Lakes and Climate: The Role of Remote Sensing
June 01-02, 2017

On the use of water color missions for lakes in 2021

Cédric G. Fichot
Department of Earth and Environment

BOSTON UNIVERSITY

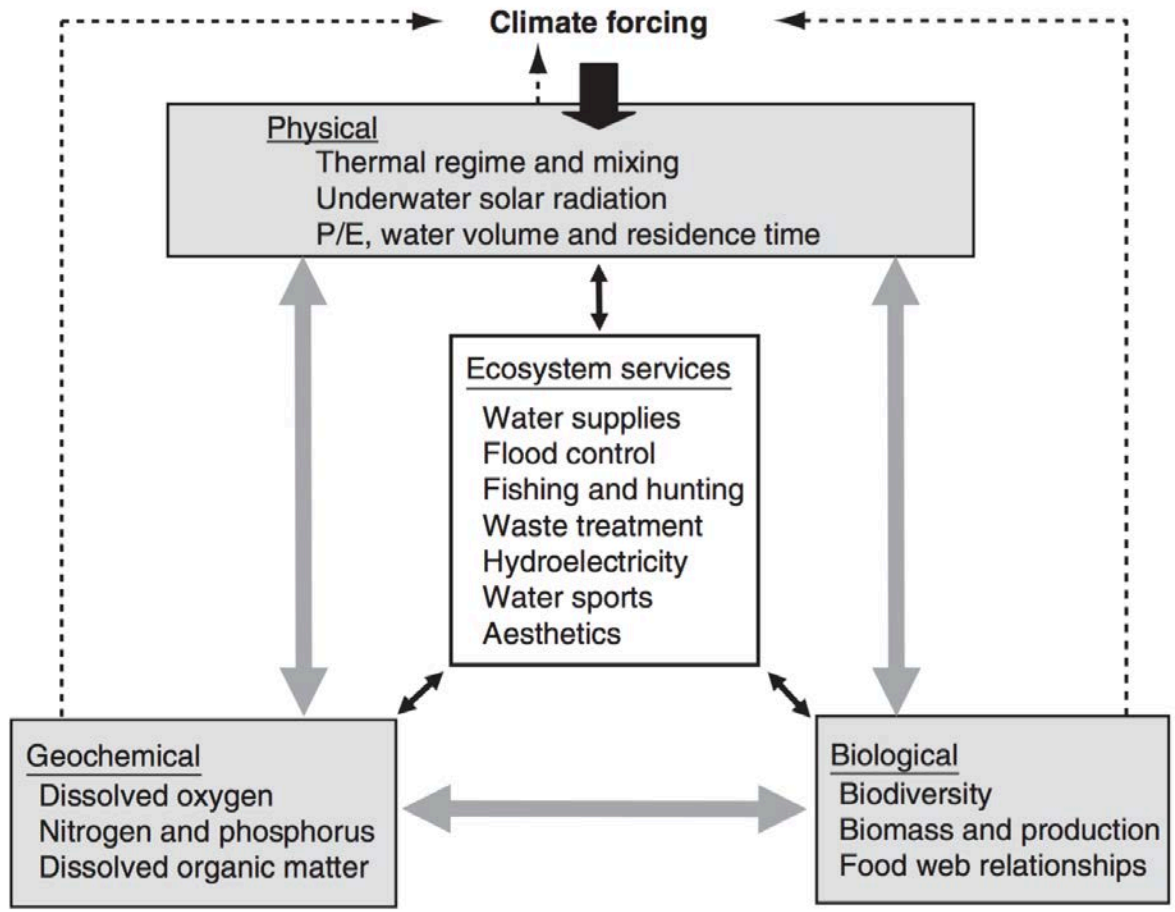
Overview

1. Past and still-ongoing water color missions and their limitations

2. New and future water color missions: pros/cons for lakes

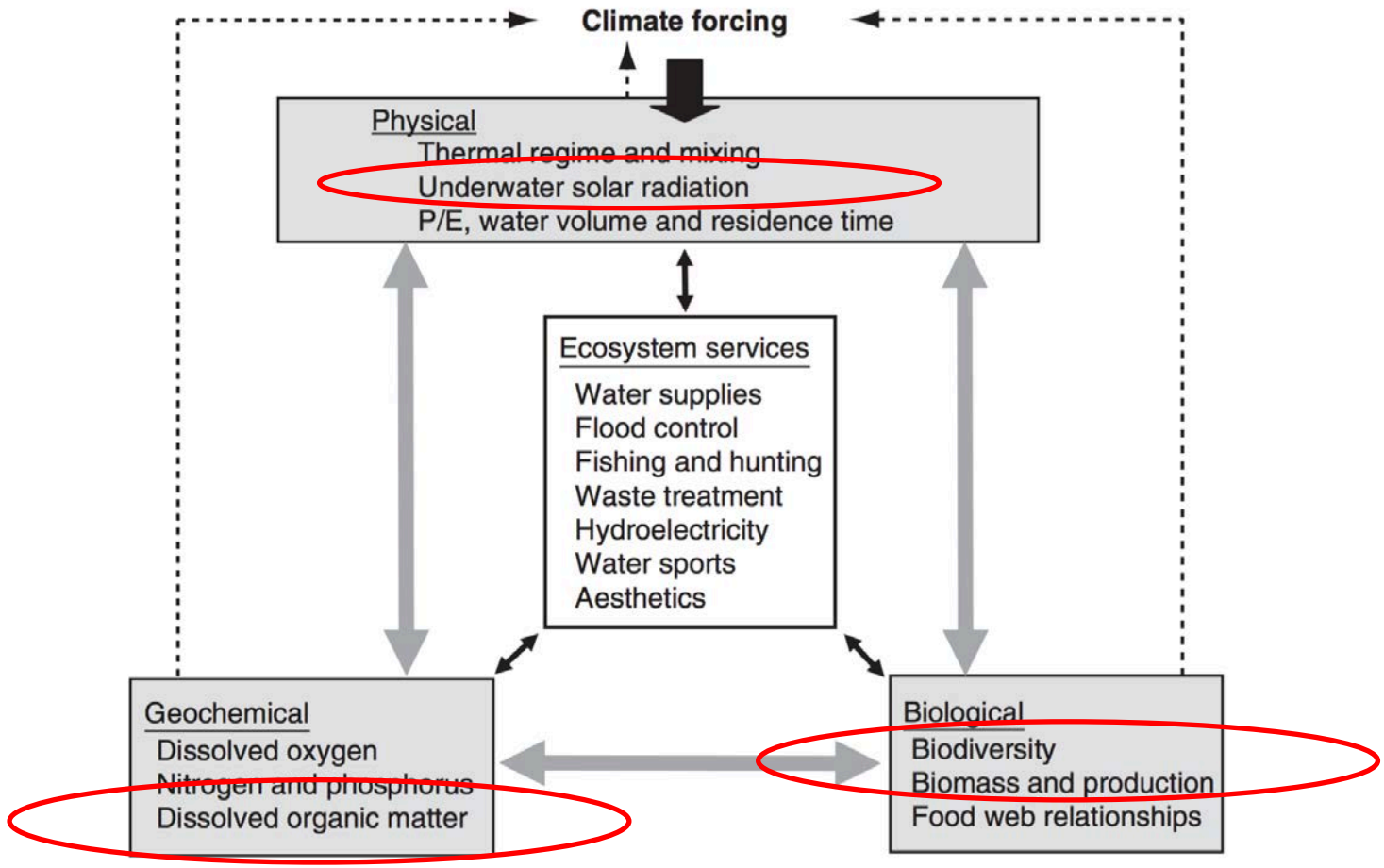
3. Some of the challenges of measuring water color in lakes

Impacts of climate change on lake water color and quality



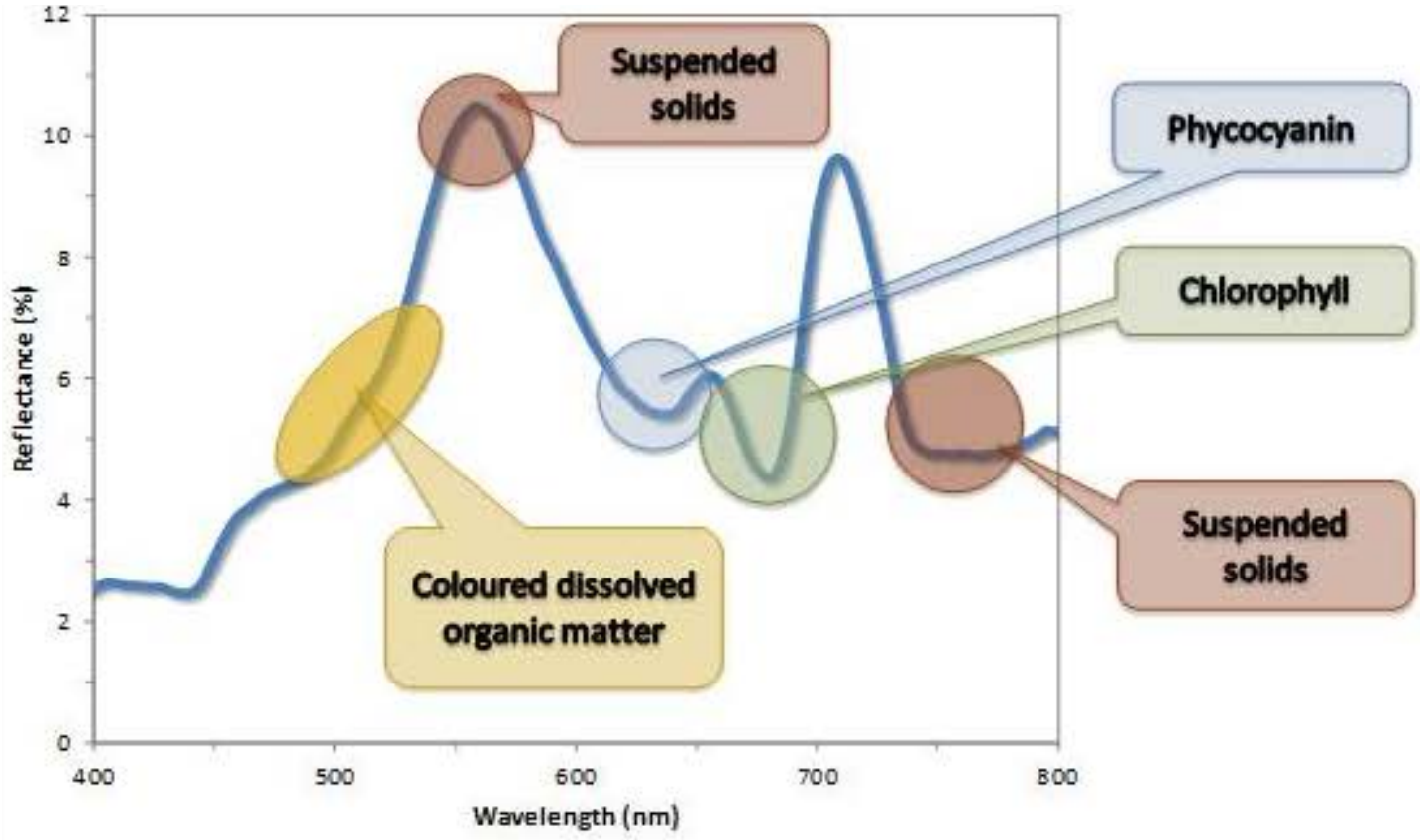
From W. Vincent (2009)

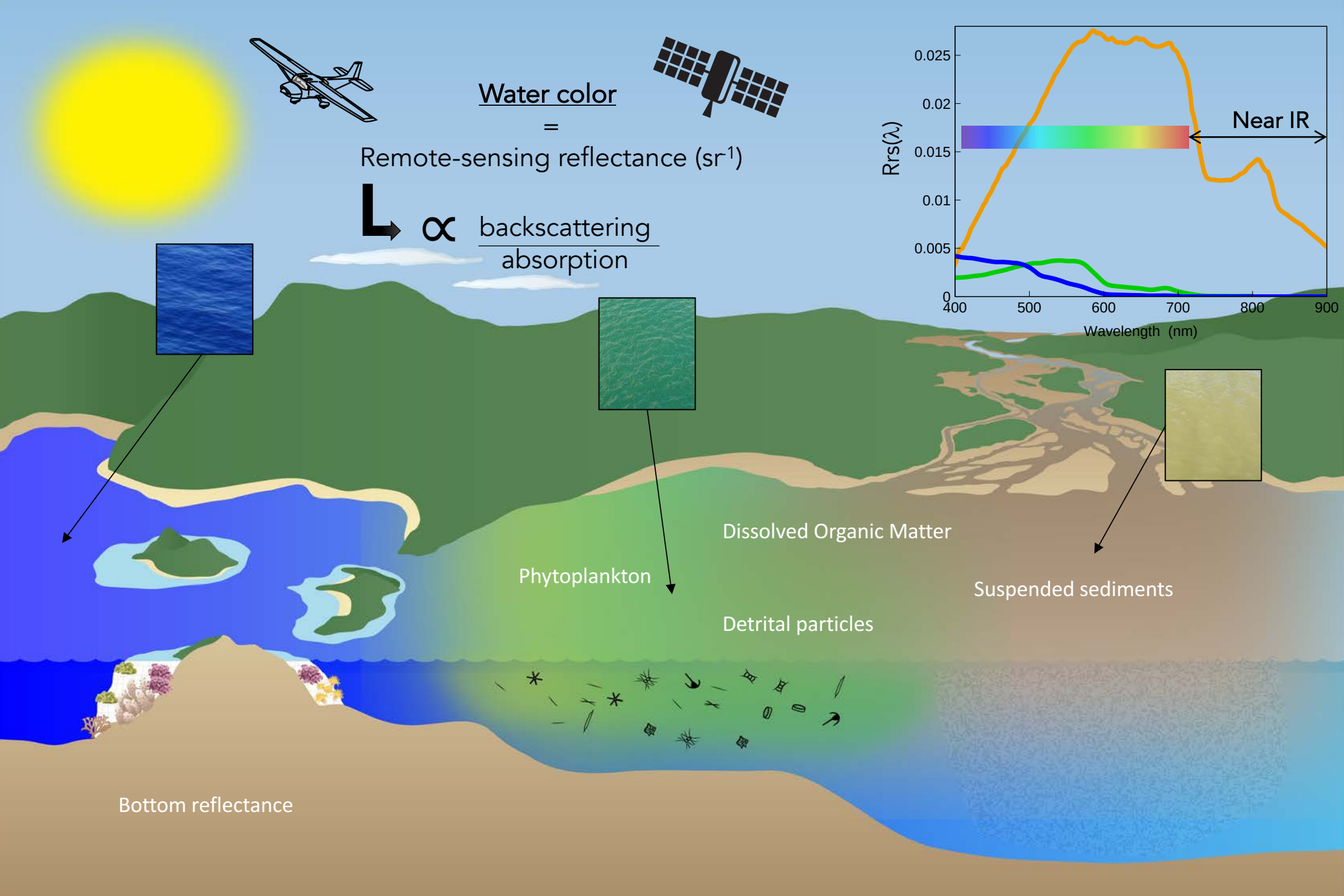
Impacts of climate change on lake water color and quality



