“ OCEAN COLOR REMOTE SENSING “

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"Fundamentals of Remote Sensing & GIS and Oceanographic Applications"

during 10 - 14 April 2023

Organized by

International Training Centre for Operational Oceanography (ITCOocean) ESSO-INCOIS, Hyderabad, India

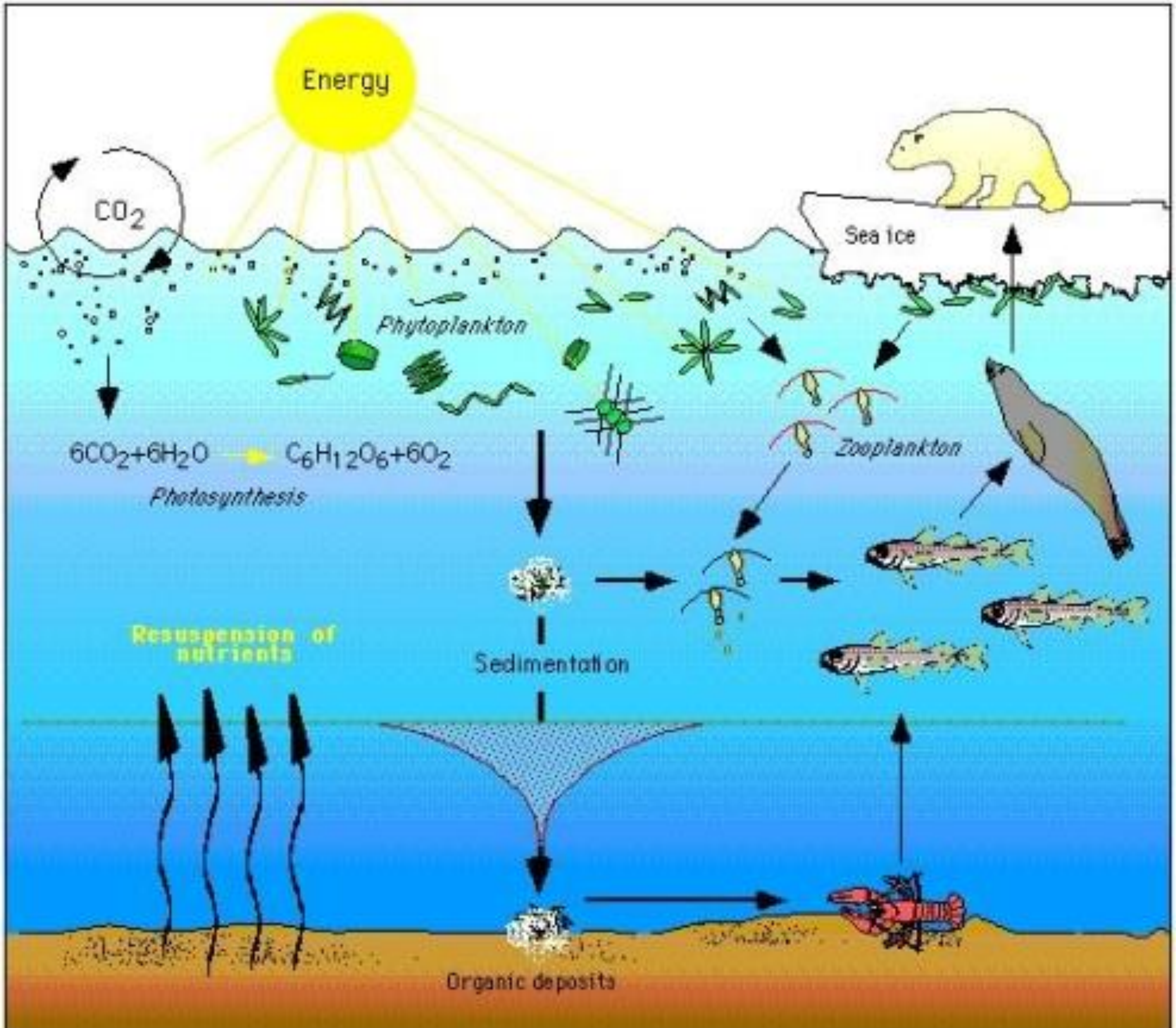
Ocean Colour Remote sensing

Why do we call it Ocean Color?

