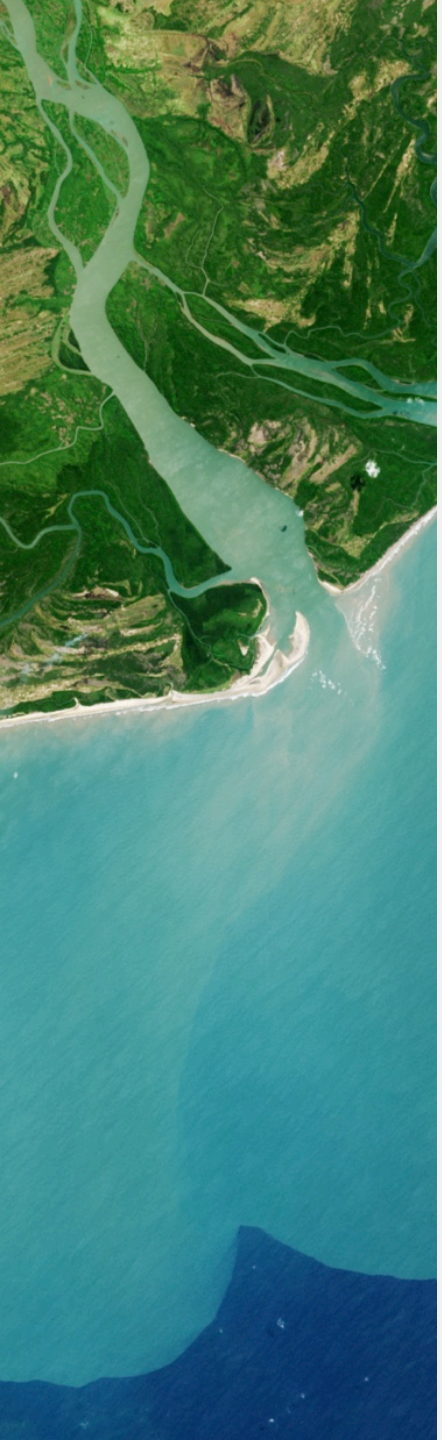


National Aeronautics and
Space Administration

ARSET

Applied Remote Sensing Training

http://arset.gsfc.nasa.gov

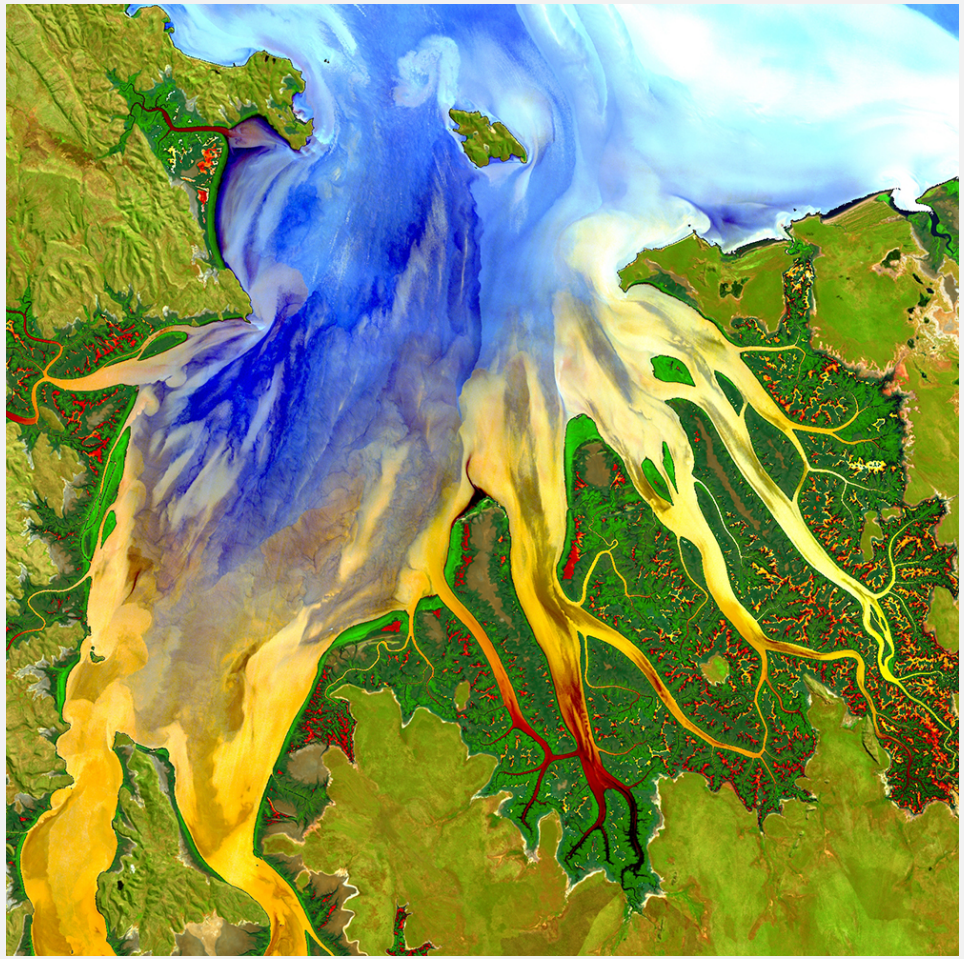
@NASAARSET

Fundamentals of Aquatic Remote Sensing

Sherry L. Palacios, Ph.D.

Course Objective

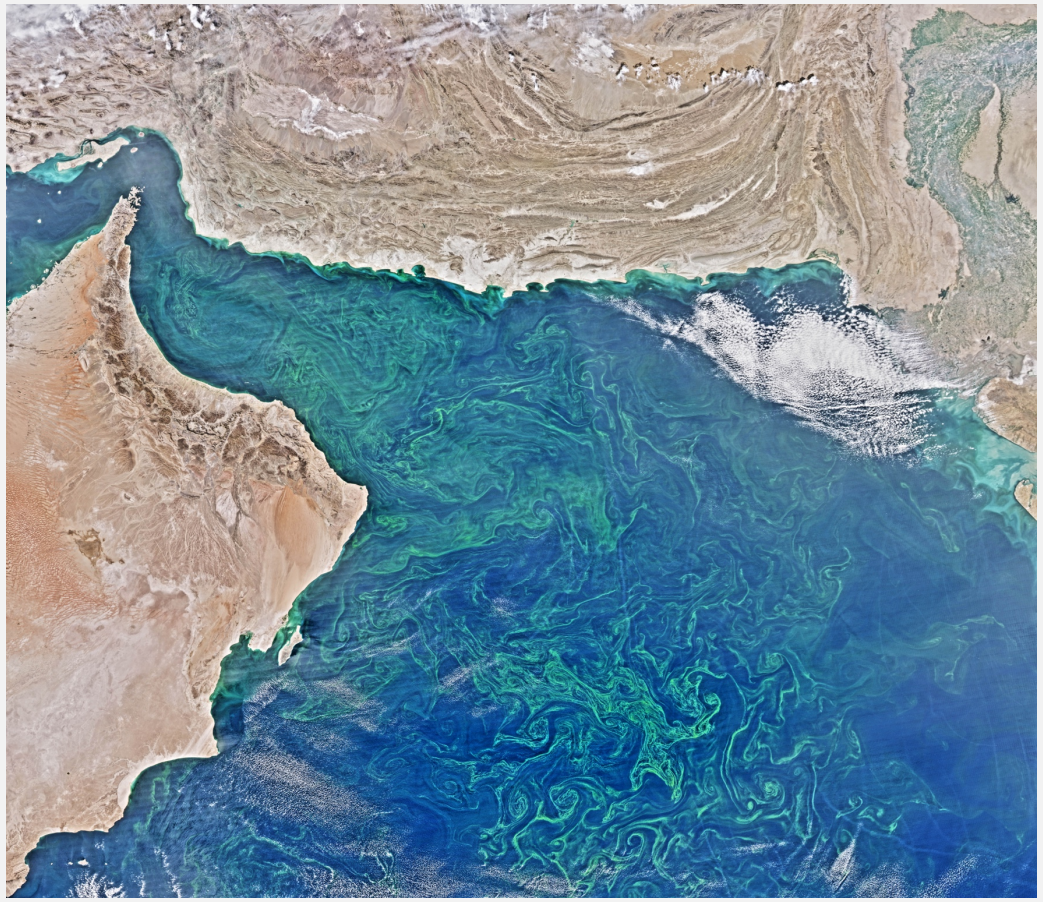
- Provide an overview of aquatic optics, the remote sensing of water targets, and NASA Earth observation resources available for aquatic applications.



Credit: NASA/USGS Landsat; Geoscience Australis

Agenda

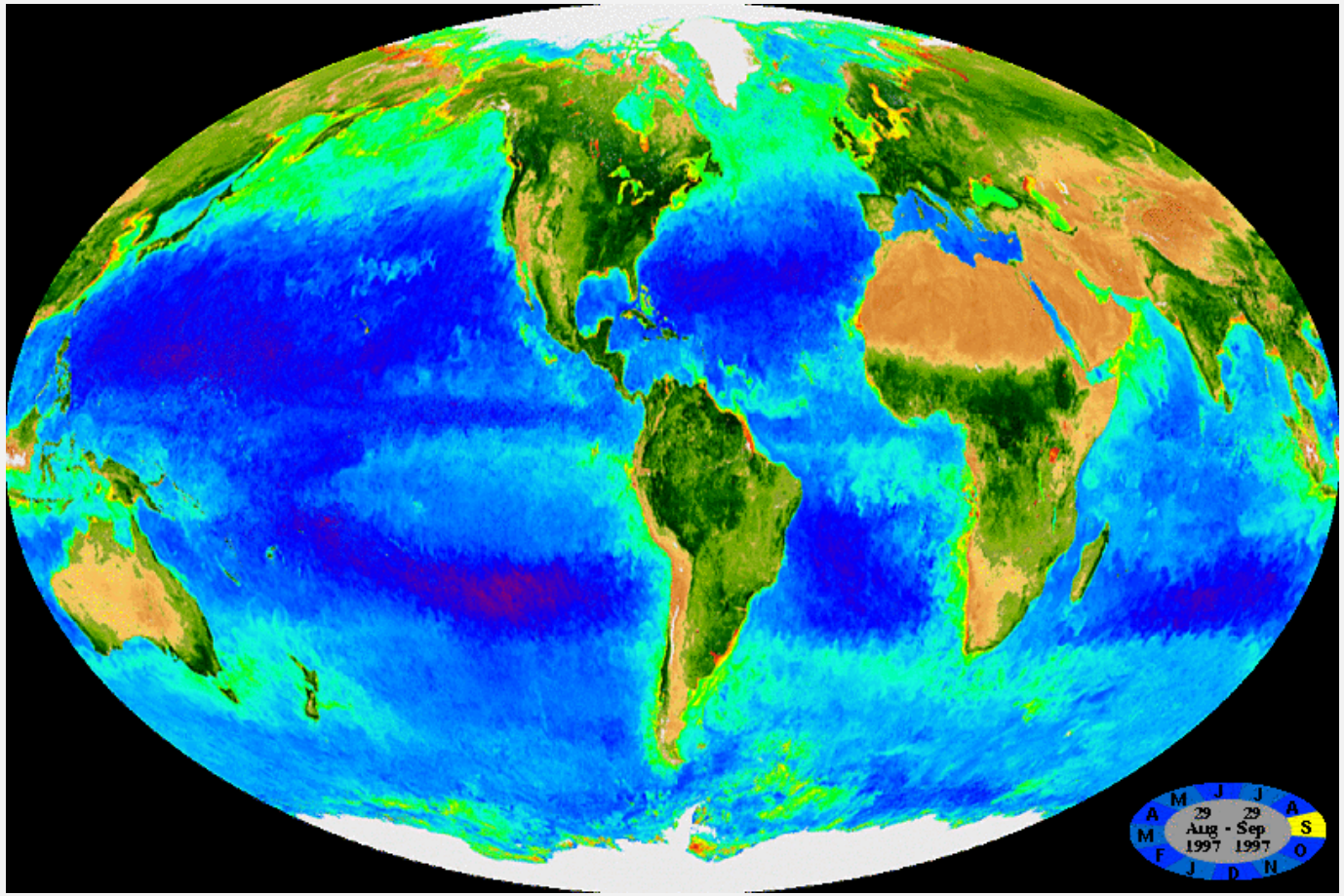
- Light and Water
- Fundamentals of Remote Sensing
- Aquatic Remote Sensing Data Products and Their Uses
- Accessing NASA Satellite Imagery
- NASA Satellite Data Processing Tools



Phytoplankton Bloom in the Arabian Sea
Credit: N. Kuring, http://earthobservatory.nasa.gov/IOTD/view.php?id=85718

Why Do We Observe from Space?

To Understand Earth's Processes on a Global Scale



SeaWiFS Chlorophyll
Credit: OBPG, NASA Goddard

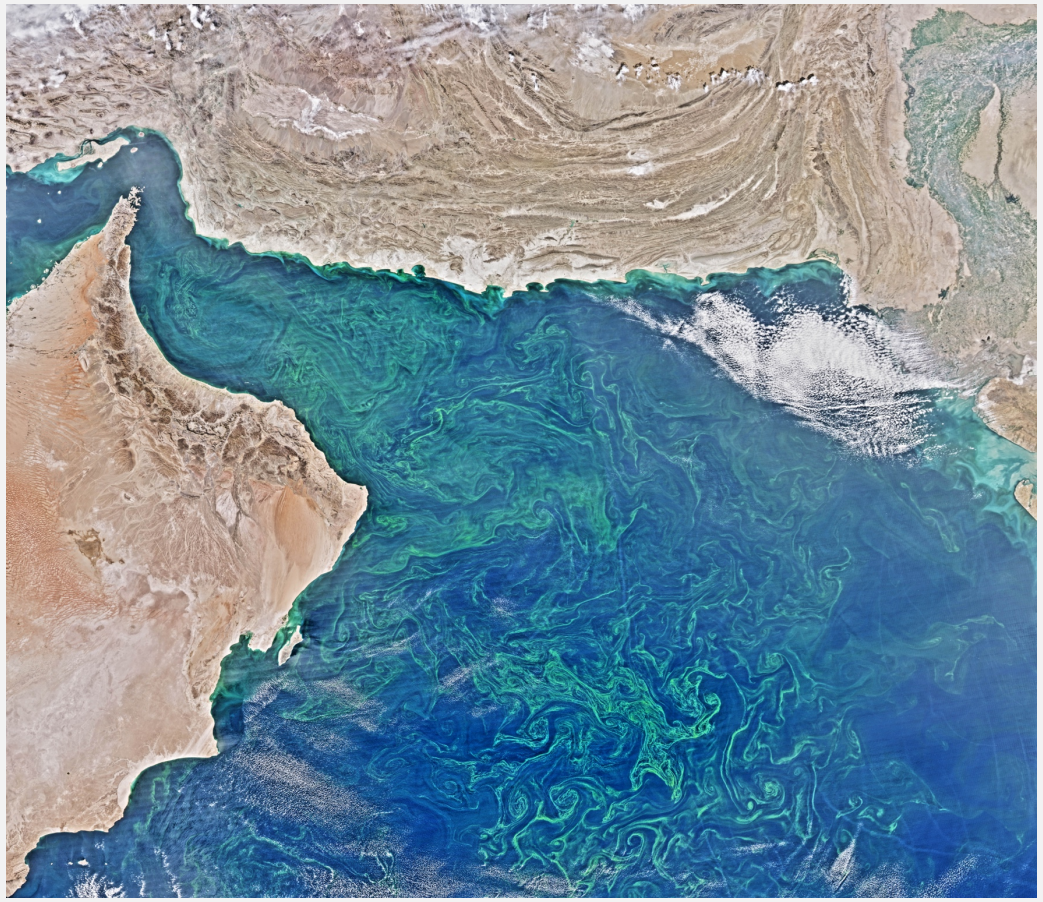
Advantages of Remote Sensing of Aquatic Environments

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

Light and Water

Agenda

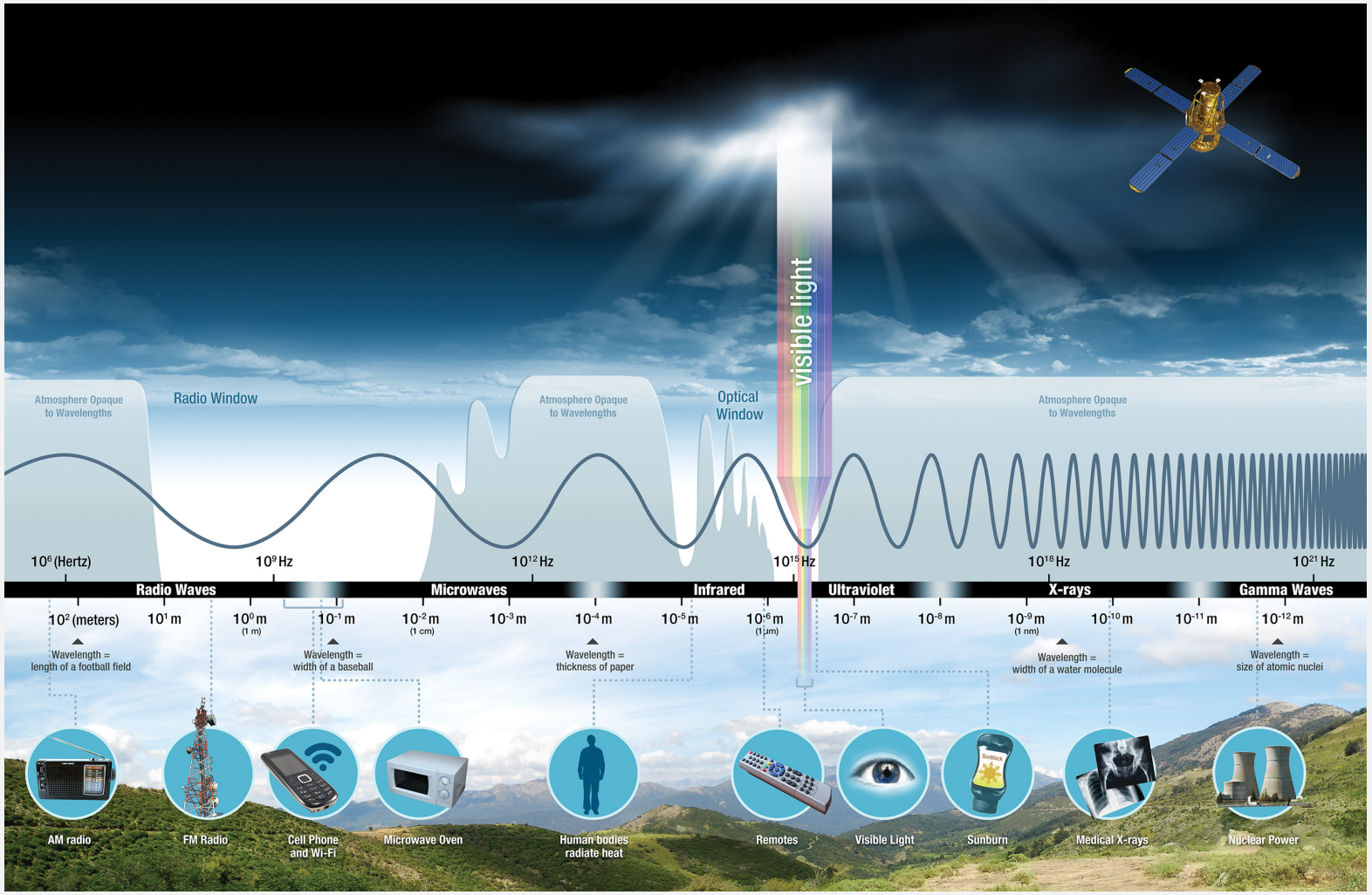
- Light and Water
  - How light propagates through the atmosphere and water column, and back to sensor
  - Constituents of the water column and their inherent optical properties
- Fundamentals of Remote Sensing
- Aquatic Remote Sensing Data Products and Their Uses
- Accessing NASA Satellite Imagery
- NASA Satellite Data Processing Tools



Phytoplankton Bloom in the Arabian Sea
Credit: N. Kuring, http://earthobservatory.nasa.gov/IOTD/view.php?id=85718