From W. Vincent (2009)

Impacts of climate change on lake water color and quality



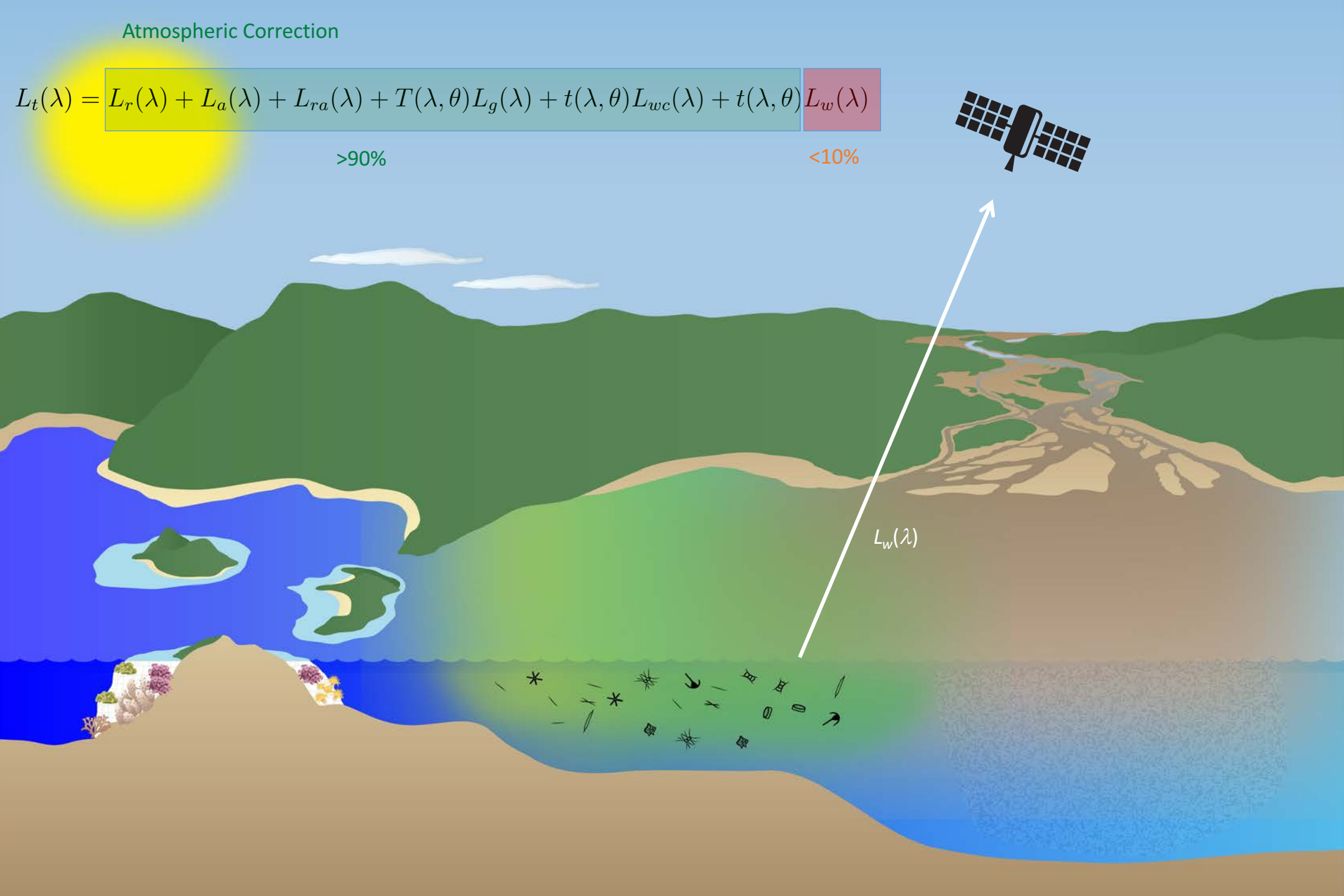

Water color
=
Remote-sensing reflectance (sr-1)
∝
backscattering
absorption
Rrs(λ)
0.025
0.02
0.015
0.01
0.005
0
Near IR
400
500
600
700
800
900
Wavelength (nm)
Dissolved Organic Matter
Phytoplankton
Suspended sediments
Detrital particles
Bottom reflectance

Atmospheric Correction

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

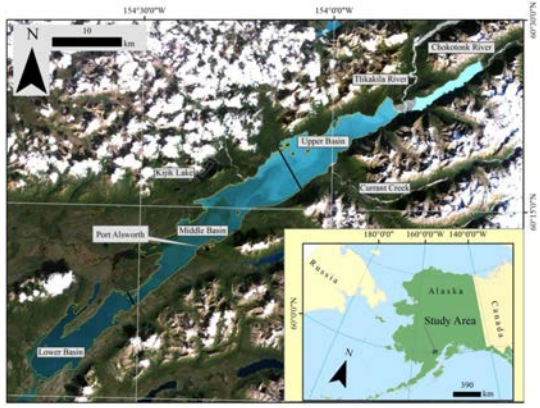
>90%

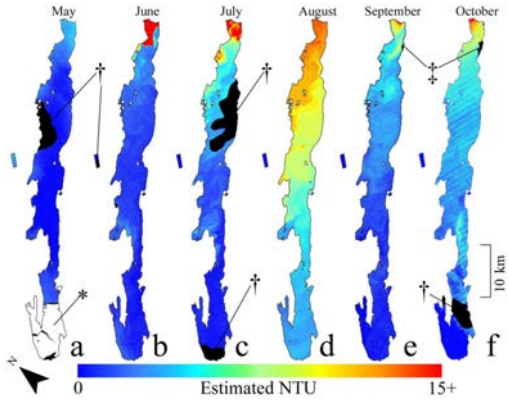
<10%



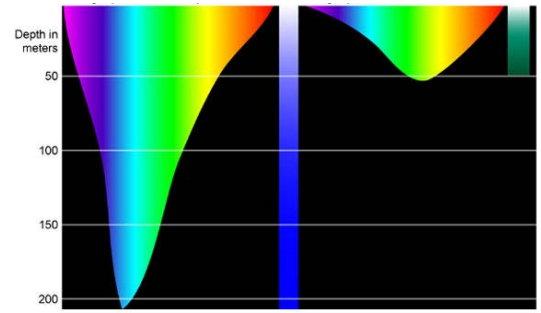
Satellite water color has found many application in lakes

Turbidity

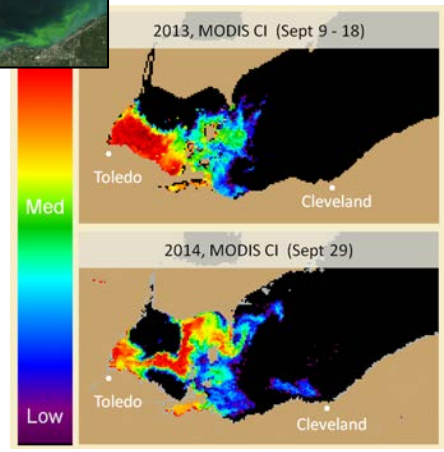


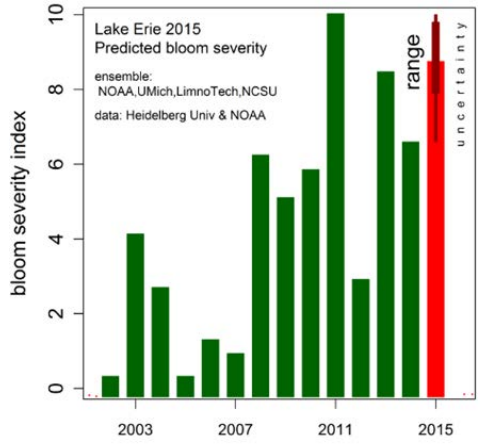


Vertical light penetration

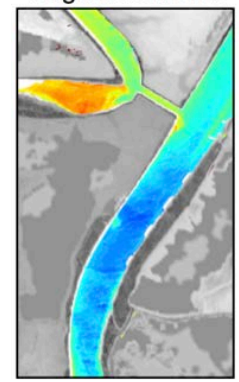


Chlorophyll-a and harmful algal blooms

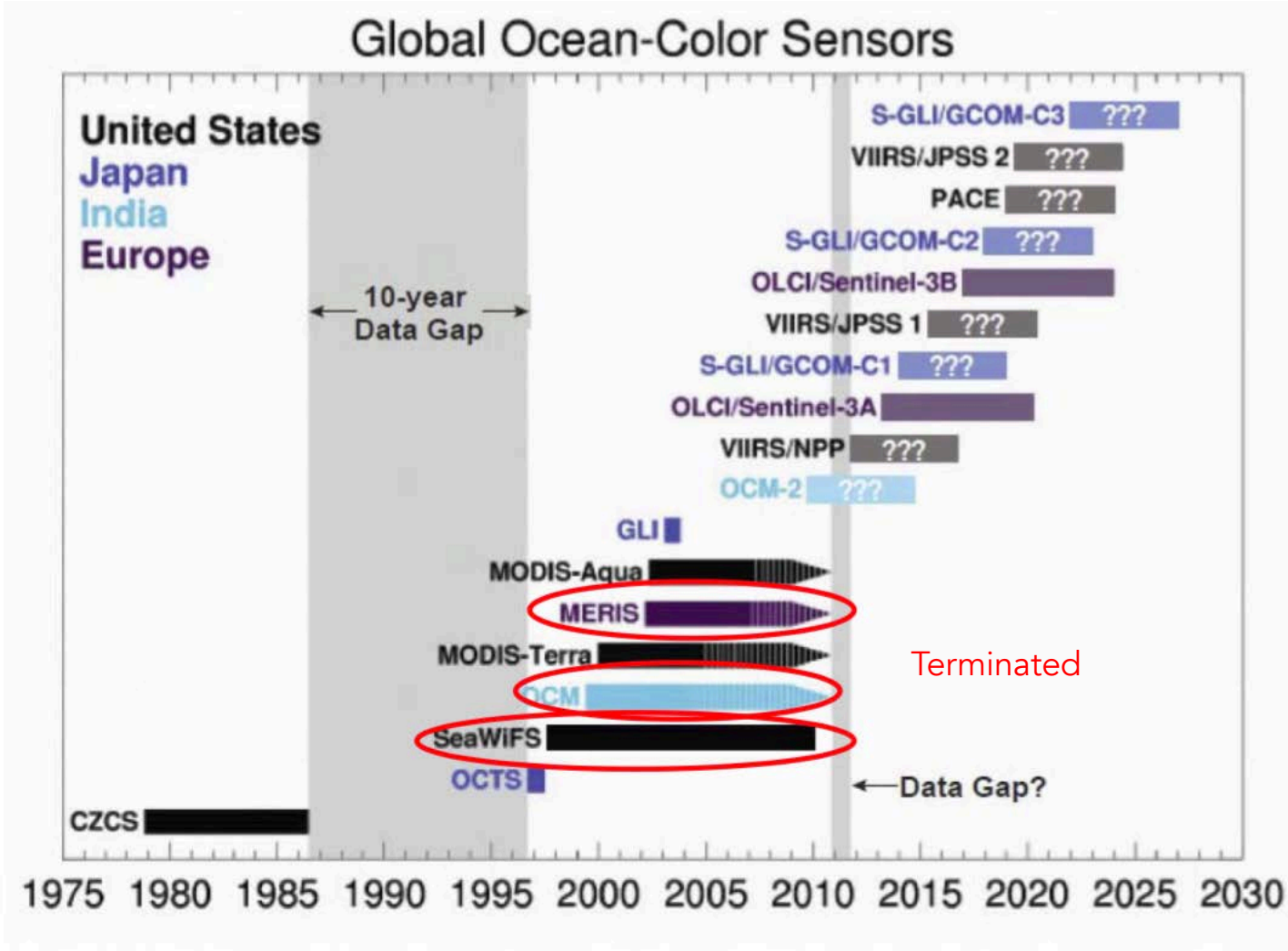




Dissolved Organic Matter /Carbon

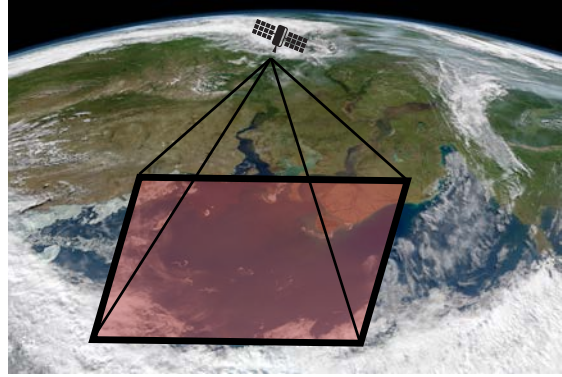


Water color missions



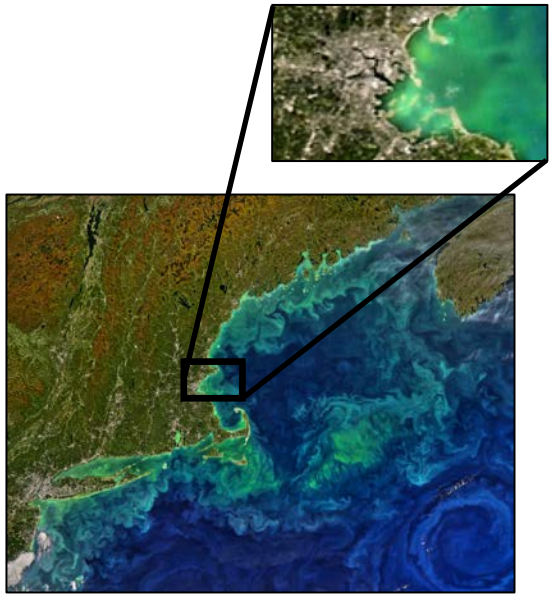
NRC, 2011

Water color missions are optimized for the ocean

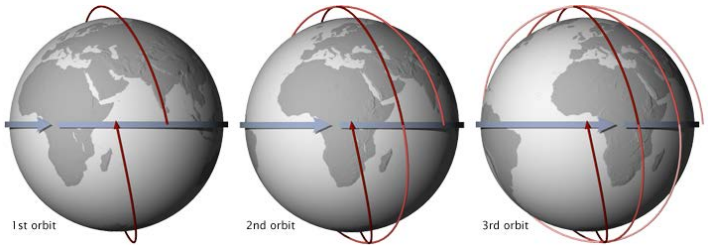


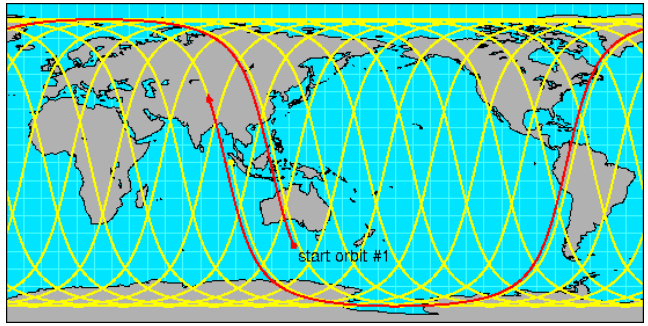
- Compromise between the different resolutions (Spatial, Temporal, Spectral)
- Linked to signal-to-noise ratio

