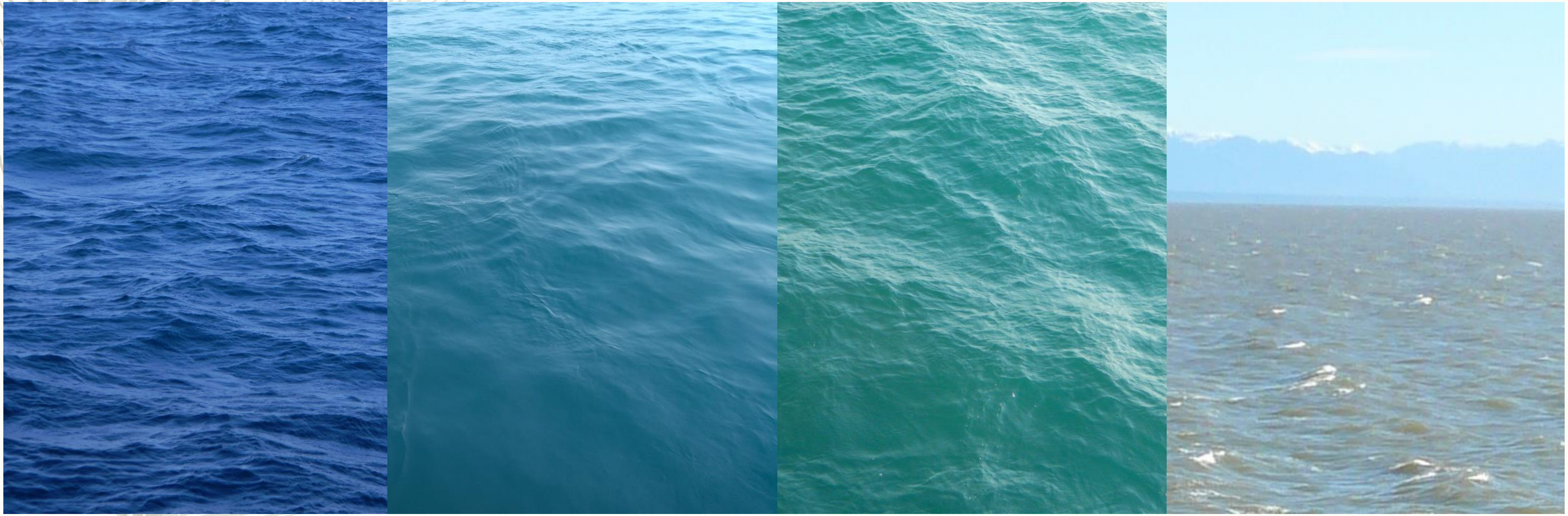
“Ocean colour remote sensing and harmful algal bloom”

Deep Blue Sea

Varying Colour of our Ocean

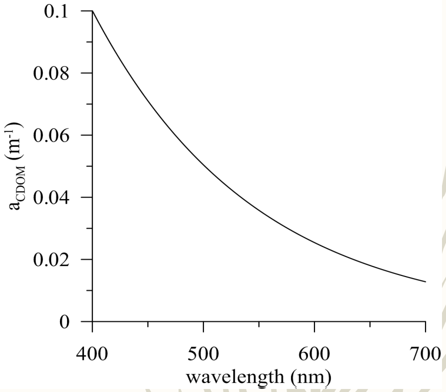


Ocean Colour

- **Study of ocean in visible spectrum**

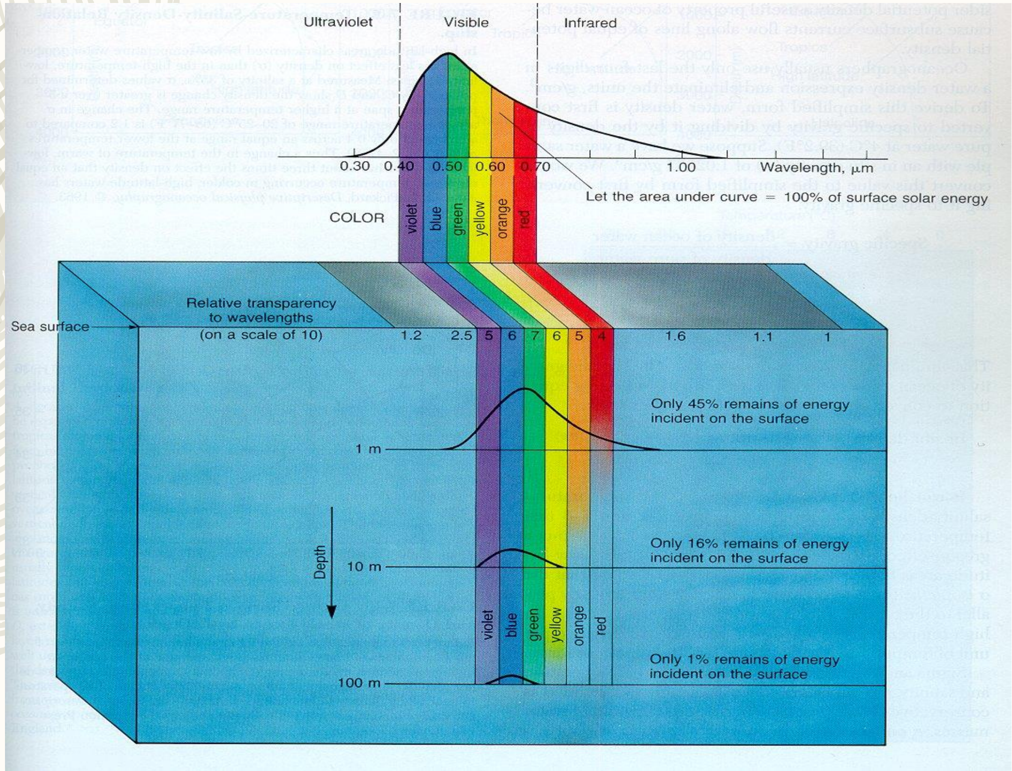
Optically active substances in ocean

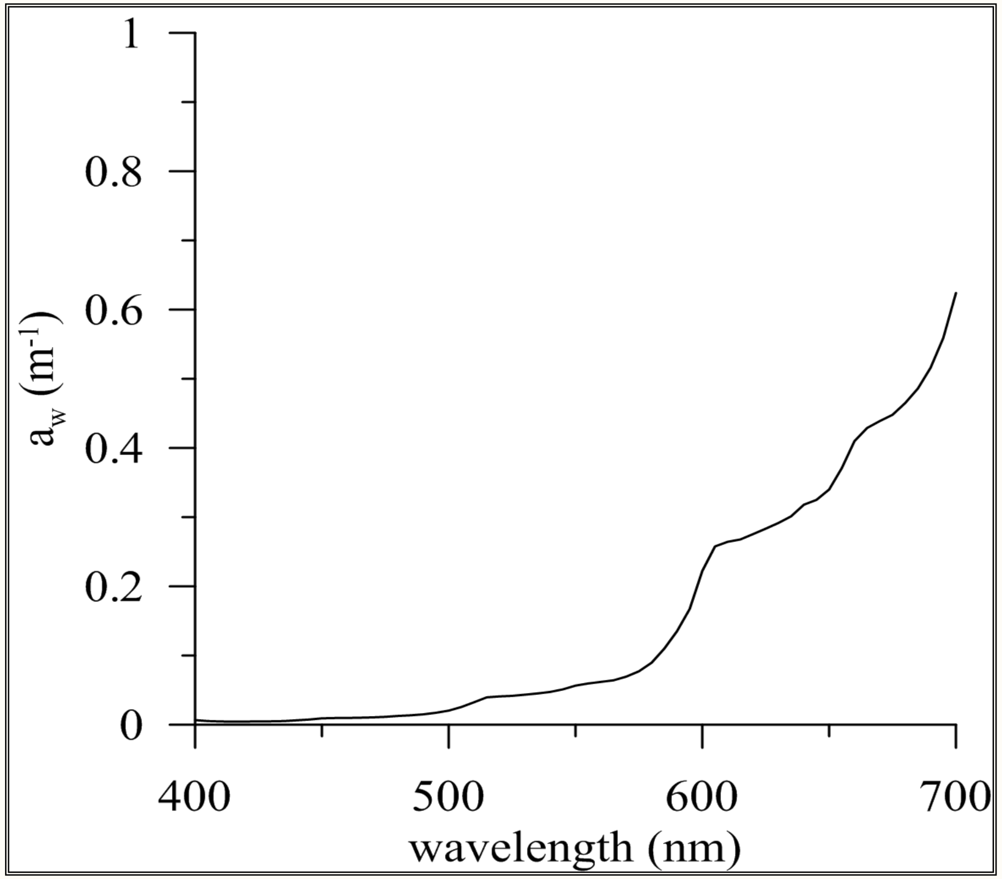
- **Water**
- **Chlorophyll**
- **CDOM**
- **TSM**



Optically active substances In Ocean

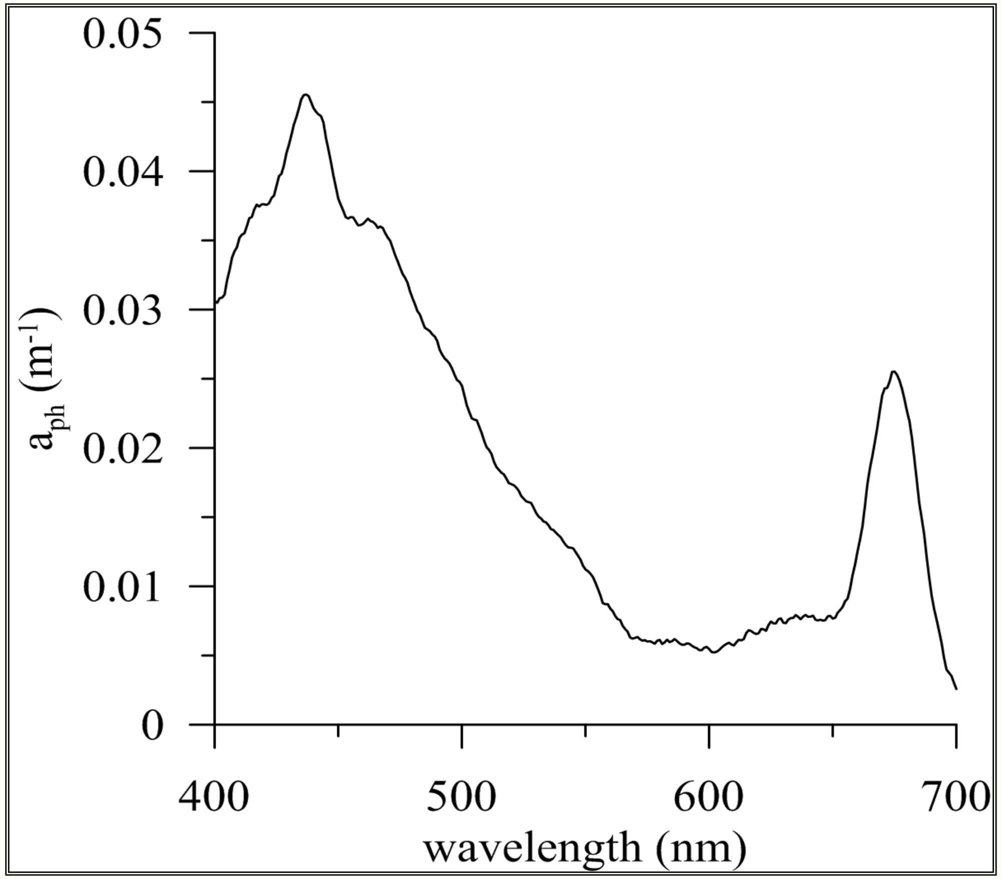
1. Water itself.





