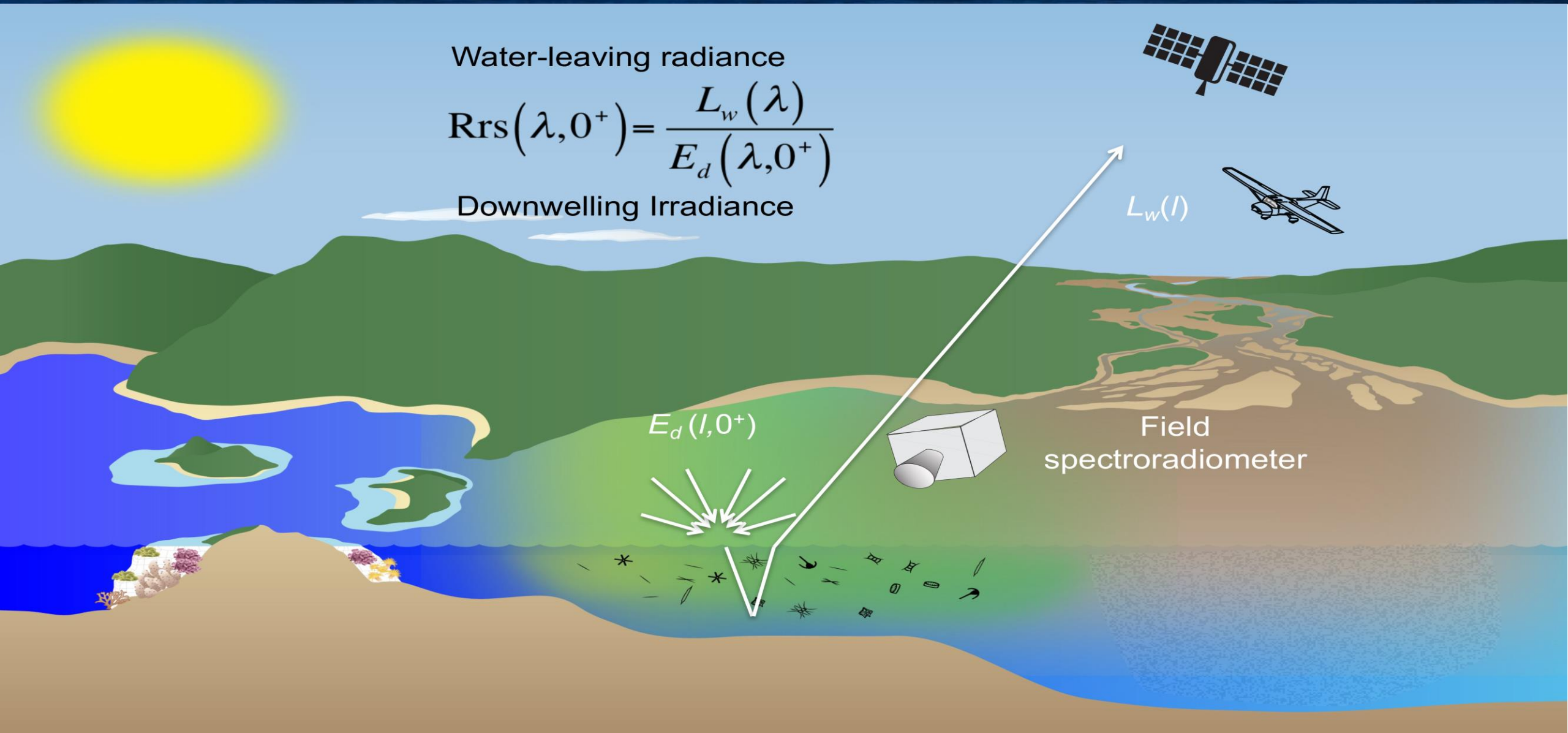


# Remote Sensing of Water Bodies

Water-leaving radiance

$$R_{rs}(\lambda, 0^+) = \frac{L_w(\lambda)}{E_d(\lambda, 0^+)}$$

Downwelling Irradiance



# 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%

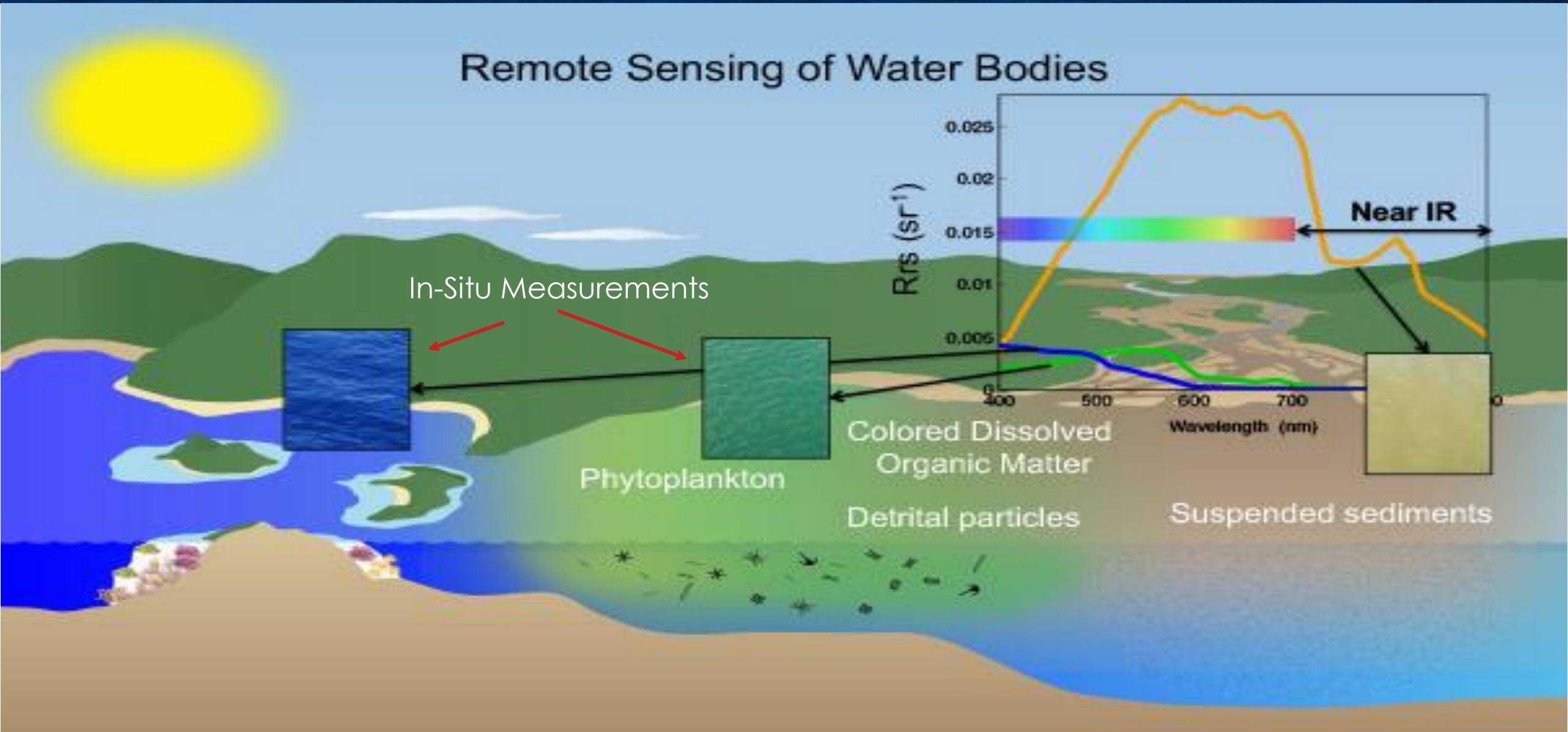