1-km spatial resolution

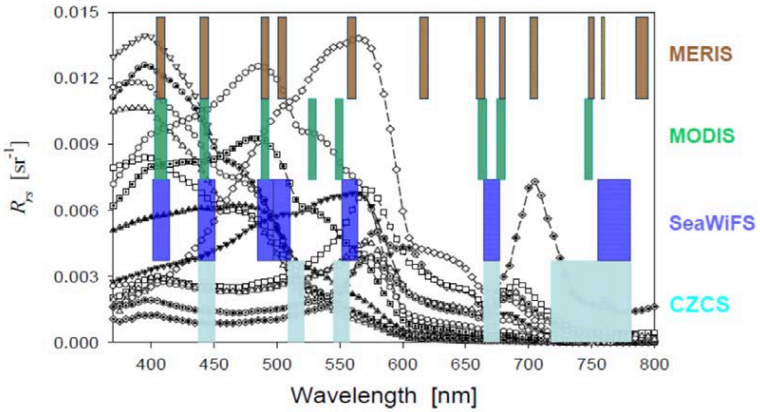


Daily coverage (if no clouds)

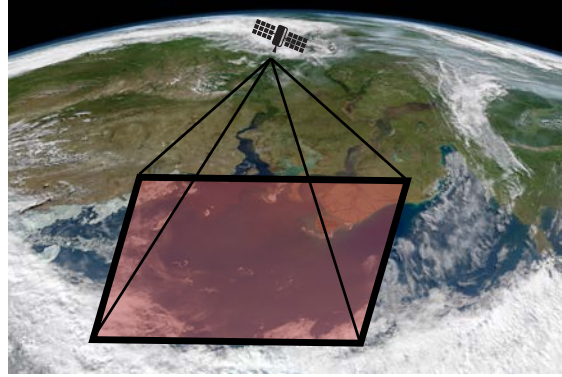




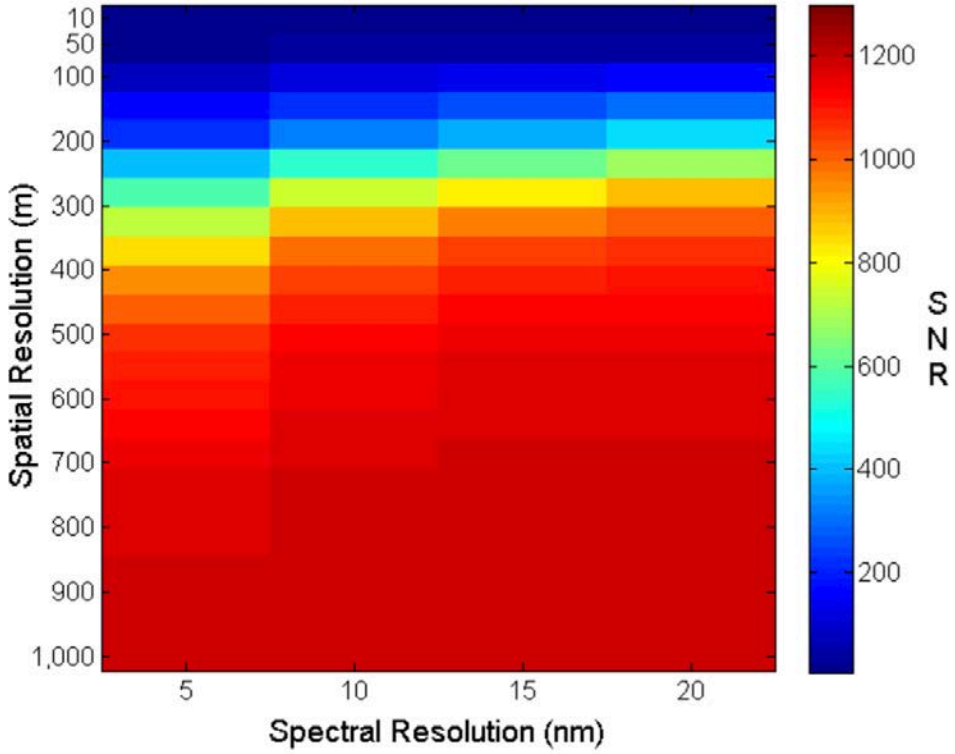
Multispectral
(several, well selected spectral bands)

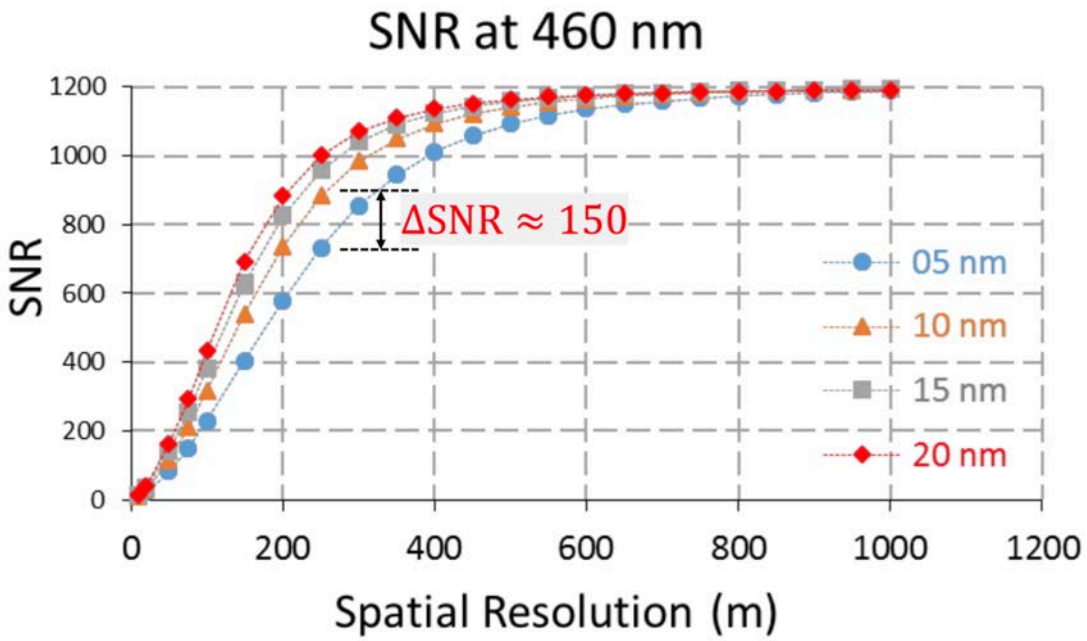


Water color missions are optimized for the ocean



- Compromise between the different resolutions (Spatial, Temporal, Spectral)
- Linked to signal-to-noise ratio