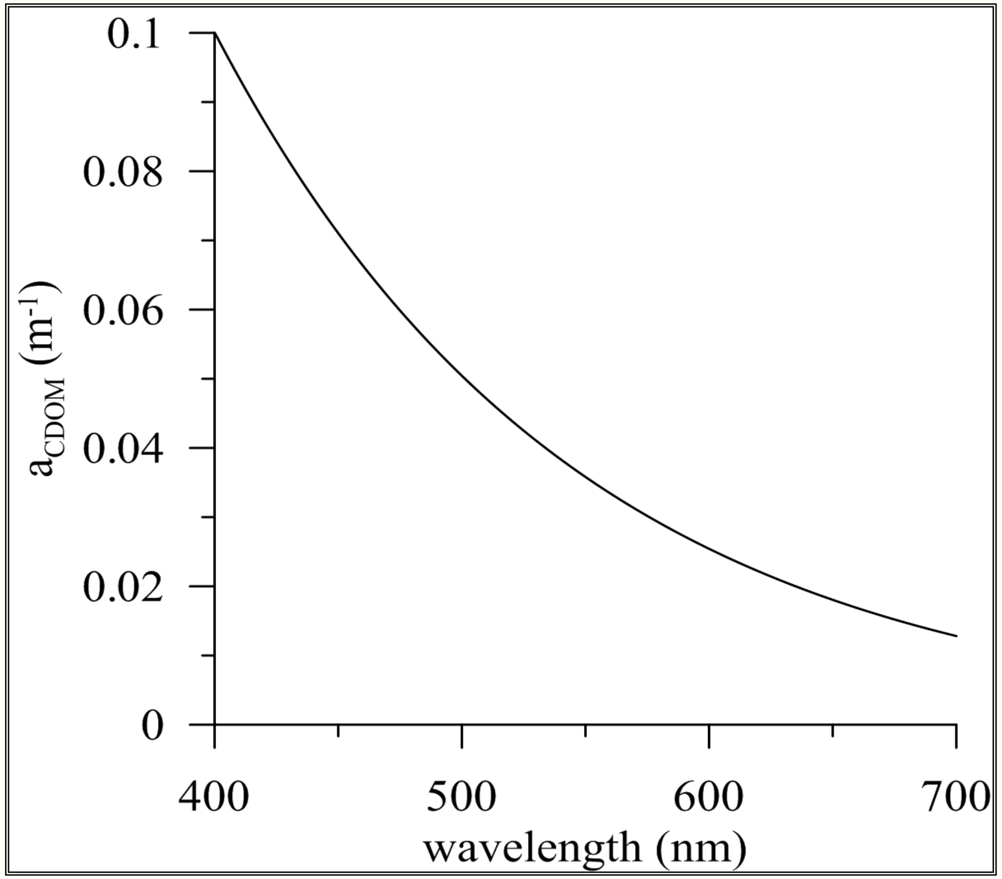
Optically active substances In Ocean

2. Chlorophyll



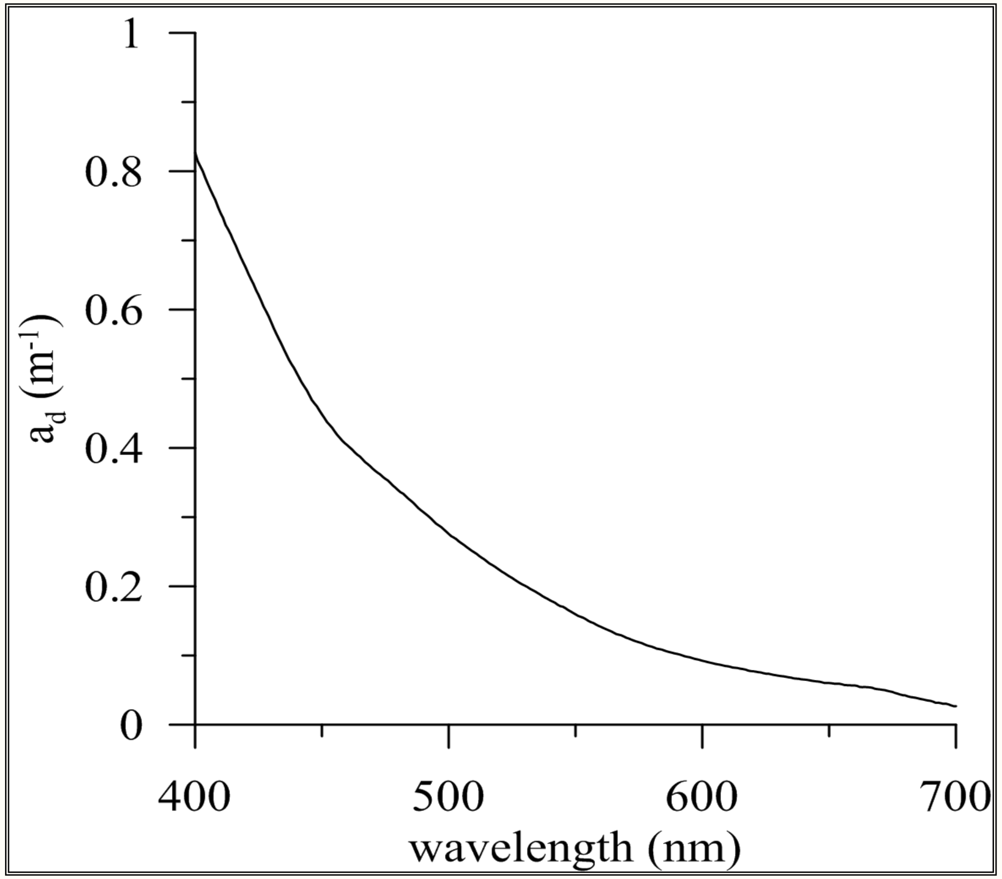
Optically active substances In Ocean

3. Colored Dissolved Organic Matter (CDOM)



Optically active substances In Ocean

4. Total Suspended Matter (TSM)



What is remote sensing?

- **Passive**
- **Active**

Why Remotely Sense The Ocean?

Because..

- 71% of earth surface is covered by saline water
- That is 4*π*6,371*6371*0.71 ~ **36,20,00,000 SqKm**

It’s vast

Because..

We don't have

- **Enough Ships**
- **Enough Instruments**
- **Enough Budget**
- **Enough Logistics**
- **Enough Trained Man Power**

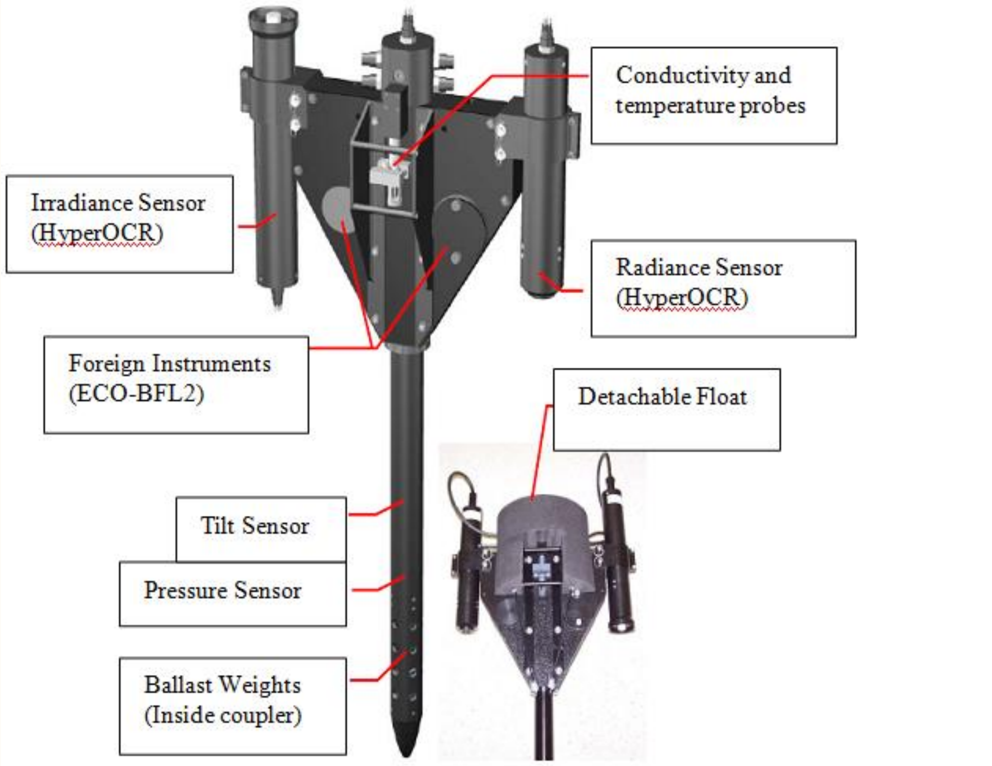
To sample the ocean, and in regular basis.

Why Ocean Colour Remote Sensing is important?

- **High and low bio-activity**
- **Food**
- **Climate**
- **Ocean current structure and behavior**
- **Seasonal influences**
- **River and Estuary influences**
- **Anthropogenic influences**
- **And more..**

Radiometer

- Limited Channel
- Hyperspectral



The Radiative transfer model (For Radiometer)

- $R_{rs}(\lambda) or\ L_{wN}(\lambda) = \frac{L_u(\lambda,0^-)}{E_d(\lambda,0^-)} = \frac{f}{q}\left(\frac{b_b(\lambda)}{b_b(\lambda)+a(\lambda)}\right)$
- $b_b(\lambda) = b_{bw}(\lambda) + b_{bp}(\lambda) + b_{bTSM}(\lambda)$
- $a(\lambda) = a_w(\lambda) + a_{ph}(\lambda) + a_{CDOM}(\lambda) + a_{TSM}(\lambda)$

- $L_u(\lambda) = L_{uw}(\lambda) + L_{up}(\lambda) + L_{uCDOM}(\lambda) + L_{uTSM}(\lambda) + L_{ub}(\lambda)$

Satellite Remote Sensing

- What are extra to consider than field radiometer?

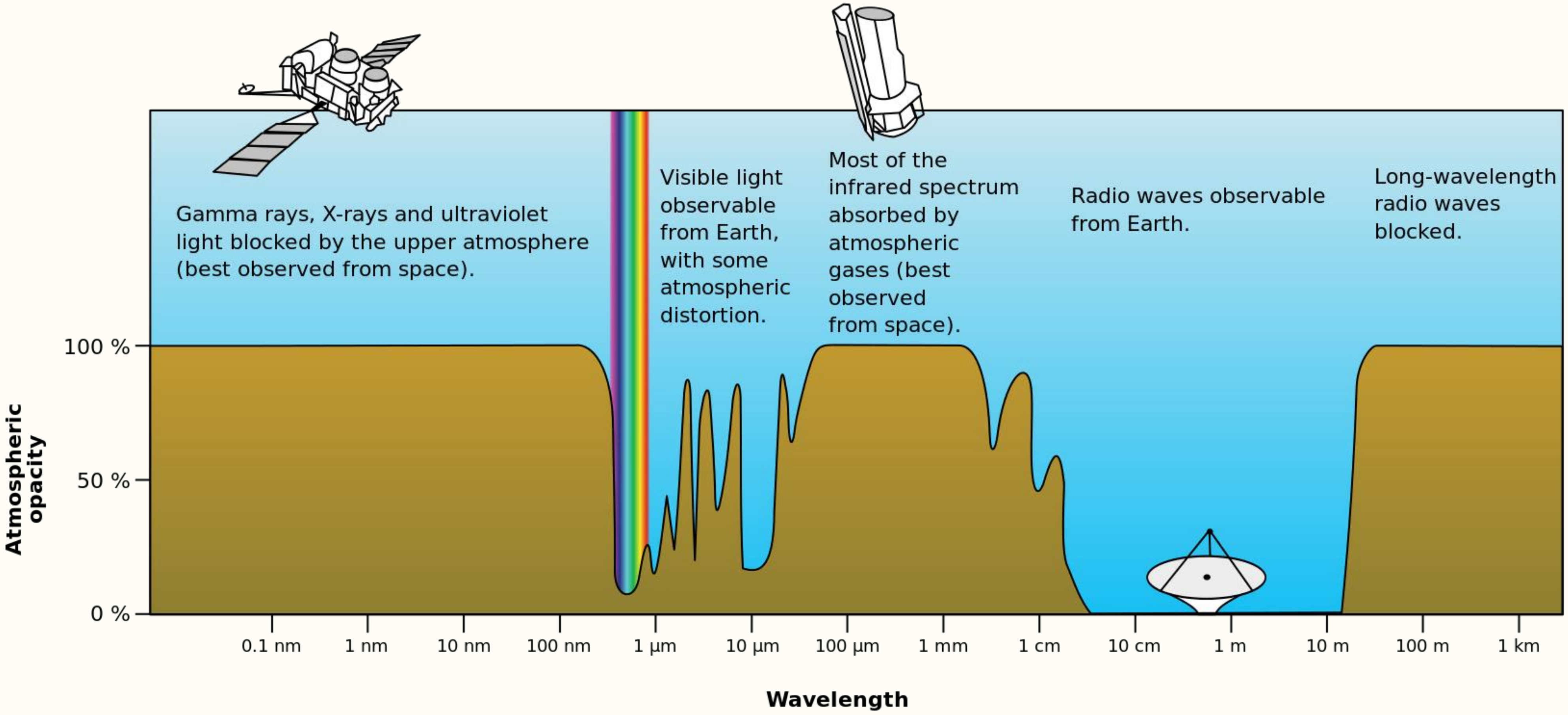
The Radiative transfer model (For Satellite)

- $R_{rs}(\lambda) or\ L_{wN}(\lambda) = \frac{L_W(\lambda,0^+)}{E_d(\lambda,0^+)} = \frac{f}{q}\left(\frac{b_b(\lambda)}{b_b(\lambda)+a(\lambda)}\right)$
- $b_b(\lambda) = b_{bw}(\lambda) + b_{bp}(\lambda) + b_{bTSM}(\lambda)$
- $a(\lambda) = a_w(\lambda) + a_{ph}(\lambda) + a_{CDOM}(\lambda) + a_{TSM}(\lambda)$

- $L_t(\lambda) = [L_r(\lambda) + L_a(\lambda) + L_{sg}(\lambda) + L_{wcp}(\lambda) + L_w(\lambda)]t_{gUp}(\lambda)t_{gDn}(\lambda)f_{pol}(\lambda)$

- $L_w(\lambda) = L_{ww}(\lambda) + L_{wp}(\lambda) + L_{wCDOM}(\lambda) + L_{wTSM}(\lambda) + L_{wb}(\lambda)$ **(10-20 % Only)**

Atmospheric Window



Some of the current Ocean Colour Satellites..

SENSOR/ Data Link	AGENCY	SATELLITE	LAUNCH DATE	SWATH (km)	SPATIAL RESOLUTION (m)	BANDS	SPECTRAL COVERAGE (nm)	ORBIT
MODIS-Aqua	NASA (USA)	Aqua (EOS-PM1)	4 May 2002	2330	250/500/1000	36	405-14,385	Polar
MODIS-Terra	NASA (USA)	Terra (EOS-AM1)	18 Dec. 1999	2330	250/500/1000	36	405-14,385	Polar
OCM-2	ISRO (India)	Oceansat-2 (India)	23 Sept. 2009	1420	360/4000	8	400 - 900	Polar
VIIRS	NOAA (USA)	Suomi NPP	28 Oct. 2011	3000	375 / 750	22	402 - 11,800	Polar
OCLI	ESA/EUMETSAT (EU)	Sentinel-3	16 Feb. 2016	1270	300/1200	21	400 – 1,020	Polar

Geostationary & Polar orbiting Ocean Colour satellite

- Spatial Coverage
- Atmospheric correction problem at high zenith angle
- Temporal Coverage
- Spatial Resolution?

Why not Hyper-Spectral Satellite like Radiometer?

Is it Essential?

For Hyperspectral Earth Observation Good SNR (Signal to Noise Ratio) and Good MTF (Modulation Transfer Function) is extremely difficult to achieve, specially in a small platform.