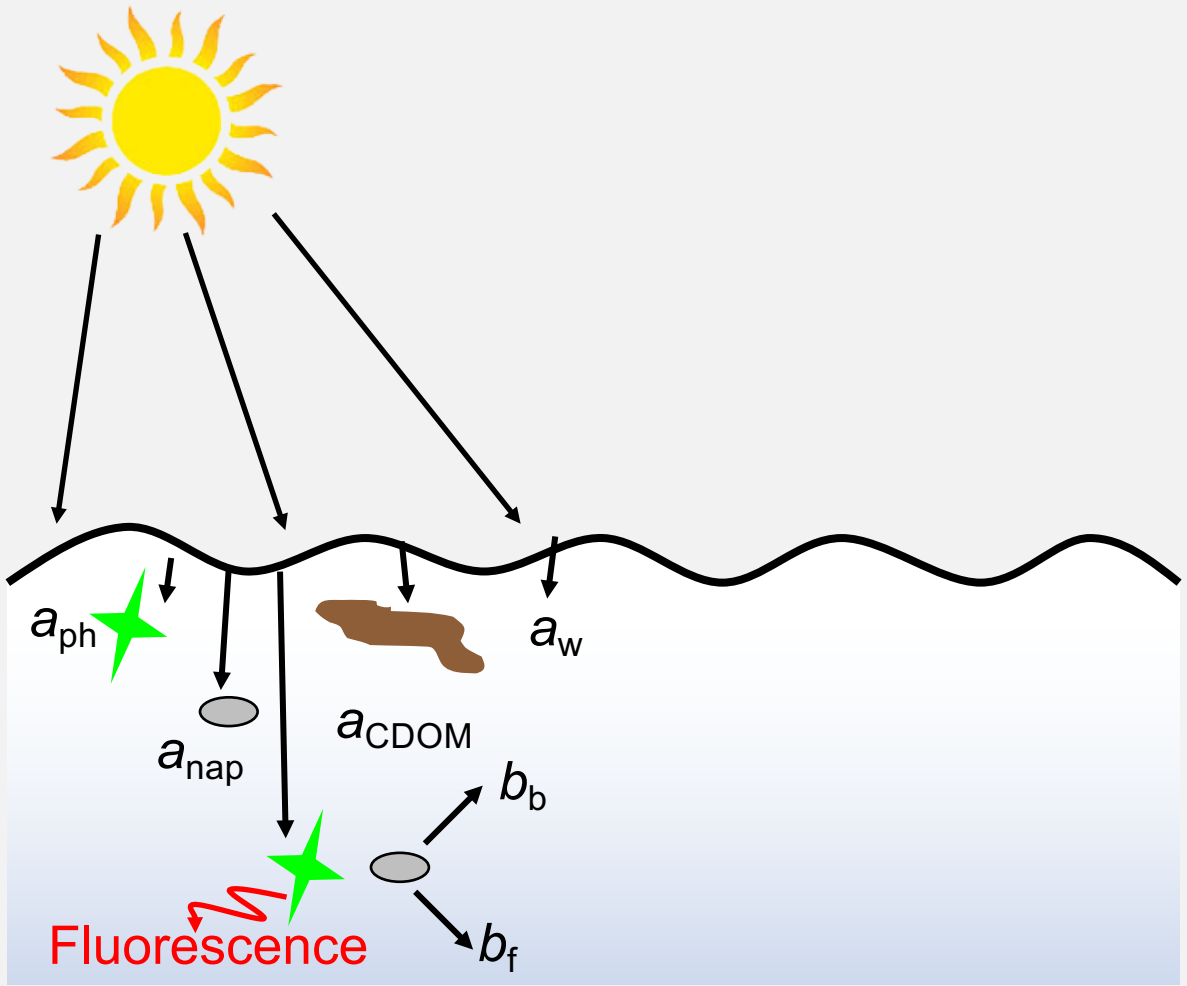
First, an Aquatic Optics Primer…

The Electromagnetic Spectrum



How Light Interacts with Water

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



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

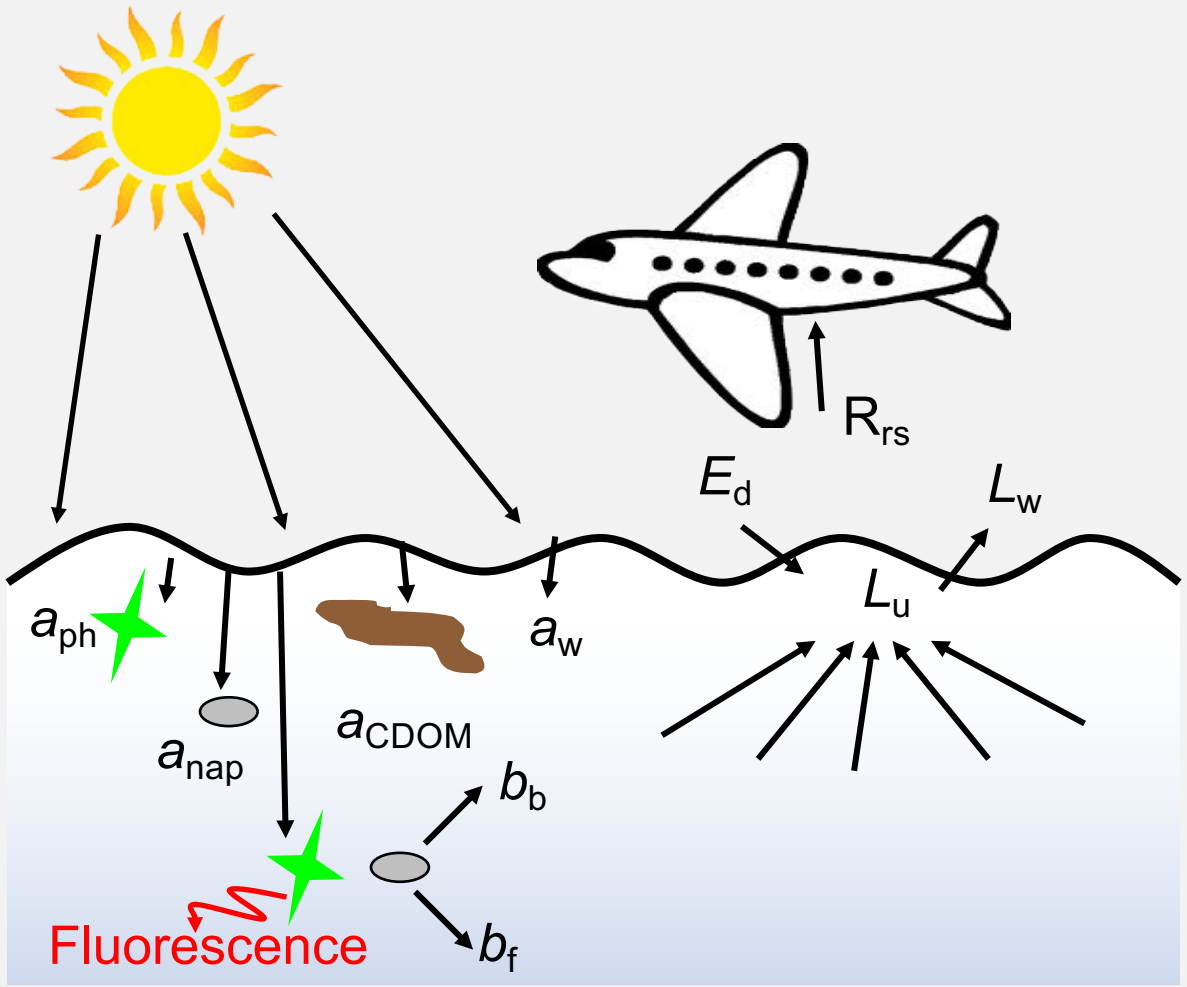
Inherent Optical Properties

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'



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

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

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

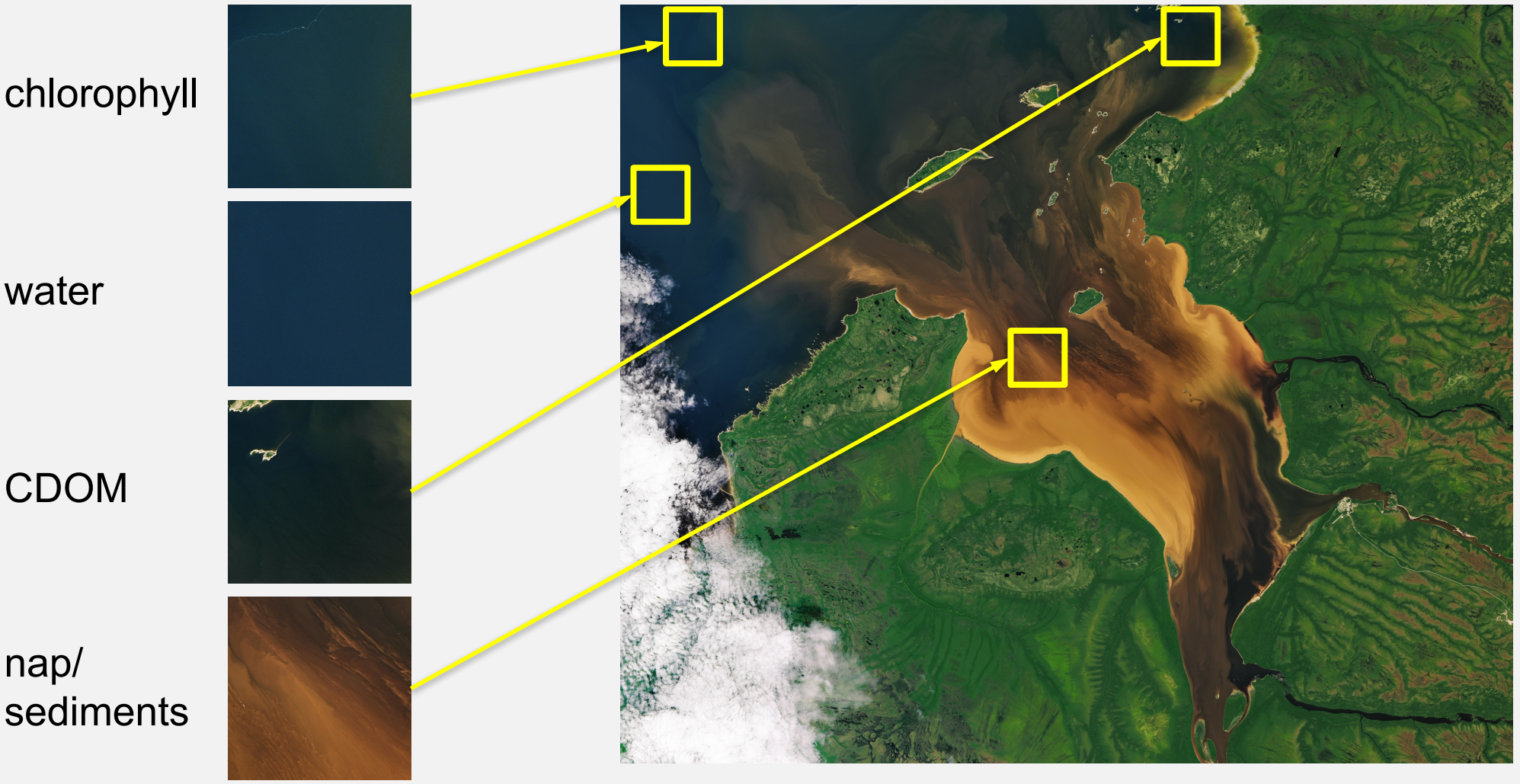
Light absorption (a) by photoplankton (ph), non-algal particles (nap), water (w), and colored dissolved organic matter (CDOM)

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

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

$$b = b_f + b_b$$

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



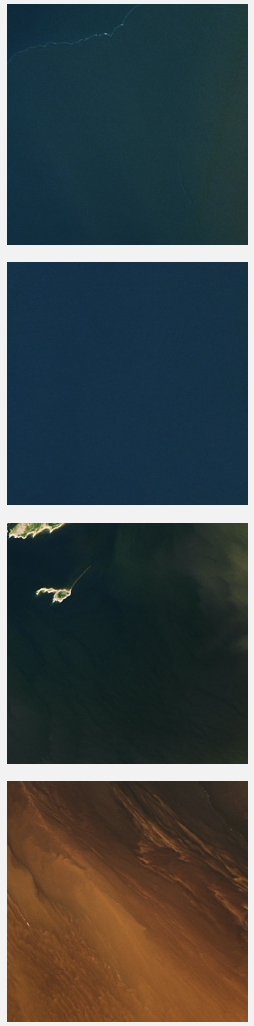
Inherent Optical Properties (IOPs) and the ‘Color’ of Water

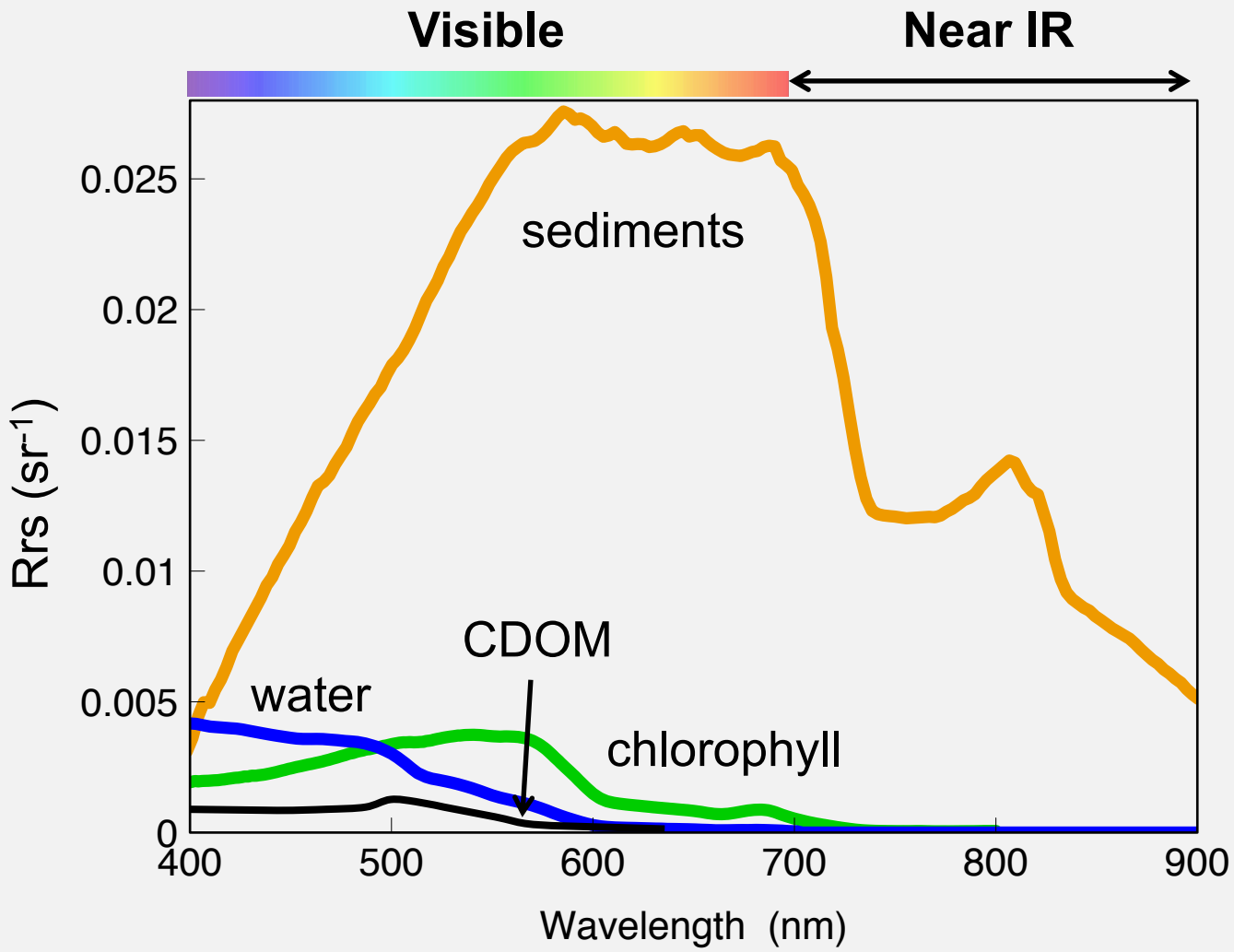
chlorophyll

water

CDOM

nap/
sediments

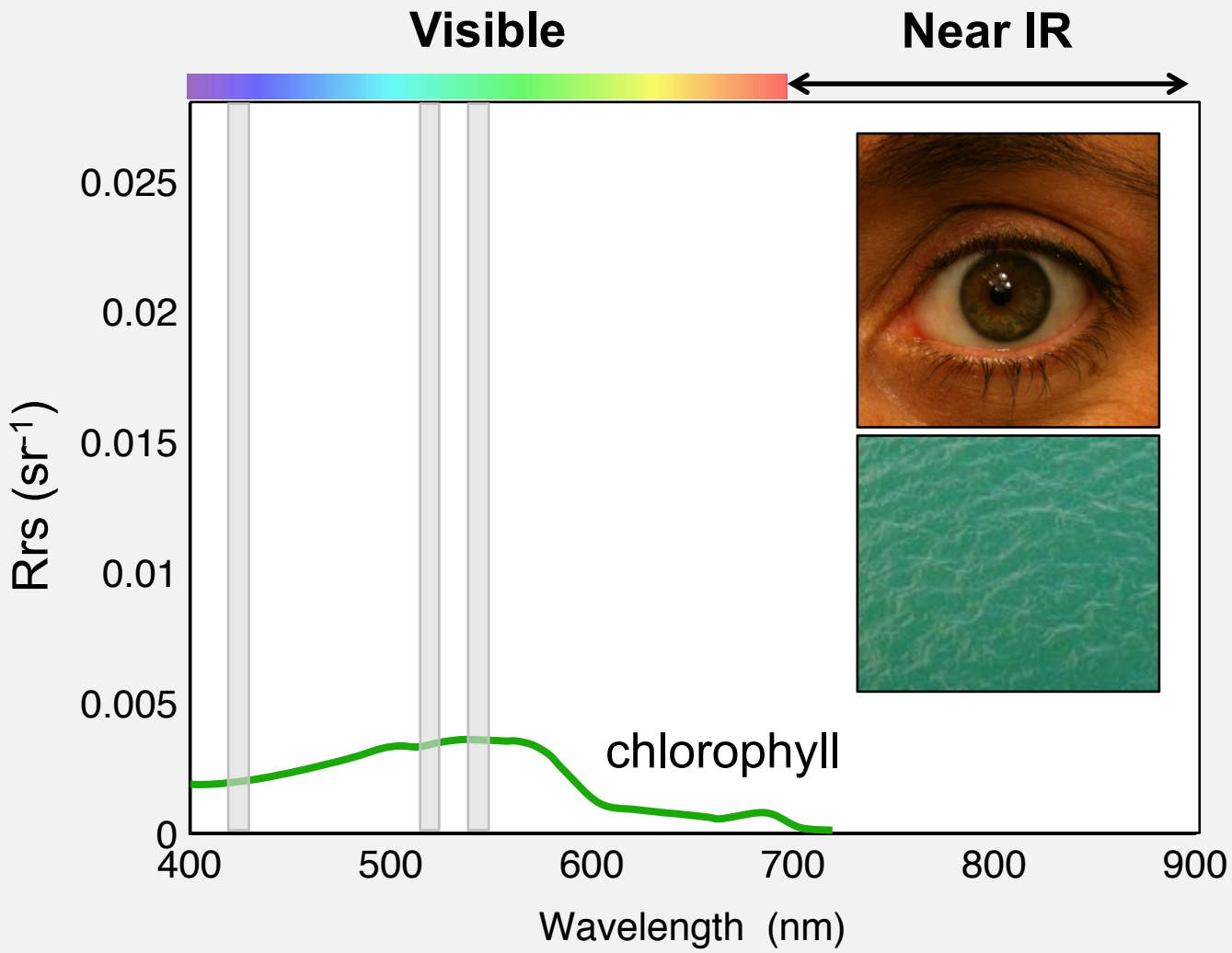




Inherent Optical Properties (IOPs) and the ‘Color’ of Water

- The typical human eye has color-detecting receptors that sense light at:
  - 420-440 nm ‘blue’
  - 534-555 nm ‘green’
  - 564-580 nm ‘red’