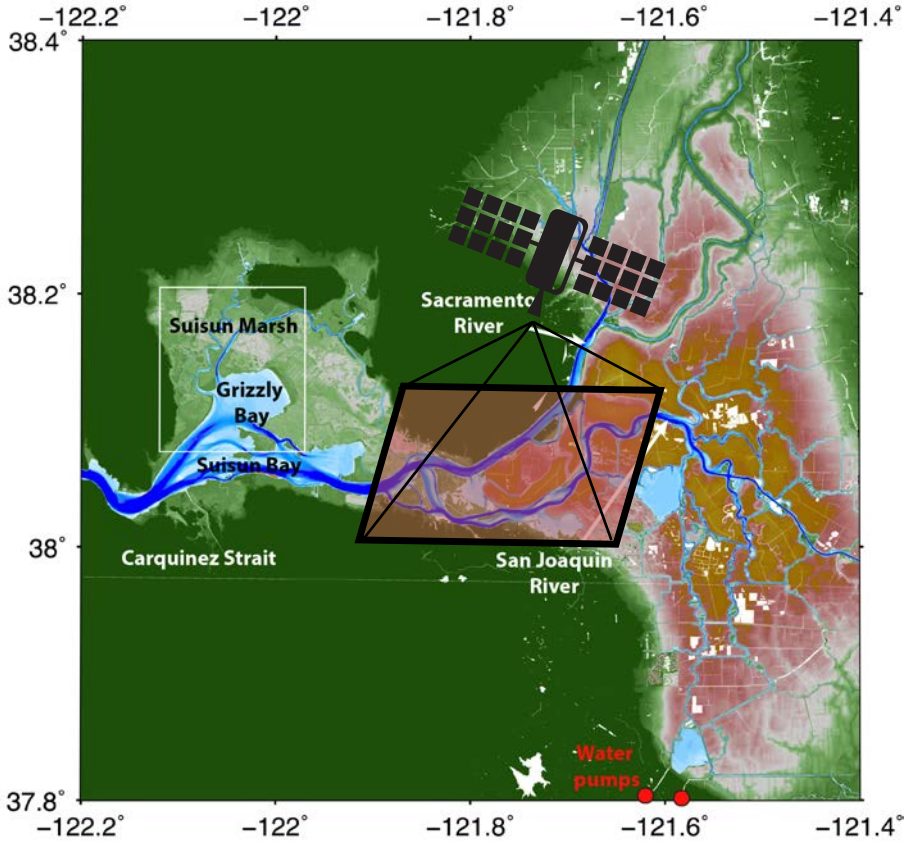




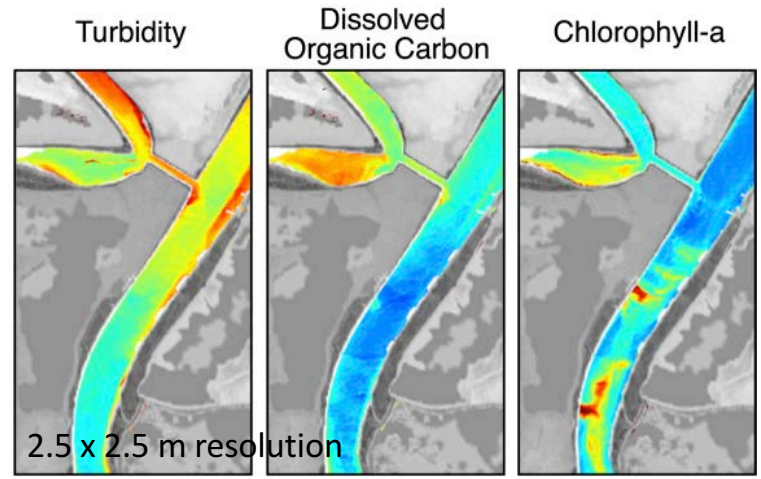
Source: Wes Moses

Spatial resolution limitations

Limitations for use in inland or estuarine waters



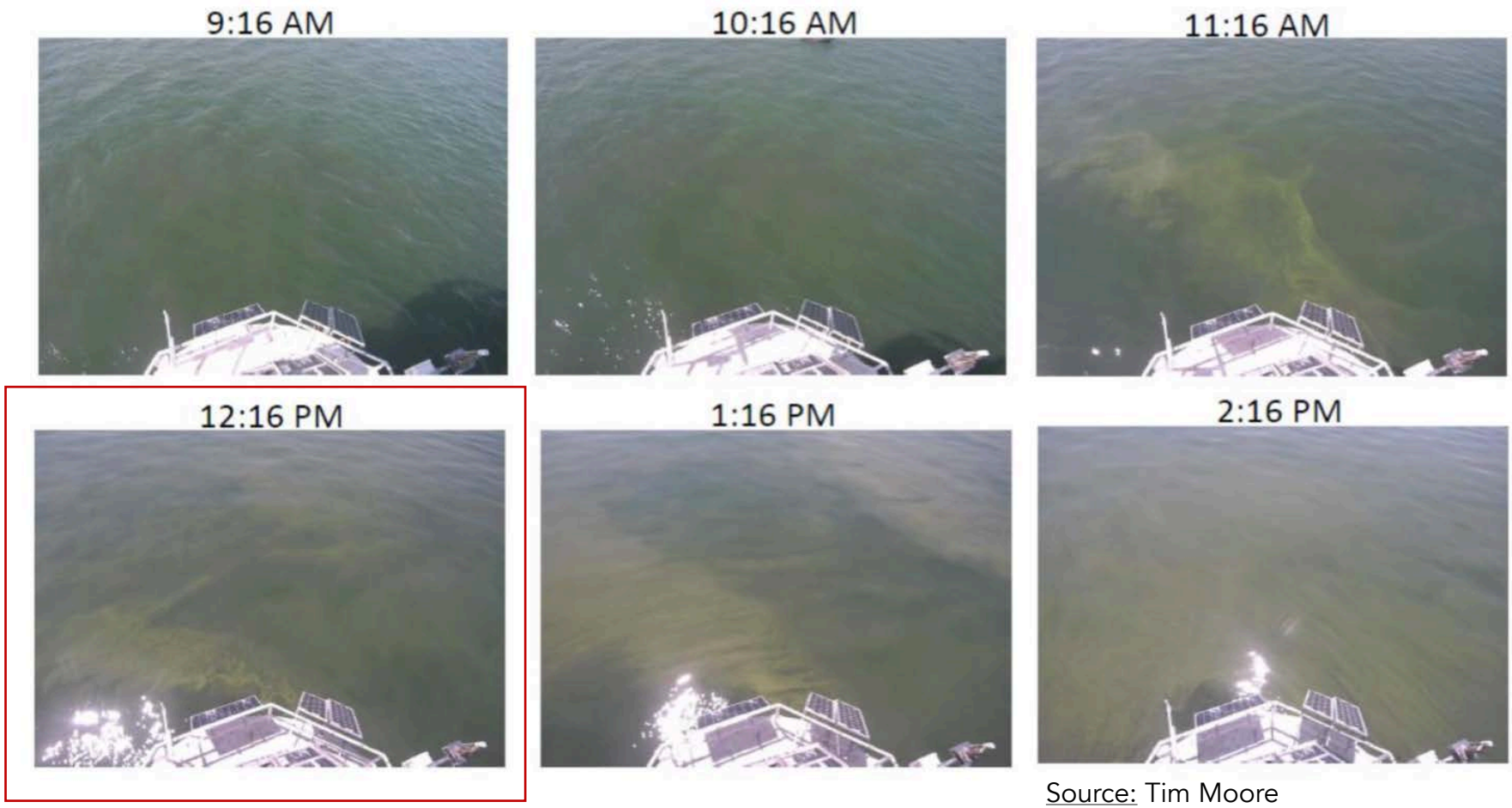
300-m resolution



Temporal resolution limitations

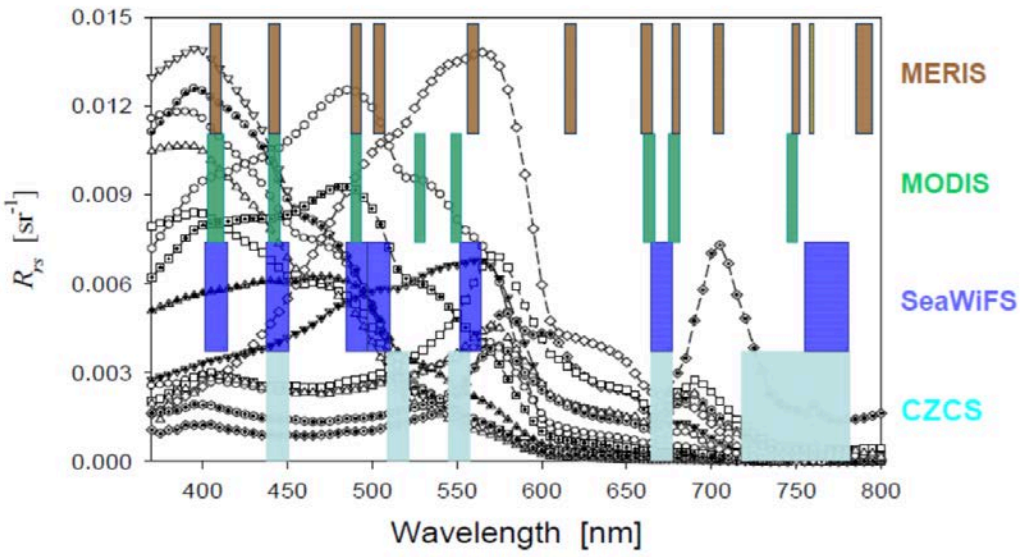
Large freshwater cyanobacteria surface colony can develop in matters of hours

July, 23 2016

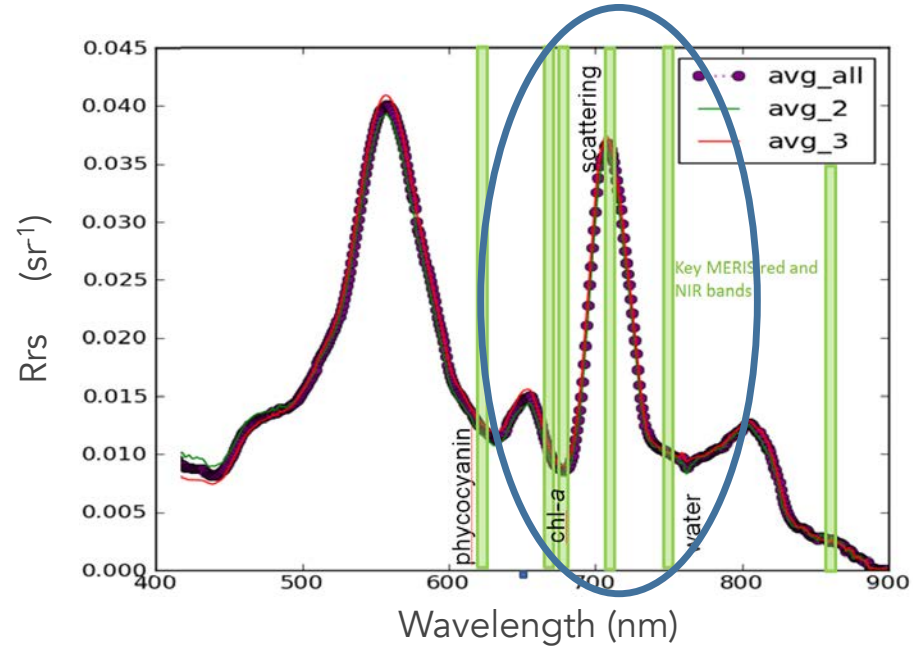


Source: Tim Moore

Spectral resolution and range limitations



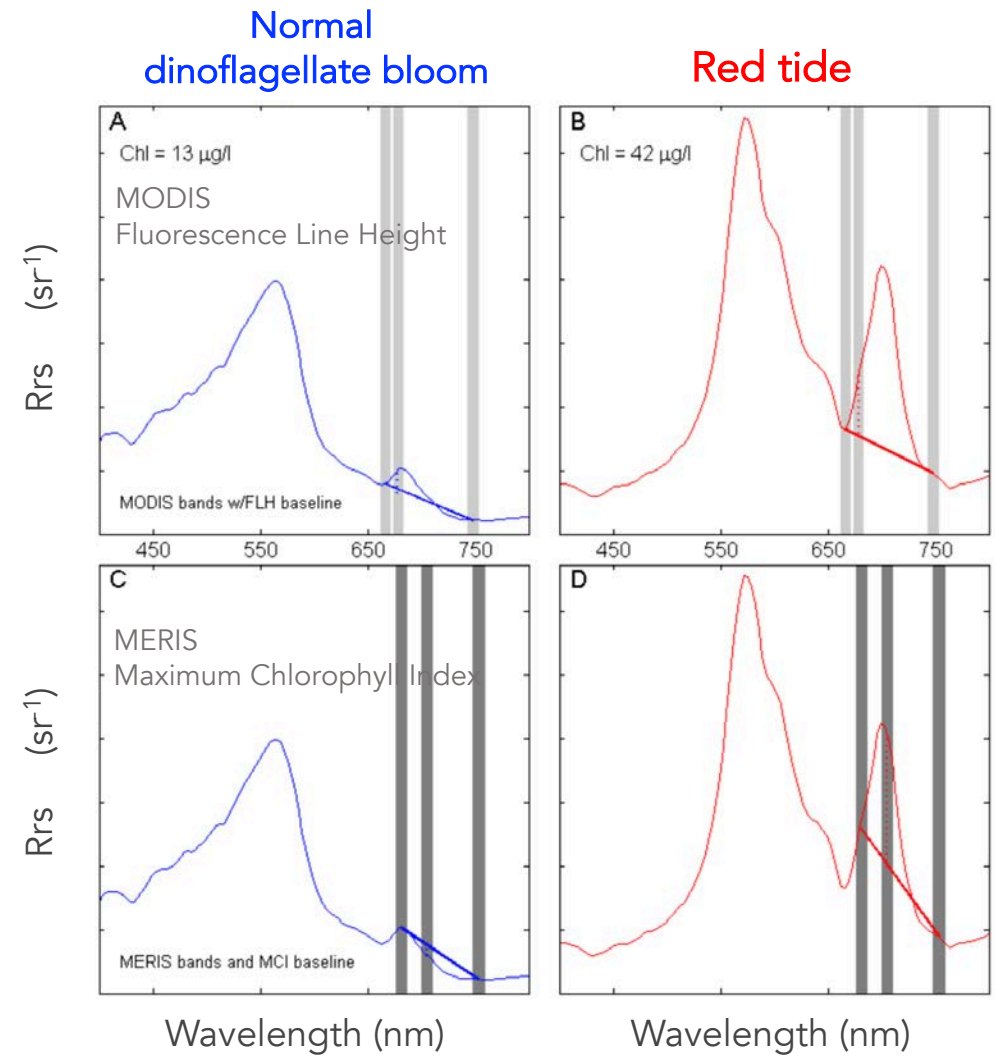
Red-NIR part of spectrum
is sensitive to high-biomass variations



Spectral resolution and range limitations

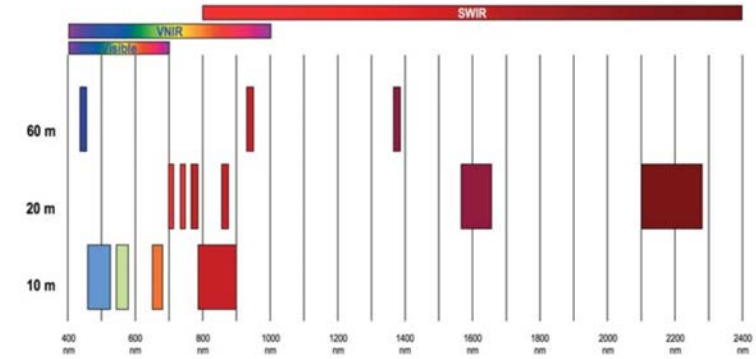
MODIS Fluorescence Line Height method
Good for lower phytoplankton biomass

MERIS Maximum Chlorophyll Index
Good for higher phytoplankton biomass (red tide)



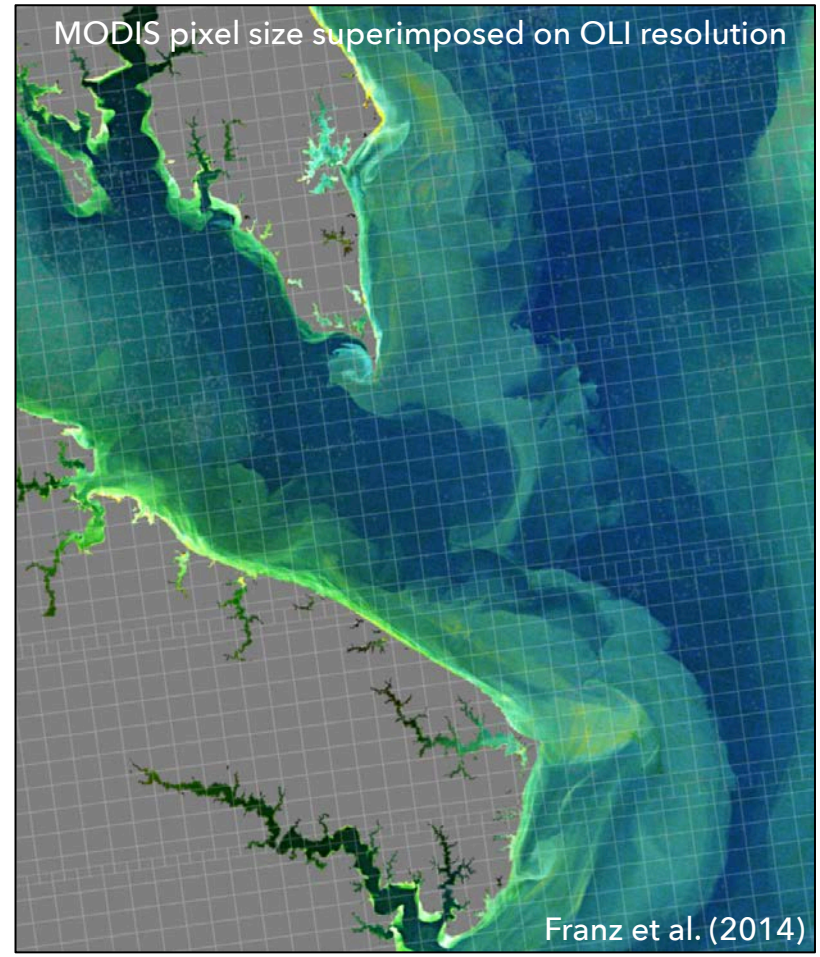
New and future
Water Color Missions and Sensors

Landsat-8 and Sentinel-2



Landsat-8 Operational Land Imager (OLI)

Sentinel-2A and 2B Multi-Spectral Imager (MSI)



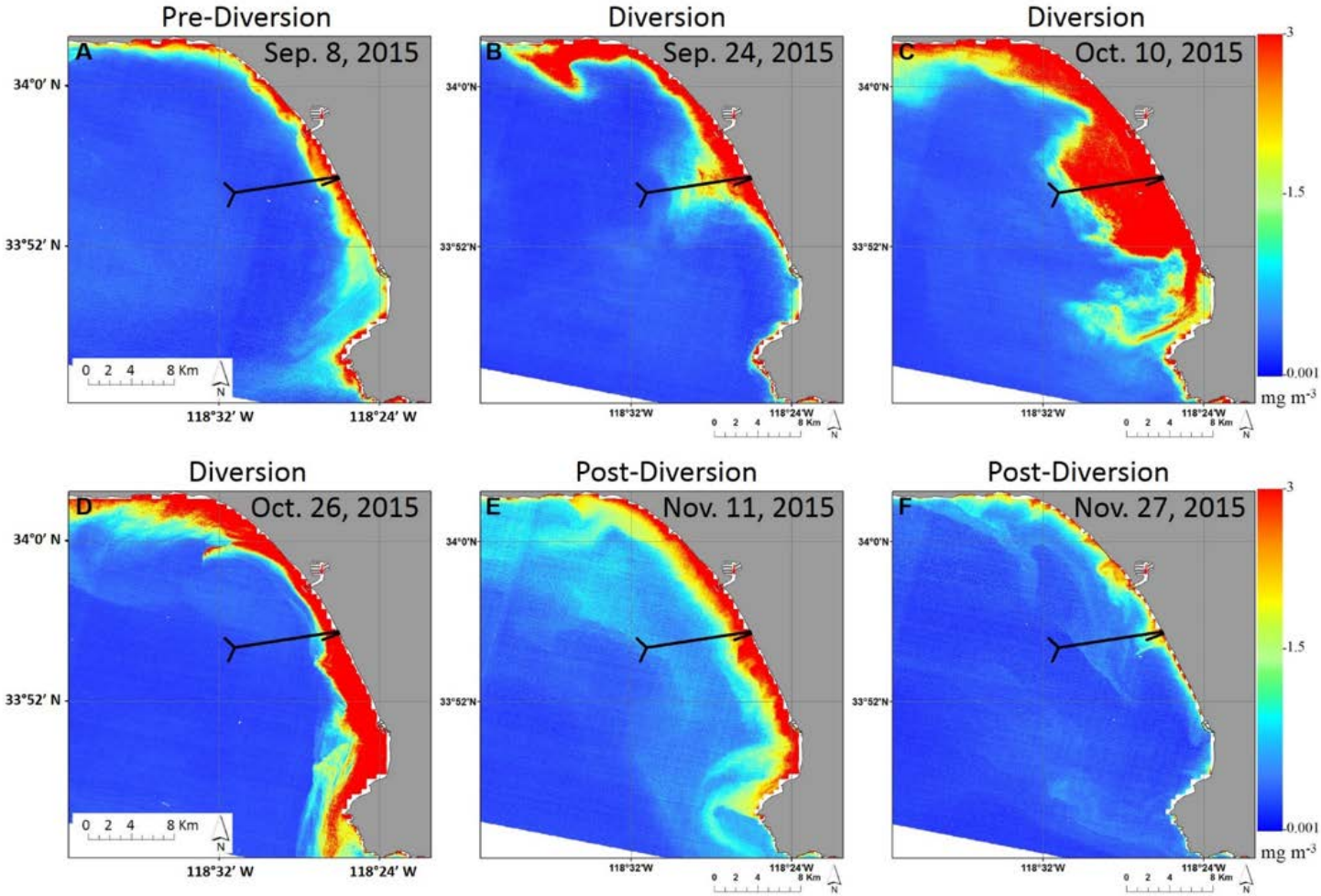
PROS:

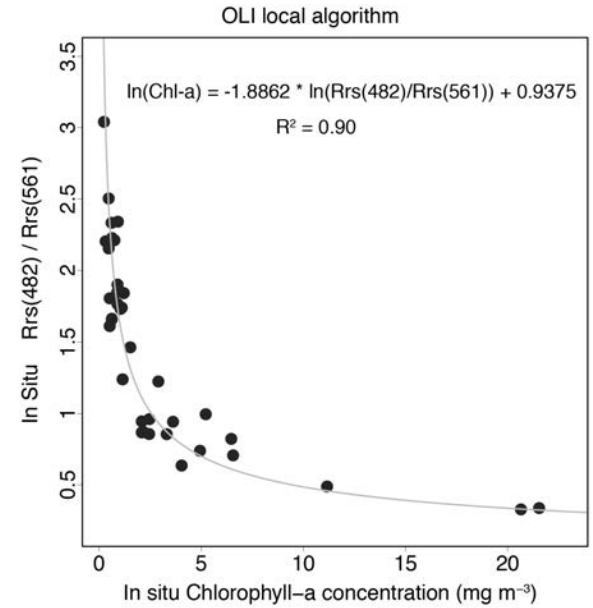
- Much improved SNR compared to previous landsat missions: facilitates measurements over water
- High-spatial resolution (10-30 m) opens new applications
- SWIR bands to improve atmospheric corrections in turbid waters

CONS:

- Restricted spectral resolution limits range of applications
- Limited temporal coverage (5-day revisit time at best) for a number of applications

Impacts of a wastewater diversion on chlorophyll-a concentration in coastal waters

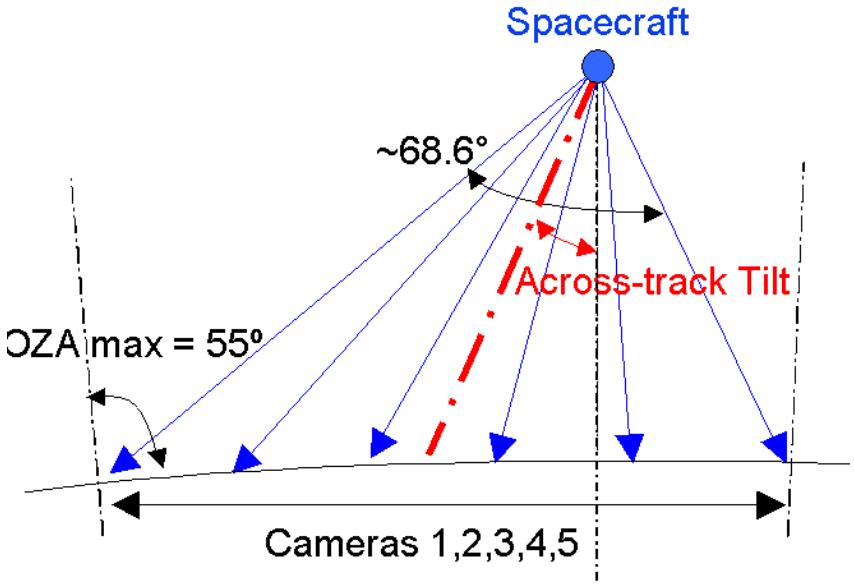




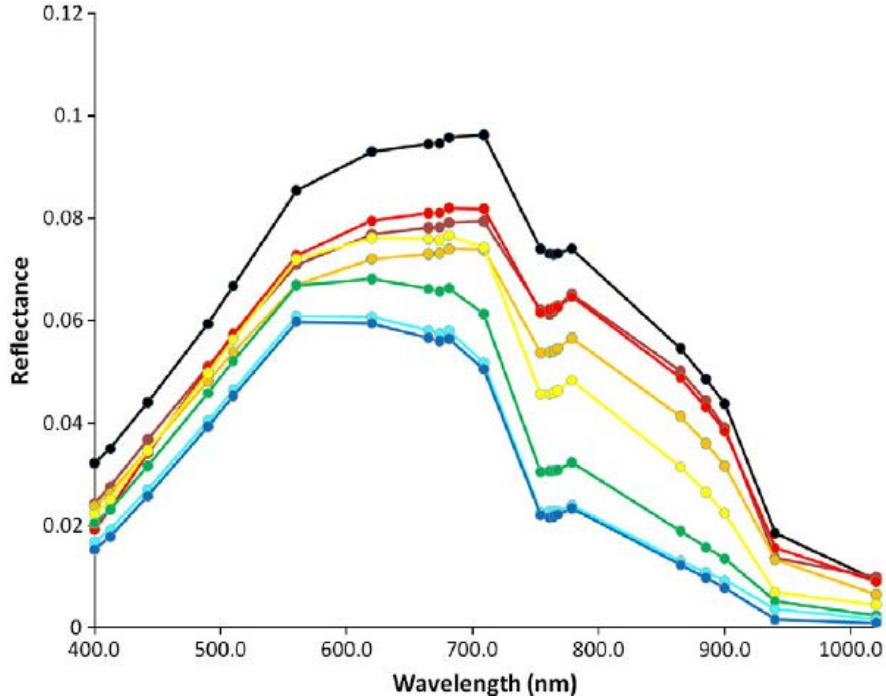
Sentinel-3 Ocean and Land Colour Instrument (OLCI)

Sentinel 3-A: launched in Feb. 2016
Sentinel 3-B: to be launched end of this year

- Pushbroom, 5-camera system
- 21 narrow spectral bands: 400 - 1020 nm
- 300-m spatial resolution
- Swath of 1270 m

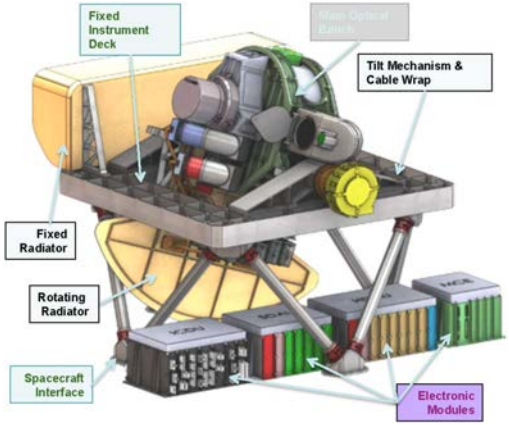


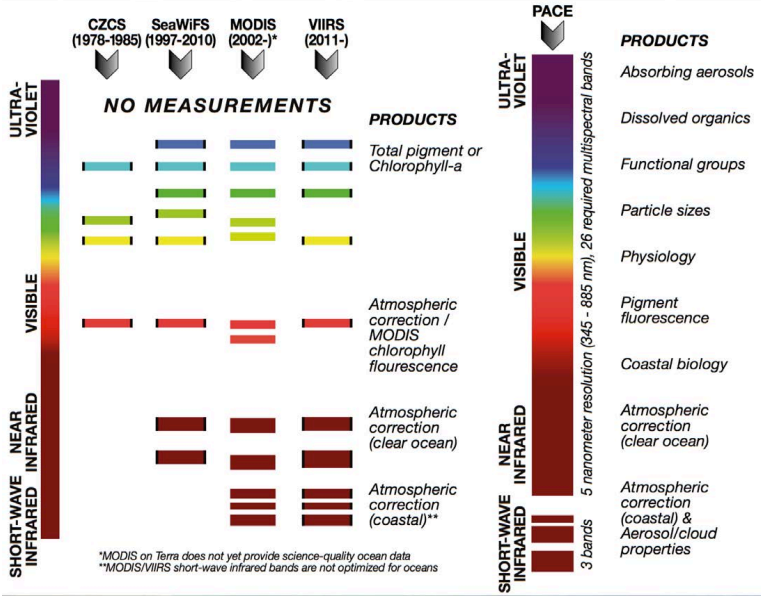
21 narrow spectral bands



NASA PACE Mission

PACE = Plankton, Aerosol, Cloud, ocean Ecosystem)

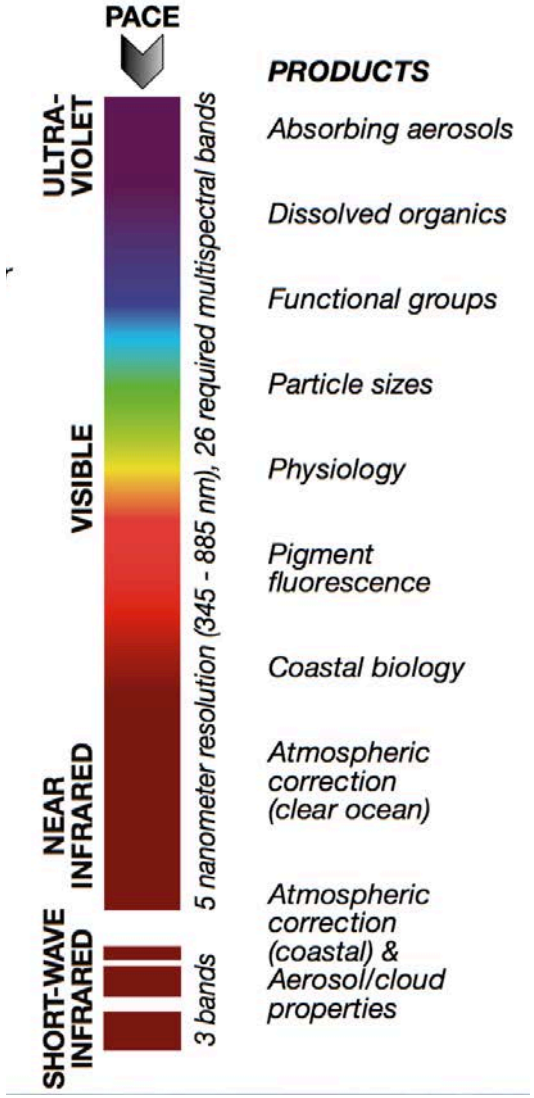


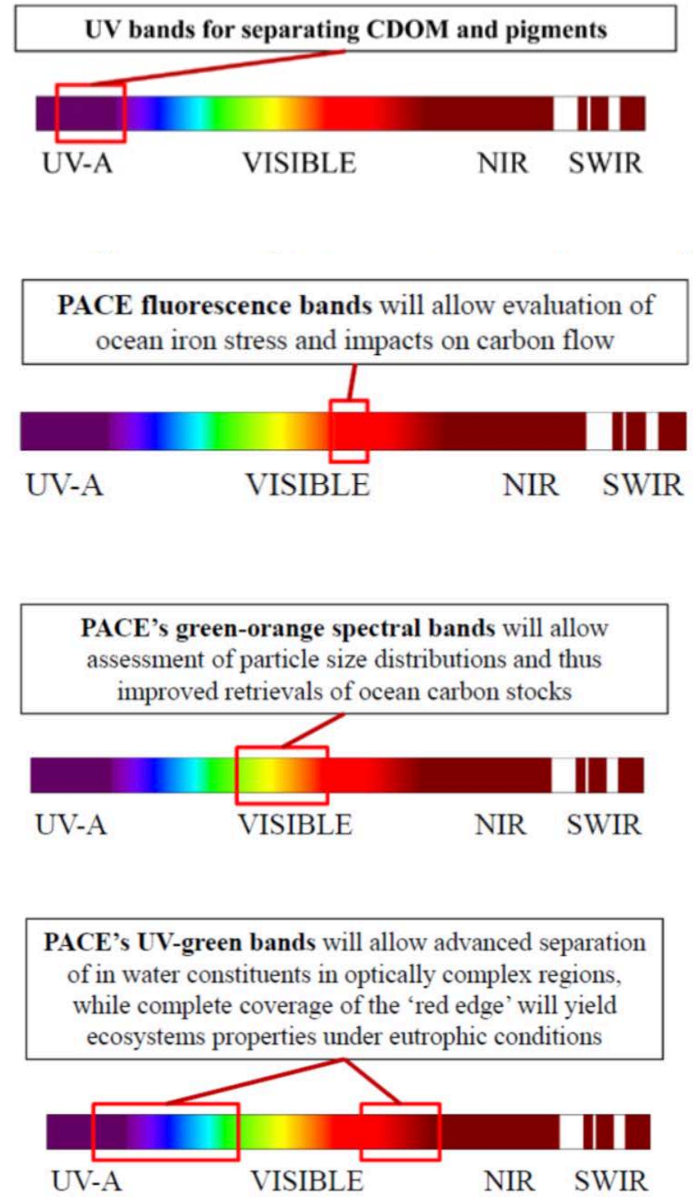


2022 timeframe

- Single detector, rotating telescope scanner (like SeaWiFS)
- 20-degree tilt to avoid sun glint
- Monthly lunar calibration of all science detectors
- Ground sample distance ~ 1 km^2 at nadir
- 5 nanometer (nm) resolution from 350 to 890 nm
- Plus short-wave infrared (SWIR) bands centered on: 940, 1240, 1380, 1640, 2130 & 2250 nm
- Image artifacts <0.5% at calibrated, top-of-atmosphere radiances