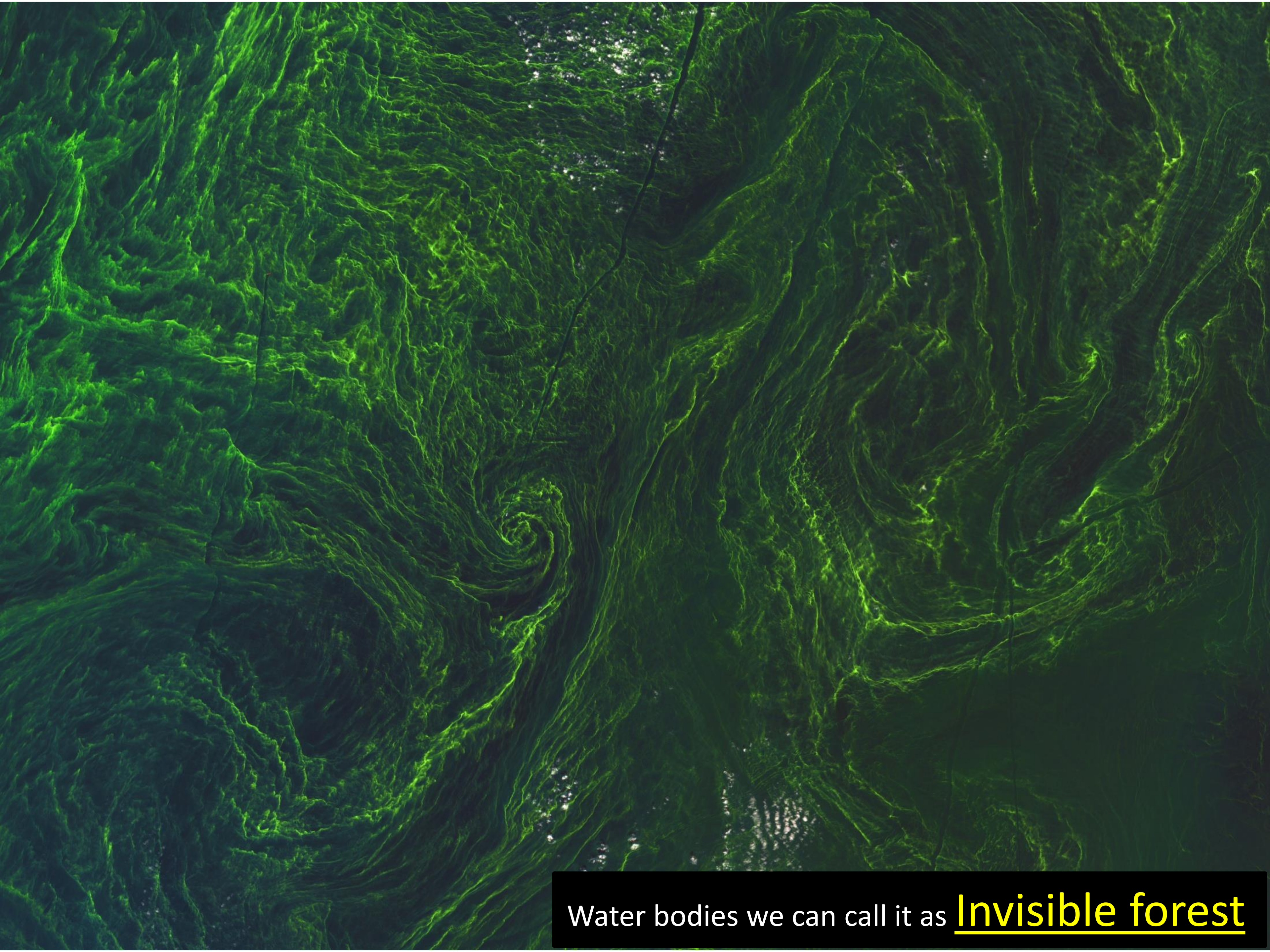
Visible light (400 - 700 nm)