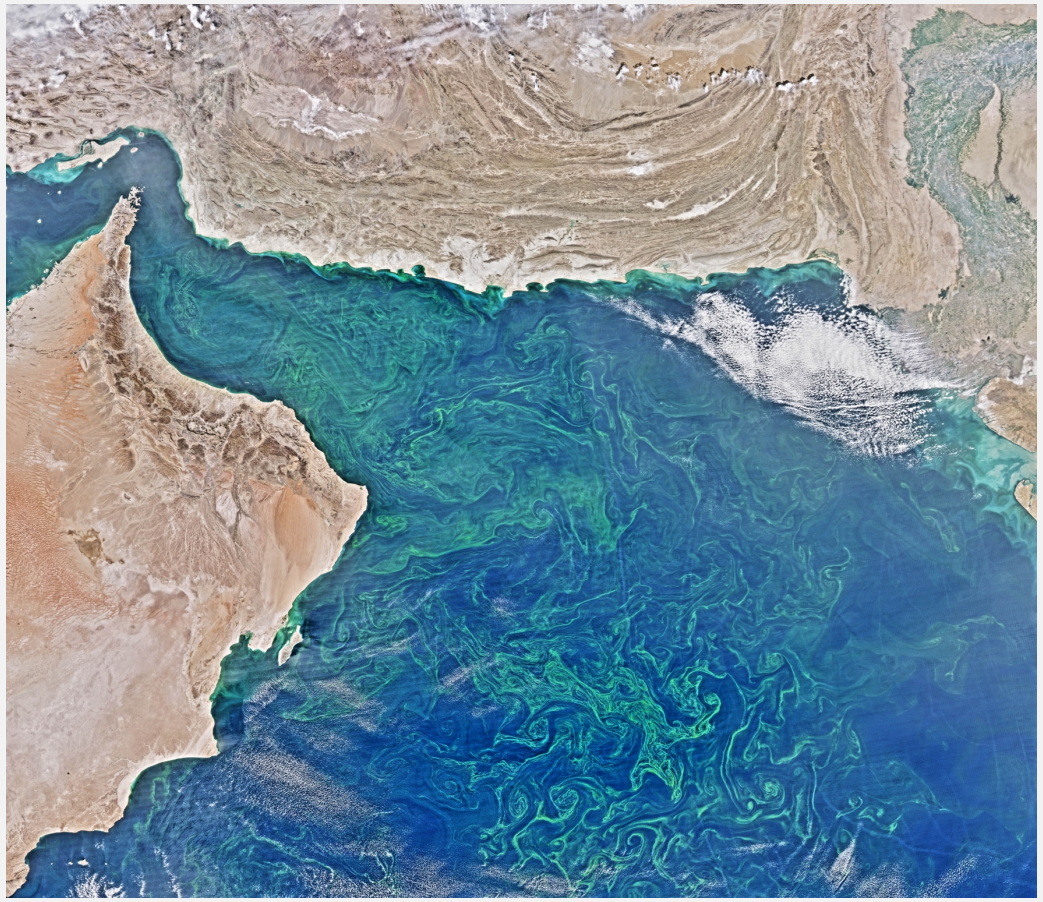
- Water with high chlorophyll content looks green because it reflects strongly in the green part of the spectrum



Fundamentals of Remote Sensing

Agenda

- Light and Water
- Fundamentals of Remote Sensing
  - Spatial, Temporal, Spectral Resolution
  - NASA Satellites and Sensors for Aquatic Applications
  - Image “Correction”
  - Satellite Data Processing Levels
- Aquatic Remote Sensing Data Products and Their Uses
- Accessing NASA Satellite Imagery
- NASA Satellite Data Processing Tools



Phytoplankton Bloom in the Arabian Sea
Credit: N. Kuring, http://earthobservatory.nasa.gov/IOTD/view.php?id=85718

Types of Resolution

Spatial Resolution

- Decided by its pixel size
- Pixel: smallest unit measured by a sensor

Temporal Resolution

- How frequently a satellite observes the same area of the Earth

Spectral Resolution

- Ability of a sensor to define fine wavelength intervals
- Finer spectral channels enable remote sensing of different parts of the atmosphere

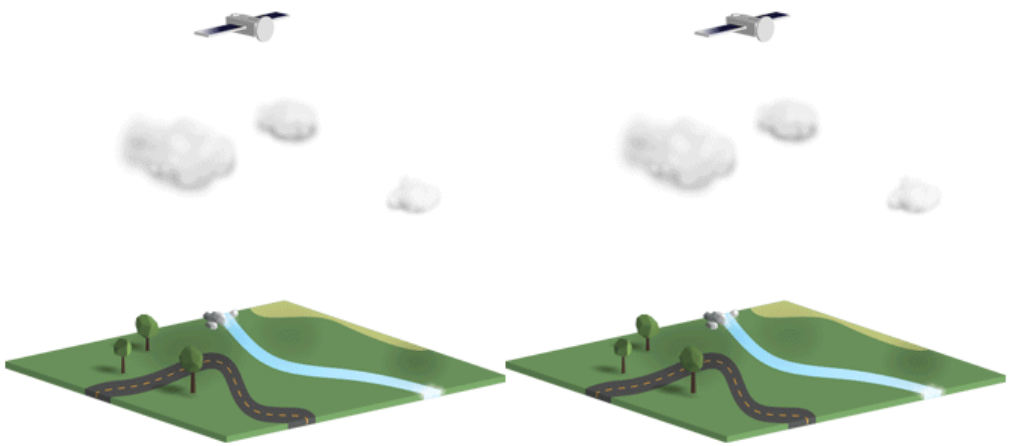
*Credit: Natural Resources Canada

Satellite (Sensor)	Spatial Resolution	Temporal Resolution	Spectral Bands
Landsat 8 (OLI)	15 m, 30 m	16 day revisit	9 bands (blue-green, green, red, near IR, shortwave and thermal IR)
Terra, Aqua (MODIS)	250 m – 1 km	2 times per day	36 bands (red, blue, IR, NIR, MIR)

How Do We Observe From Space?

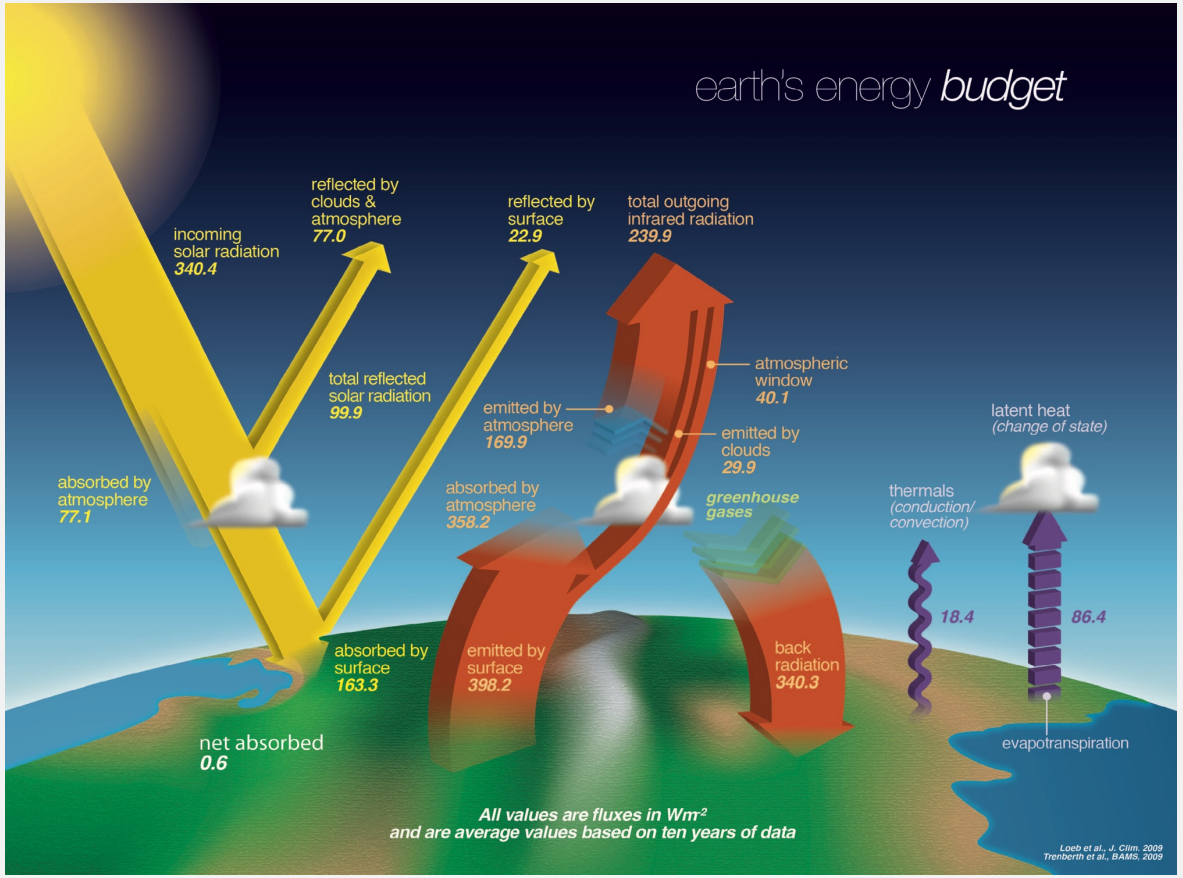
Overview of Active & Passive Remote Sensing

- Satellites carry instruments and sensors to measure:
  - reflected solar radiation
  - emitted infrared and microwave radiation

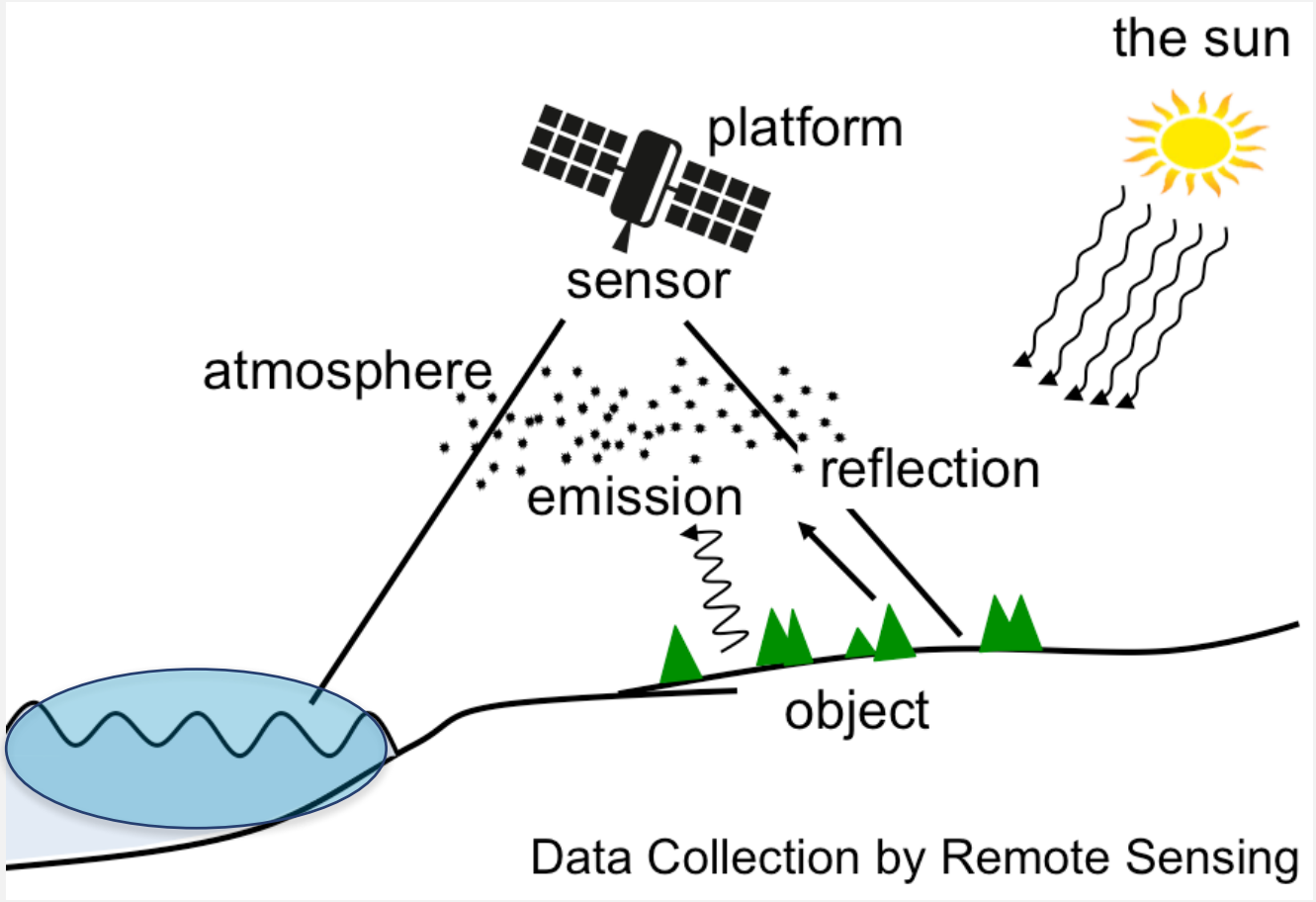


Passive | Sensors detect only what is emitted from the landscape, or reflected from another source (e.g., light reflected from the sun).

Active | Instruments emit their own signal and the sensor measures what is reflected back. Sonar and radar are examples of active sensors.



Data Collection by Satellites



Atmosphere

- Clouds
- Aerosols
- Gases

Earth's Surface

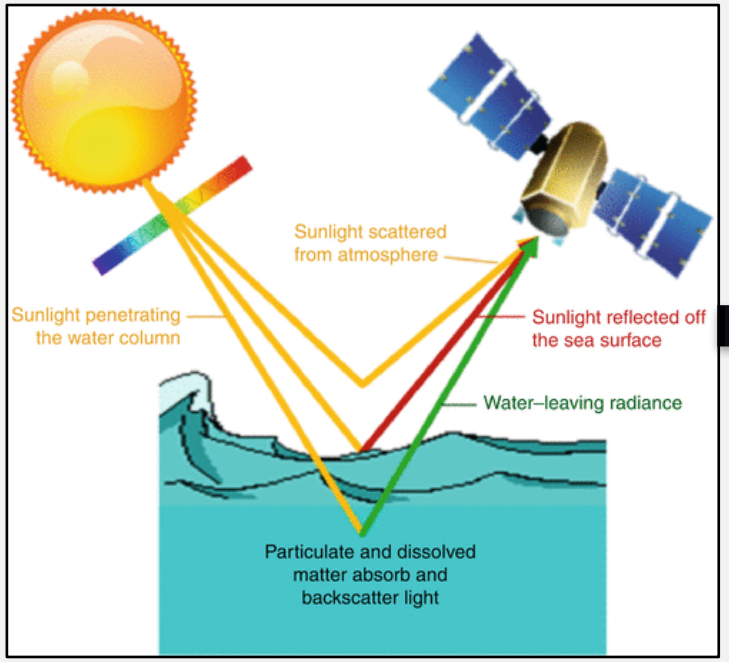
- Snow/Ice
- Land (land use, vegetation)
- **Water**

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

Coccolithophore Bloom, Norway



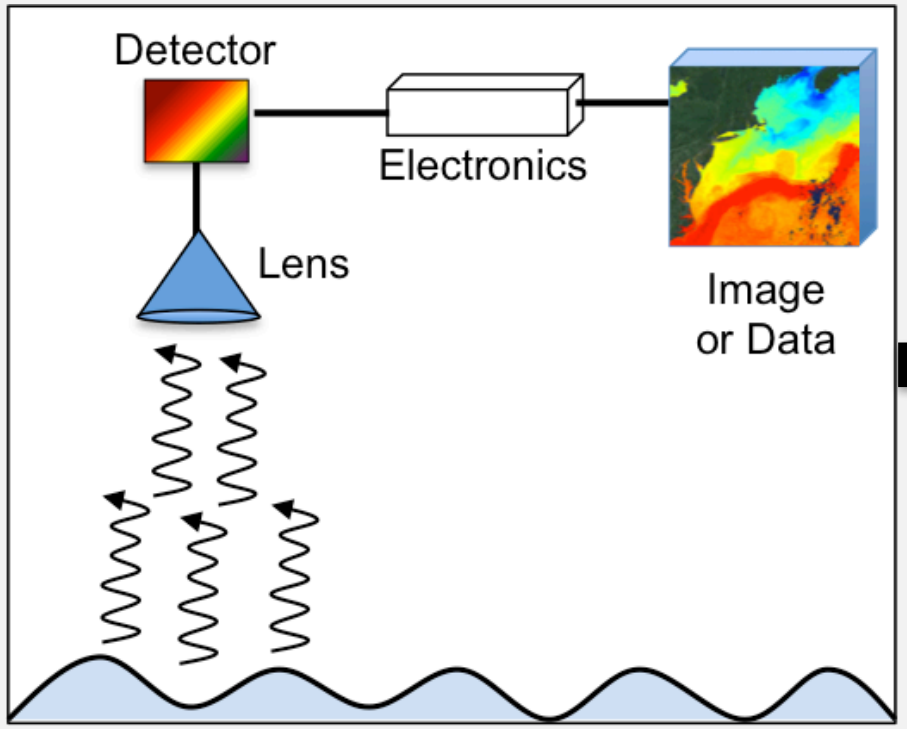
- Suspended Sediments
- Algae
- Colored Dissolved Organic Matter
- Detrital Organic Matter
- Submerged or floating vegetation
- Oil

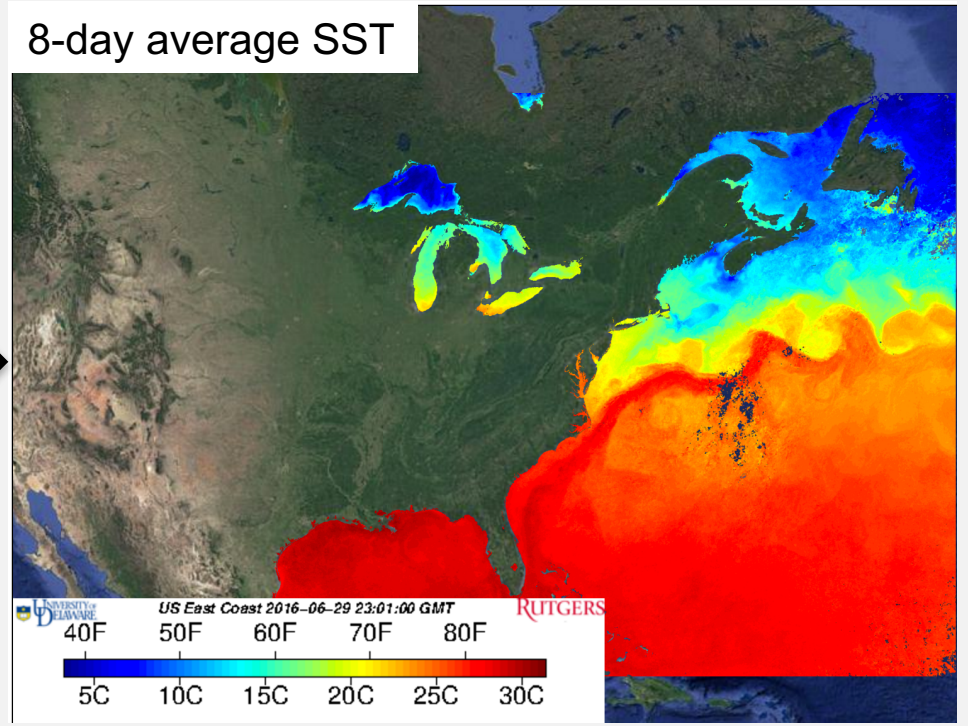
- Contaminants
- Pathogens

Remote Sensing of Water Bodies

Emitted Thermal Radiation

- Used to derive the surface temperature of water bodies





MARACOOS, ORB Lab, courtesy M. Oliver

NASA Satellites and Sensors for Aquatic Applications

Overview of NASA Satellites & Sensors for Water Quality Monitoring

- Currently several satellites observe water surface properties in:
  - the open ocean
  - coastal oceans and estuaries
  - many inland lakes
- A number of water quality parameters are operationally available from these satellites
  - e.g. temperature, chlorophyll-a