Other Constrains:

1. Power Consumption
2. Extra weight
3. Data Volume
4. Budgetary problems & Technical Complexity.

** Villafranca, A. et al.. (2012): Limitations of Hyperspectral Earth Observation on Small Satellites

Availability of Ocean colour data

- https://oceancolor.gsfc.nasa.gov/
- https://www.eumetsat.int/website/home/index.html
- http://oceanwatch.pifsc.noaa.gov/
- And others…

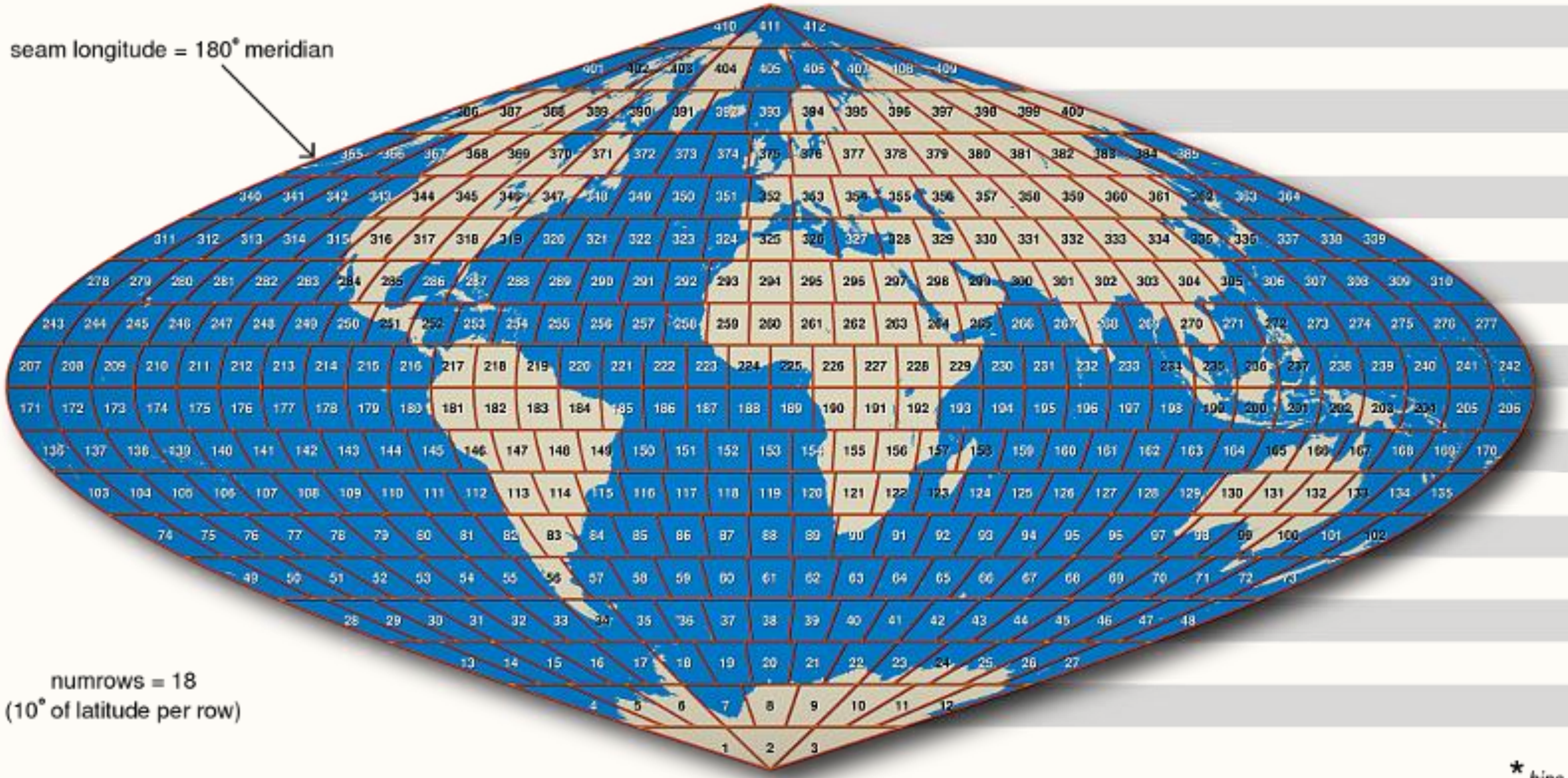
Satellite Data Levels

- Level 0
- Level 1A
- Level 1B
- Level 2A
- Level 2B
- Level 3A
- Level 3B
- Level 4

Level2 Flags

For More visit https://oceancolor.gsfc.nasa.gov/atbd/ocl2flags/

Binning

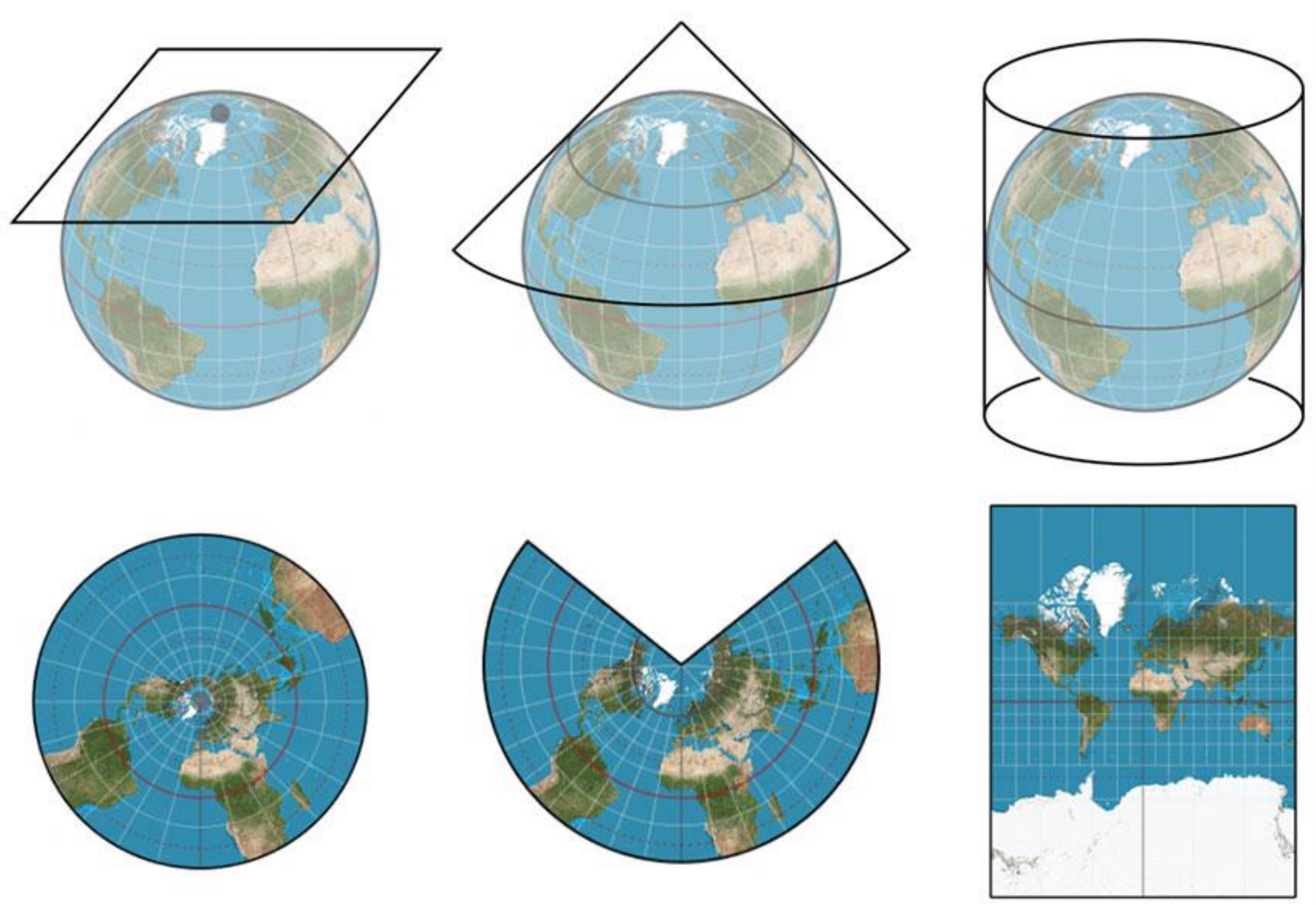


row	central latitude	bins per row*
17	85	3
16	75	9
15	65	15
14	55	21
13	45	25
12	35	29
11	25	33
10	15	35
9	5	36
8	-5	36
7	-15	35
6	-25	33
5	-35	29
4	-45	25
3	-55	21
2	-65	15
1	-75	9
0	-85	3

* *bins per row = 2 x numrows x cos(central latitude) rounded to the nearest integer*

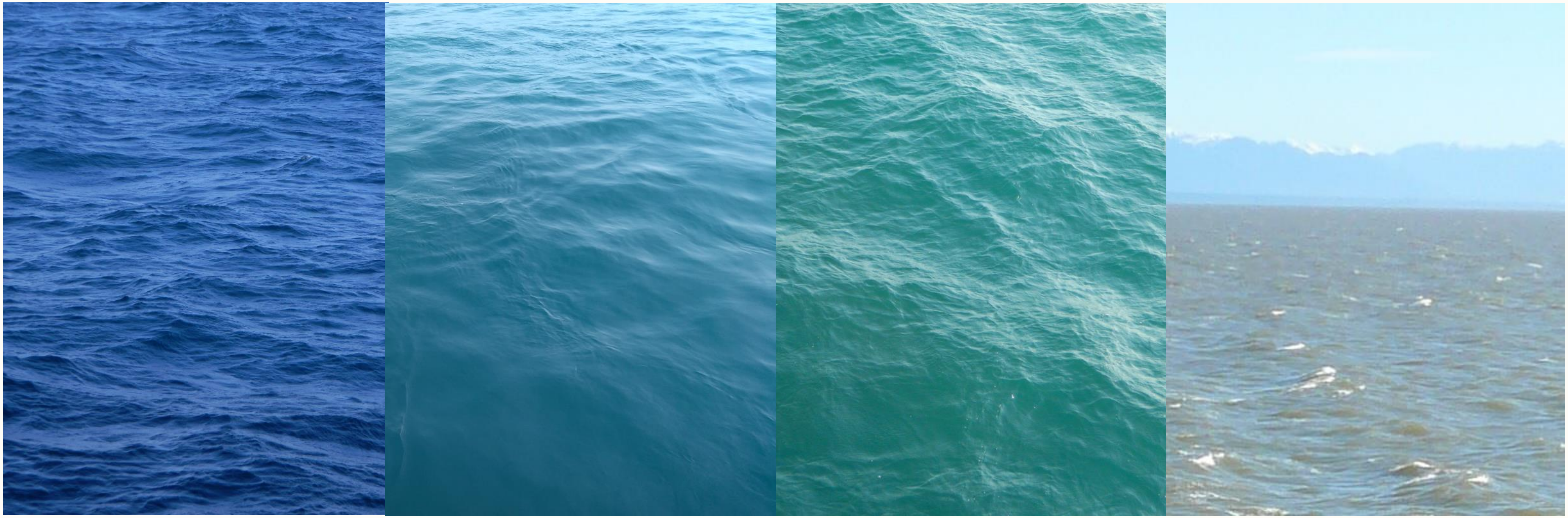
Map Projection

– Why is it necessary?