Atmospheric correction





# Remote Sensing of Water Bodies



# Remote Sensing of Water Bodies

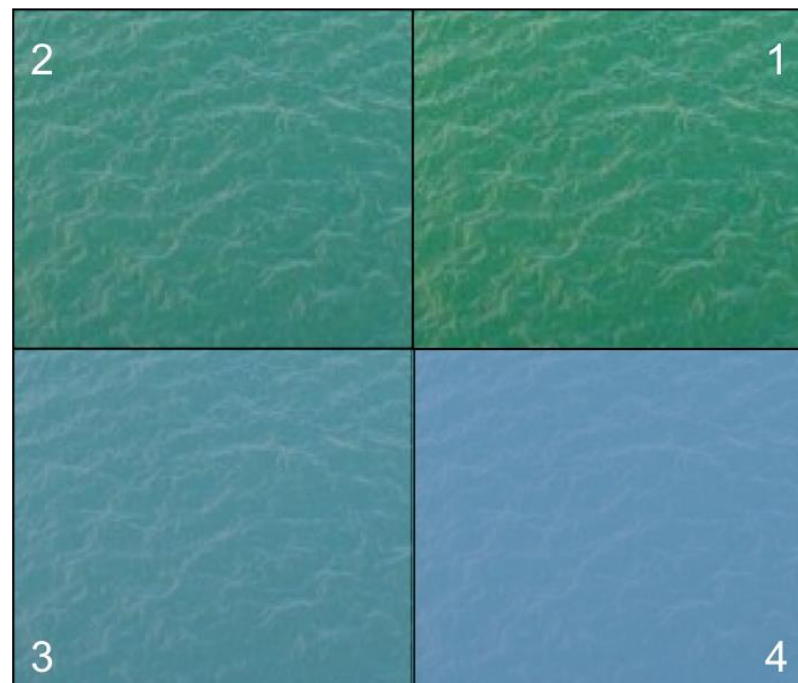
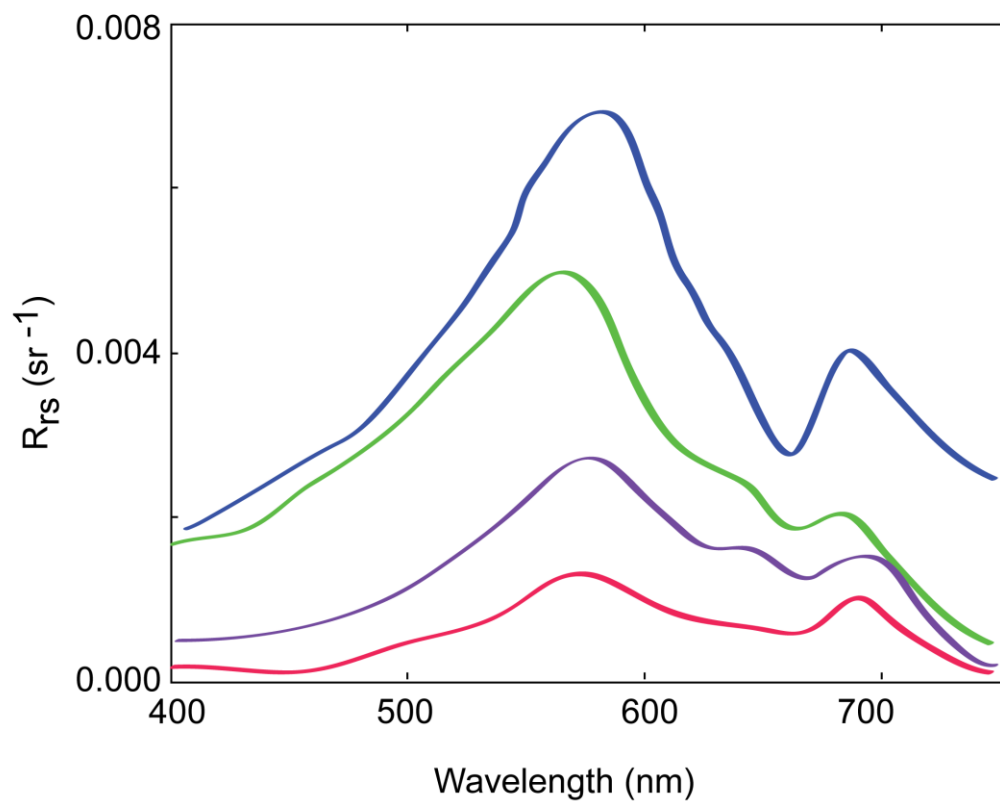
## How *In Situ* and Satellite Observations Roughly Correspond