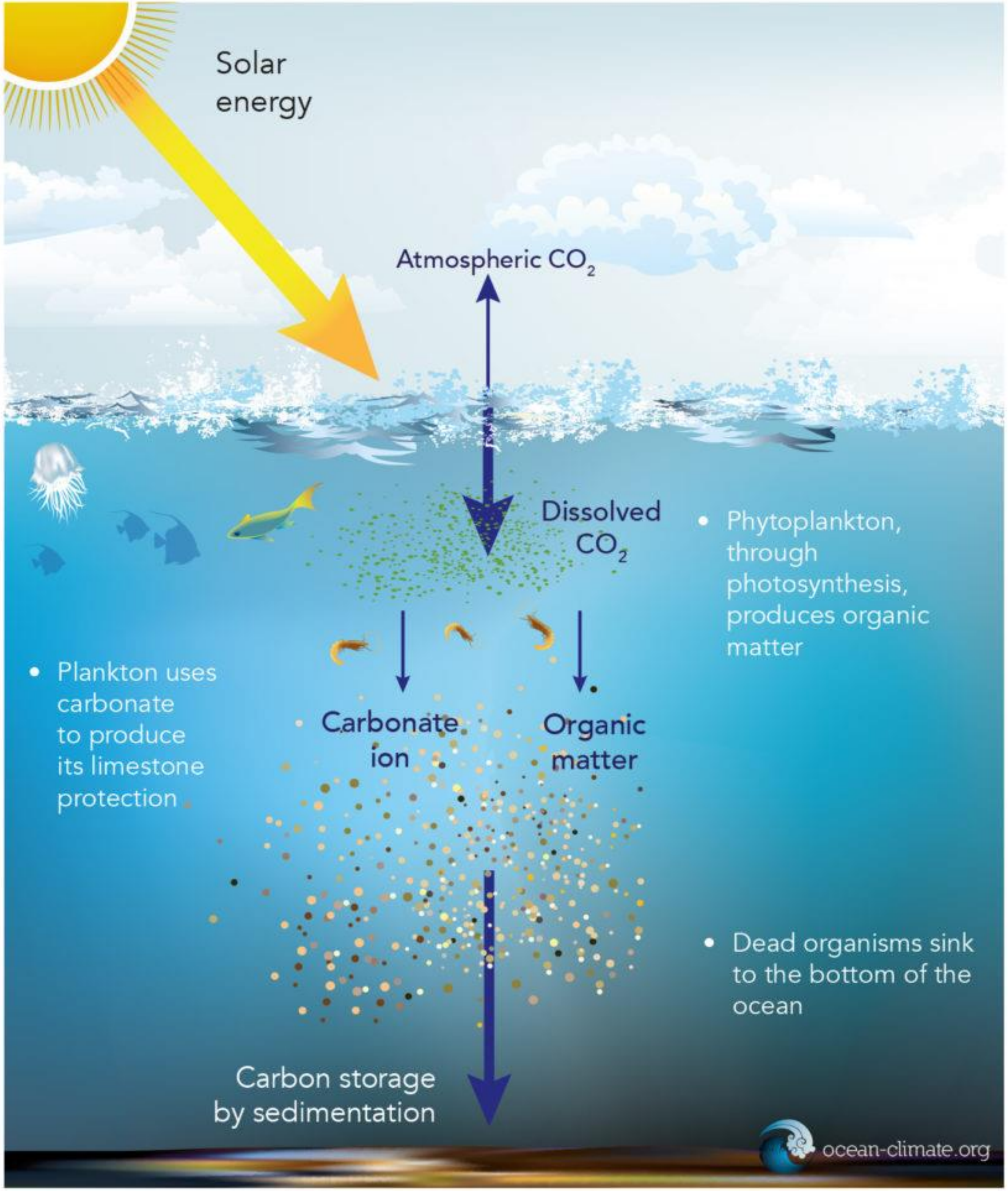
What do we measure from the color of the Ocean?