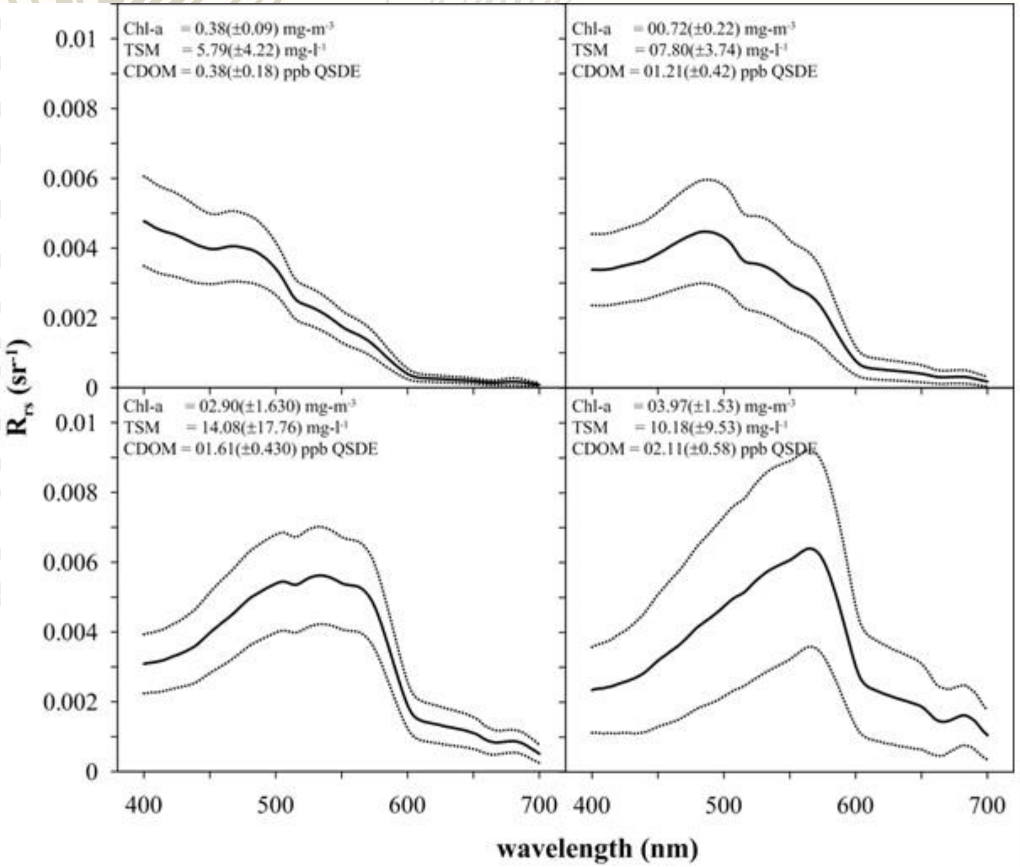


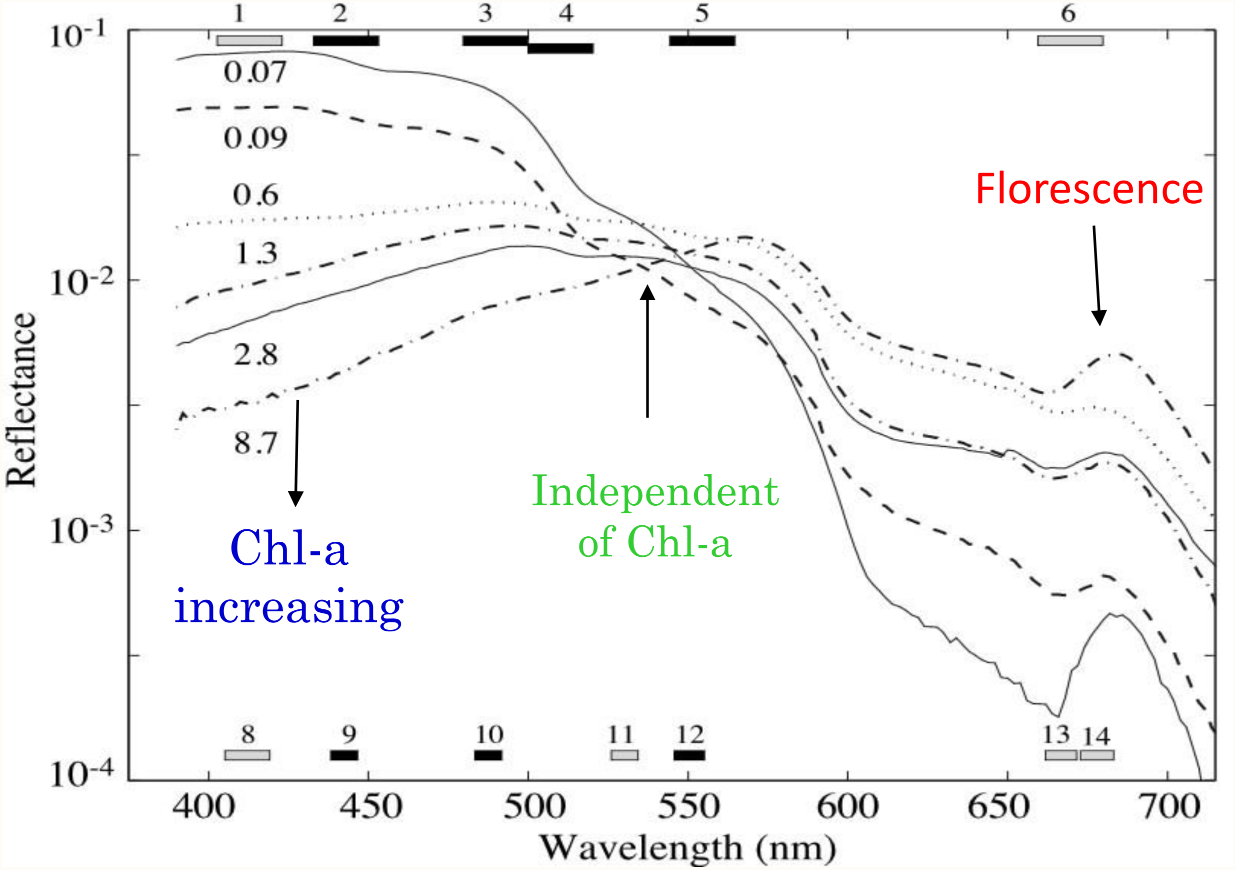
Live Demo using SeaDAS

Let's Start Again..

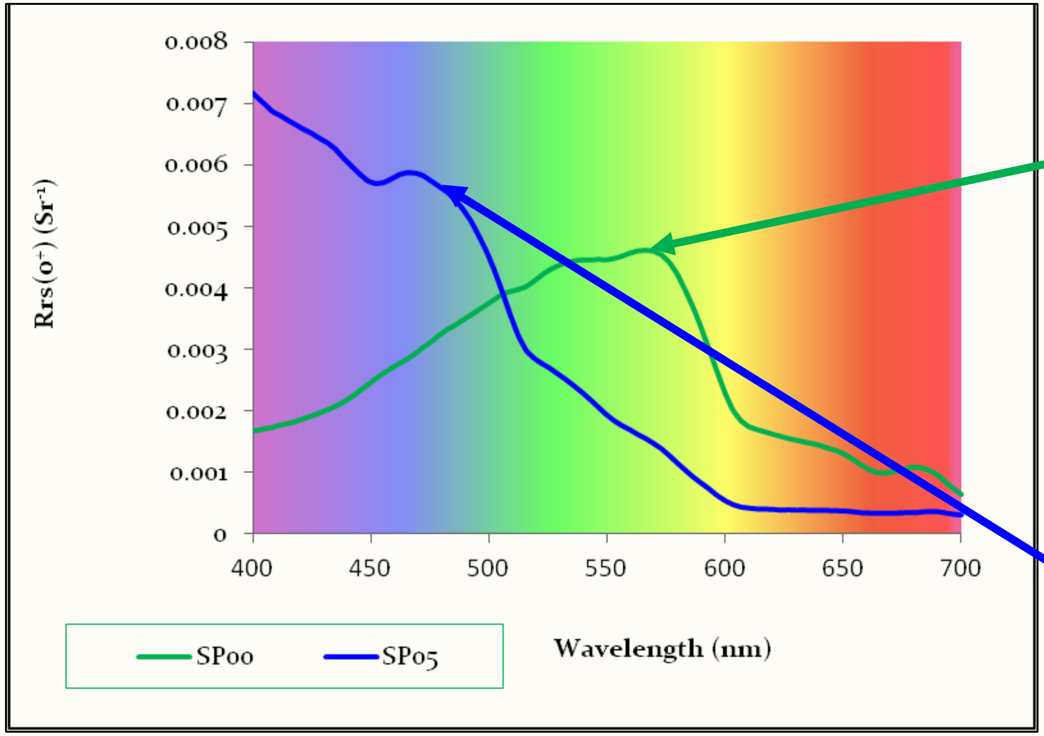


Variation of Rrs spectra with chlorophyll concentration.

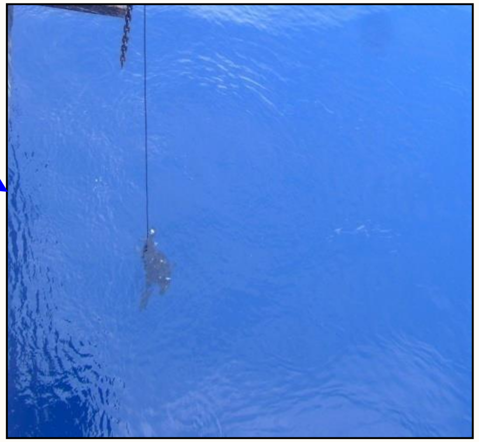




Water colour & Rrs Spectra



Estuarine waters of Goa



Offshore waters of Goa

Station	CDOM	Chl-a(µg/l)	TSM(mg/l)
SP 00	0.62612	2.08052	5.2
SP 05	0.43158	0.17607	2.425

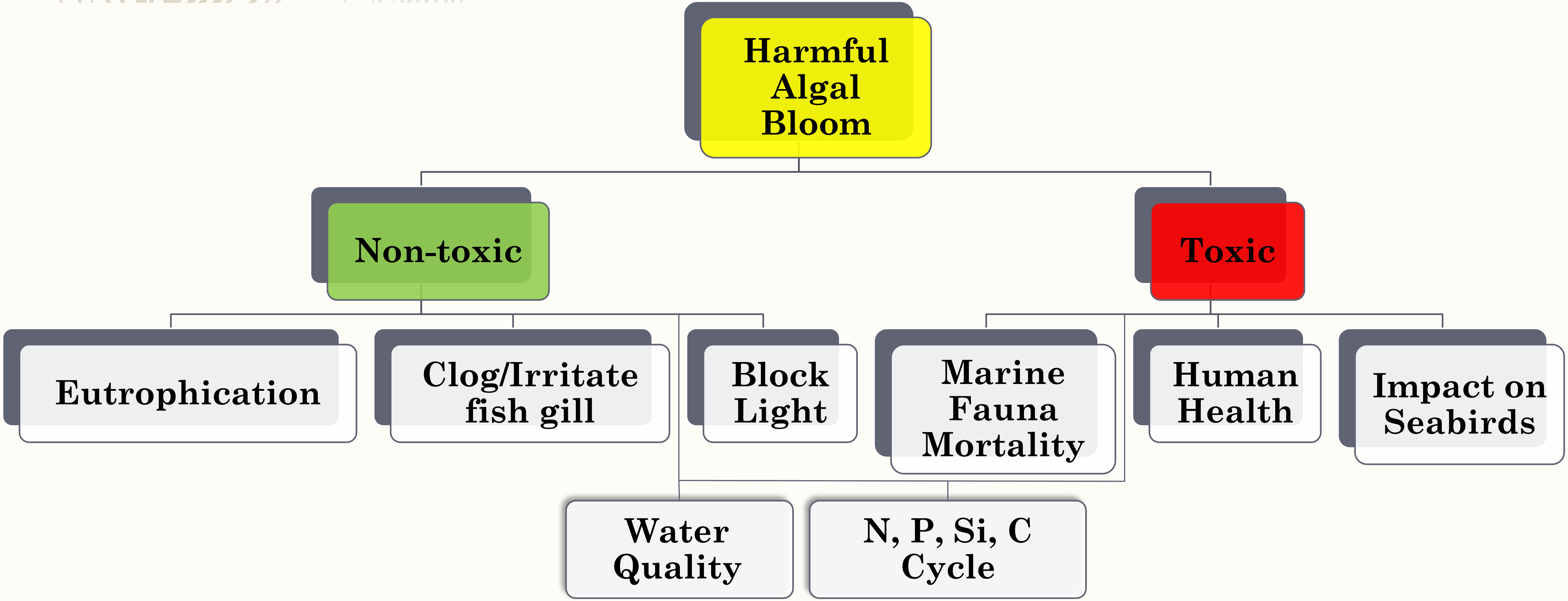
*** Menon, H. B., Lotliker, A., & Nayak, S. R. (2005). Pre-monsoon bio-optical properties in estuarine, coastal and Lakshadweep waters. Estuarine, Coastal and Shelf Science, 63(1), 211-223.*



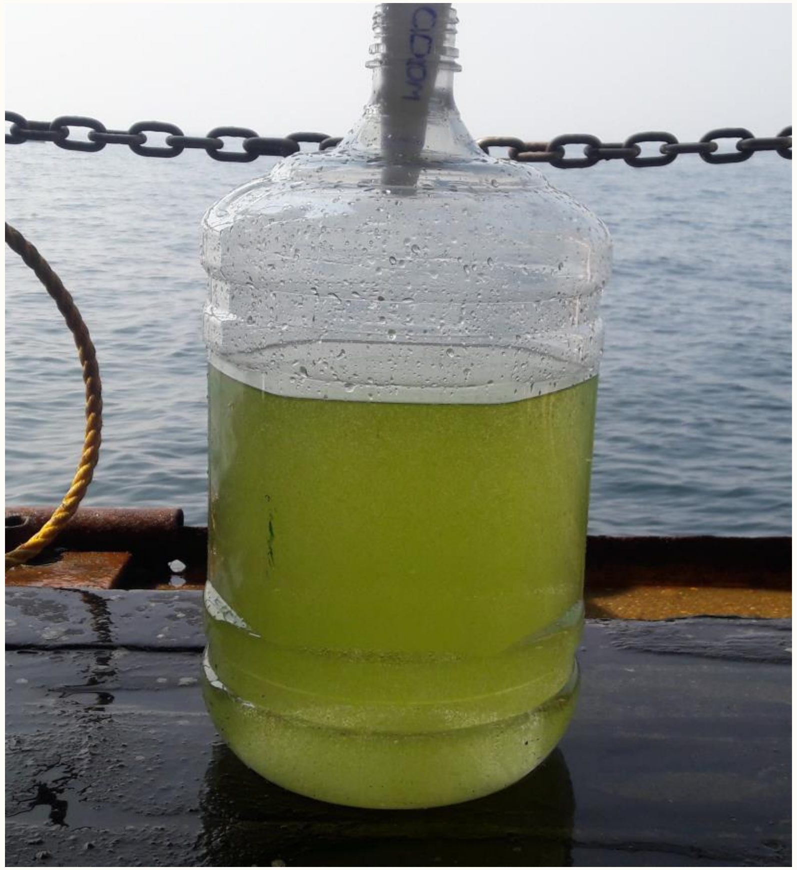


What is Algal Bloom?

Is it always harmful?

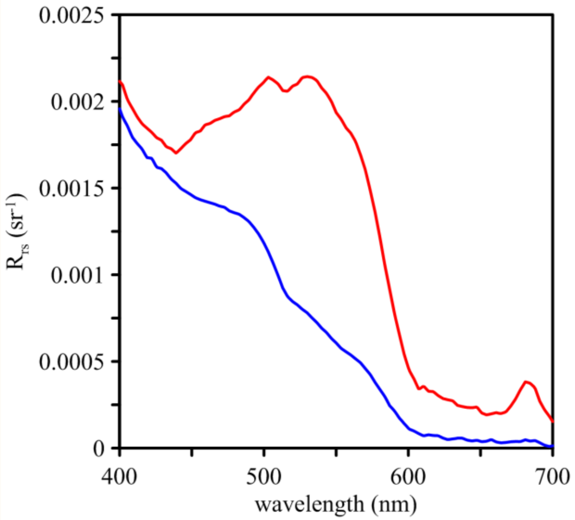


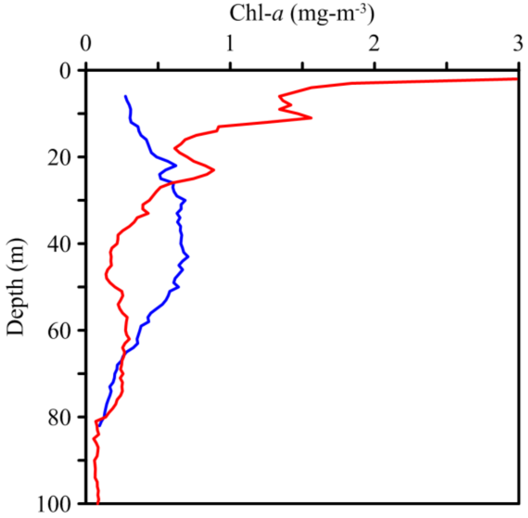


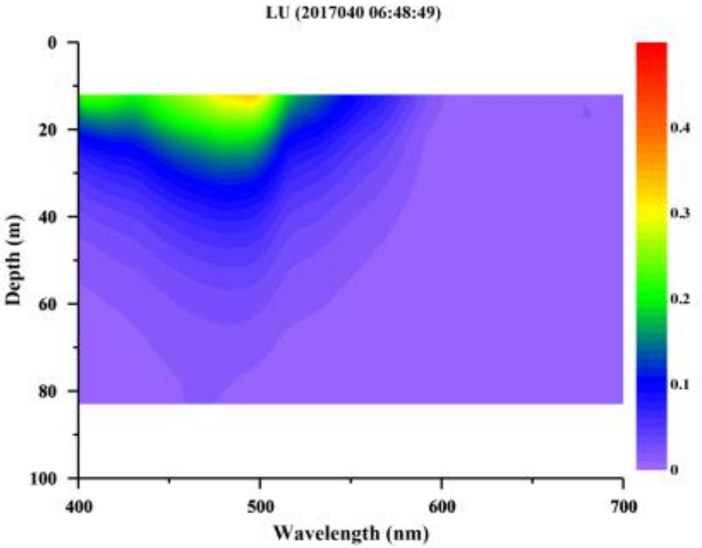


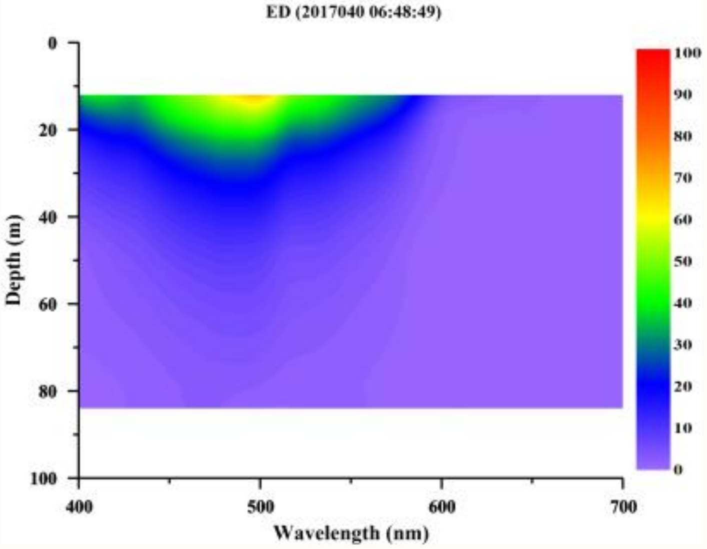
Change in ocean optics during a bloom.