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

# Remote Sensing of Water Bodies

## Chlorophyll-a from Remote Sensing Reflectance ( $R_{rs}$ )

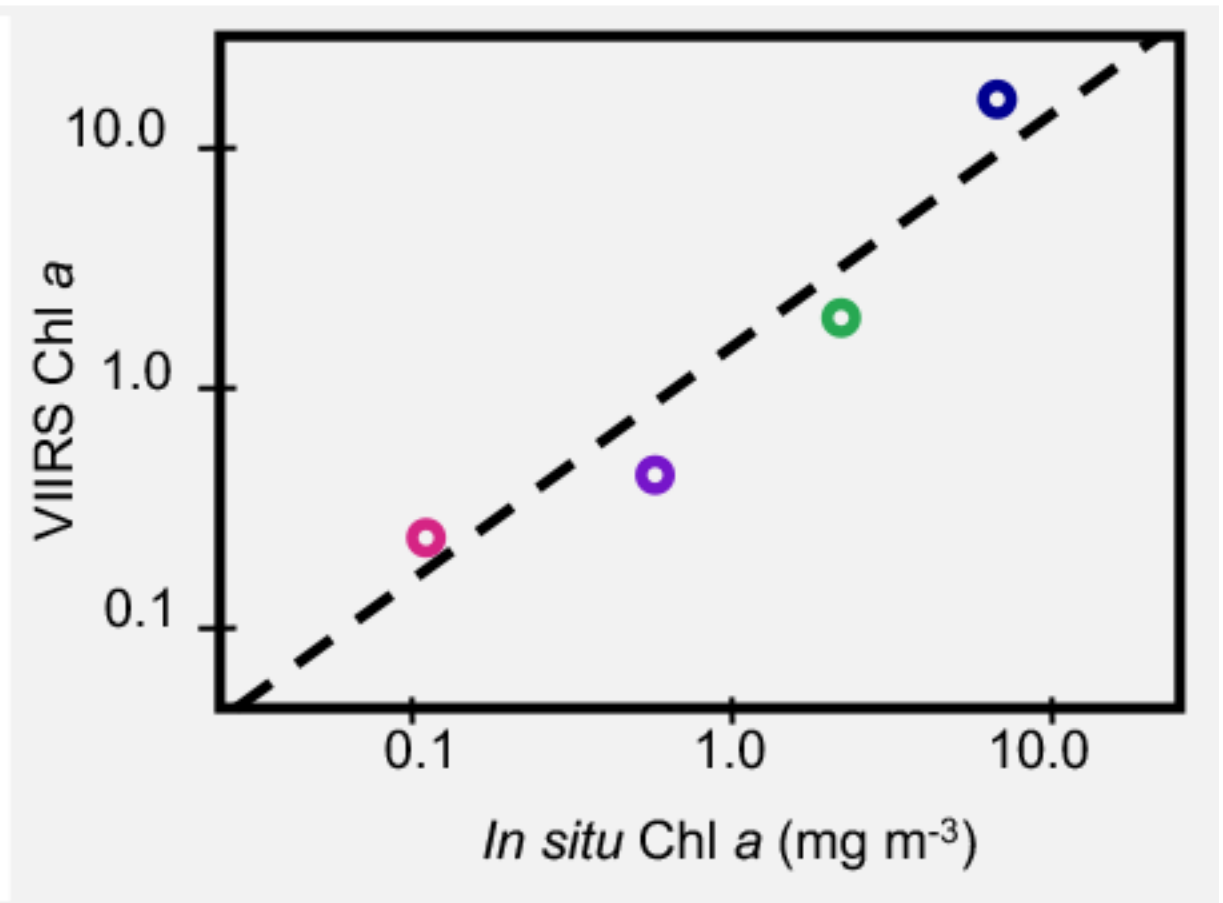
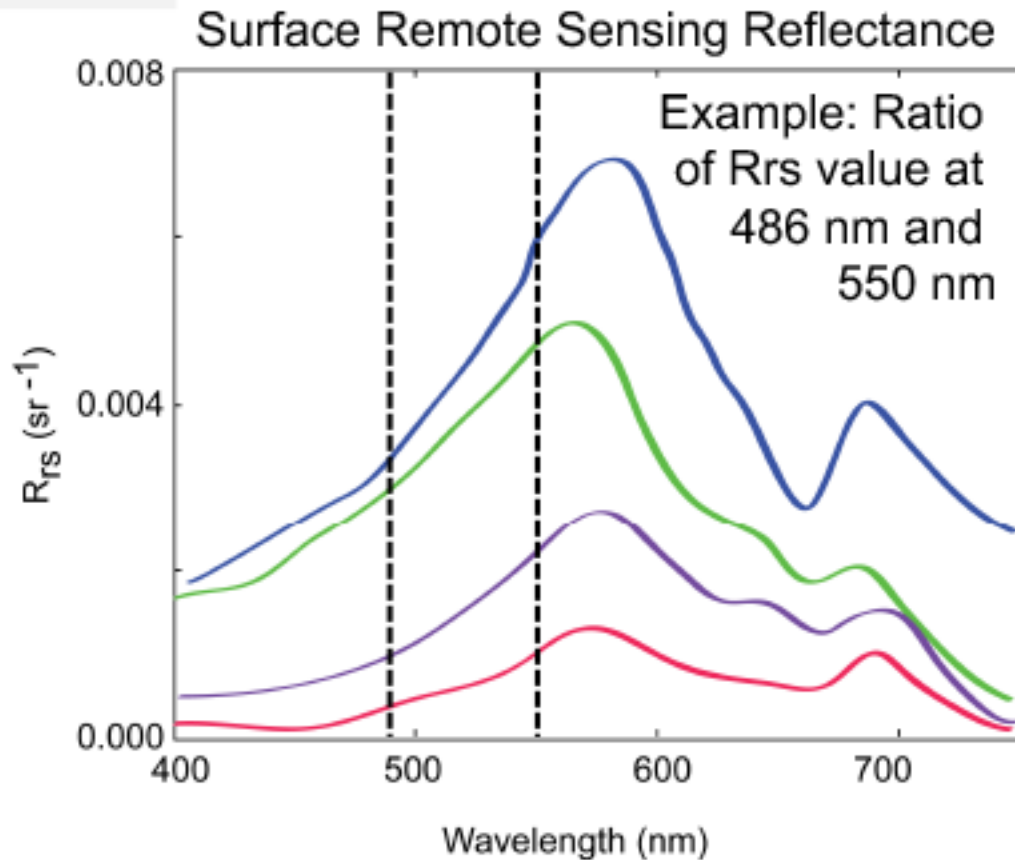
$R_{rs}$  at Different Chlorophyll-a Concentrations