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

Landsat Satellites and Sensors

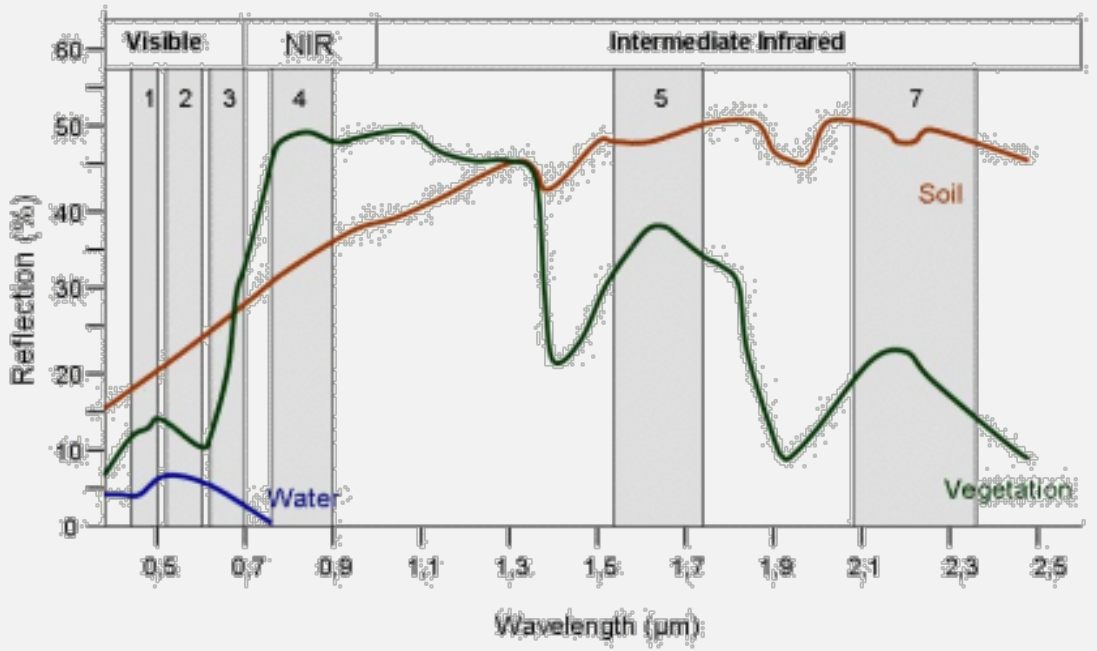
http://landsat.gsfc.nasa.gov/

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

Landsat-7 Enhanced Thematic Mapper (ETM+)

http://geo.arc.nasa.gov/sge/landsat/l7.html

- Flying on-board Landsat 7 polar orbiting satellites
- Spatial Coverage and Resolution:
  - Global, swath 185 km
  - Spatial Resolution: 15 m, 30 m, 60 m
- Temporal Coverage and Resolution
  - April 15, 1999 – present
  - 16 day revisit time
- Spectral Bands
  - 8 bands (major bands include: blue-green, green, red, reflected and thermal IR, and panchromatic)

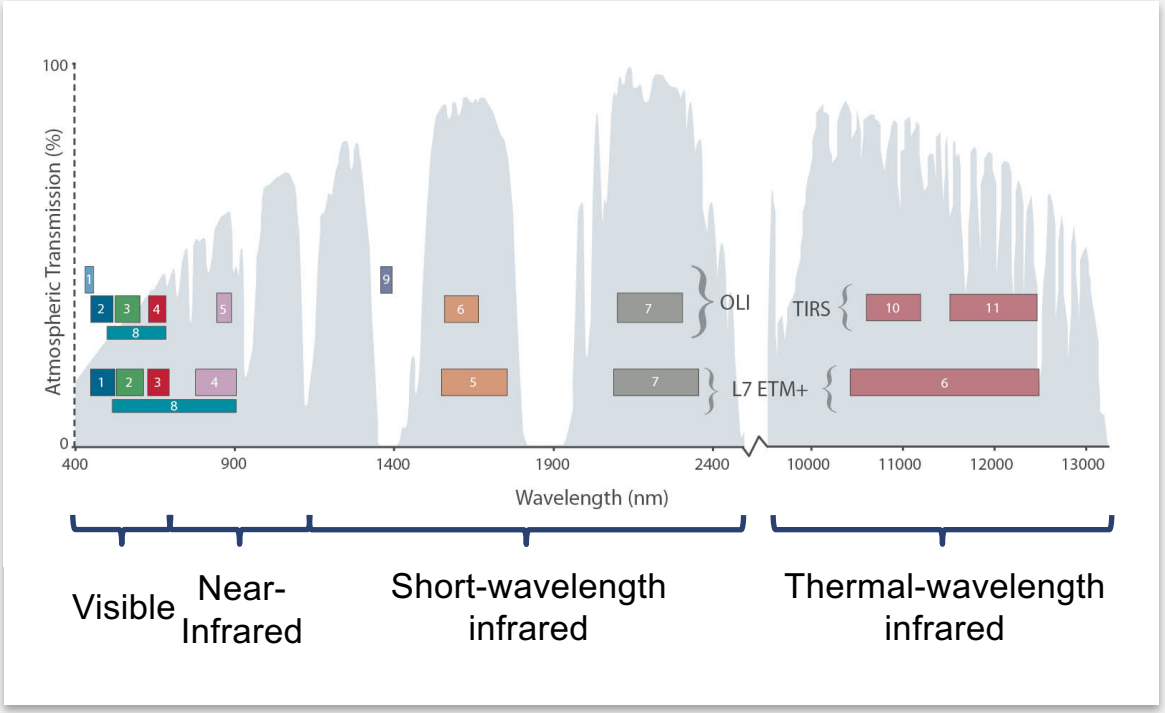


- Spectral Bands
  - Bands 1-5, 7: 30 m
  - Band 6: 60 m
  - Band 8: 15 m

Landsat-8 Operational Land Imager (OLI)

http://landsat.usgs.gov/landsat8.php; http://landsat.gsfc.nasa.gov/?p=5779

- 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)

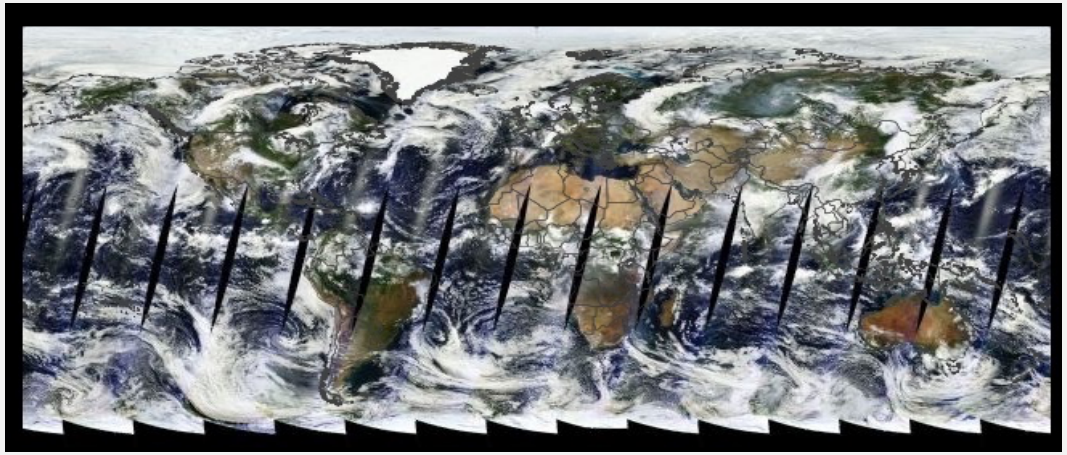


Terra and Aqua

http://terra.nasa.gov/; http://aqua.nasa.gov/

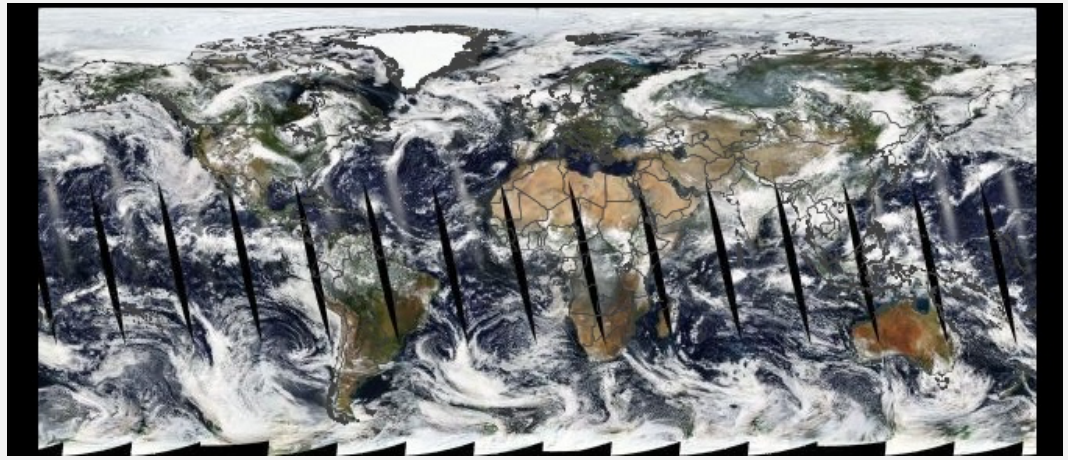
Terra

- 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



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



MODerate Resolution Imaging Spectroradiometer (MODIS)

http://modis.gsfc.nasa.gov

- 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

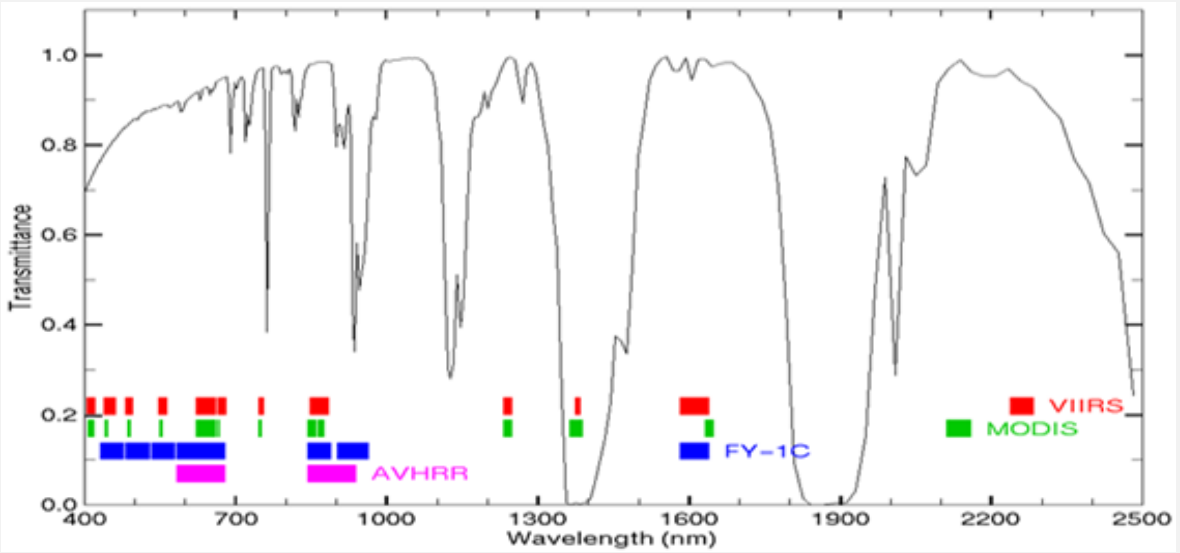
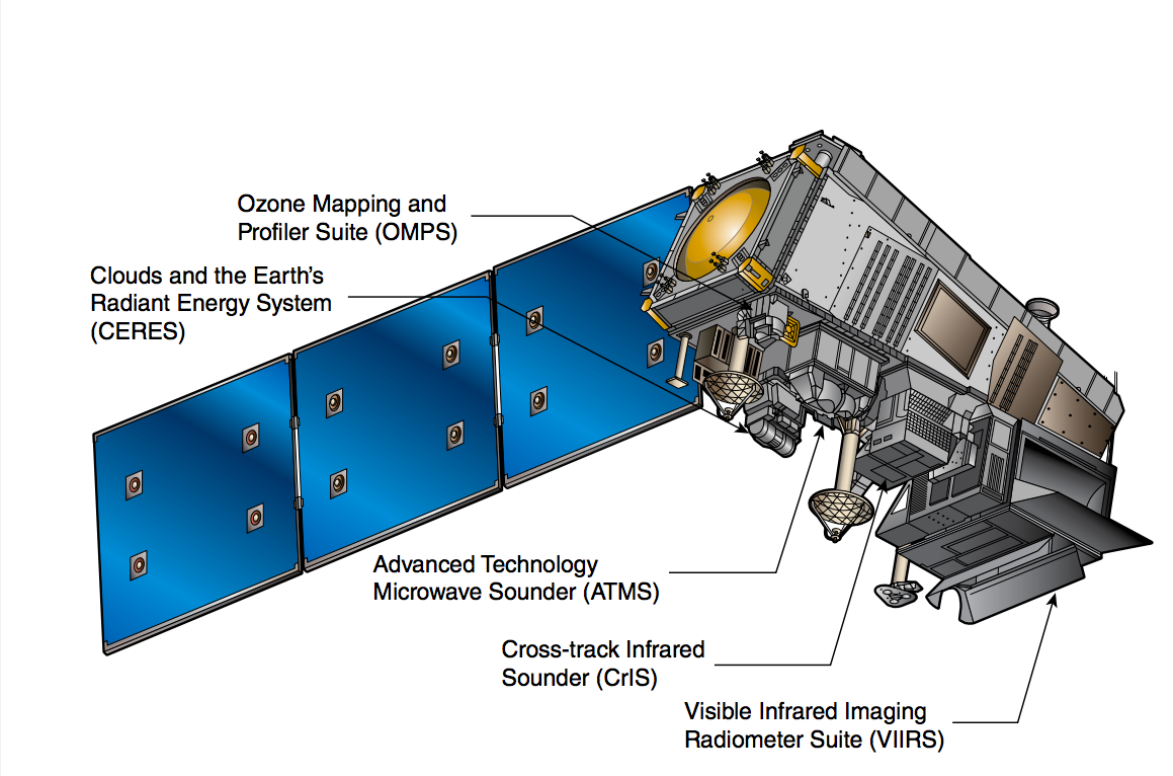


Image Credit: http://cimss.ssec.wisc.edu/

National Polar Partnership (NPP)

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



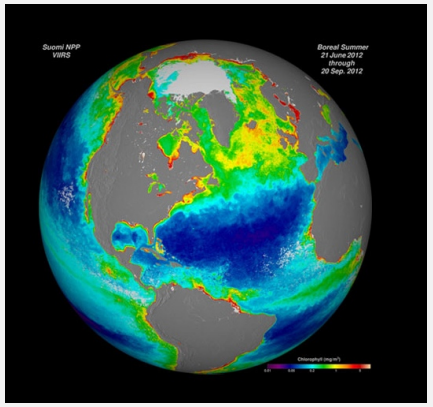
NASA/NOAA

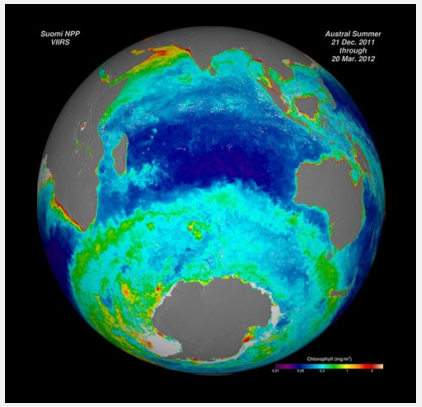
- Polar orbit
- 1:30 p.m. equator crossing time
- Global coverage
- November 21, 2011 – present
- 1-2 observations per day
- Sensors:
  - VIIRS
  - ATMS
  - CrIS
  - OMPS
  - CERCES

Visible Infrared Imaging Radiometer Suite (VIIRS)

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

- 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



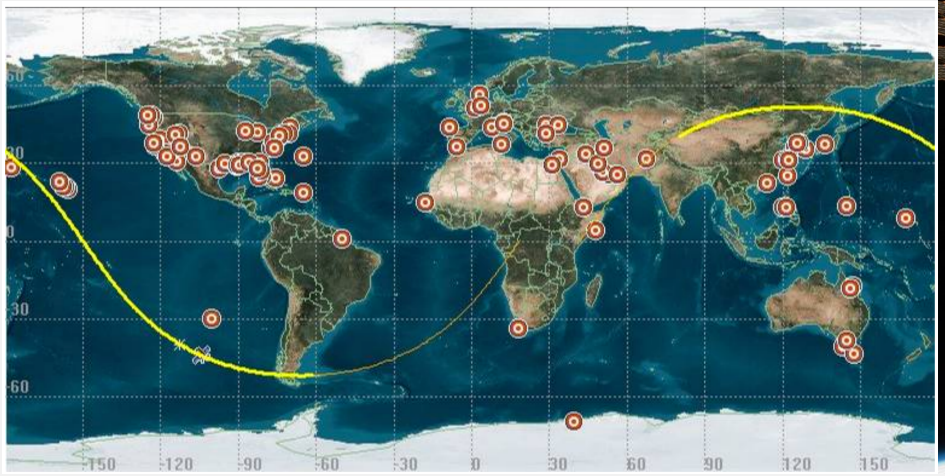


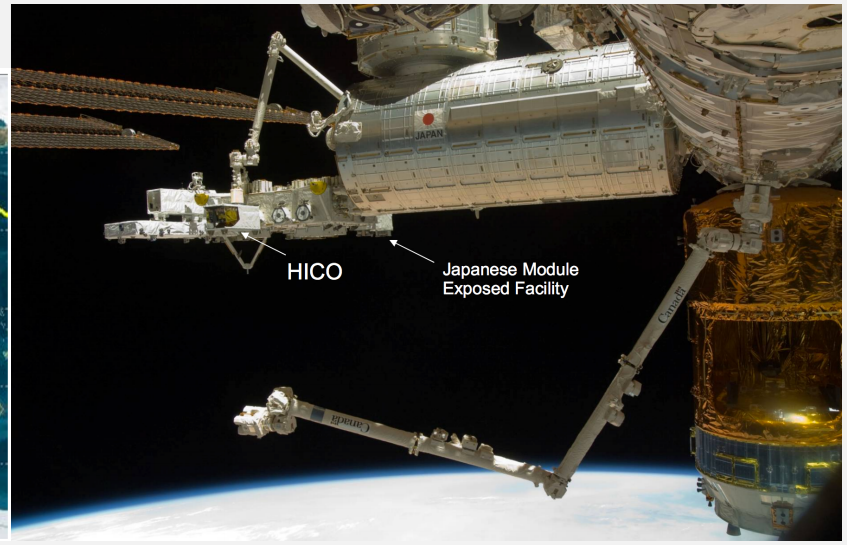
- Spectral Bands
  - 15 bands (major bands include visible, red, blue, green, short, middle, and long-wave IR)
  - Ocean Color Bands 1-7: 0.402 - 0.682 µm
  - Sea Surface Temperature Bands 12-13: 3.660 - 4.128 µm

Hyperspectral Imager for the Coastal Ocean (HICO)

http://hico.coas.oregonstate.edu/; http://oceancolor.gsfc.nasa.gov/cms/data/hico

- Partnership with U.S. Naval Research Lab, Office of Naval Research, Oregon State University, and NASA
- Active 2009 – 2014 aboard the International Space Station (ISS)
- 380 nm to 960 nm at 5.7 nm spectral resolution
- 90 m^2 spatial resolution
- Targeted data collection

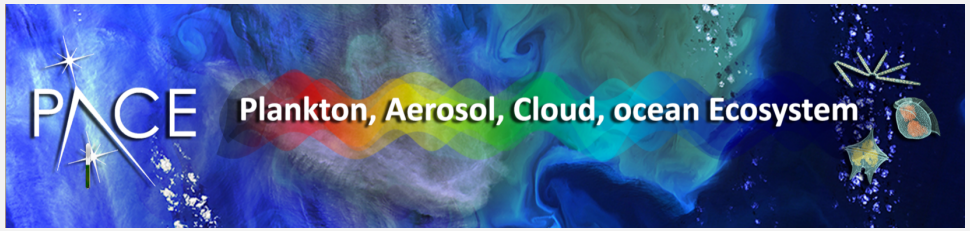




Davis, C. O. (n.d.). *The Hyperspectral Imager for the Coastal Ocean (HICO): Sensor and Data Processing Overview* [PDF]. International Ocean Colour Coordinating Group.