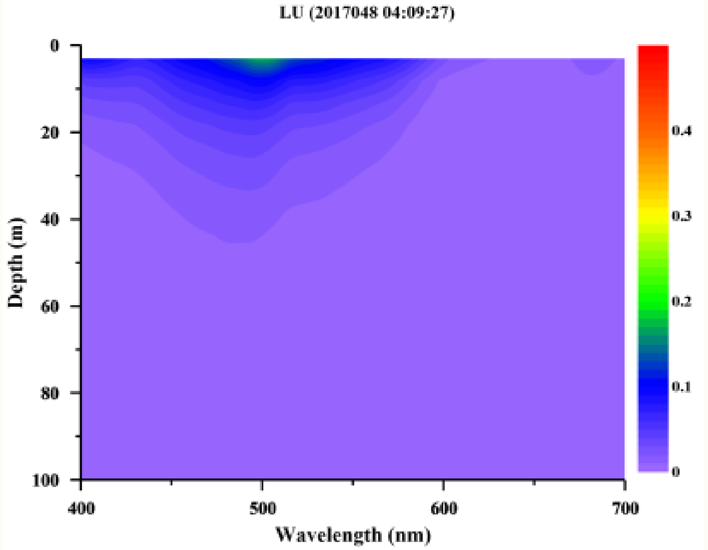
- Rrs maxima shifts to higher wavelength
- Ocean becomes opaque
- Kd increases
- PAR decreases rapidly over depth

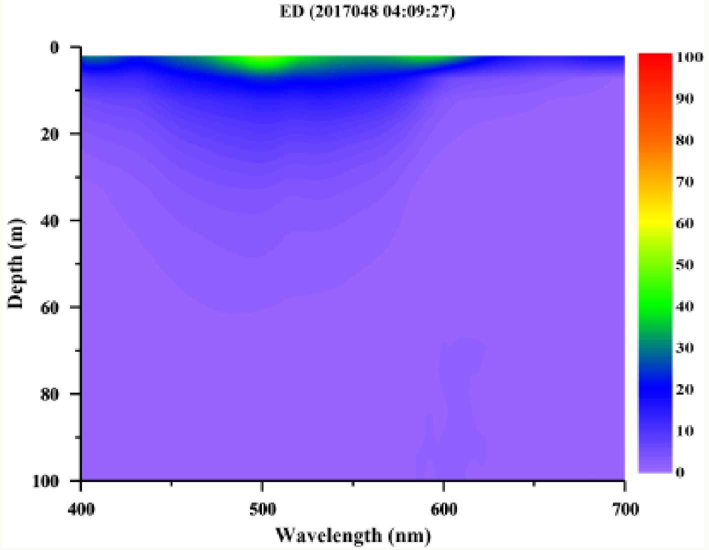

0.0025
0.002
0.0015
0.001
0.0005
0
R_{rs} (sr^{-1})
400
500
600
700
wavelength (nm)


Chl-*a* (mg·m^{-3})
0
1
2
3
0
20
40
60
80
100
Depth (m)

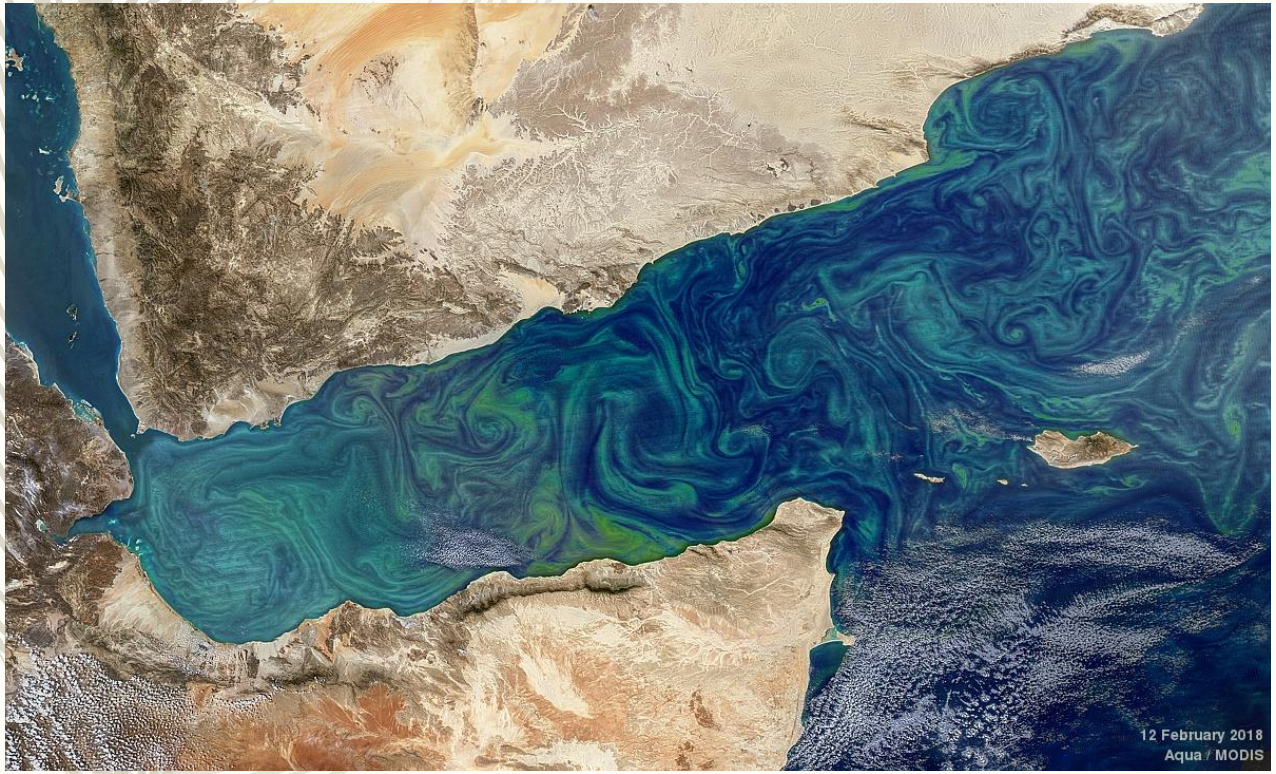

LU (2017040 06:48:49)
Depth (m)
Wavelength (nm)
0
20
40
60
80
100
400
500
600
700
0.4
0.3
0.2
0.1
0


ED (2017040 06:48:49)
Depth (m)
Wavelength (nm)
0
20
40
60
80
100
400
500
600
700
100
90
80
70
60
50
40
30
20
10
0

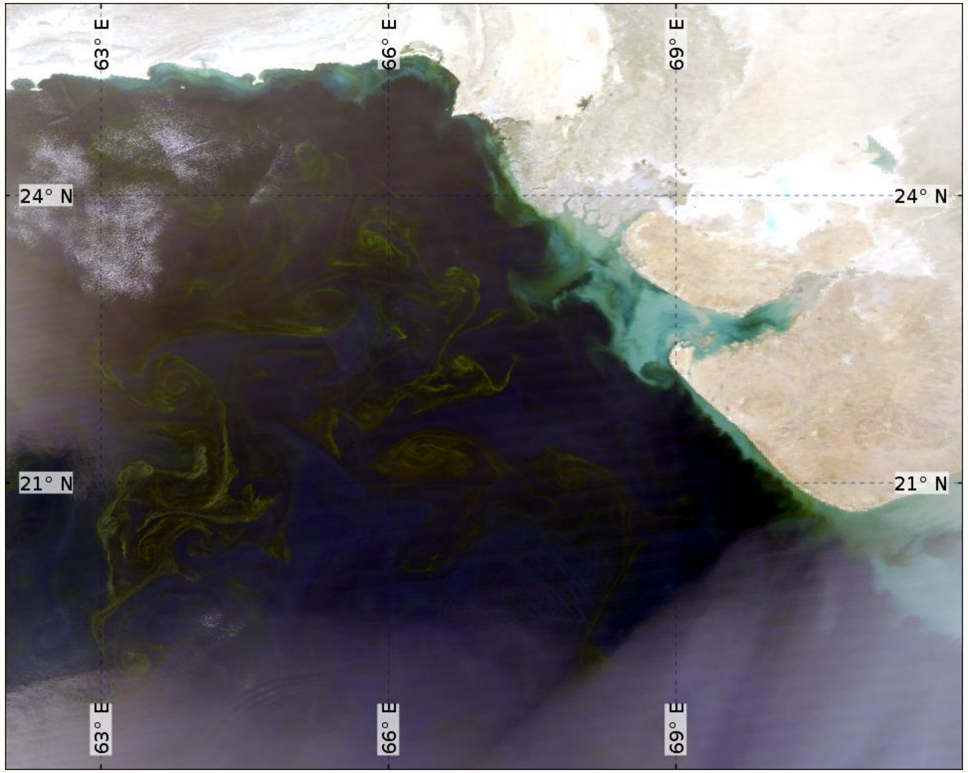

LU (2017048 04:09:27)
Depth (m)
Wavelength (nm)
0
20
40
60
80
100
400
500
600
700
0.4
0.3
0.2
0.1
0


ED (2017048 04:09:27)
Depth (m)
Wavelength (nm)
0
20
40
60
80
100
400
500
600
700
100
90
80
70
60
50
40
30
20
10
0

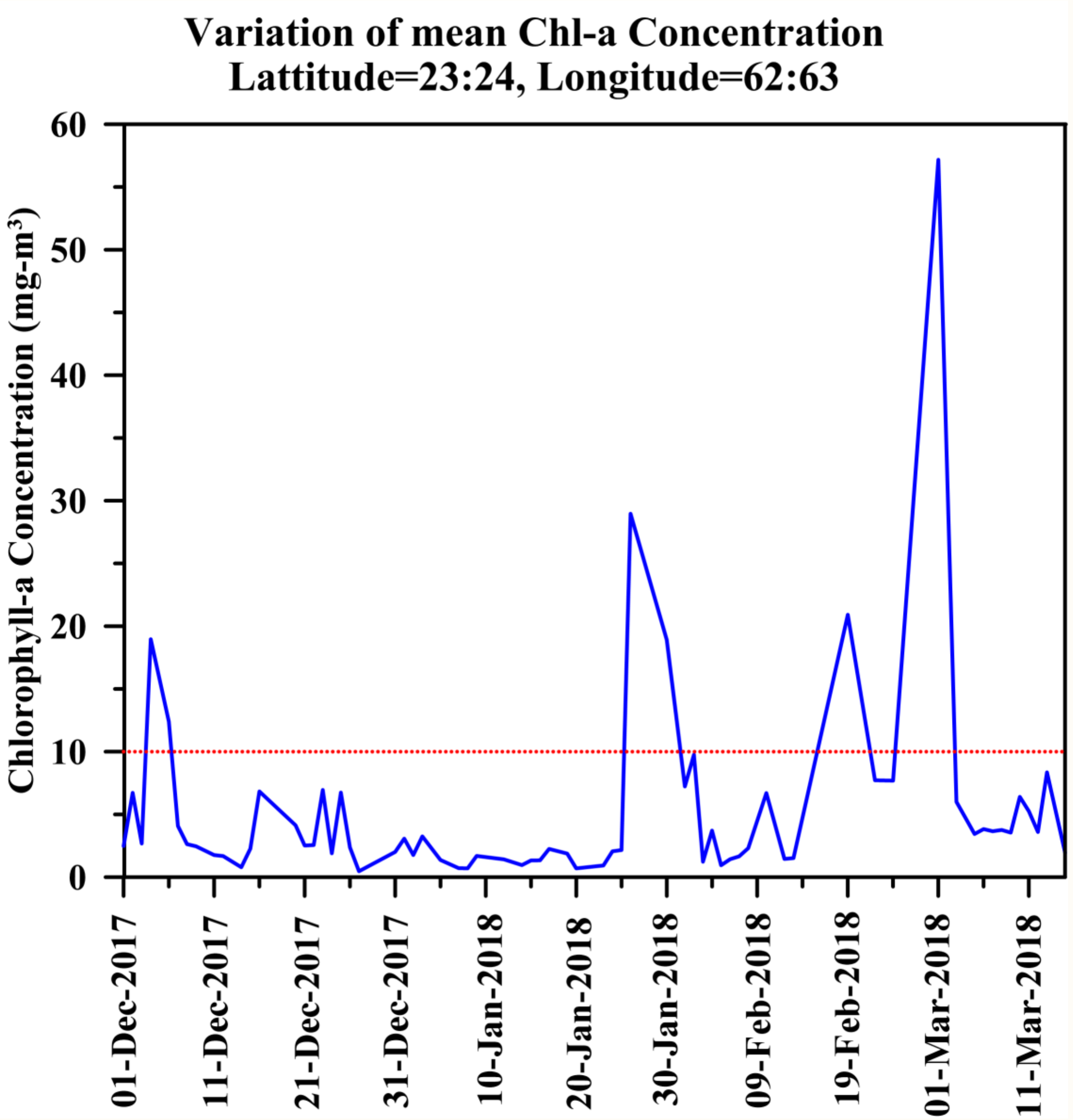
This is how it looks from space



(12th February 2018)