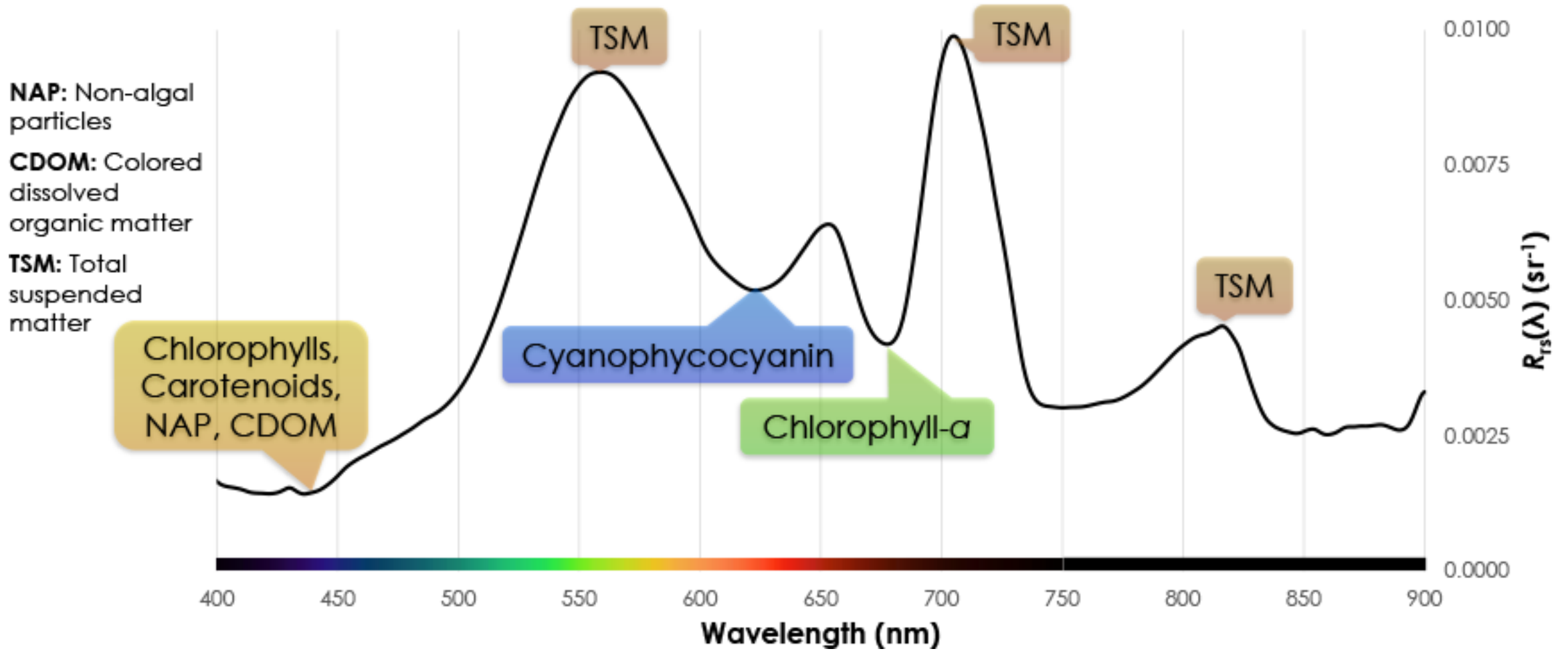
# Remote Sensing of Water Bodies

## Chlorophyll-a Estimates

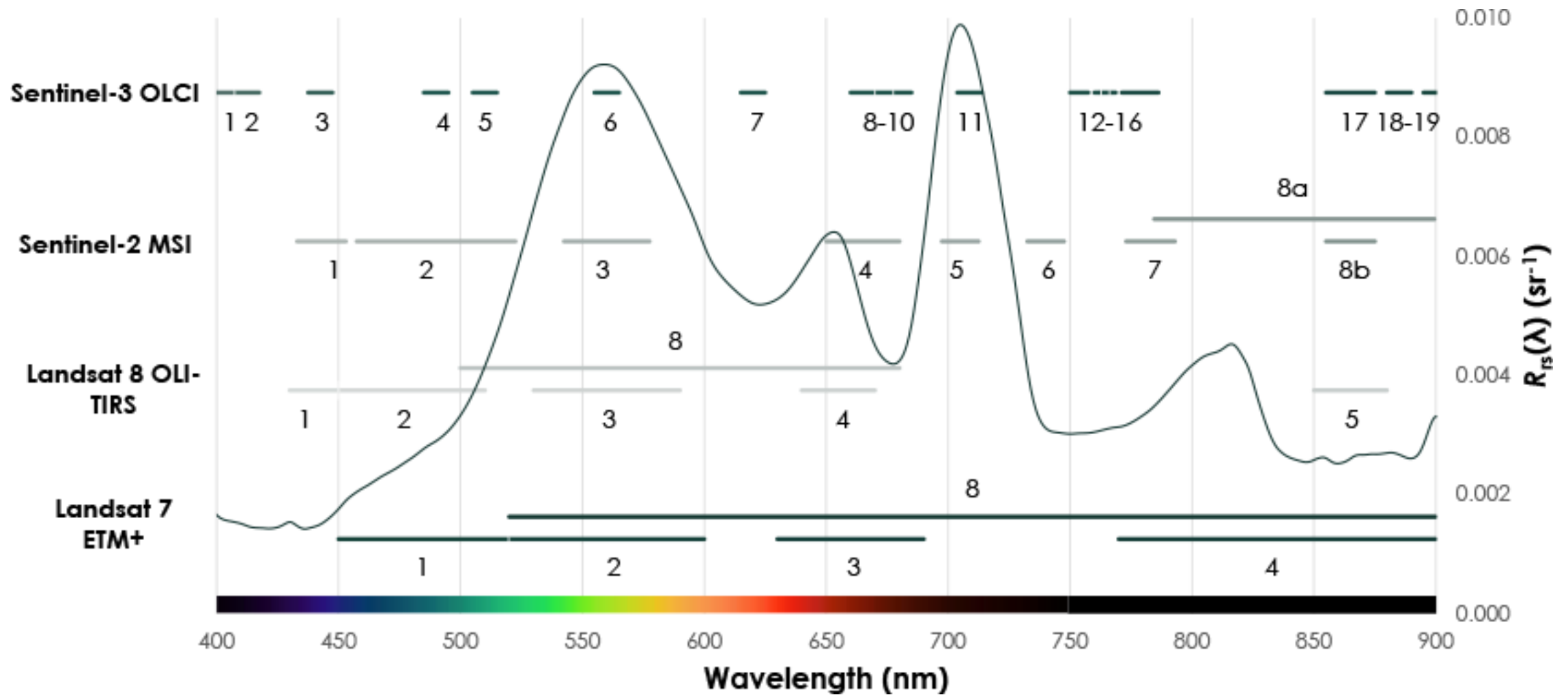
Estimations are a function of the ratios of Rrs values