Plankton, Aerosol, Clouds, Ocean Ecosystem (PACE)

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



- 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

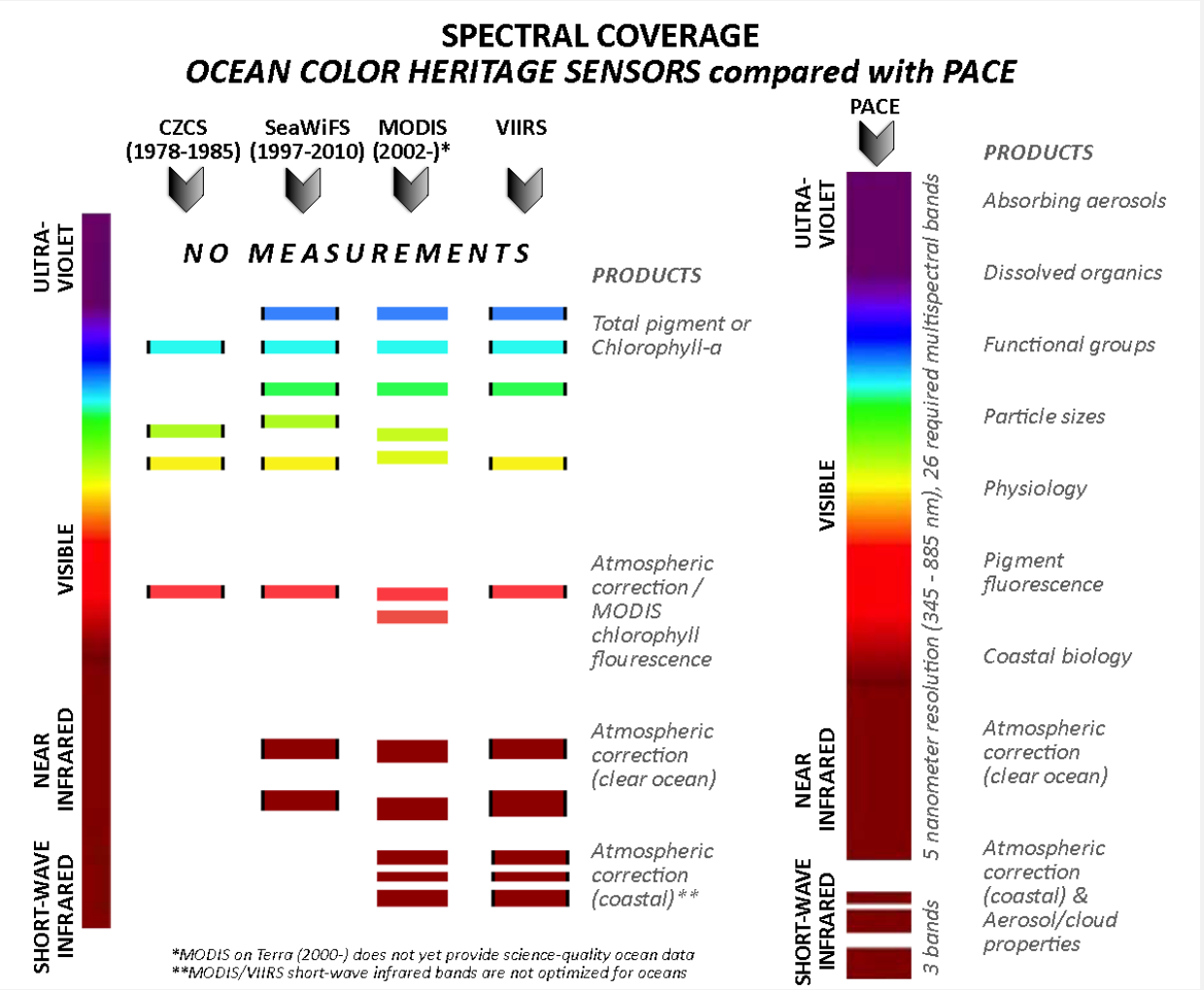
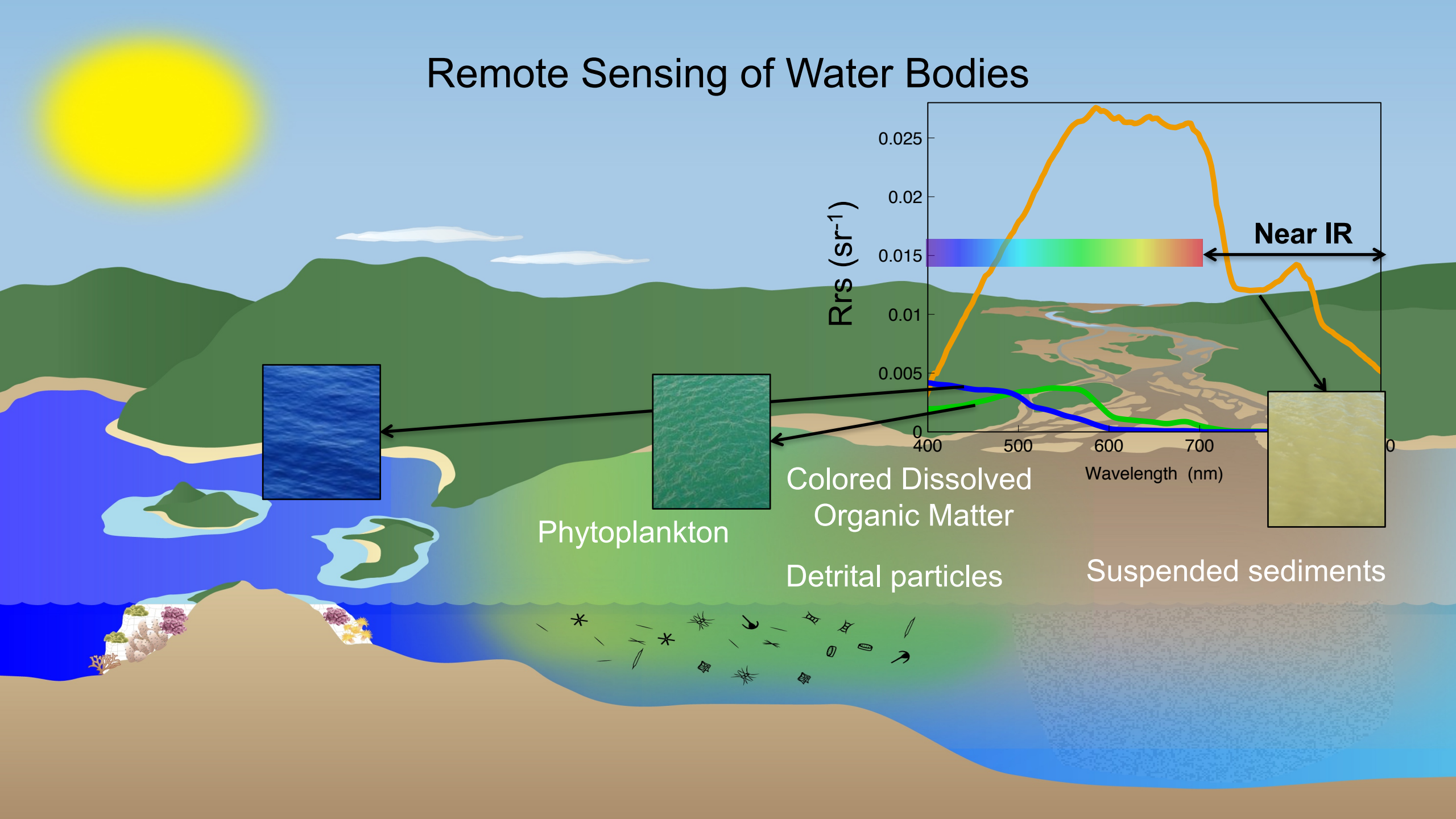


Image “Correction”

Remote Sensing of Water Bodies

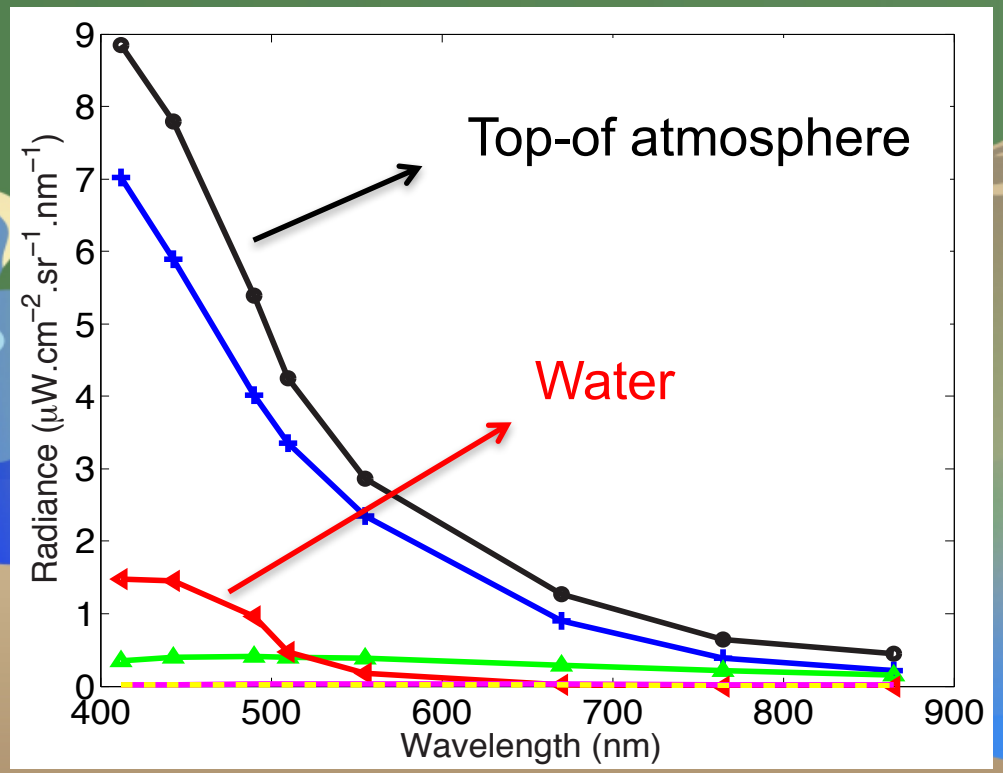


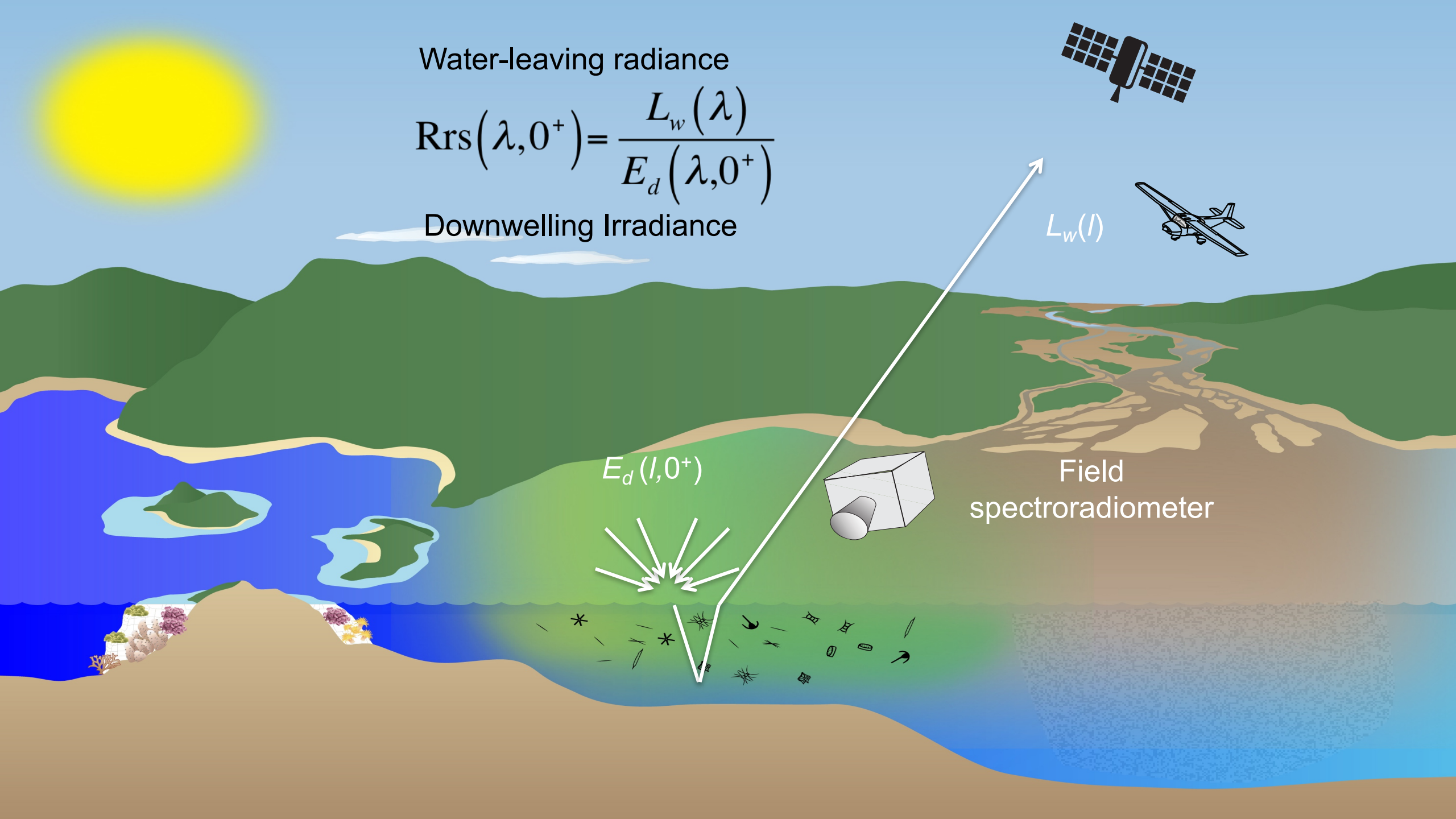
Atmospheric Correction

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

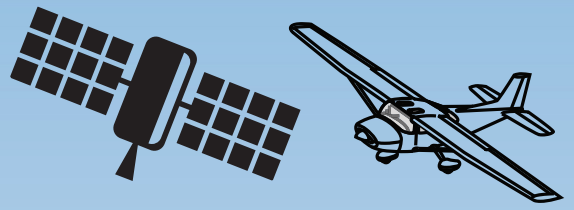
>90%

<10%




Water-leaving radiance
$\mathrm{Rrs}(\lambda,0^+) = \frac{L_w(\lambda)}{E_d(\lambda,0^+)}$
Downwelling Irradiance
$L_w(l)$
$E_d(l,0^+)$
Field
spectroradiometer

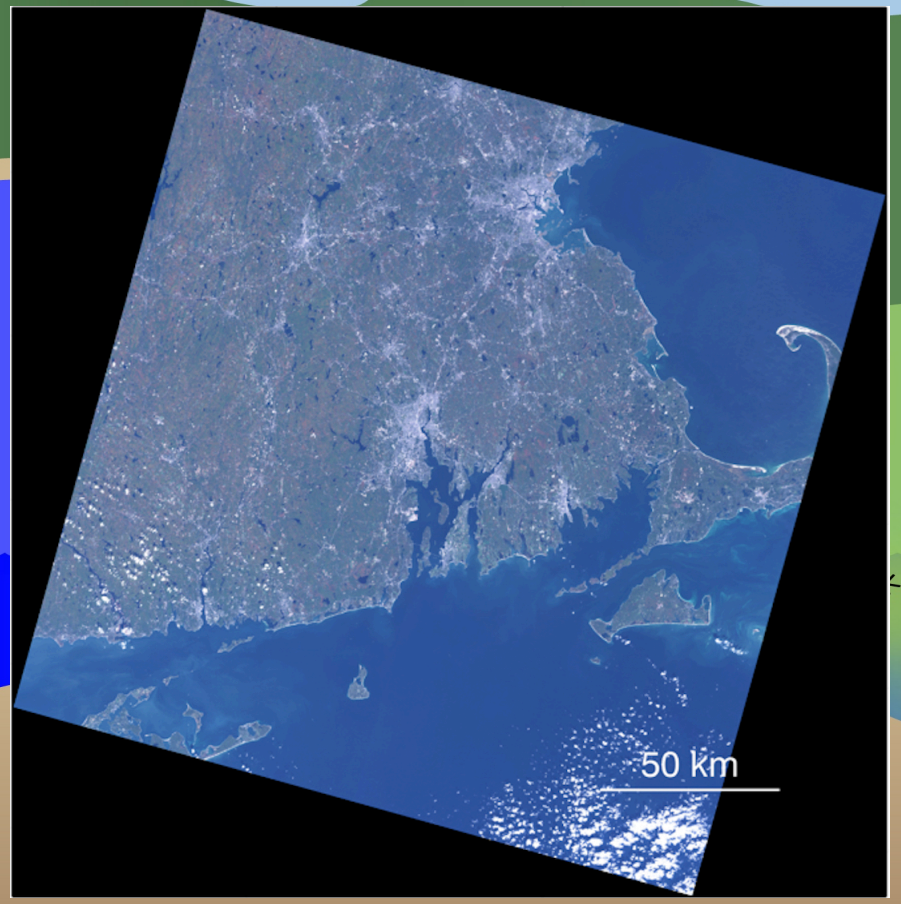
Atmospheric Correction



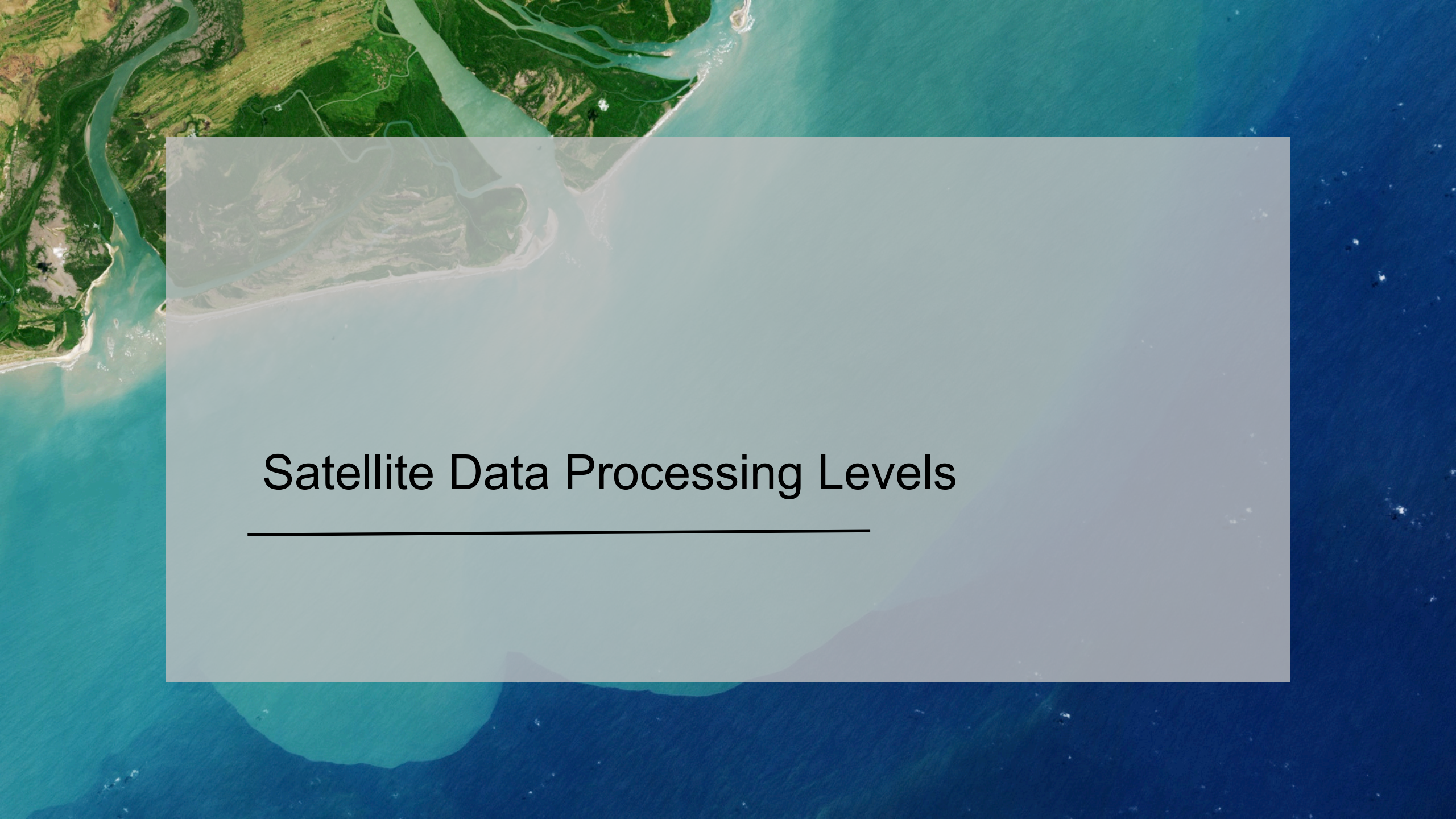
$$L_t(\lambda) = L_r(\lambda) + L_a(\lambda) + L_{ra}(\lambda) + T(\lambda,\theta)L_g(\lambda) + t(\lambda,\theta)L_{wc}(\lambda) + t(\lambda,\theta)L_w(\lambda)$$