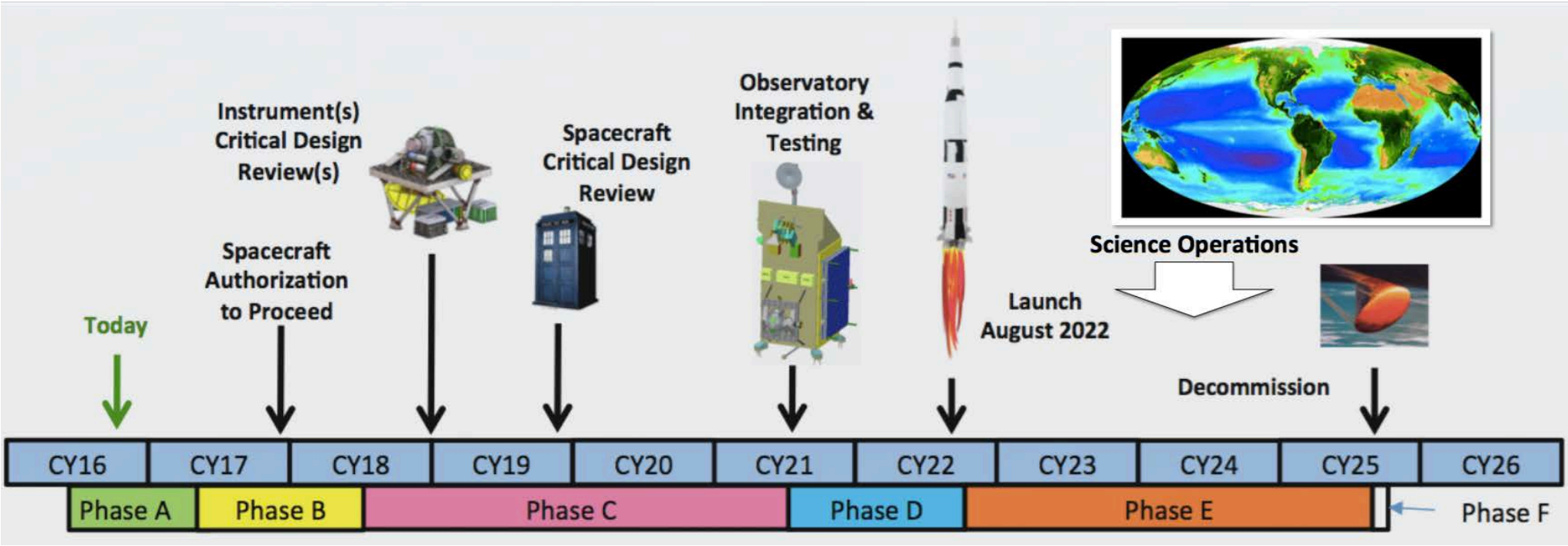
NASA PACE Mission





Source: PACE STR

PACE timeline



PROS:

- Good SNR
- Daily coverage (higher at higher latitudes)
- Hyperspectral!!!

CONS:

- Spatial resolution of 1 km^2 (limits use to large lakes)
- Daily coverage

GEOstationary Coastal and Air Pollution Events (GEO-CAPE)

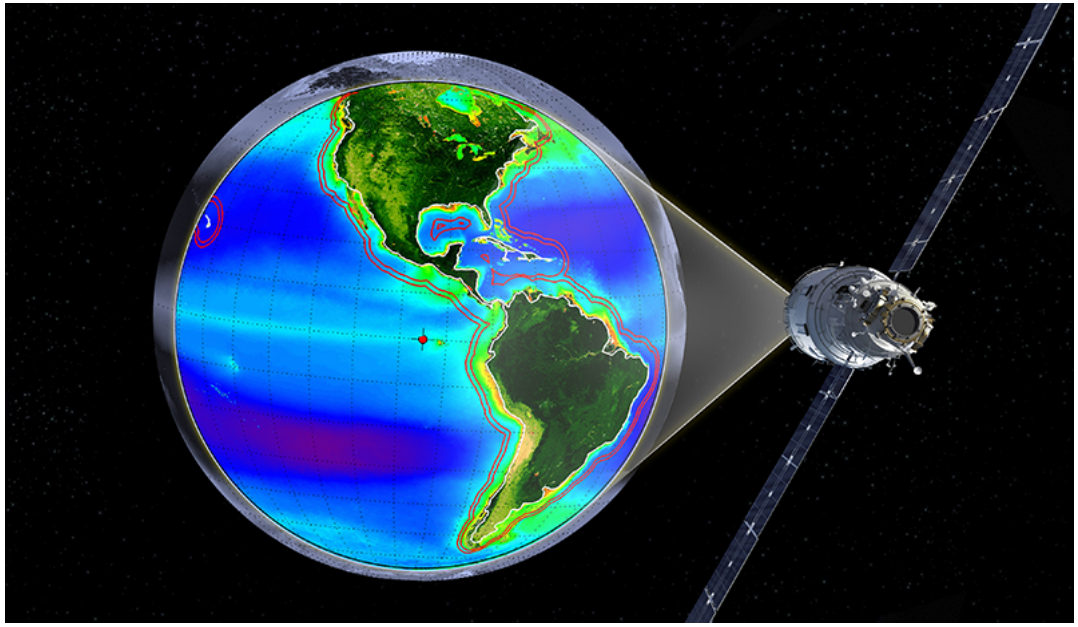
- Geostationary satellite (36,000 km altitude)
- Constant coverage of Americas every 3h
- Target areas up to 1 h
- Post-2022

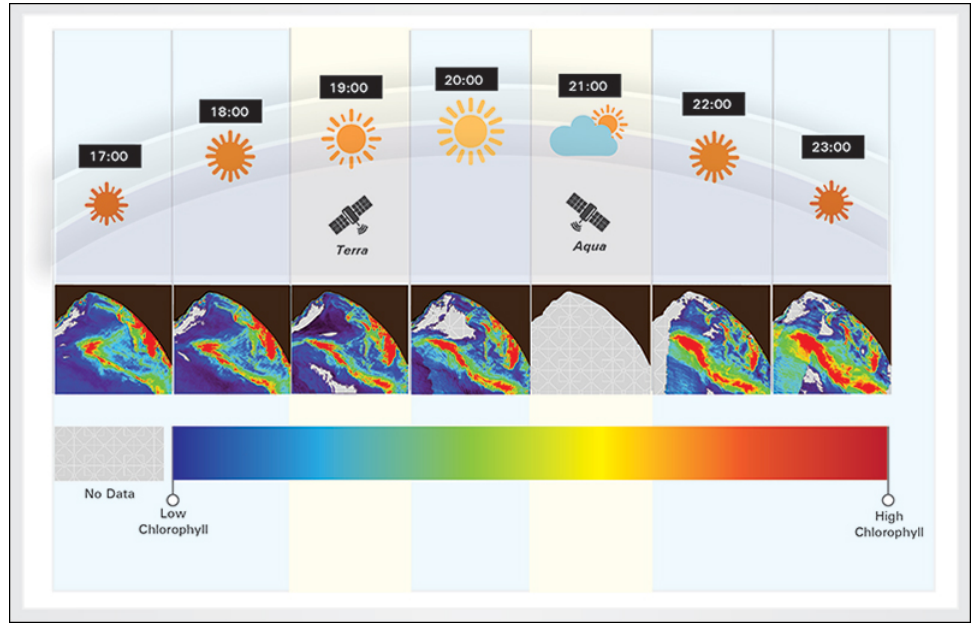
Resolutions

Spectral: UV-Vis-NIR Spectrometer
Multi- or hyperspectral

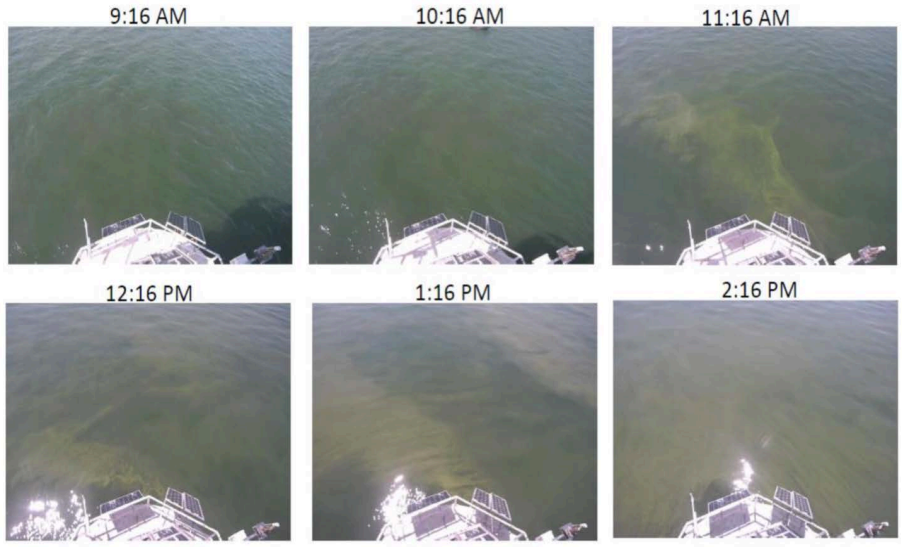
Spatial: 200-300 m (potentially less)

Temporal: up to hourly





GEOstationary Coastal and Air Pollution Events (GEO-CAPE)



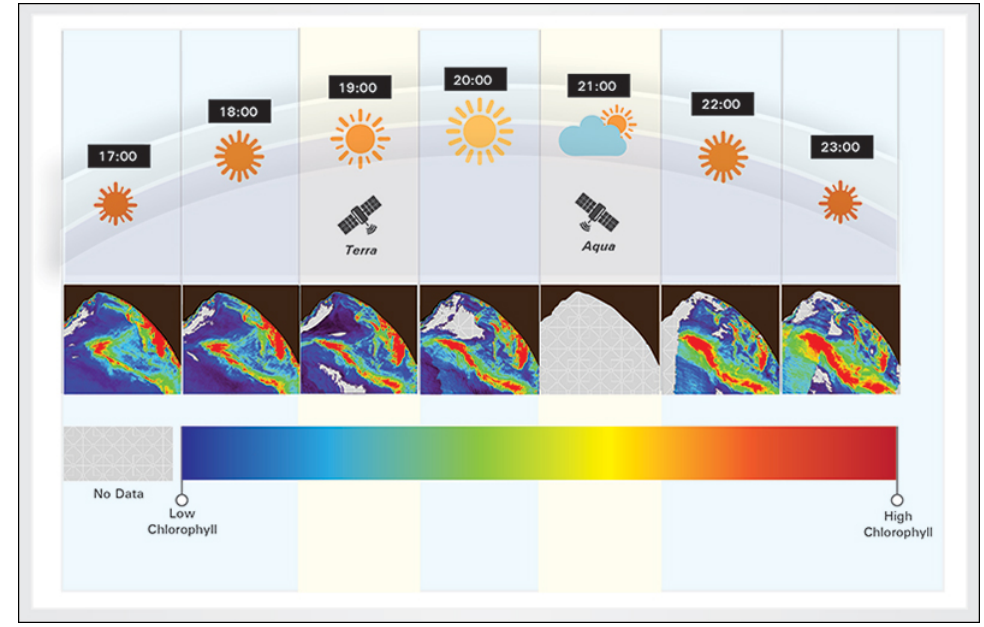
Source: Tim Moore

Resolutions

Spectral: UV-Vis-NIR Spectrometer
Multi- or hyperspectral

Spatial: 200-300 m (potentially less)

Temporal: up to hourly



PROS:

- Up to hourly coverage
- Spatial resolution 200-300 m
- Hyperspectral?

CONS:

- Spatial resolution 200-300 m
- Not global

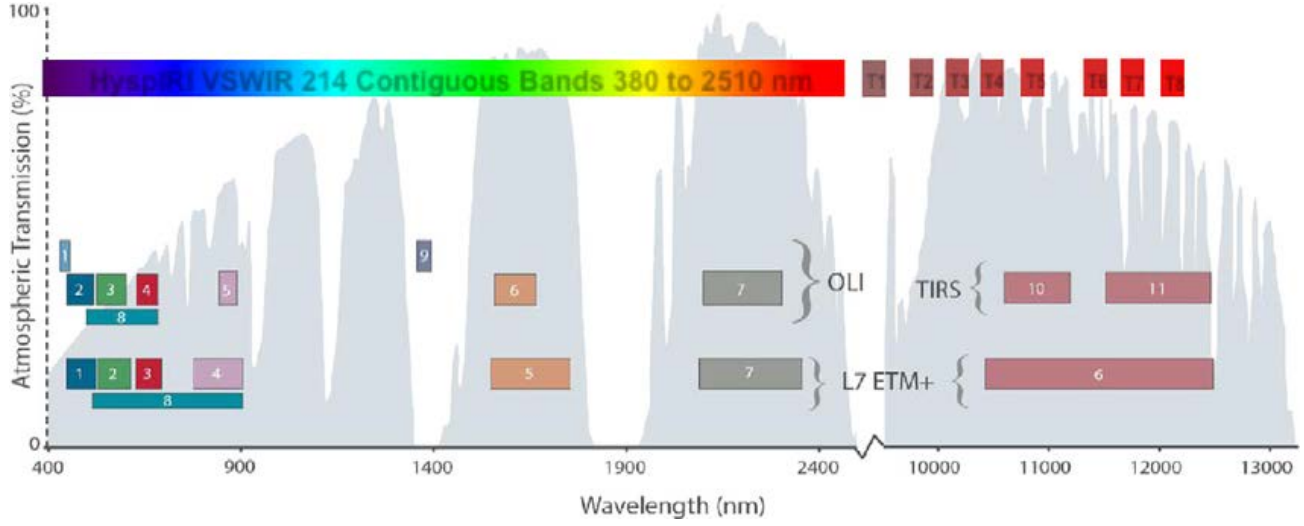
Hyperspectral InfraRed Imager (HyspIRI)

- Timeframe is post > 2025???
- Essentially a hyperspectral Landsat

Visible to short wave infrared (VSWIR: 380 nm - 2500 nm) in 10 nm contiguous bands

A multispectral imager measuring from 3 to 12 um in the mid and thermal infrared (TIR).