# 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)	<ul style="list-style-type: none"> <li>• Thematic Mapper (TM)</li> <li>• Enhanced Thematic Mapper (ETM+)</li> <li>• Operational Land Imager (OLI)</li> </ul>	<ul style="list-style-type: none"> <li>• Spectral Reflectance</li> </ul>
Terra (12/1999 - present)	Moderate Resolution Imaging Spectroradiometer (MODIS)	<ul style="list-style-type: none"> <li>• Spectral Reflectance</li> <li>• Chlorophyll-a Concentration</li> <li>• Temperature</li> <li>• Colored Dissolved Organic Matter (CDOM)</li> <li>• Turbidity</li> <li>• Euphotic Depth</li> </ul>
Aqua (5/2002 - present)		
Terra (12/1999 – present)	Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER)	<ul style="list-style-type: none"> <li>• Spectral Reflectance</li> <li>• Temperature</li> </ul>



# NASA Satellites & Sensors for Ocean and Coastal Systems

Satellite	Sensor	Parameter
National Polar Partnership (NPP) (11/2011-present)	Visible Infrared Imaging Radiometer Suite (VIIRS)	<ul style="list-style-type: none"><li>• Spectral Reflectance</li><li>• Chlorophyll Concentration</li></ul>
International Space Station	Hyperspectral Imager for the Coastal Ocean (HICO) (2009 – 2014)	<ul style="list-style-type: none"><li>• Spectral Radiance</li><li>• Spectral Remote Sensing Reflectance</li></ul>
Plankton, Aerosols, Clouds, ocean Ecosystems (PACE) (proposed for 2022 or 2023)	Ocean Color Instrument	<ul style="list-style-type: none"><li>• Spectral Reflectance</li><li>• Optional Polarimeter being considered</li></ul>

# 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>

# NASA Satellites & Sensors for Ocean and Coastal Systems

## 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/>

# NASA Satellites & Sensors for Ocean and Coastal Systems

## **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
  - CrIS
  - OMPS
  - CERCES

## 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  $\mu\text{m}$
  - Sea Surface Temperature Bands 12-13: 3.660 - 4.128  $\mu\text{m}$

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

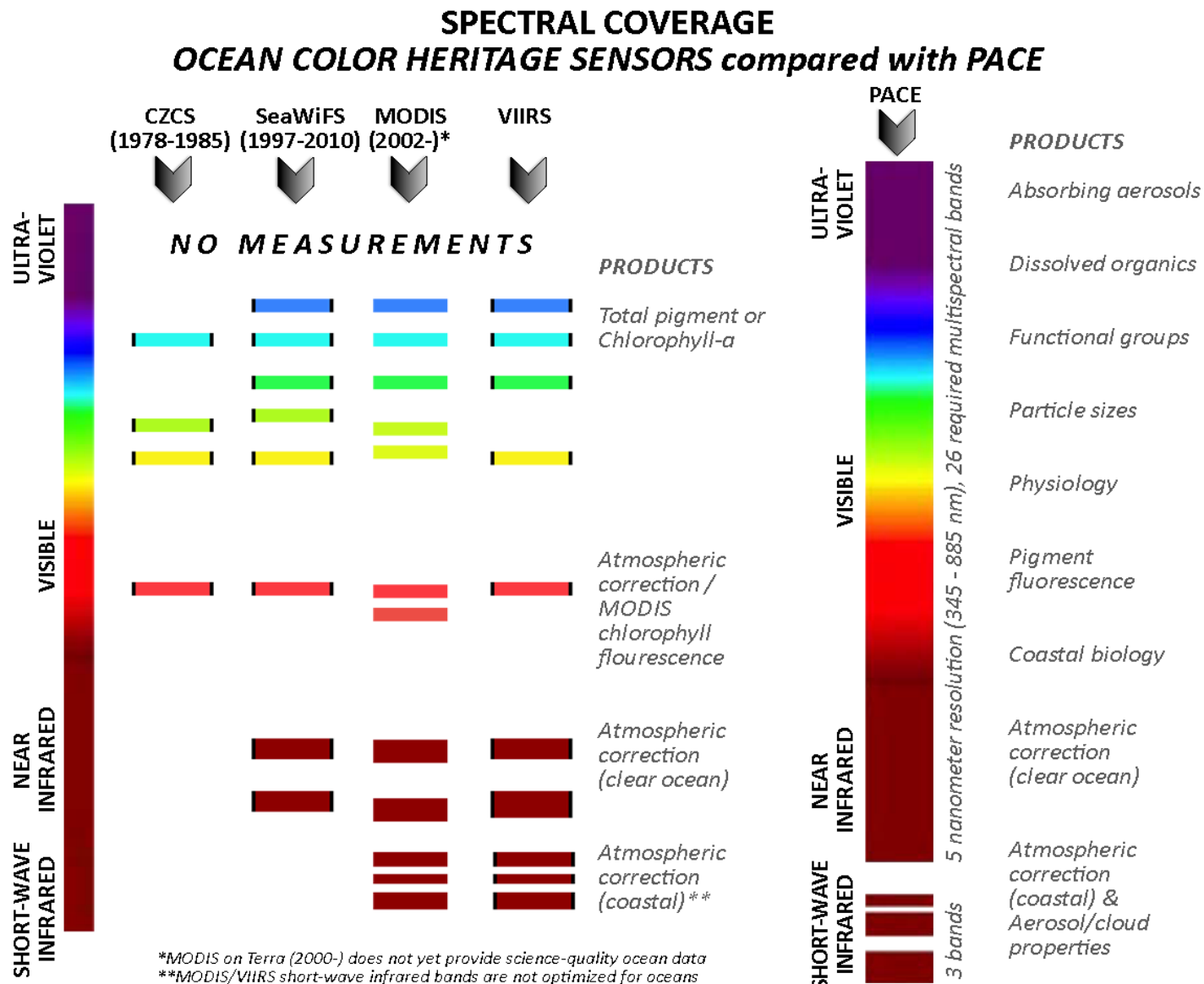
[http://www.nasa.gov/mission\\_pages/NPP](http://www.nasa.gov/mission_pages/NPP)