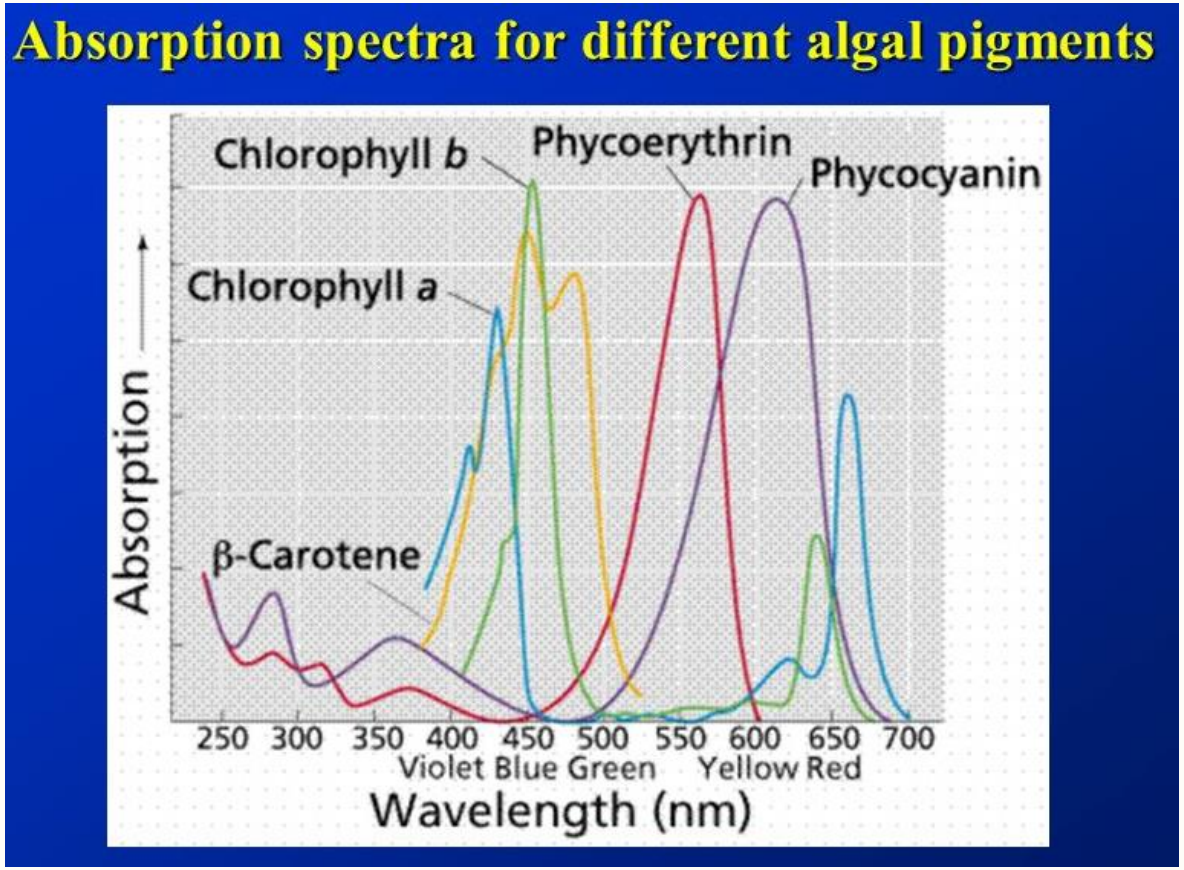
(12th March 2018)


Variation of mean Chl-a Concentration
Lattitude=23:24, Longitude=62:63
Chlorophyll-a Concentration (mg-m3)
60
50
40
30
20
10
0
01-Dec-2017
11-Dec-2017
21-Dec-2017
31-Dec-2017
10-Jan-2018
20-Jan-2018
30-Jan-2018
09-Feb-2018
19-Feb-2018
01-Mar-2018
11-Mar-2018

Every visible bloom leaves it's signature in Rrs Spectra.

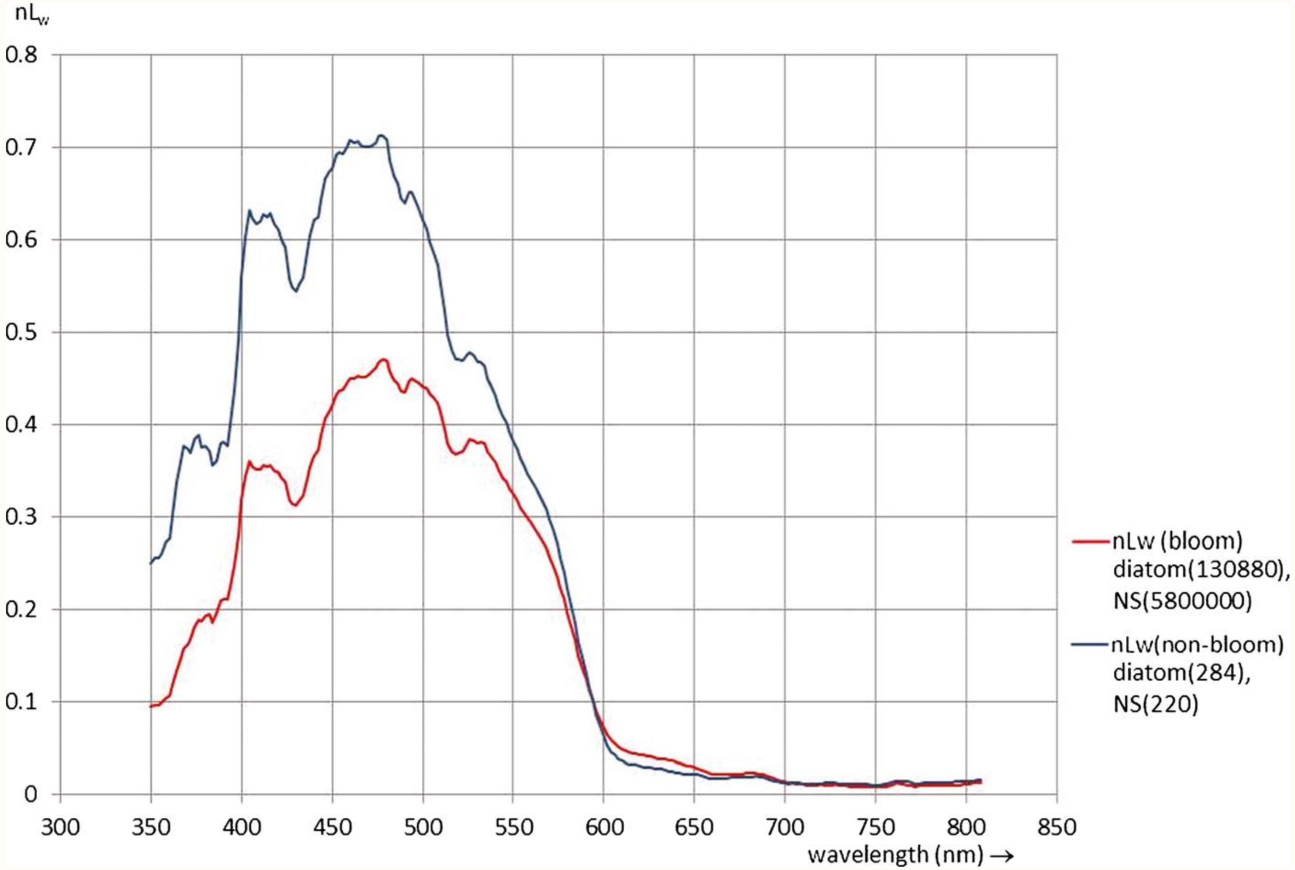
$$a(\lambda) = a_w(\lambda) + a_{ph}(\lambda) + a_{CDOM}(\lambda) + a_{TSM}(\lambda)$$