- 30-60 m spatial resolution
- 16-day revisit time



Challenges of doing remote sensing over inland waters

Measuring water color in lakes represent a challenge

- Very variable in size, dynamics, and range and characteristics of in-water constituents

- Very optically complex water bodies (with many independently varying in-water constituents)

<u>Need of algorithm blending:</u>

- Water-type specific (adaptive) algorithms
- Allows to tune optical models to specific water types
- How to define the water types

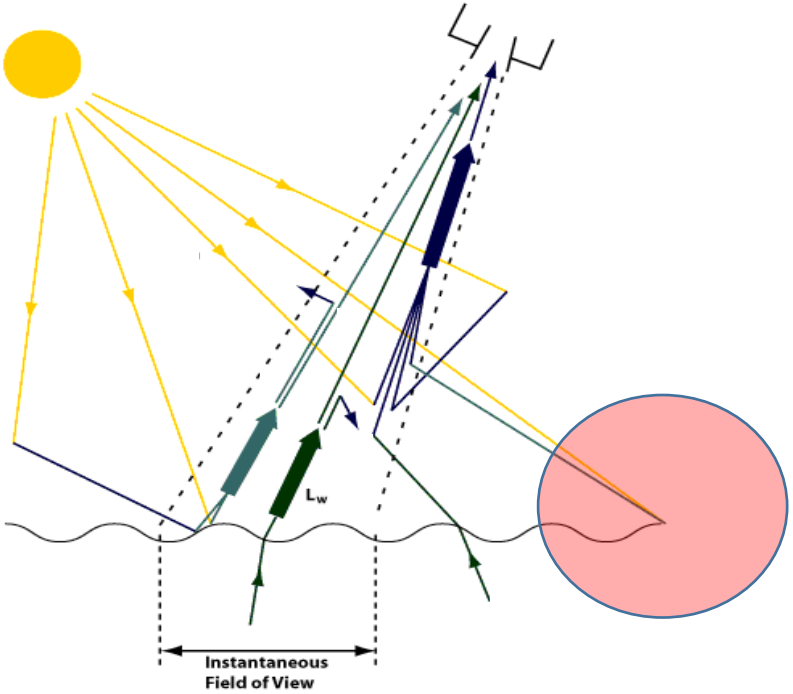
Measuring water color in lakes represent a challenge

Many other challenges and issues faced in inland waters:

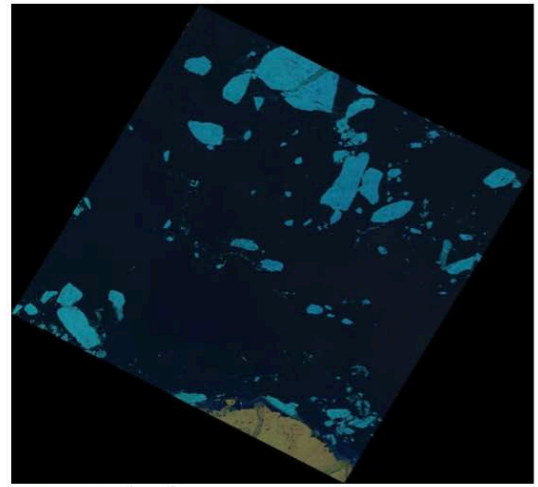
- Aerosols
- Dark, highly absorbing waters
- Extremely turbid
- Bottom reflectance
- Calibration errors
- Trace gases (e.g., NO_2)
- Adjacency effects
- Sunglint
- Cloud shadows & wave facets

Challenges: Adjacency effects

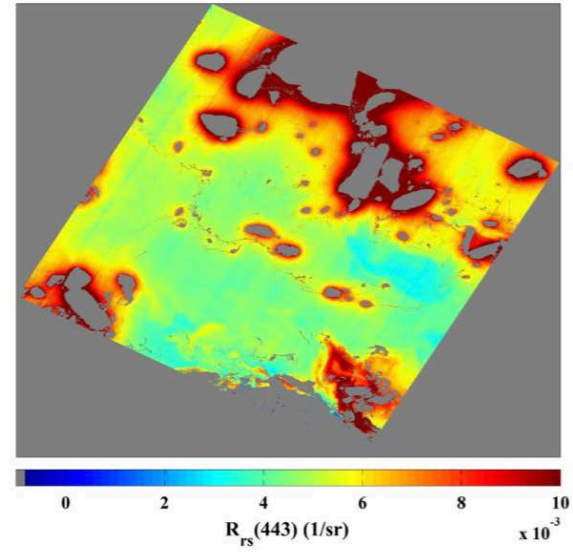
Caused by atmospheric scattering of radiance that originates outside of the sensor element's



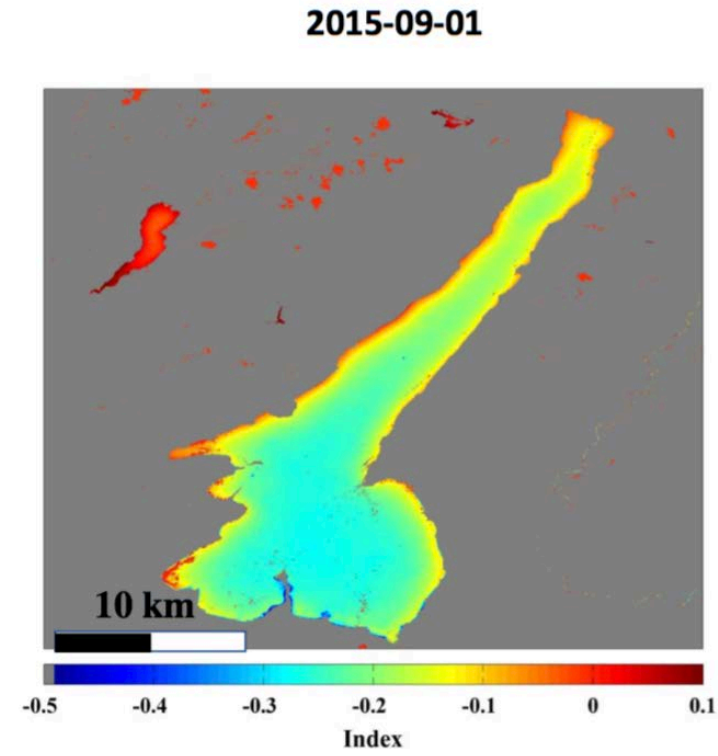
Mackenzie River Delta (June 24th 2016)



Landsat-8 (OLI)

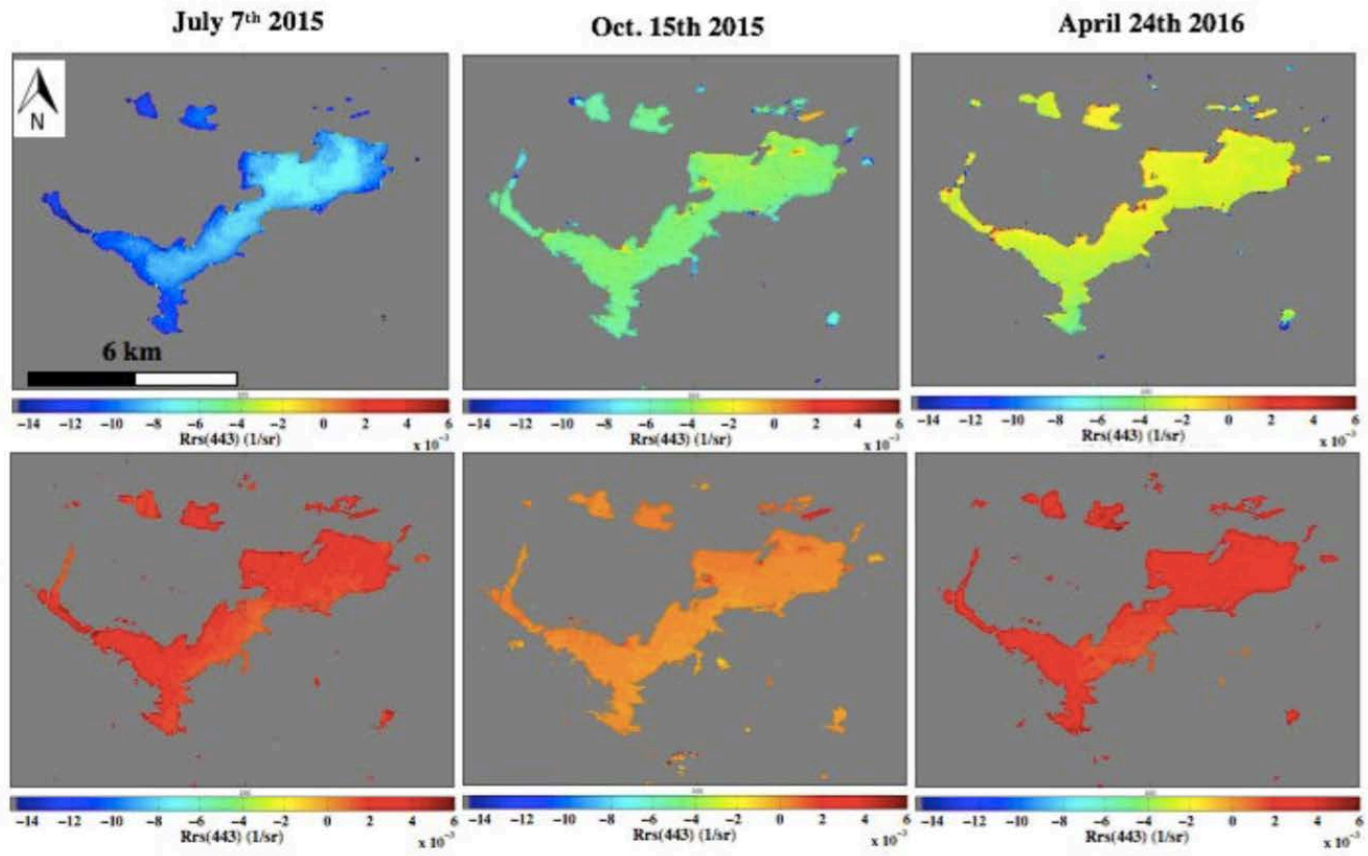


Challenges: Adjacency effects



Challenges: Inadequate aerosol models for inland waters

Landsat-8 derived $R_{rs}(443)$ over Wachusett Reservoir in Massachusetts



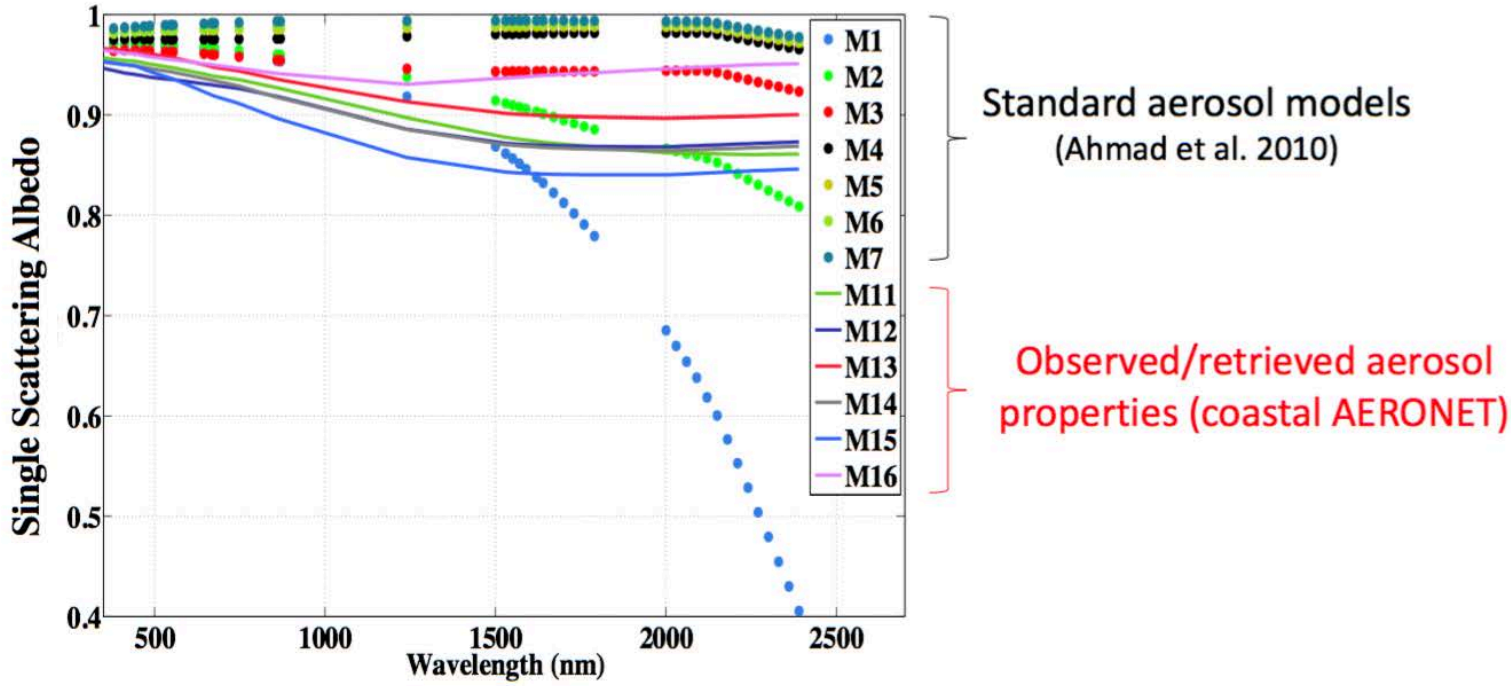
Automated removal of aerosols using existing aerosol LUTs

Manual removal of aerosols using observed AOT spectra

Source: Nima Pahlevan

Challenges: Inadequate aerosol models for inland waters

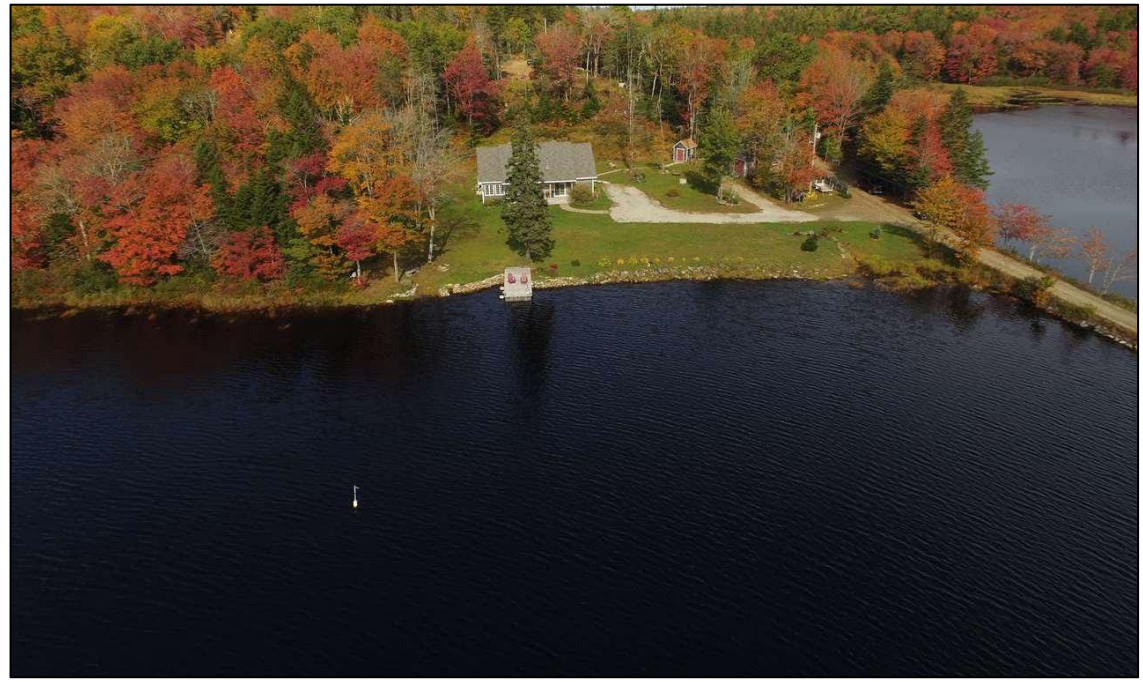
Standard aerosol models used for atmospheric corrections over oceans are not adequate for inland waters