# NASA Satellites & Sensors for Ocean and Coastal Systems

## 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/>

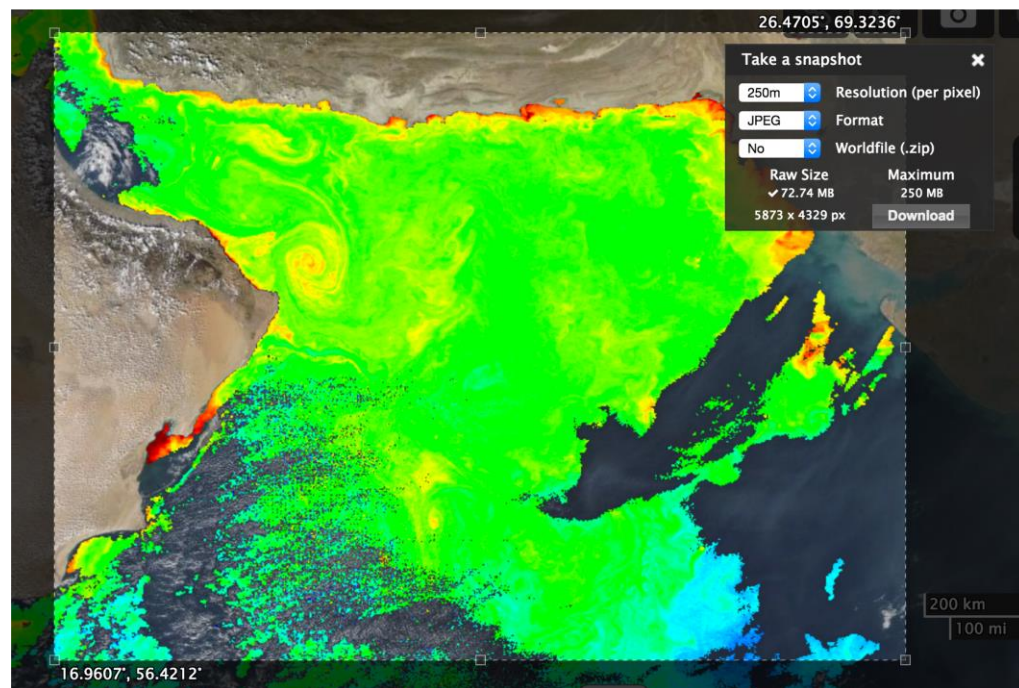


# Accessing NASA Satellite Data

## 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**

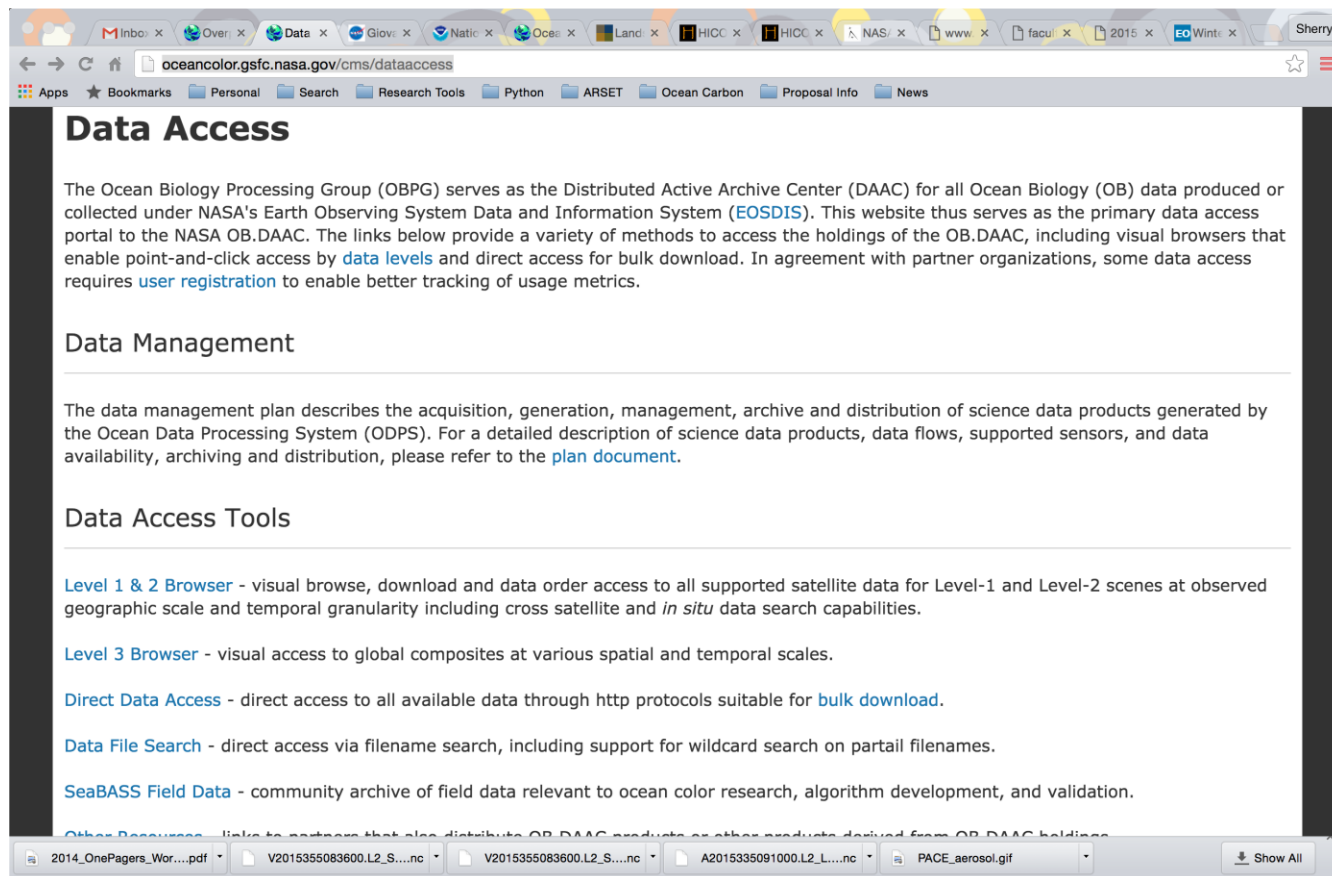
(Worldview Heritage)