>90%

<10%



Atmospheric correction

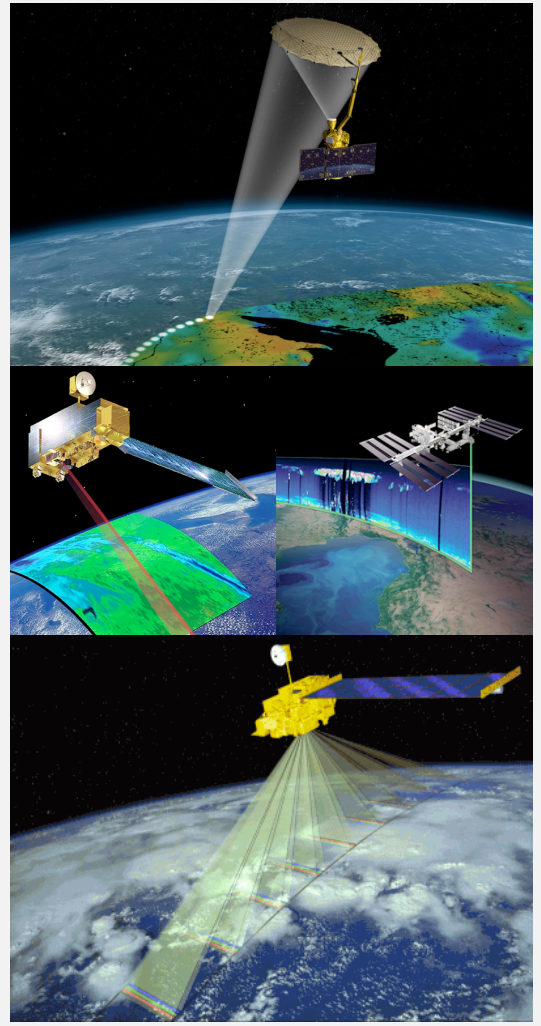


Satellite Data Processing Levels

Levels of Data Processing

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

- Level 0: unprocessed instrument data at full resolution, rawest format available
- Level 1A: reconstructed and unprocessed instrument data at full resolution
- Level 1B: L1A data with instrument/radiometric calibrations applied
- Level 2: Derived geophysical variables at same resolution as L1 data
- Level 3: L2 projected onto a well defined spatial grid over a well-defined time period
- Level 4: model output or results from analyses of lower level data
  - e.g., Primary Productivity



Data Processing Levels

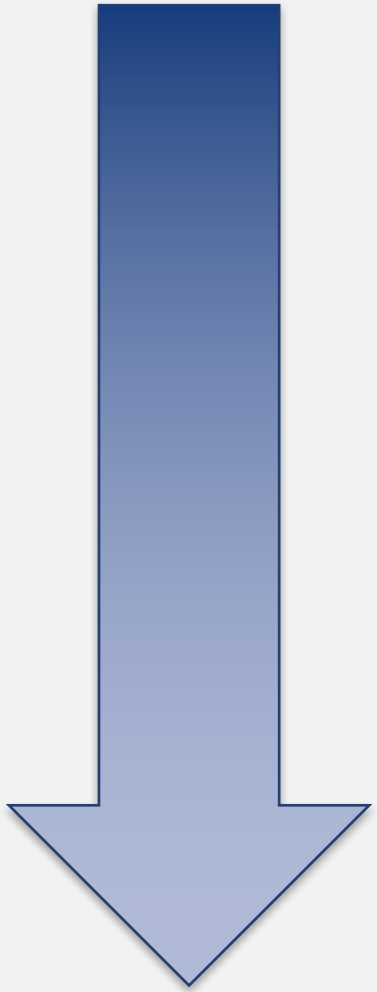
L0: Raw instrument data

L1: Geolocated and calibrated

L2: Products derived from L1B

L3: Gridded and quality controlled

L4: Model output: derived variables



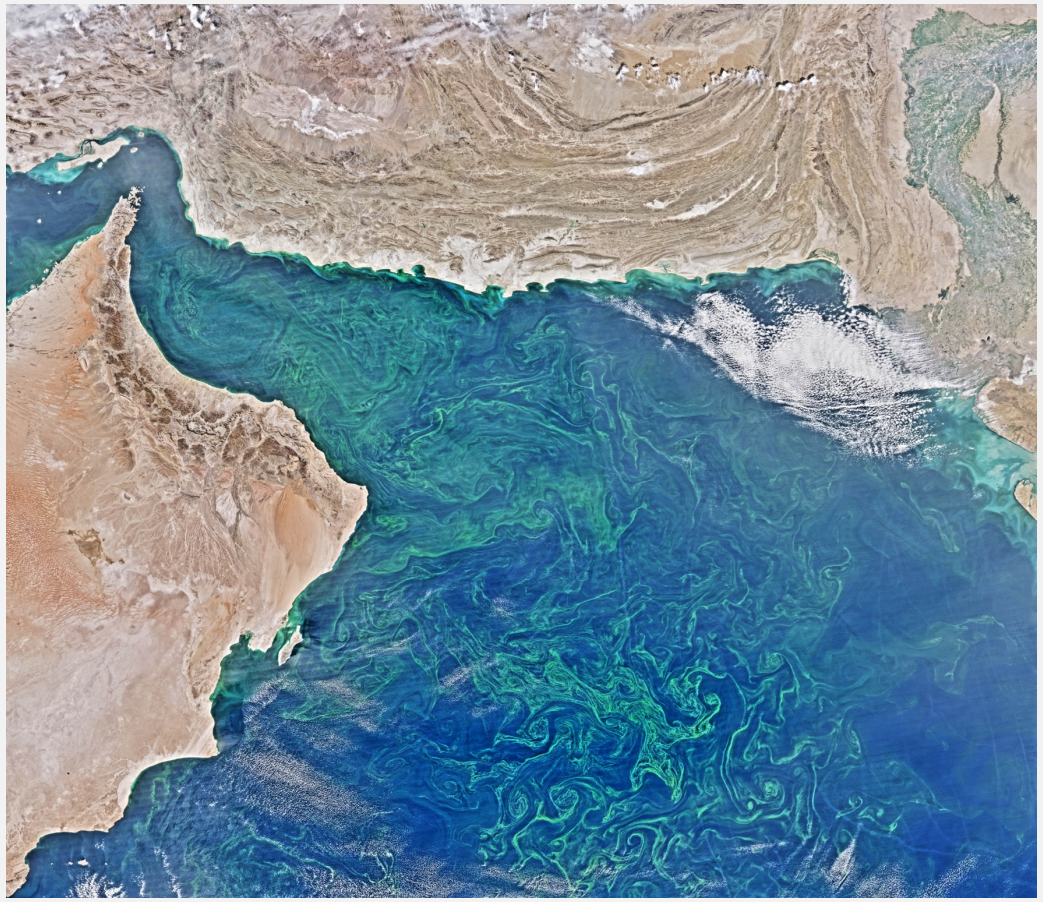
Harder to Use

Easier to Use

Aquatic Remote Sensing Data Products and Their Uses

Agenda

- Light and Water
- Fundamentals of Remote Sensing
- Aquatic Remote Sensing Data Products and Their Uses
- Accessing NASA Satellite Imagery
- NASA Satellite Data Processing Tools



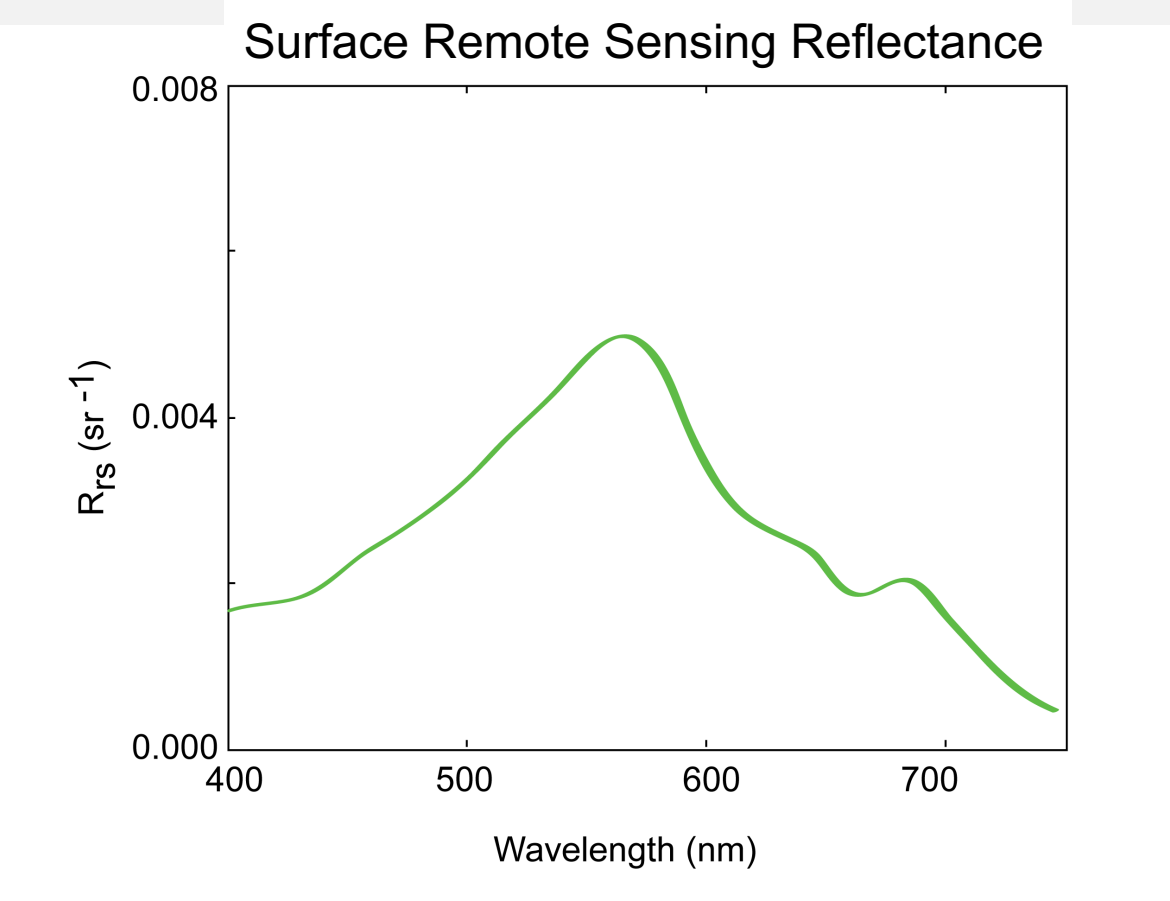
Phytoplankton Bloom in the Arabian Sea
Credit: N. Kuring, http://earthobservatory.nasa.gov/IOTD/view.php?id=85718

What Can We Observe from Space?

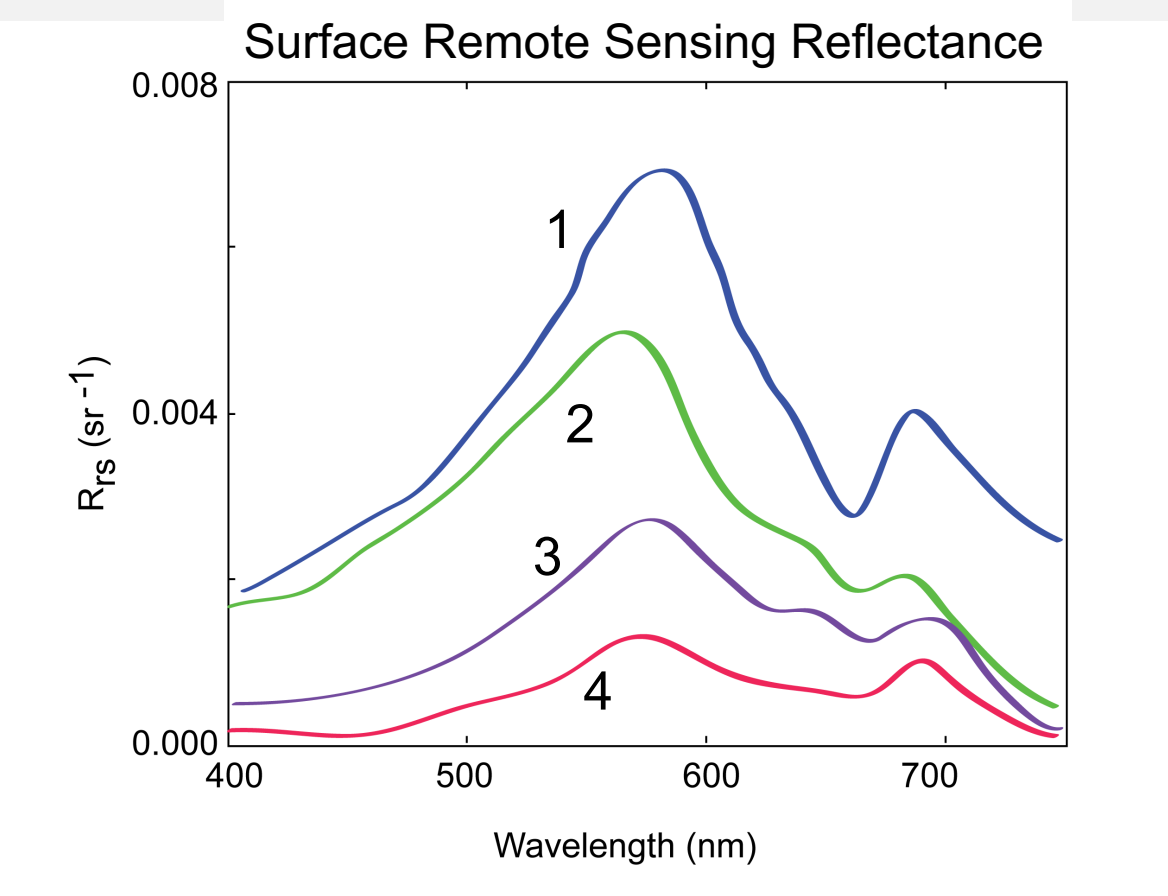
Ocean Properties Derived from Remote Sensing Imagery

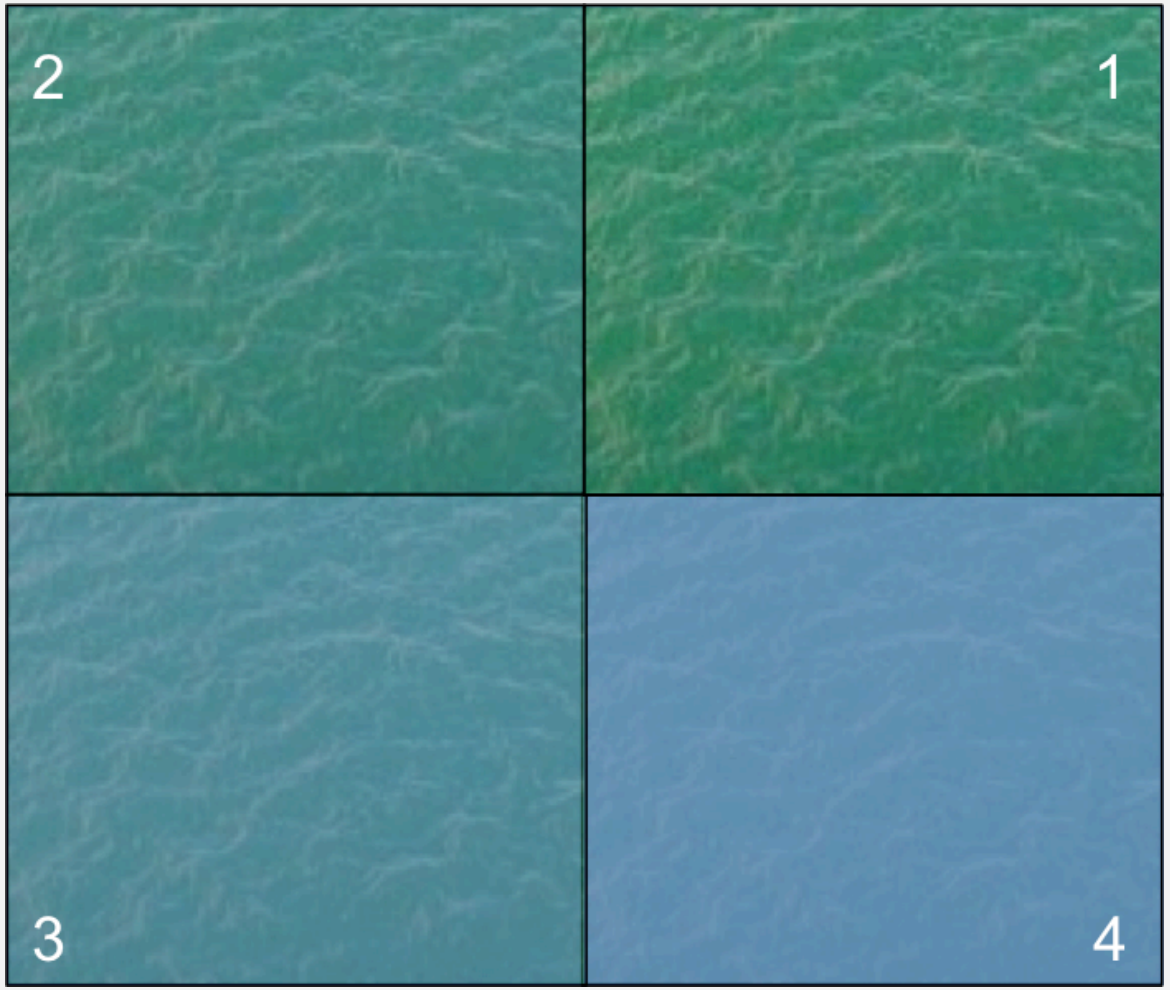
Observation	Application
Chlorophyll-a	Phytoplankton biomass, primary productivity, biogeochemical cycling
Water Turbidity	Water quality, human and ecosystem health
Colored Dissolved Organic Matter (CDOM)	Water quality, biogeochemical cycling, human and ecosystem health
Sea Surface Temperature (SST)	Currents, 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

Chlorophyll-a from Remote Sensing Reflectance (Rrs)