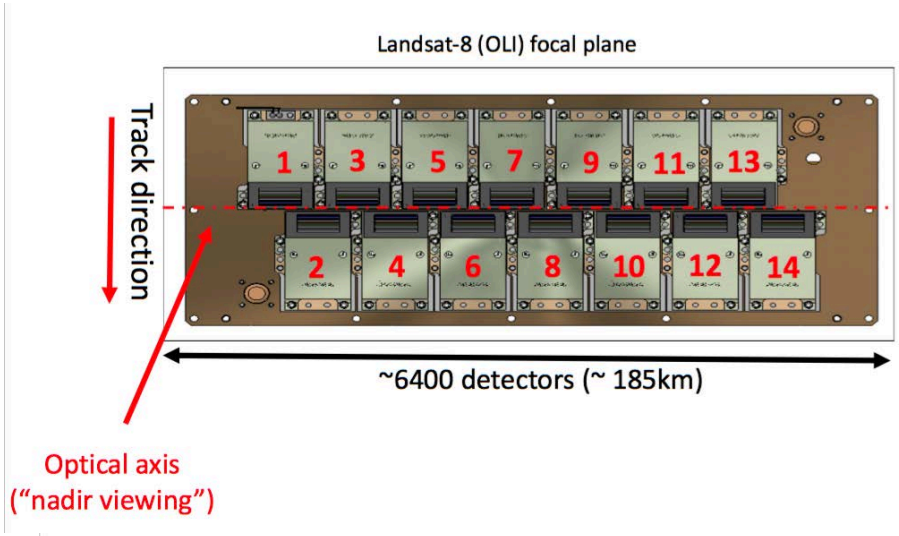
Pahlevan, N., Roger, J.-C., & Ahmad, Z. (2017). Revisiting short-wave-infrared (SWIR) bands for atmospheric correction in coastal waters. *Optics express, 25*, 6015-6035

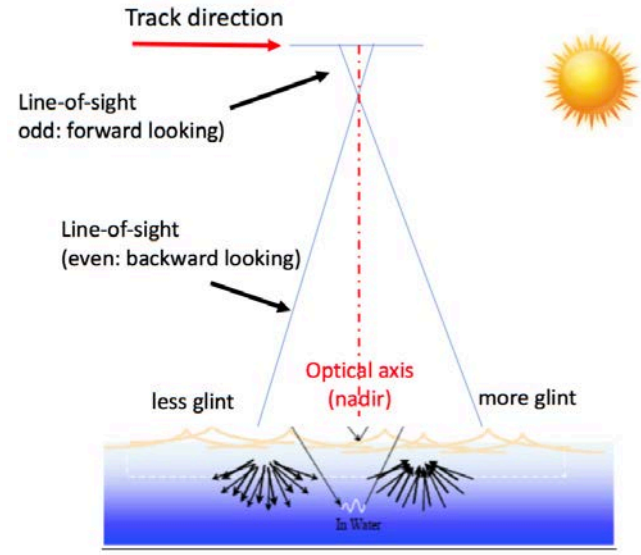
Challenges: Highly absorbing waters

- Extremely low reflectances SNR issue, especially when using high spatial resolution
- Makes atmospheric correction
- Changes in reflectances are not very sensitive to changes in concentration in CDOM at very high concentration

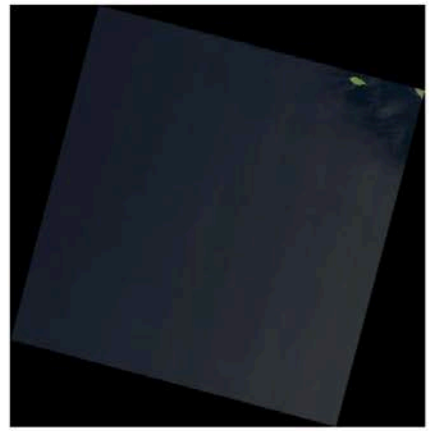


Challenges: Sunglint

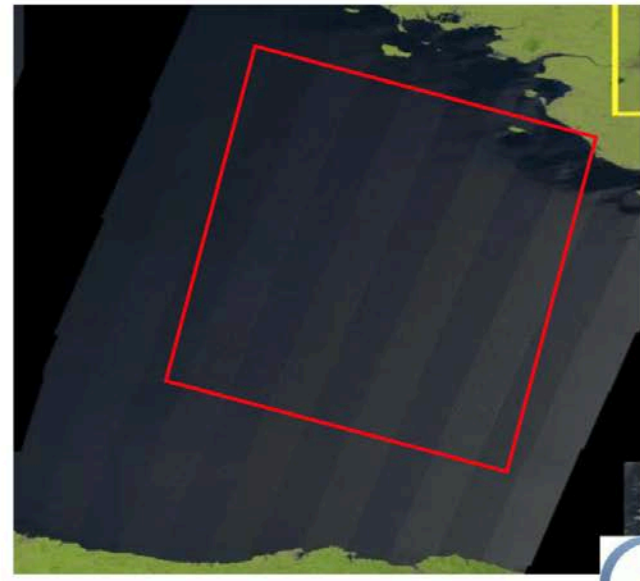




Landsat-8



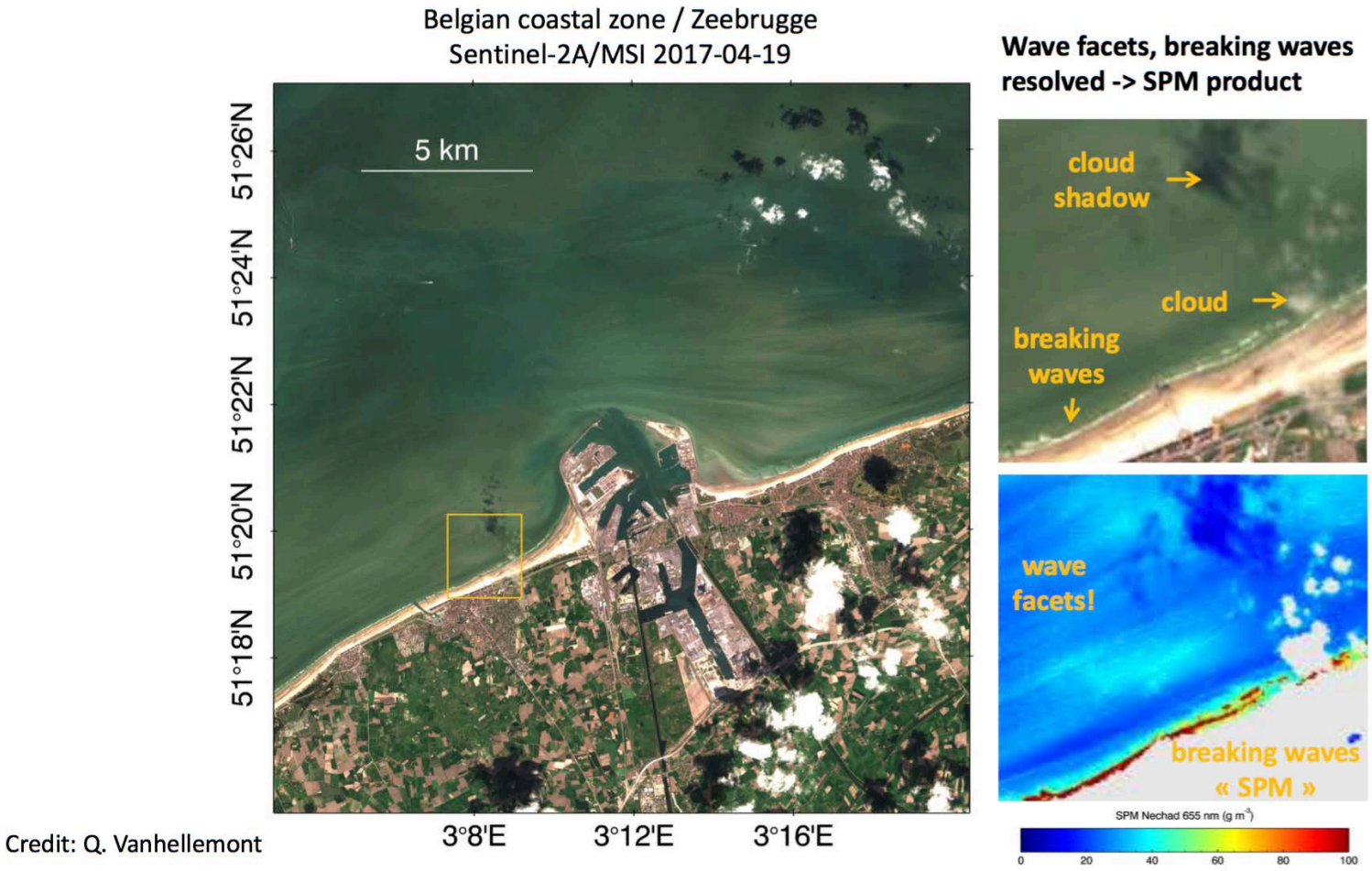
Sentinel-2A



USGS science for a changing world

opernicus The European Earth Observation Programme

Challenges: Cloud shadows

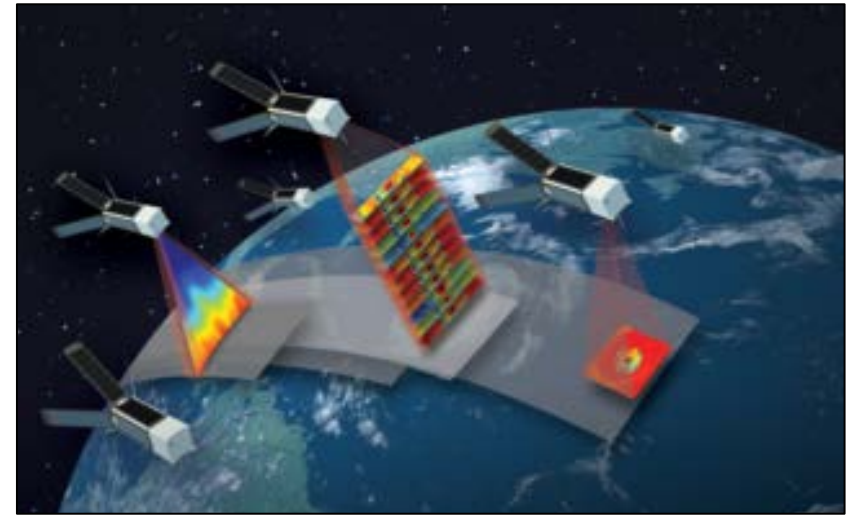


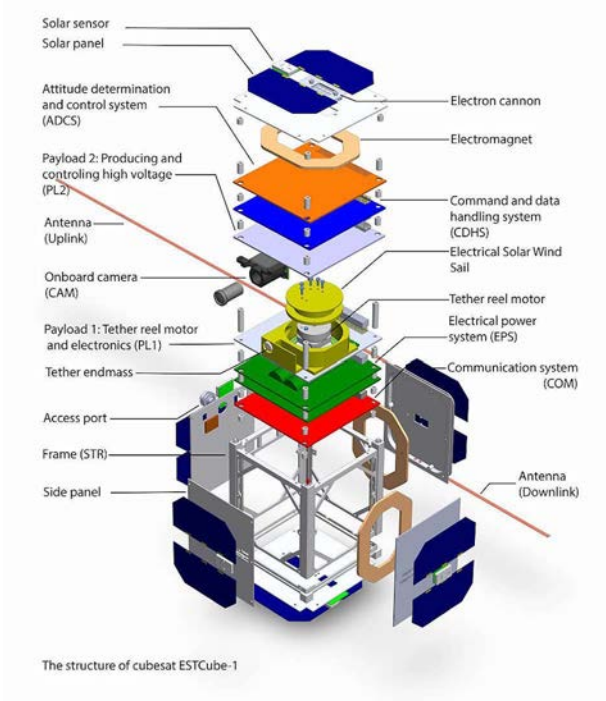
Credit: Q. Vanhellemont


Thanks!
36
39
38
33
23
7
6
21
3

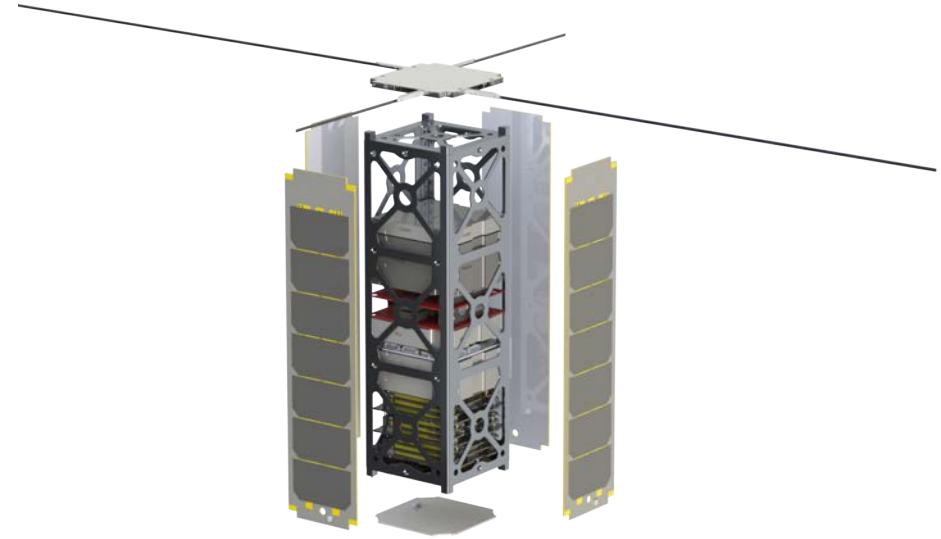
Extra slides

CubeSats?





The structure of cubesat ESTCube-1



Tilt to avoid sunglint