<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>



# Accessing NASA Satellite Data

## NASA OceanColor Web – Level 1 & 2 Browser

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

TC **CHL** SST SST4

[Comment](#) [Help](#)

SeaWiFS <input type="checkbox"/> GAC <input type="checkbox"/> MLAC	MODIS <input checked="" type="checkbox"/> Aqua <input type="checkbox"/> Terra	MERIS <input type="checkbox"/> RR <input type="checkbox"/> FRS
<input type="checkbox"/> VIIRS (Suomi-NPP) <input type="checkbox"/> OCTS (ADEOS)	<input type="checkbox"/> HICO (ISS)	<input type="checkbox"/> GOCI (COMS) <input type="checkbox"/> CZCS (Nimbus-7)

Select  Day  
 Night

Radius (km) about map click or about typed-in location:

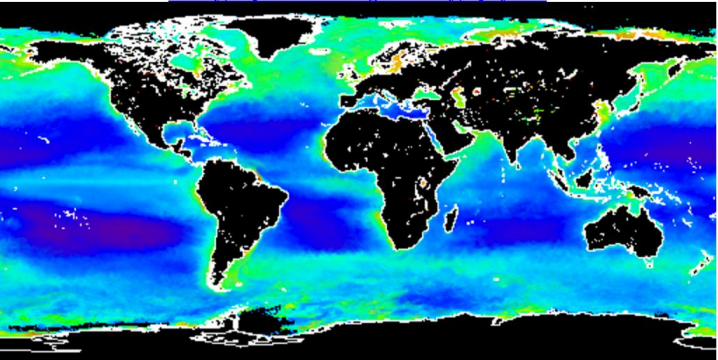
72  
 400  
 800  
 1200  
 1500

Select swaths containing (at least):

any part  
 25 %  
 50 %  
 75 %  
 all

Select only scenes having in situ matchups.

Sunday, 23 June 2002 through Saturday, 9 July 2016



Chlorophyll

Display results 10 at a time. [Reconfigure page](#)

Select one or more regions:

- AdriaticSea
- AegeanSea
- Antarctica
- ArabianSea
- AralSea
- Arctic
- Australia
- AustraliaCoast
- Azores
- Bahamas
- BalticSea

or specify boundary coordinates or a single location:

N:   
 W:  :E  
 S:   
[Find swaths](#)

Mission	2002	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	2003	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	2004	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	2005	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	2006	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	2007	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	2008	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	2009	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	2010	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	2011	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	2012	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	2013	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	2014	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	2015	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	2016	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec

May 2016						
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1	2	3	4	5	6	7
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8	9	10	11	12	13	14
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29	30	31				
xxx	xxx	xxx				

June 2016						
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July 2016						
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					xxx	xxx

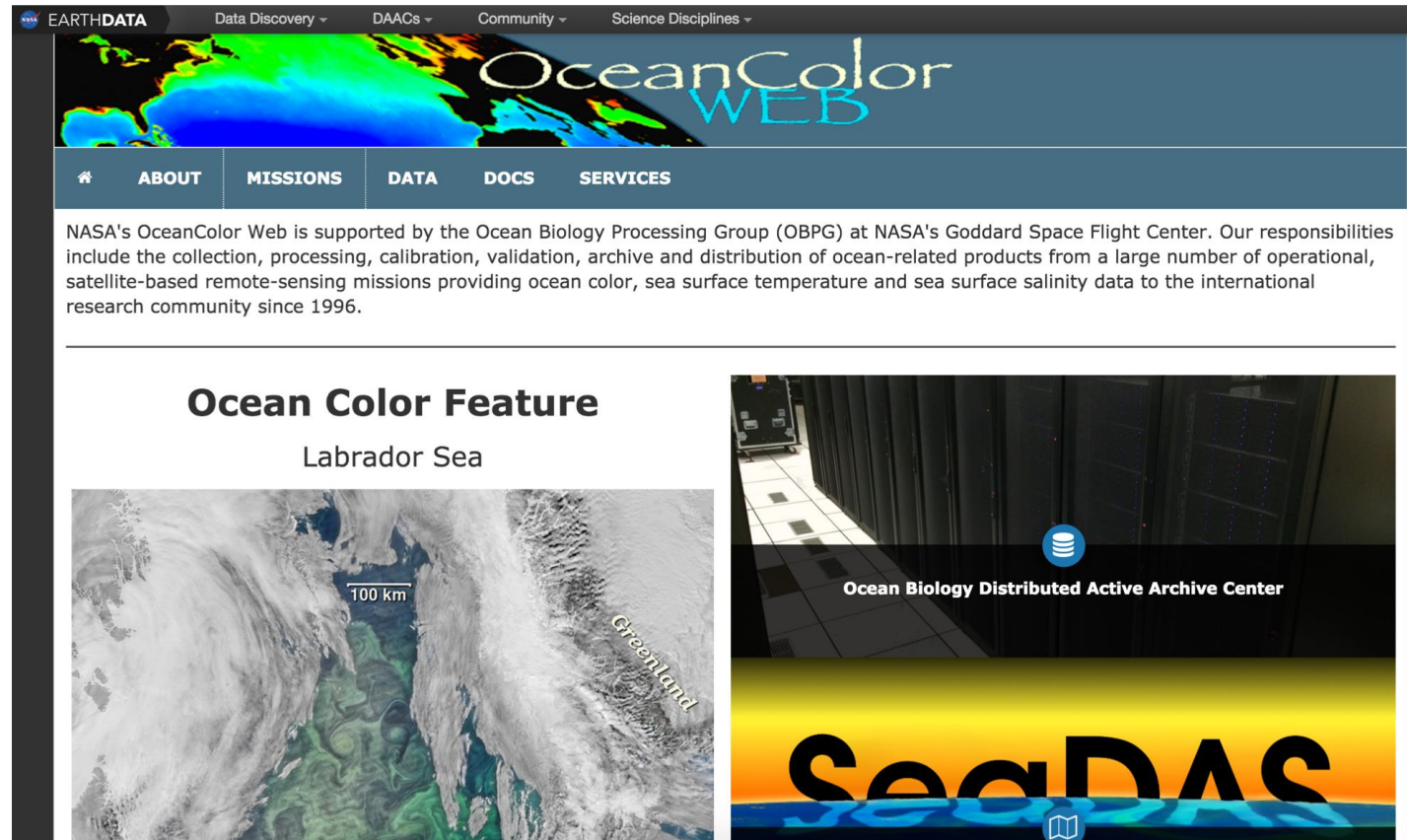
## Other Data Access Tools

- 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 Satellite Data Processing Tools