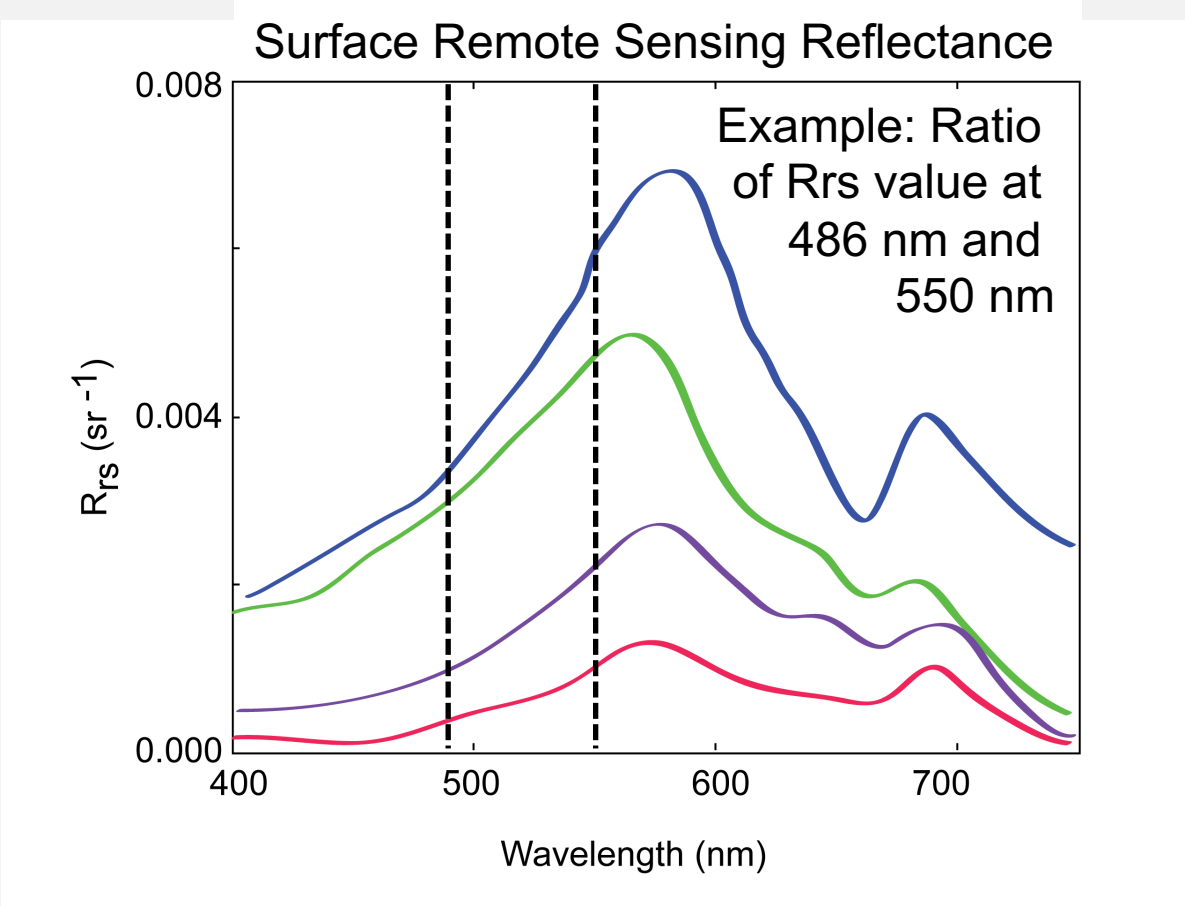
Rrs at Different Chlorophyll-a Concentrations

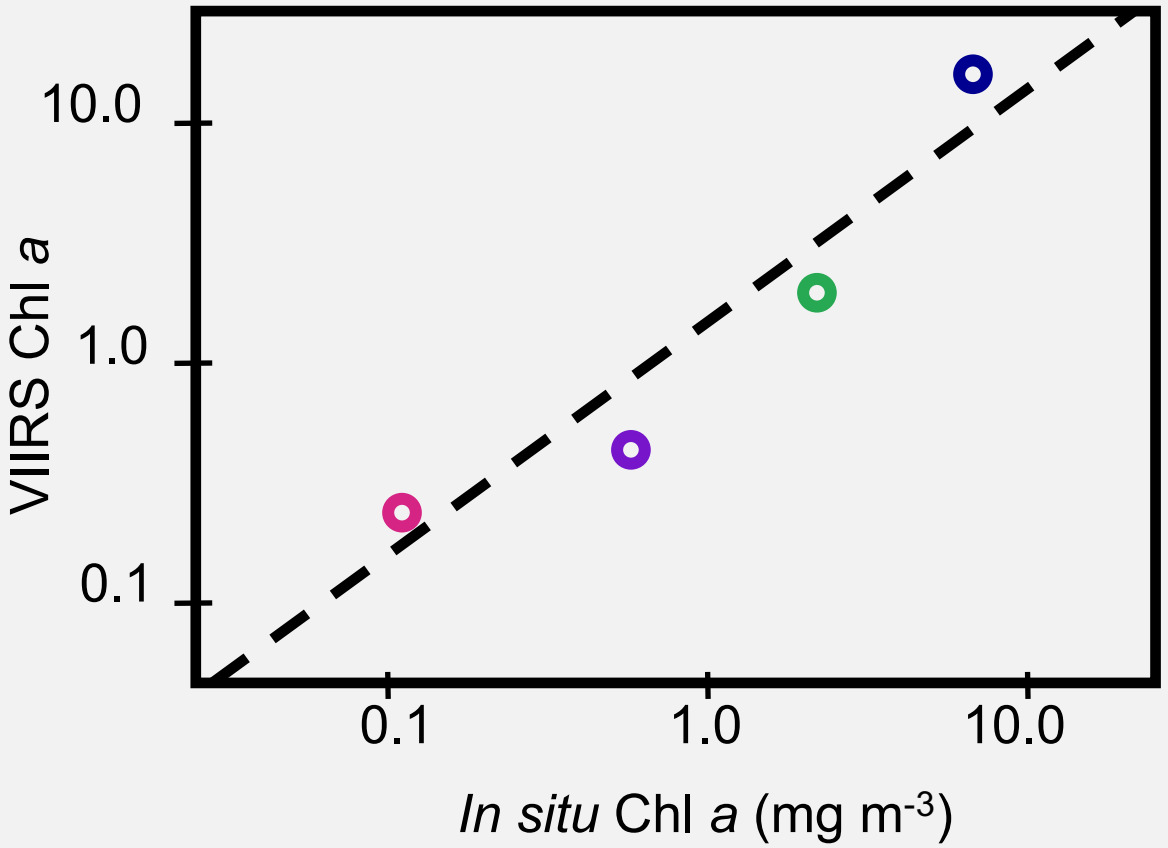




Chlorophyll-a Estimates

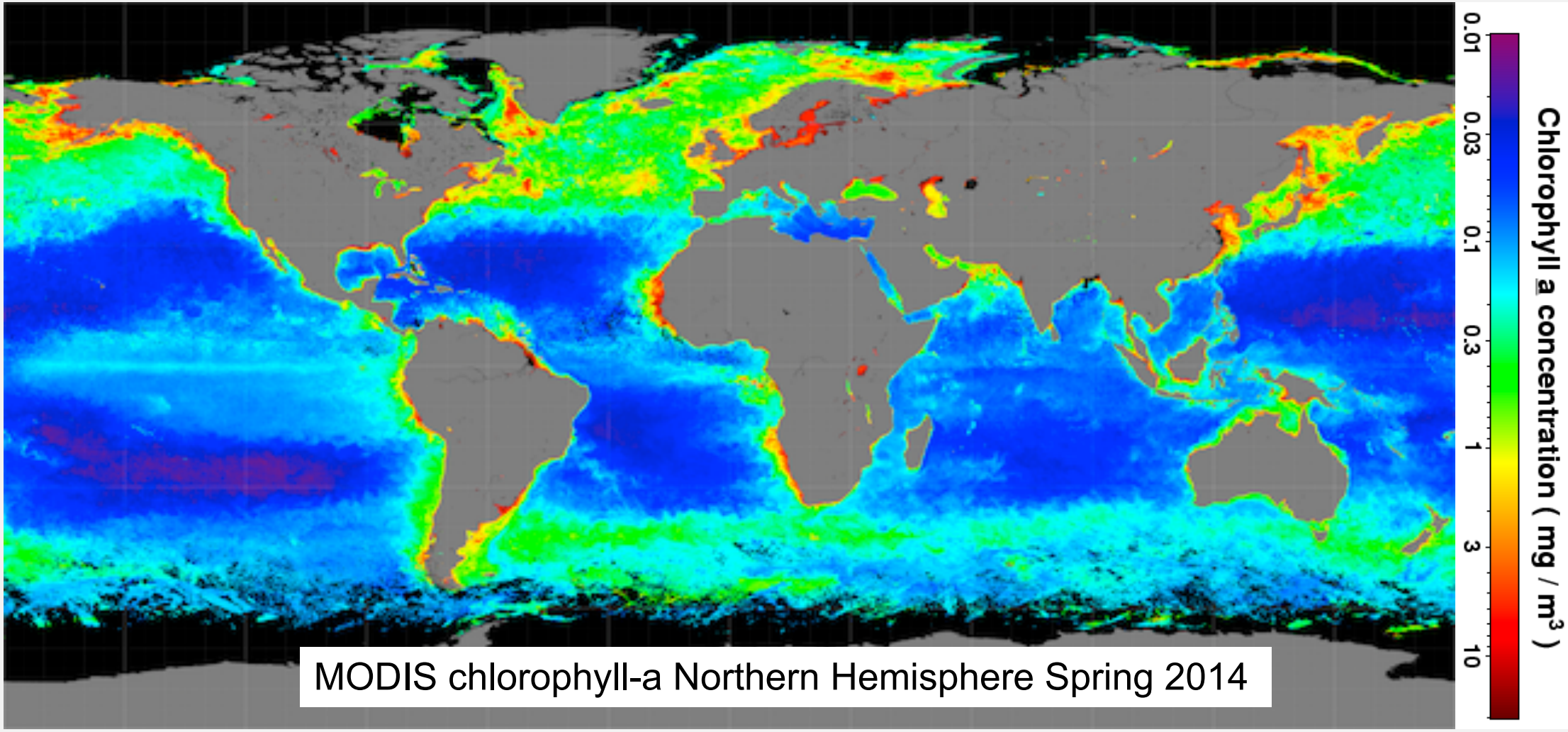
Estimations are a function of the ratios of Rrs values





Algorithm description: http://oceancolor.gsfc.nasa.gov/cms/atbd/chlor_a

Chlorophyll-a from Space

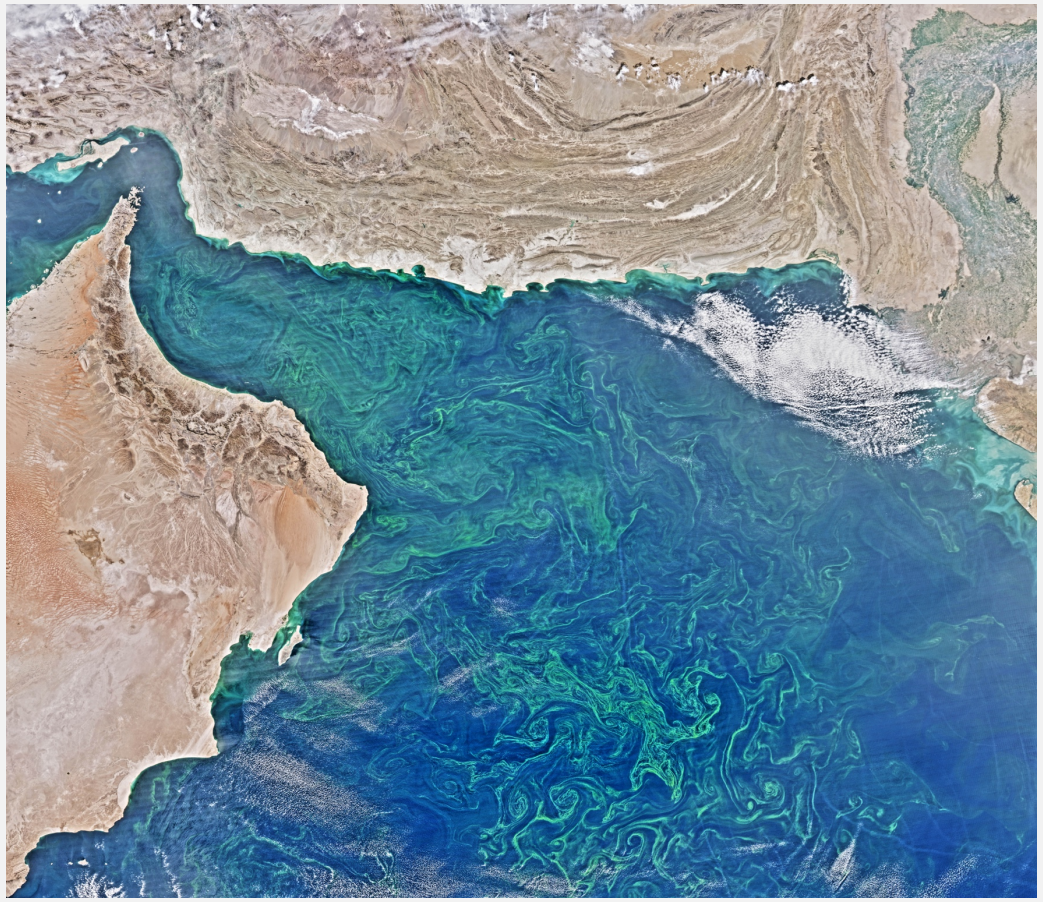


MODIS chlorophyll-a Northern Hemisphere Spring 2014

Accessing NASA Satellite Imagery

Agenda

- Light and Water
- Fundamentals of Remote Sensing
- Aquatic Remote Sensing Data Products and Their Uses
- Accessing NASA Satellite Imagery
  - Worldview
  - OceanColor Web Data Browsers
  - Other Data Access Tools
- NASA Satellite Data Processing Tools

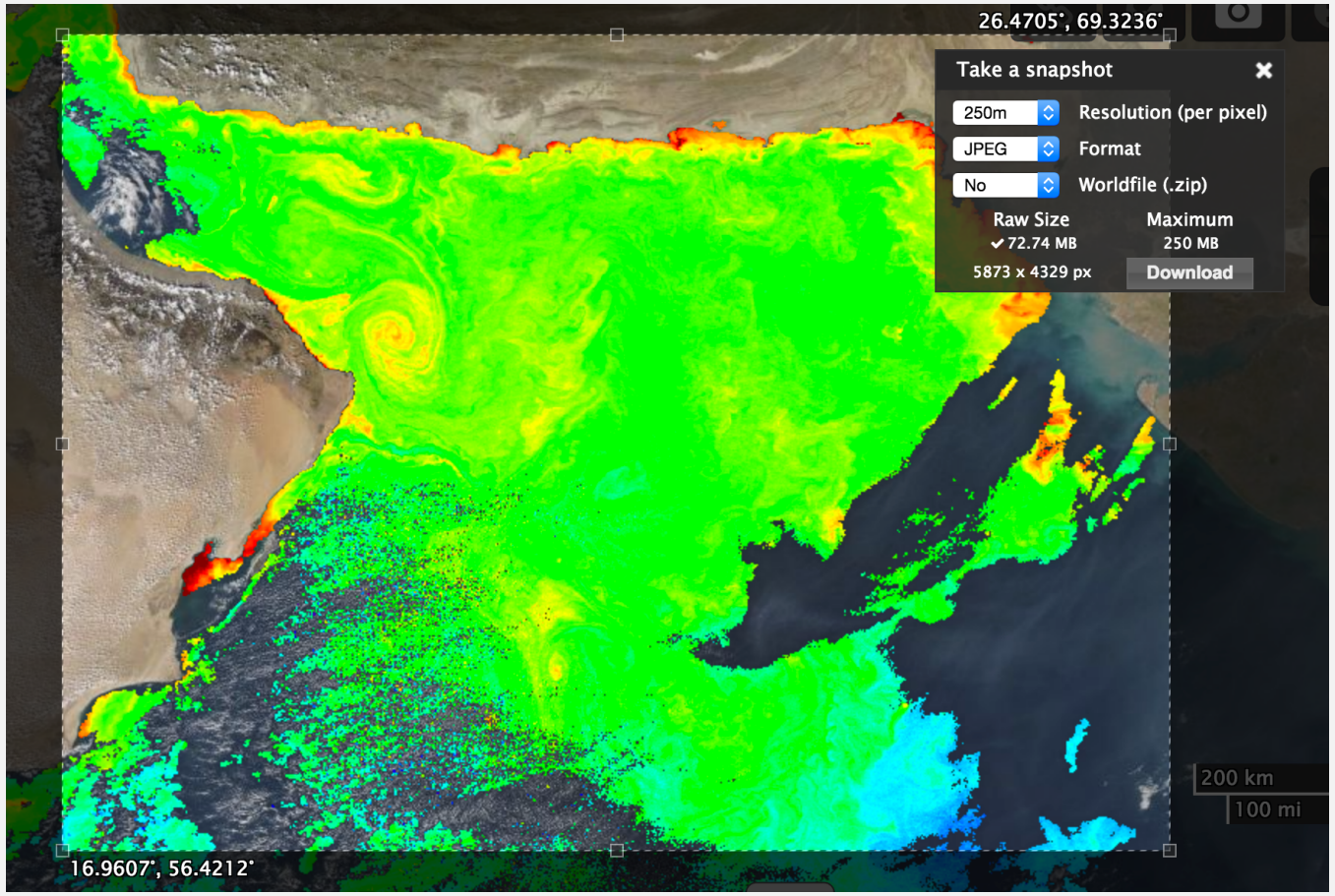


Phytoplankton Bloom in the Arabian Sea
Credit: N. Kuring, http://earthobservatory.nasa.gov/IOTD/view.php?id=85718

NASA Worldview

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

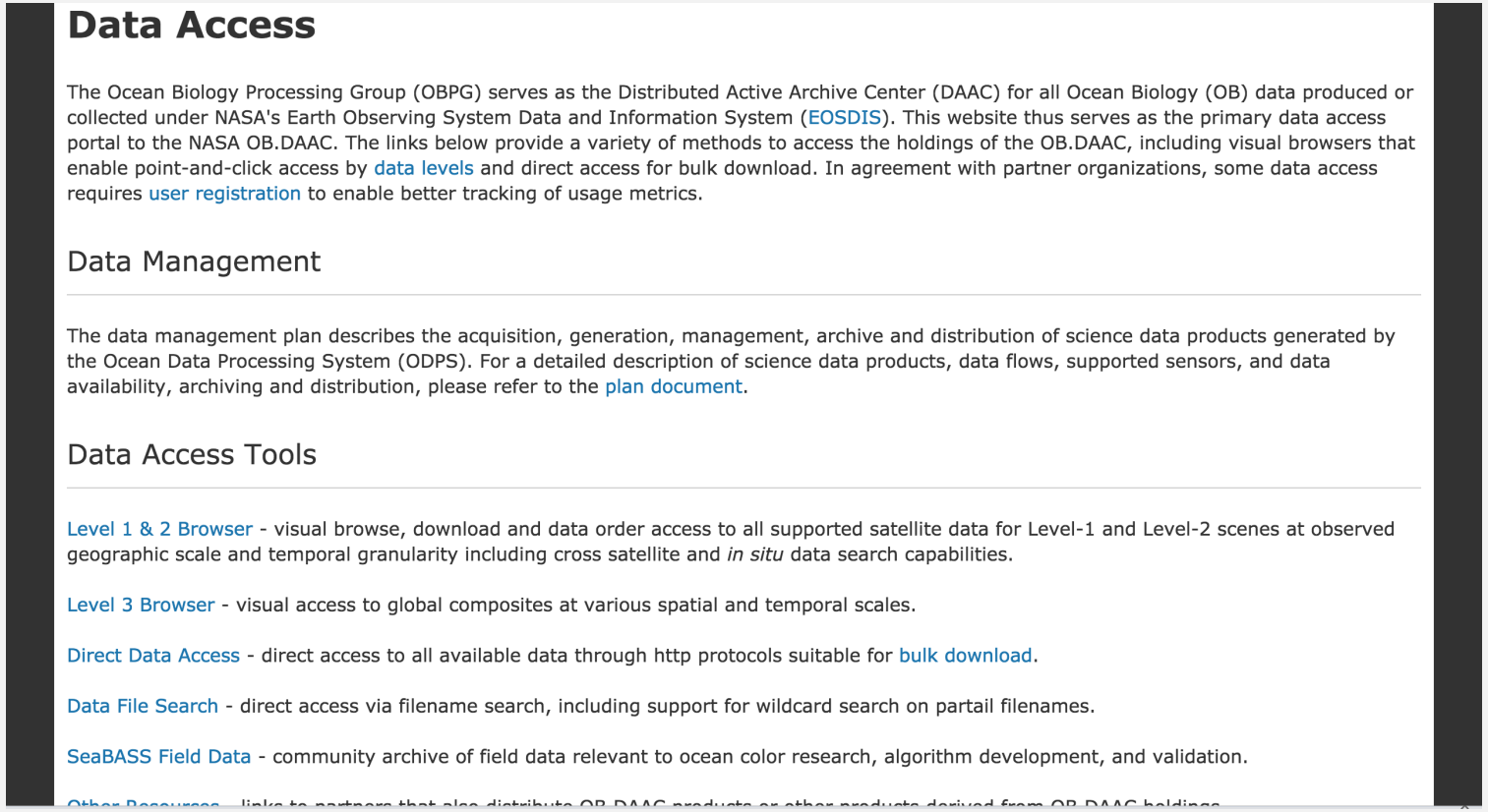
- Interactive web-based tool for browsing satellite imagery
- Imagery is generally available within four hours of observation
- Daily imagery from May 2012 to present
- Data can be downloaded
- Image output in JPEG, PNG, GeoTIFF, and KML formats



NASA OceanColor Web – Data Access

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

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



Data Access

The Ocean Biology Processing Group (OBPG) serves as the Distributed Active Archive Center (DAAC) for all Ocean Biology (OB) data produced or collected under NASA's Earth Observing System Data and Information System (EOSDIS). This website thus serves as the primary data access portal to the NASA OB.DAAC. The links below provide a variety of methods to access the holdings of the OB.DAAC, including visual browsers that enable point-and-click access by data levels and direct access for bulk download. In agreement with partner organizations, some data access requires user registration to enable better tracking of usage metrics.