$$a_{ph}(\lambda) = \sum_i a_{pig}^i(\lambda)$$



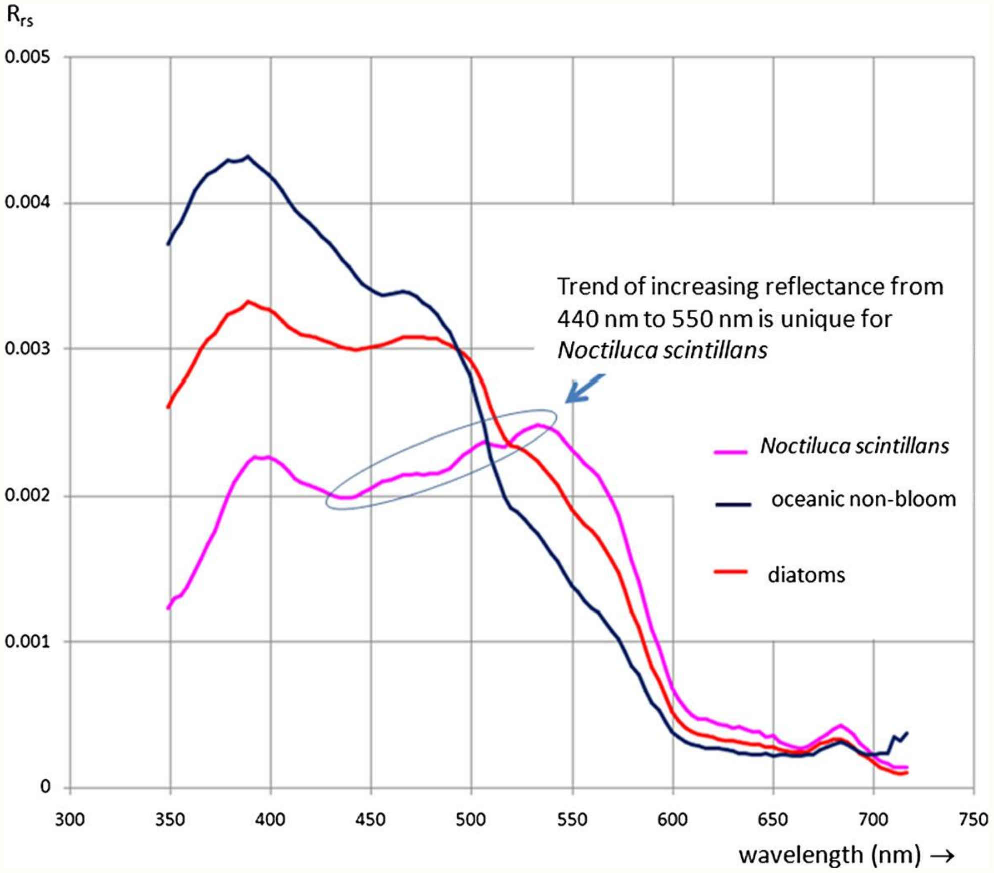
Detection of Green Noctiluca Blooms

Dwivedi et al 2015



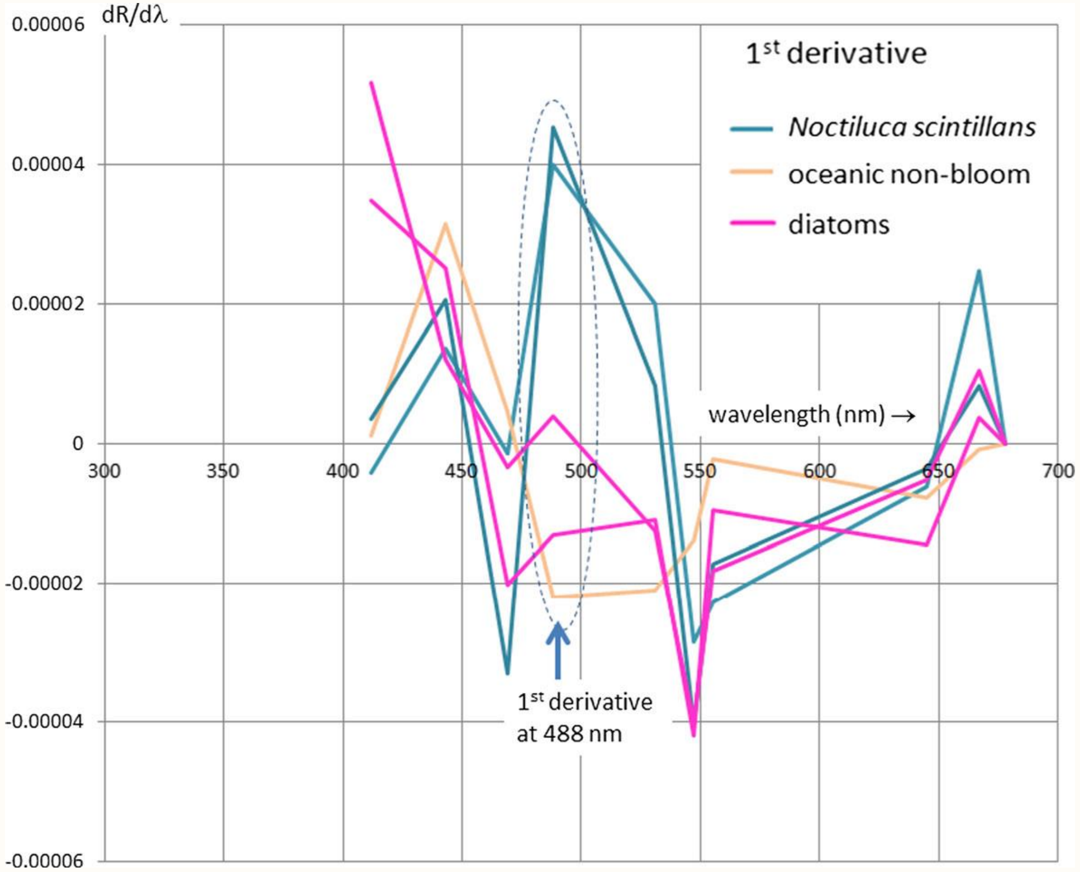
Detection of Green Noctiluca Blooms

Dwivedi et al 2015



Detection of Green Noctiluca Blooms

Dwivedi et al 2015



Detection of Green Noctiluca Blooms

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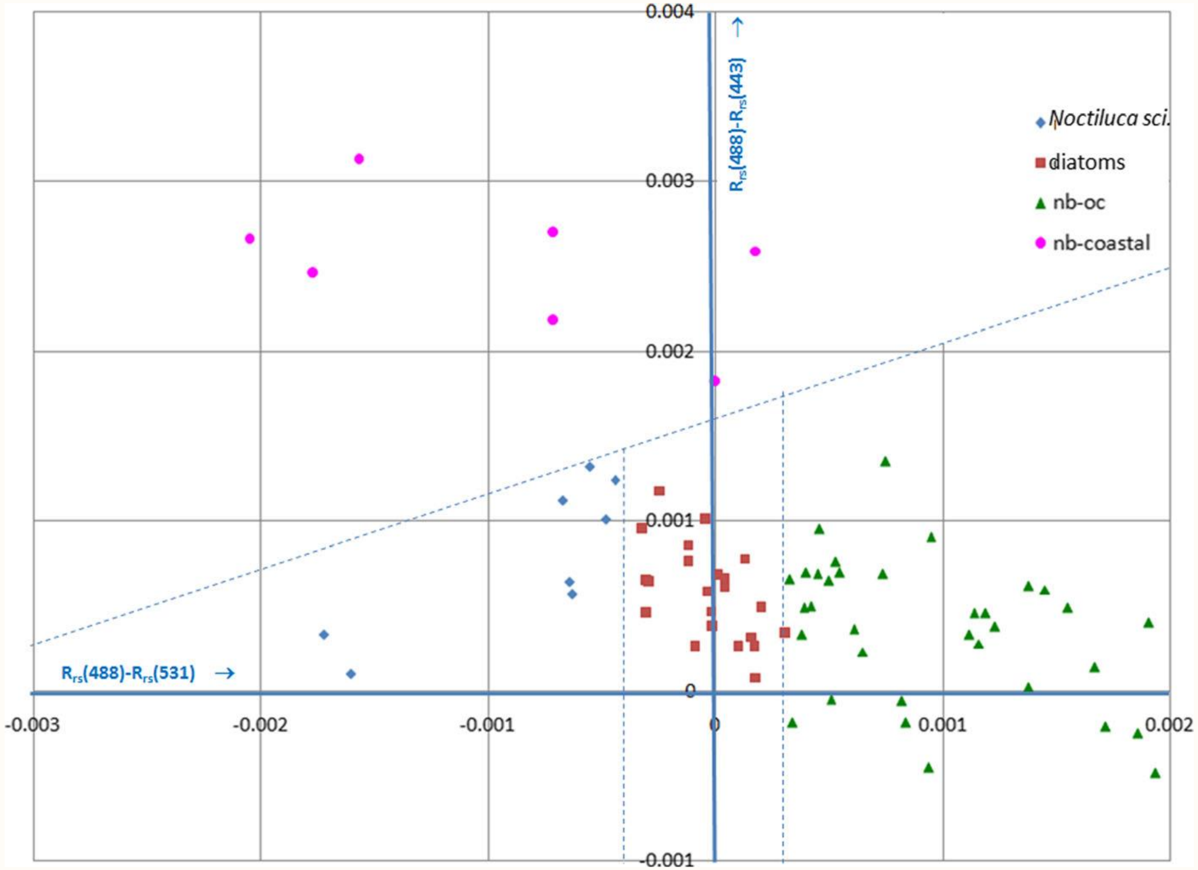
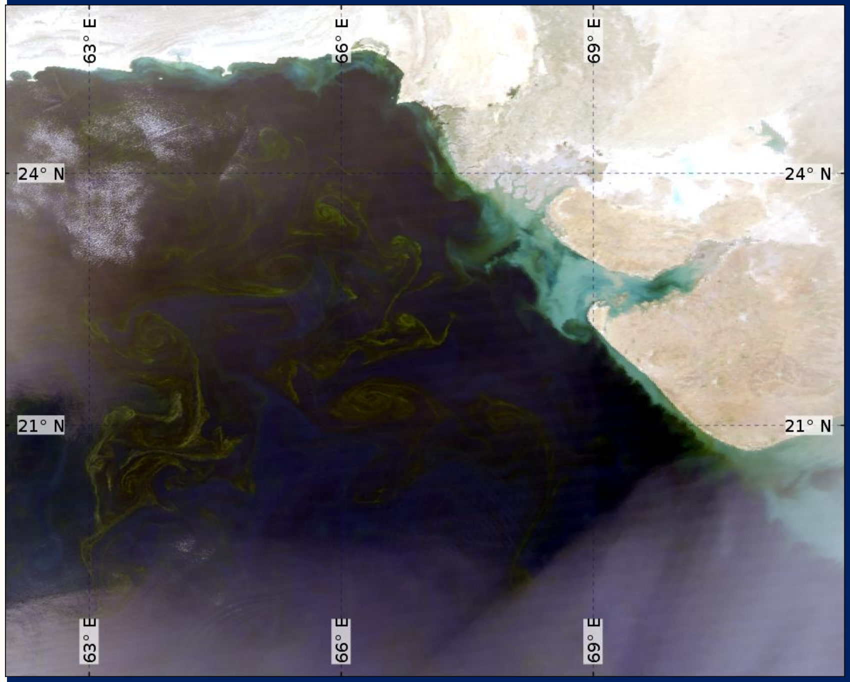
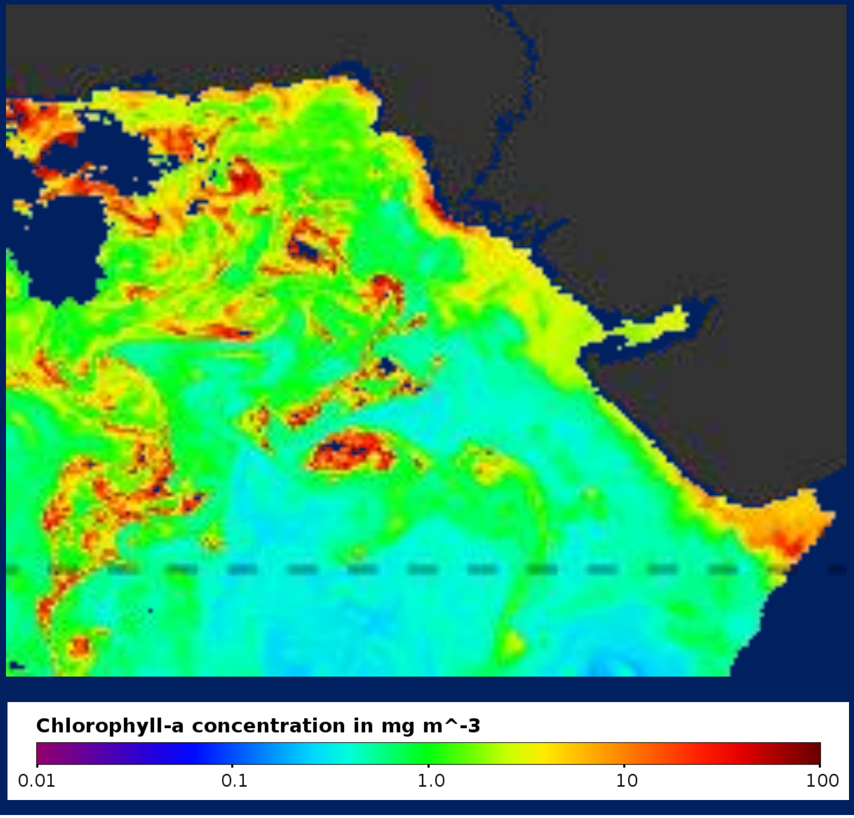
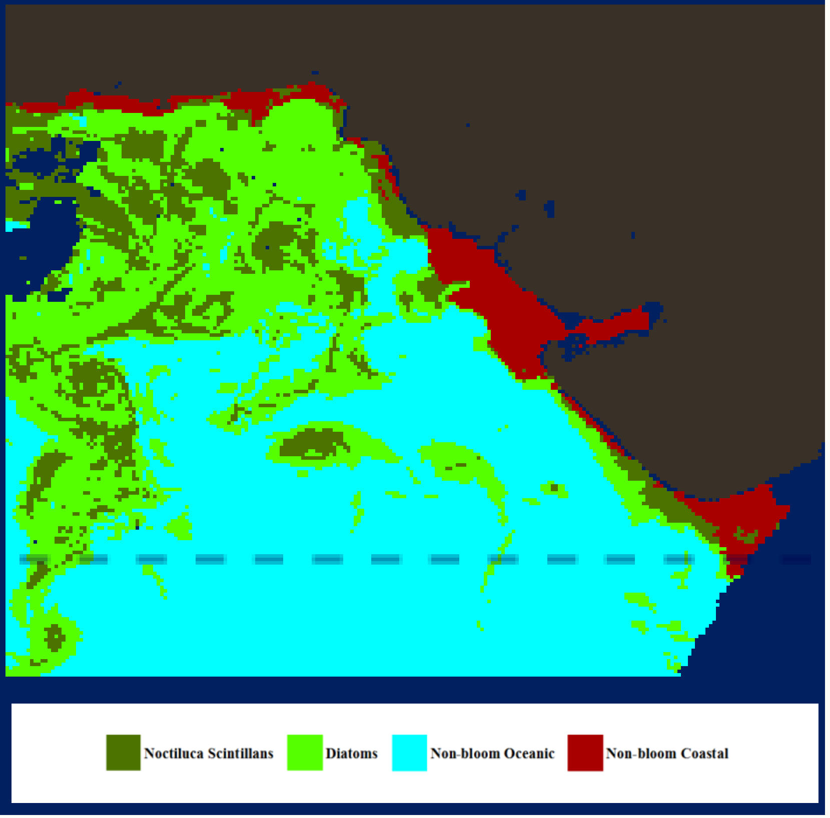


Phyto ID Product (INCOIS ADPC)