## 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



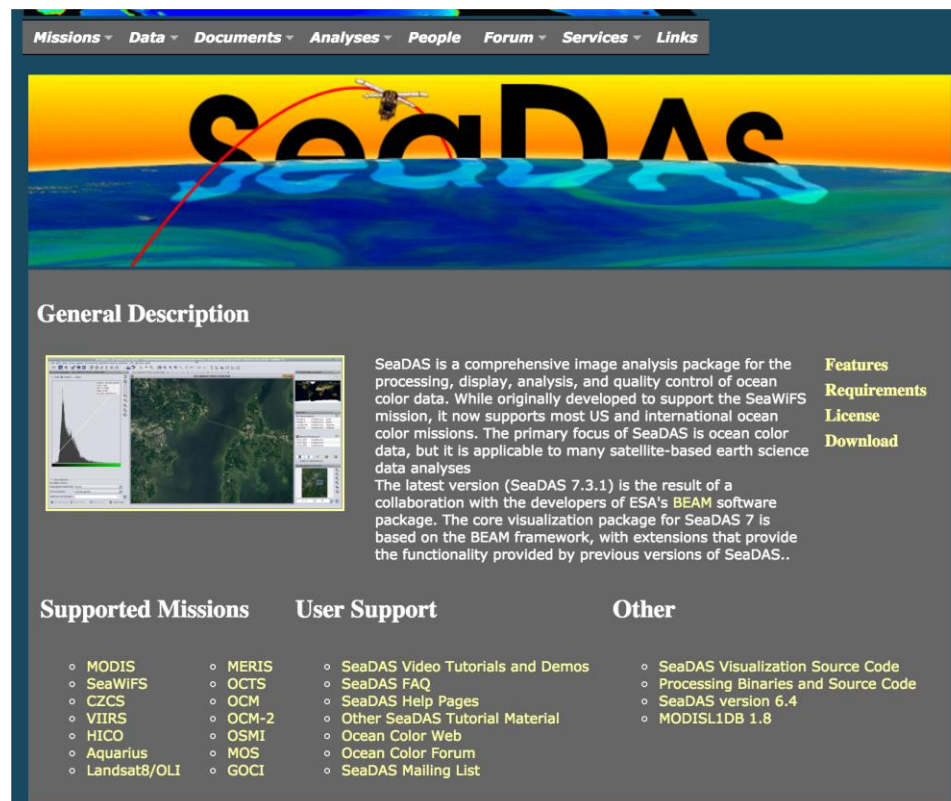
The screenshot shows the NASA OceanColor Web homepage. At the top, there is a navigation bar with the EarthData logo and menu items: Data Discovery, DAACs, Community, and Science Disciplines. Below this is a large banner image of a satellite ocean color map with the text "OceanColor WEB" overlaid. A secondary navigation bar contains links for Home, ABOUT, MISSIONS, DATA, DOCS, and SERVICES. The main content area features a paragraph describing the web's mission, supported by the Ocean Biology Processing Group (OBPG) at NASA's Goddard Space Flight Center. Below the text are two featured images: "Ocean Color Feature" showing a satellite view of the Labrador Sea with a 100 km scale bar and the label "Greenland", and "Ocean Biology Distributed Active Archive Center" (SeaDAS) showing a server room with the SeaDAS logo.

# NASA Satellite Data Processing Tools

## 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/>



Missions ▾ Data ▾ Documents ▾ Analyses ▾ People ▾ Forum ▾ Services ▾ Links

# SeaDAS

### General Description

SeaDAS is a comprehensive image analysis package for the processing, display, analysis, and quality control of ocean color data. While originally developed to support the SeaWiFS mission, it now supports most US and international ocean color missions. The primary focus of SeaDAS is ocean color data, but it is applicable to many satellite-based earth science data analyses.

The latest version (SeaDAS 7.3.1) is the result of a collaboration with the developers of ESA's BEAM software package. The core visualization package for SeaDAS 7 is based on the BEAM framework, with extensions that provide the functionality provided by previous versions of SeaDAS..

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Supported Missions	User Support	Other
<ul style="list-style-type: none"><li>◦ MODIS</li><li>◦ SeaWiFS</li><li>◦ CZCS</li><li>◦ VIIRS</li><li>◦ HICO</li><li>◦ Aquarius</li><li>◦ Landsat8/OLI</li></ul>	<ul style="list-style-type: none"><li>◦ MERIS</li><li>◦ OCTS</li><li>◦ OCM</li><li>◦ OCM-2</li><li>◦ OSMI</li><li>◦ MOS</li><li>◦ GOCI</li></ul>	<ul style="list-style-type: none"><li>◦ SeaDAS Video Tutorials and Demos</li><li>◦ SeaDAS FAQ</li><li>◦ SeaDAS Help Pages</li><li>◦ Other SeaDAS Tutorial Material</li><li>◦ Ocean Color Web</li><li>◦ Ocean Color Forum</li><li>◦ SeaDAS Mailing List</li></ul>
		<ul style="list-style-type: none"><li>◦ SeaDAS Visualization Source Code</li><li>◦ Processing Binaries and Source Code</li><li>◦ SeaDAS version 6.4</li><li>◦ MODISL1DB 1.8</li></ul>

# ESA Satellite Data Processing Tools

## SNAP

**The Sentinel Application Platform (SNAP)** is a common architecture for all Sentinel Toolboxes. The software is developed by Brockmann Consult, Skywatch, Sensor 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***