Data Management

The data management plan describes the acquisition, generation, management, archive and distribution of science data products generated by the Ocean Data Processing System (ODPS). For a detailed description of science data products, data flows, supported sensors, and data availability, archiving and distribution, please refer to the plan document.

Data Access Tools

Level 1 & 2 Browser - visual browse, download and data order access to all supported satellite data for Level-1 and Level-2 scenes at observed geographic scale and temporal granularity including cross satellite and *in situ* data search capabilities.

Level 3 Browser - visual access to global composites at various spatial and temporal scales.

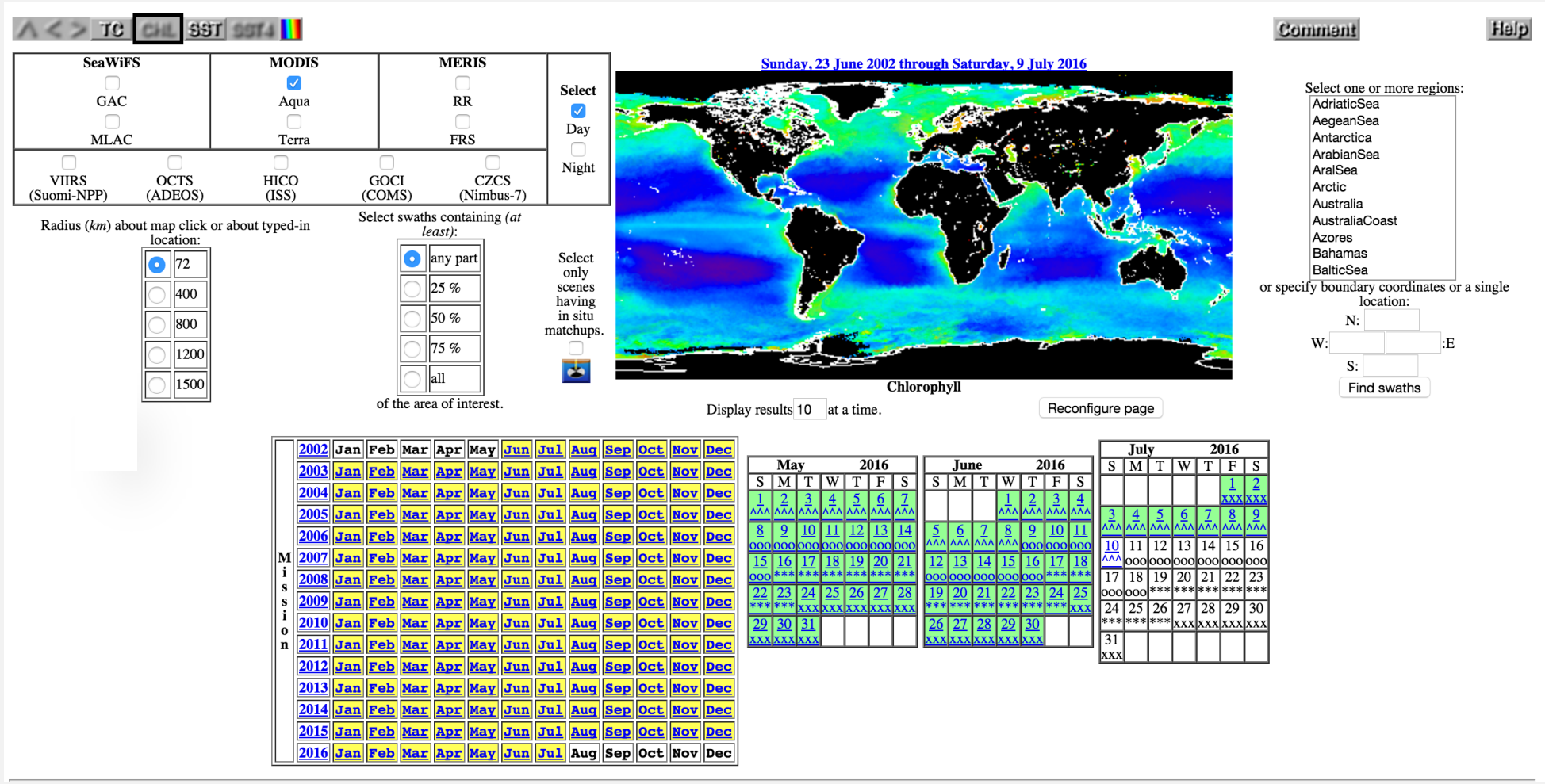
Direct Data Access - direct access to all available data through http protocols suitable for bulk download.

Data File Search - direct access via filename search, including support for wildcard search on partail filenames.

SeaBASS Field Data - community archive of field data relevant to ocean color research, algorithm development, and validation.

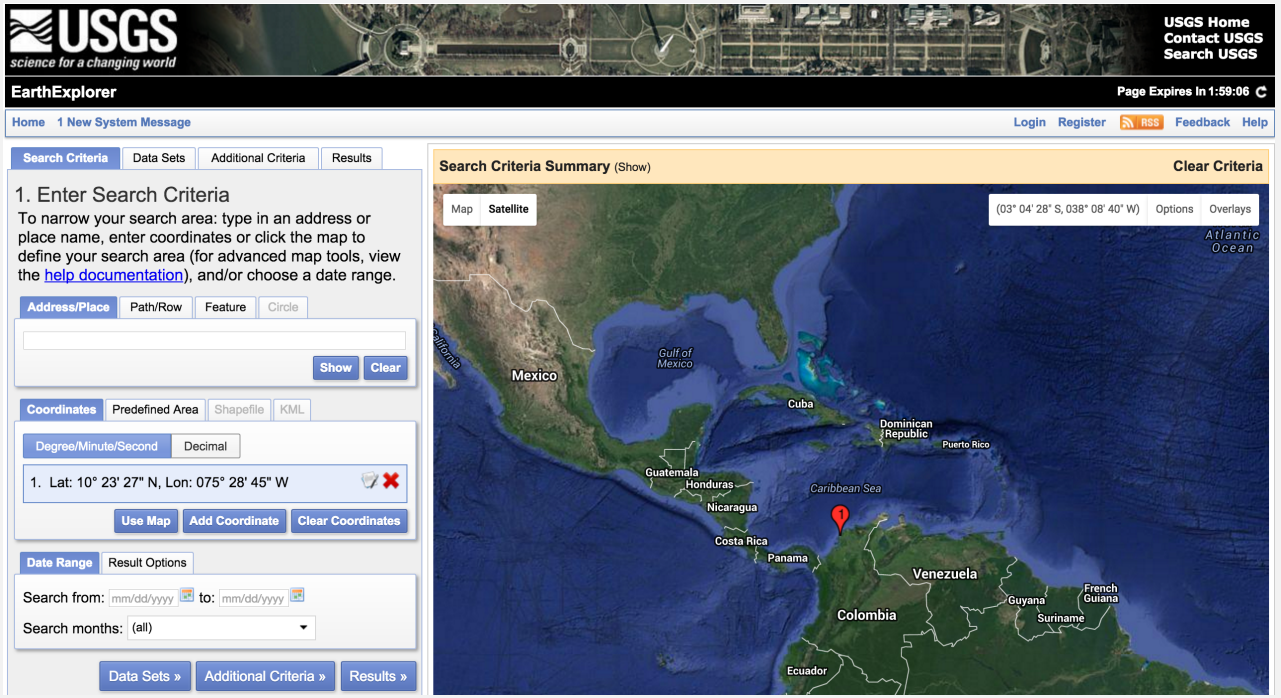
NASA OceanColor Web – Level 1 & 2 Browser

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



Some 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/



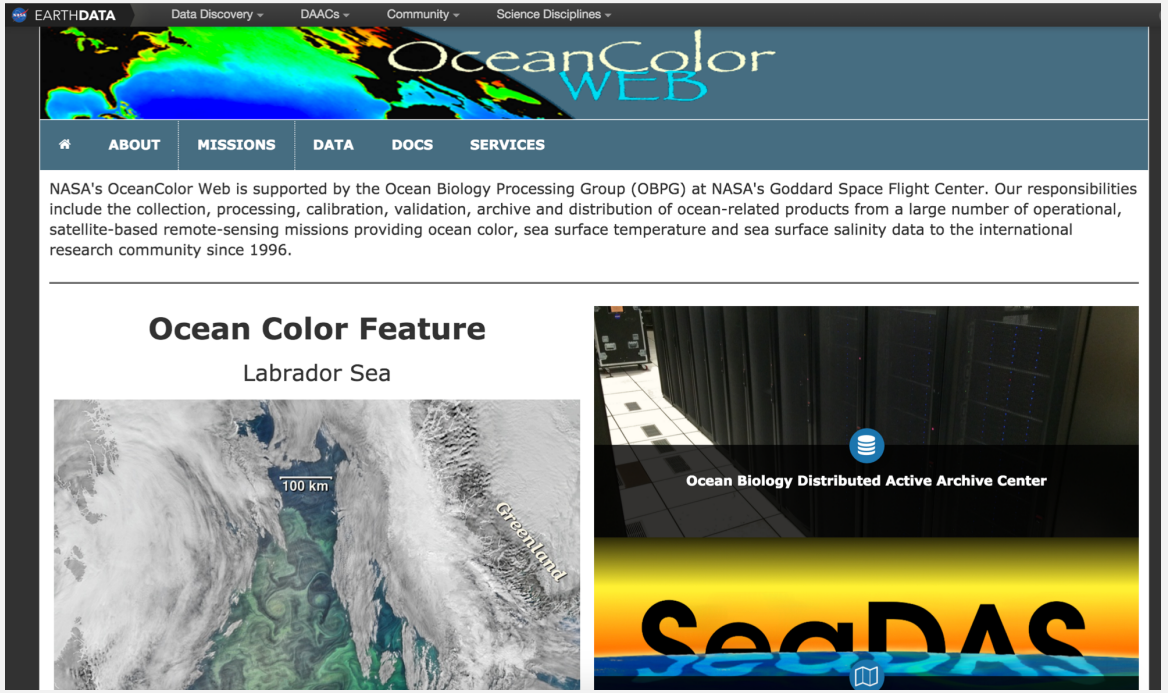
NASA Satellite Data Processing Tools

NASA OceanColor Web

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

- 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)

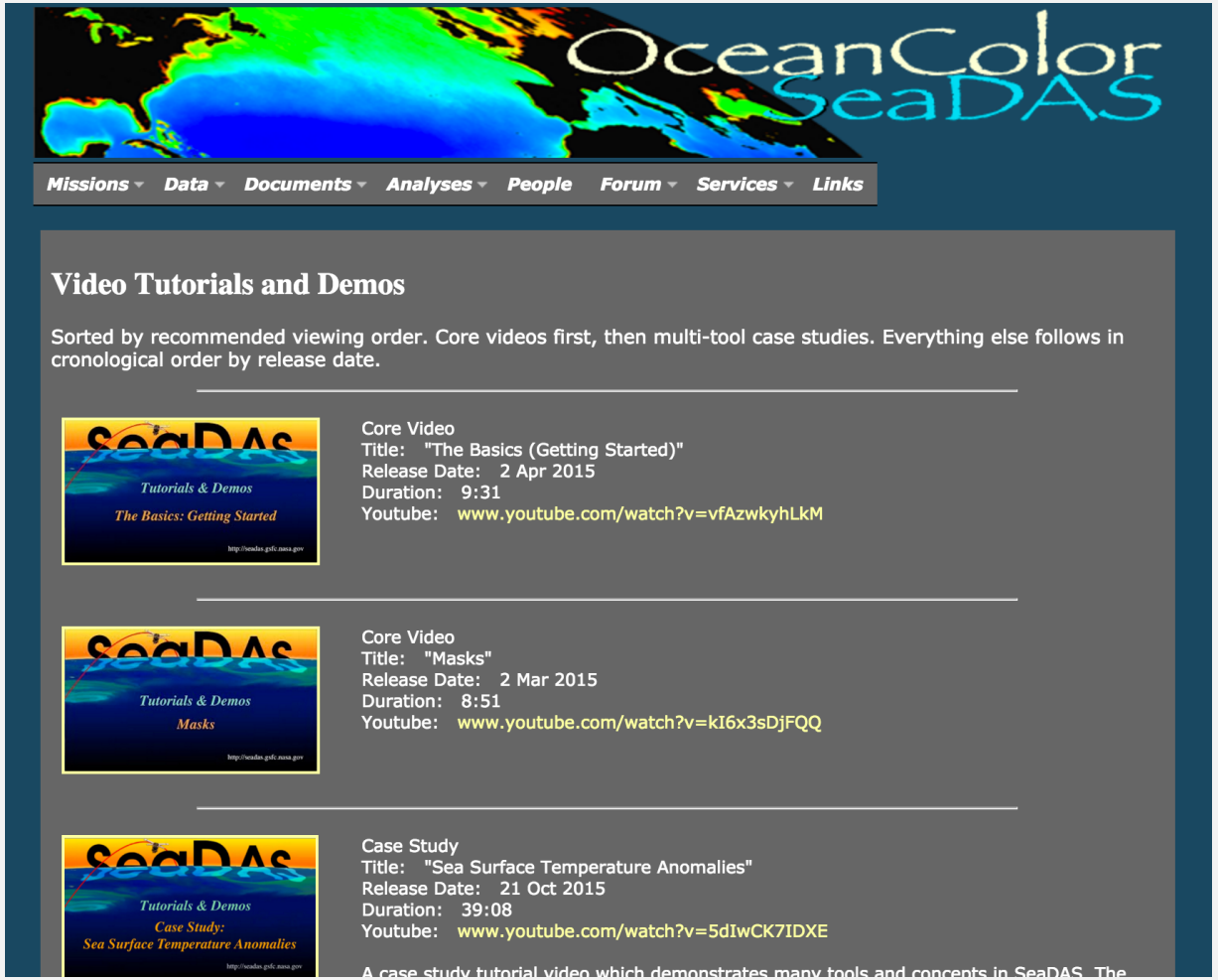
http://seadas.gsfc.nasa.gov/

- 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

Online Tutorials and Webinars for SeaDAS

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

- Strongly recommend completing all of the on-demand tutorials listed on this webpage
- SeaDAS supports a wide variety of satellite sensors so your investment in learning it will be time well spent
- Check out this SeaDAS webinar from June 15, 2016:
  - https://earthdata.nasa.gov/user-resources/webinars-and-tutorials

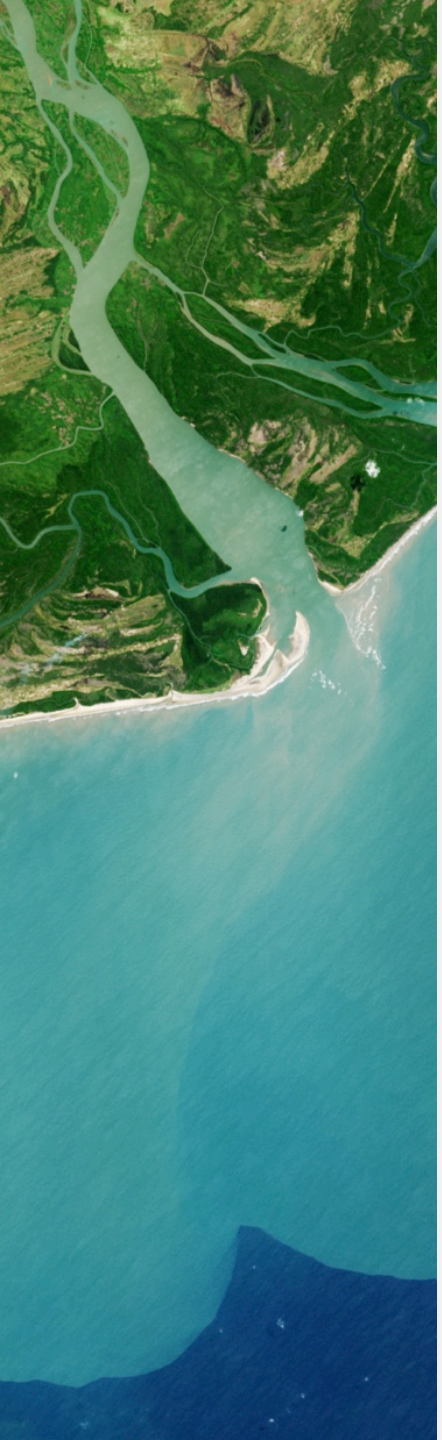


Interested in a More In-Depth Understanding of Aquatic Optics and Remote Sensing Imagery?

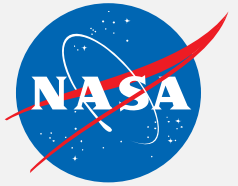
- For a more solid foundation in aquatic optics:
  - Ocean Optics Web Book: http://www.oceanopticsbook.info/
  - IOCCG Summer Lecture Series, 2016: http://ioccg.org/what-we-do/training-and-education/ioccg-summer-lecture-series-2016/#lectures
- For remote sensing imagery information, data access, and processing tools:
  - NASA's OceanColor Web: http://oceancolor.gsfc.nasa.gov/cms

Summary

- Light and Water
  - How light propagates through the atmosphere and water column, and back to sensor
  - Constituents of the water column and their inherent optical properties
- Fundamentals of Remote Sensing
  - Spatial, Temporal, Spectral Resolution
  - NASA Satellites and Sensors for Aquatic Applications
  - Image “Correction”
  - Satellite Data Processing Levels
- Aquatic Remote Sensing Data Products and Their Uses
- Accessing NASA Satellite Imagery
  - Worldview
  - OceanColor Web
  - Other Data Access Tools
- NASA Satellite Data Processing Tools
  - SeaDAS



National Aeronautics and
Space Administration



ARSET

Applied Remote Sensing Training

http://arset.gsfc.nasa.gov

@NASAARSET

Thank you!

http://arset.gsfc.nasa.gov/webinars/fundamentals-remote-sensing