using Dwivedi et al 2015



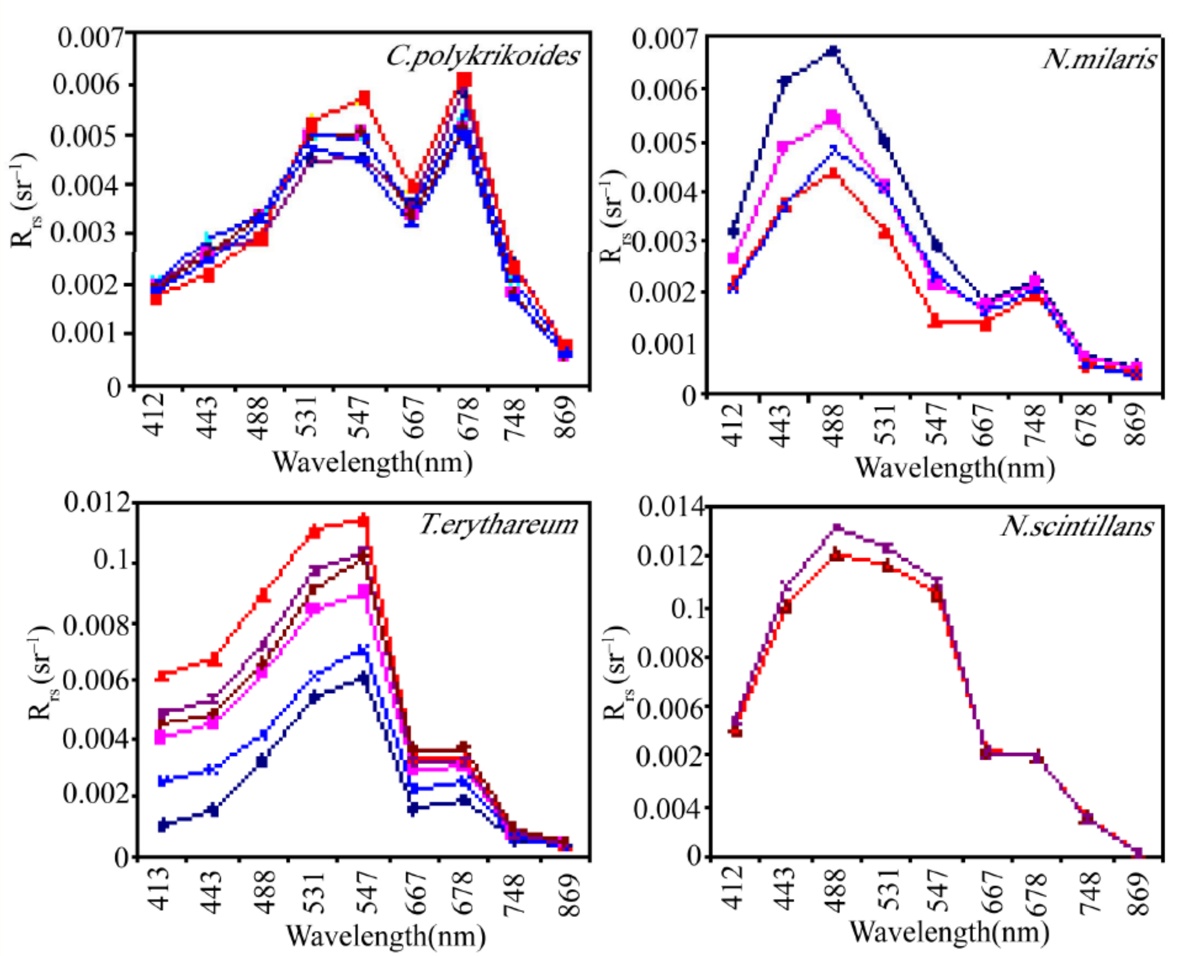




12th March 2018

Detection of N. scintillans, N. milaris, T. erythareum and *C. ploykrikoides*

Simon et al 2015



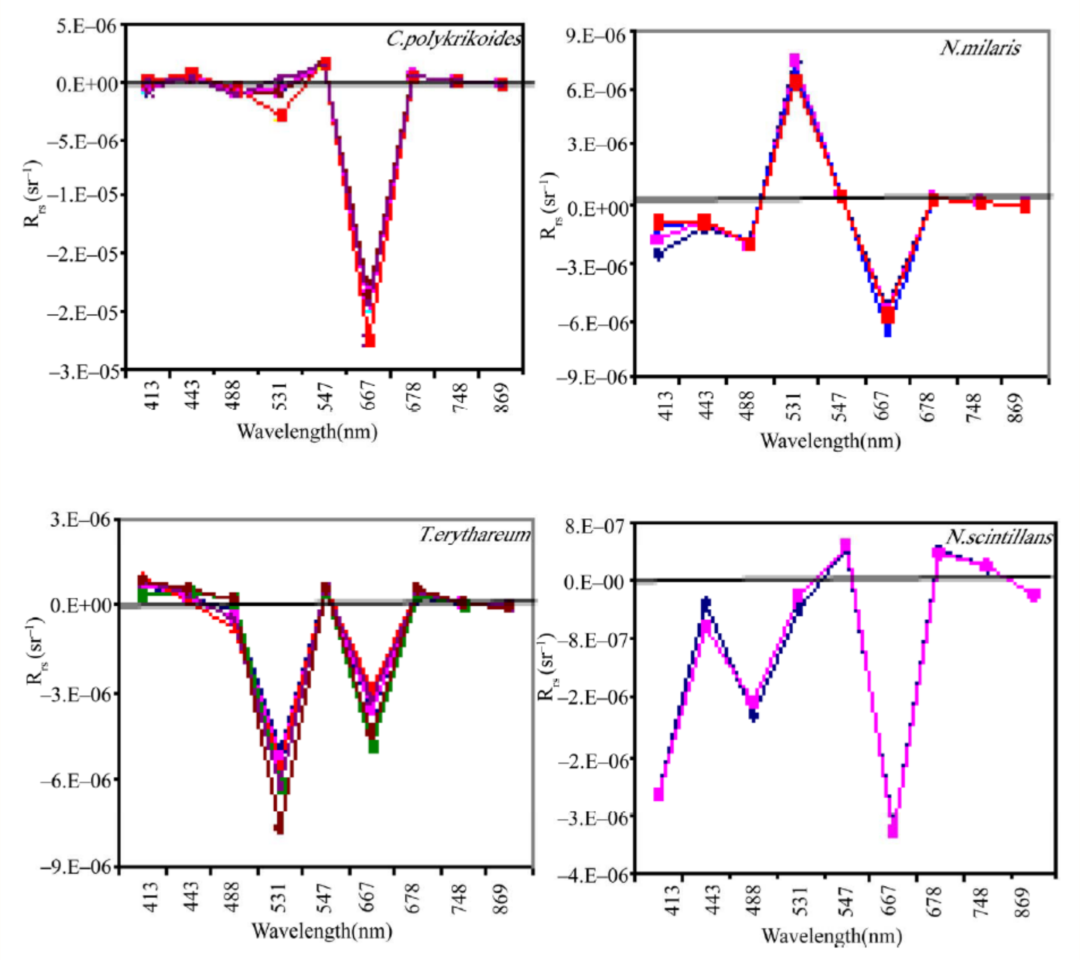
Detection of N. scintillans, N. milaris, T. erythareum and *C. ploykrikoides*

Simon et al 2015

$$\frac{d^2 R_{rs}}{d\lambda^2} = \frac{(R_{rs}(\lambda_{i+1}) - 2R_{rs}(\lambda_i) + R_{rs}(\lambda_{i-1}))}{\Delta\lambda^2}$$

Detection of N. scintillans, N. milaris, T. erythareum and *C. ploykrikoides*

Simon et al 2015



Detection of N. scintillans, N. milaris, T. erythareum and *C. ploykrikoides*

Simon et al 2015

Neqn equations

$$\left[\frac{(R_{rs}488)}{(R_{rs}547 - R_{rs}488)}\right] * \left[d^2R_{rs}488 - d^2R_{rs}443\right]$$

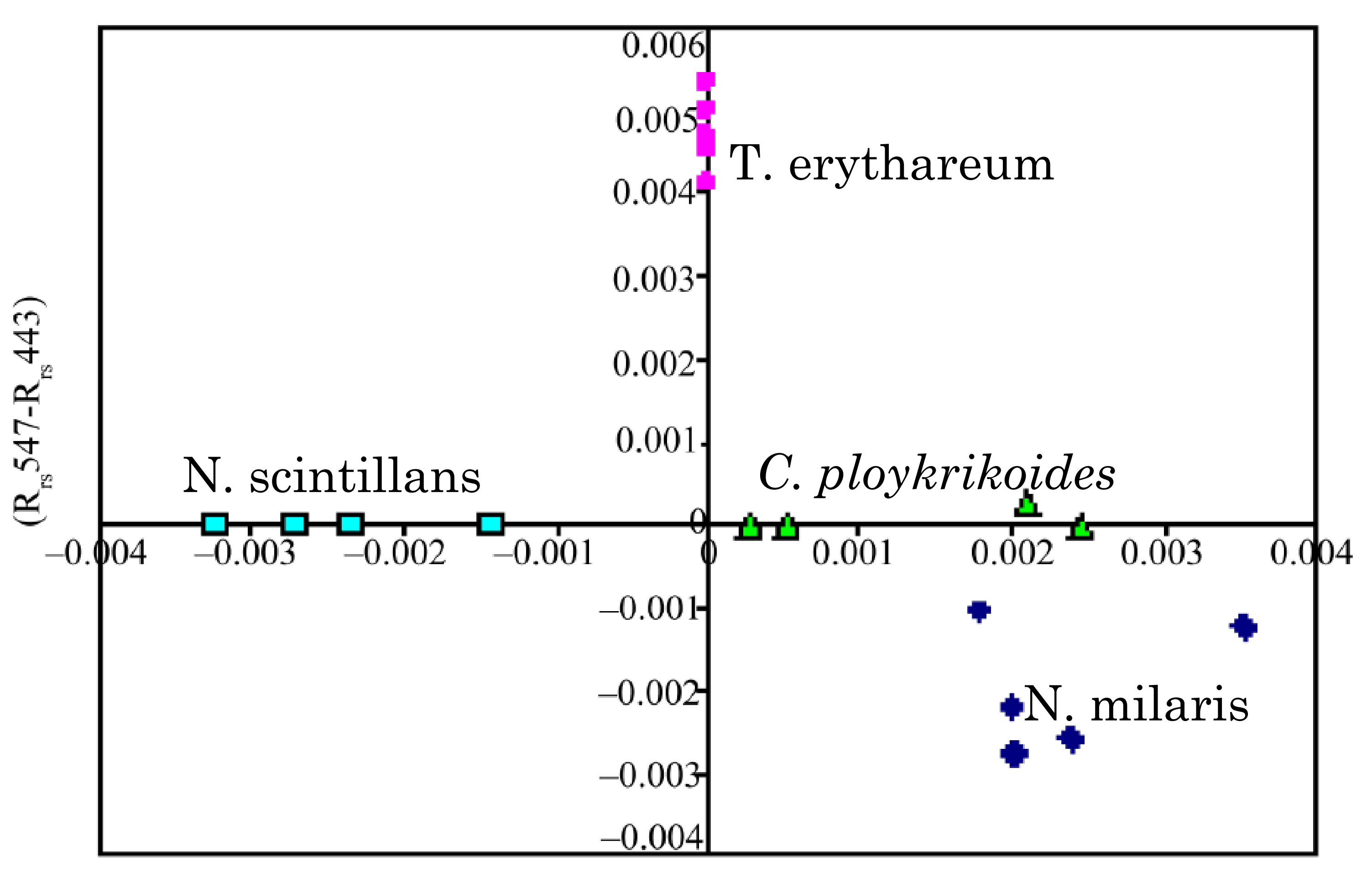
for *T. erythareum*

$$\left[\frac{(R_{rs}488)}{R_{rs}547 - R_{rs}488}\right] - \left[\frac{R_{rs}443}{R_{rs}547}\right] * \left[d^2R_{rs}488 - d^2R_{rs}443\right]$$

for *N. scintillans*, *N. miliaris* and *C. polykrikoides*

Detection of N. scintillans, N. milaris, T. erythareum and *C. ploykrikoides*

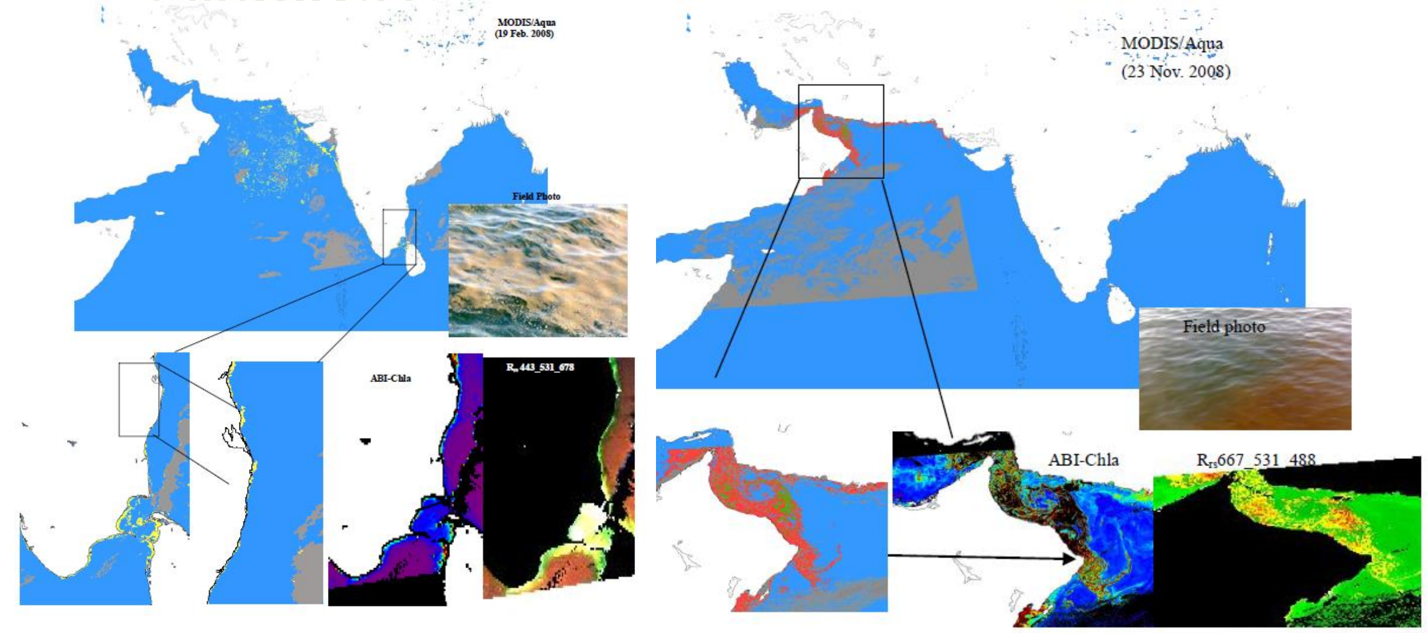
Simon et al 2015

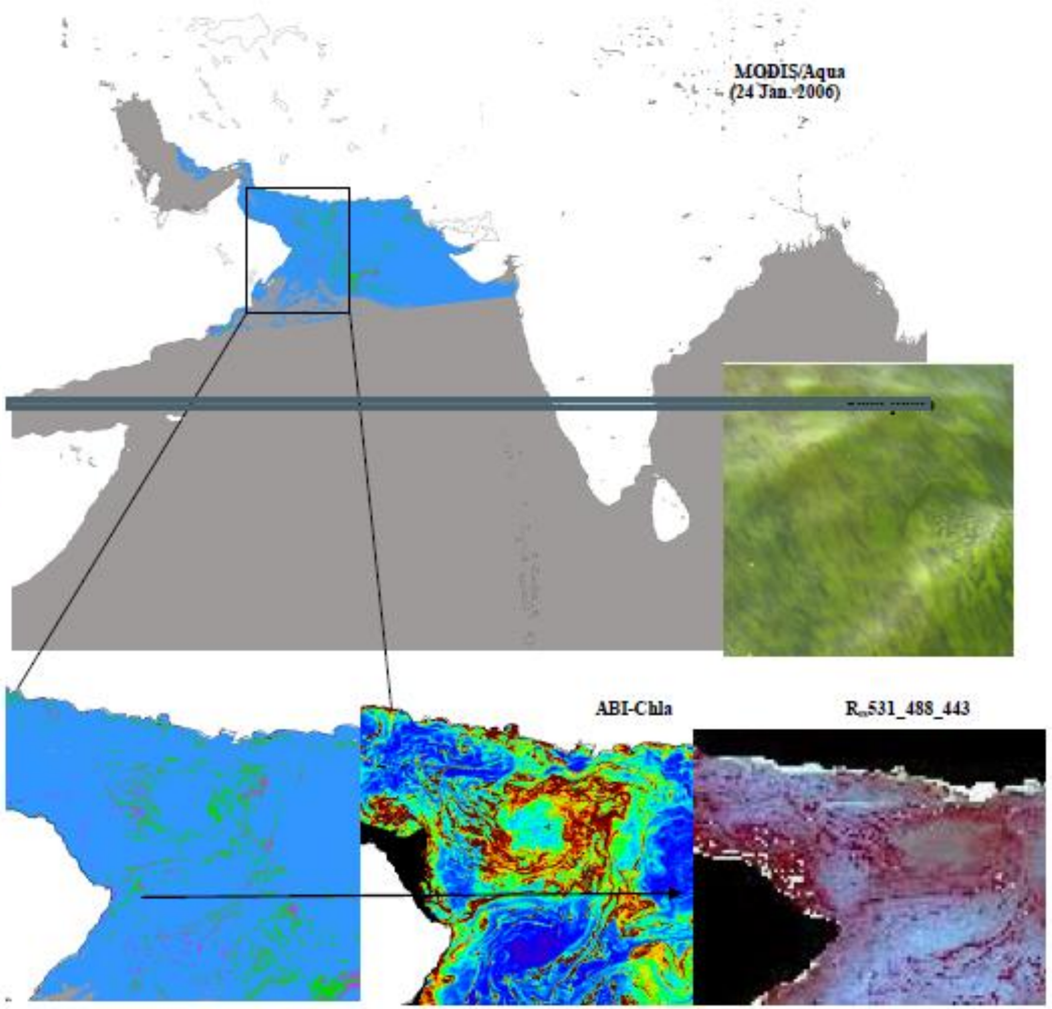


Results of Neqn equations

Detection of N. scintillans, N. milaris, T. erythareum and *C. ploykrikoides*

Simon et al 2015





- ***C. Ploykrikoides***
- **T. erythareum**
- **N. scintillans**
- **N. milaris**
- **Clear water**

Challenges & Scope

Thank You!!

Early Satellite Detection

CZCS Chlorophyll-a January 1981 monthly composite.