Why do we apply Atmospheric correction?



Drawn by Christopher Krembs


Water bodies we can call it as Invisible forest



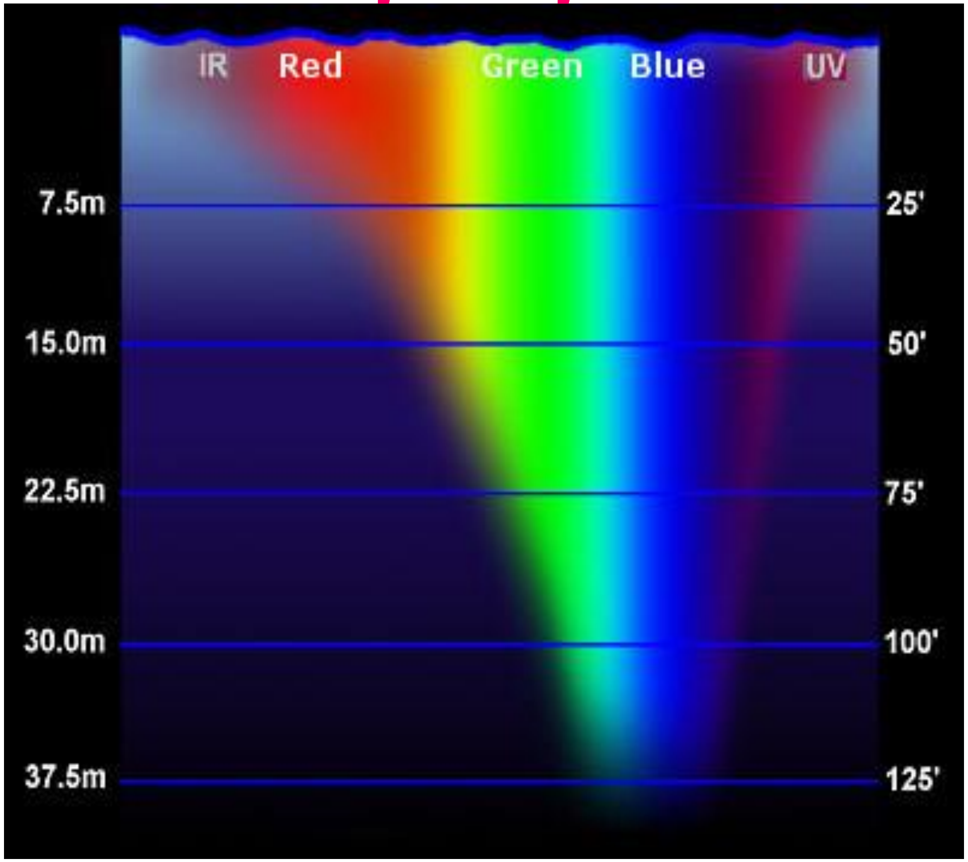
Biological carbon pump

With remote sensing, four main parameters can be found in seawater:

1. Pure Water (H_2O)
2. Pigments in algae like Chlorophyll-a
3. small particles, like Sediment (SPM)
4. Coloured dissolved material, like CDOM

Water quality parameters

5. Few cases Ocean Bathymetry



Patterns of light penetration into water. Source: Tom Morris, Fullerton College.

Light Interaction with ocean waters & Atmosphere

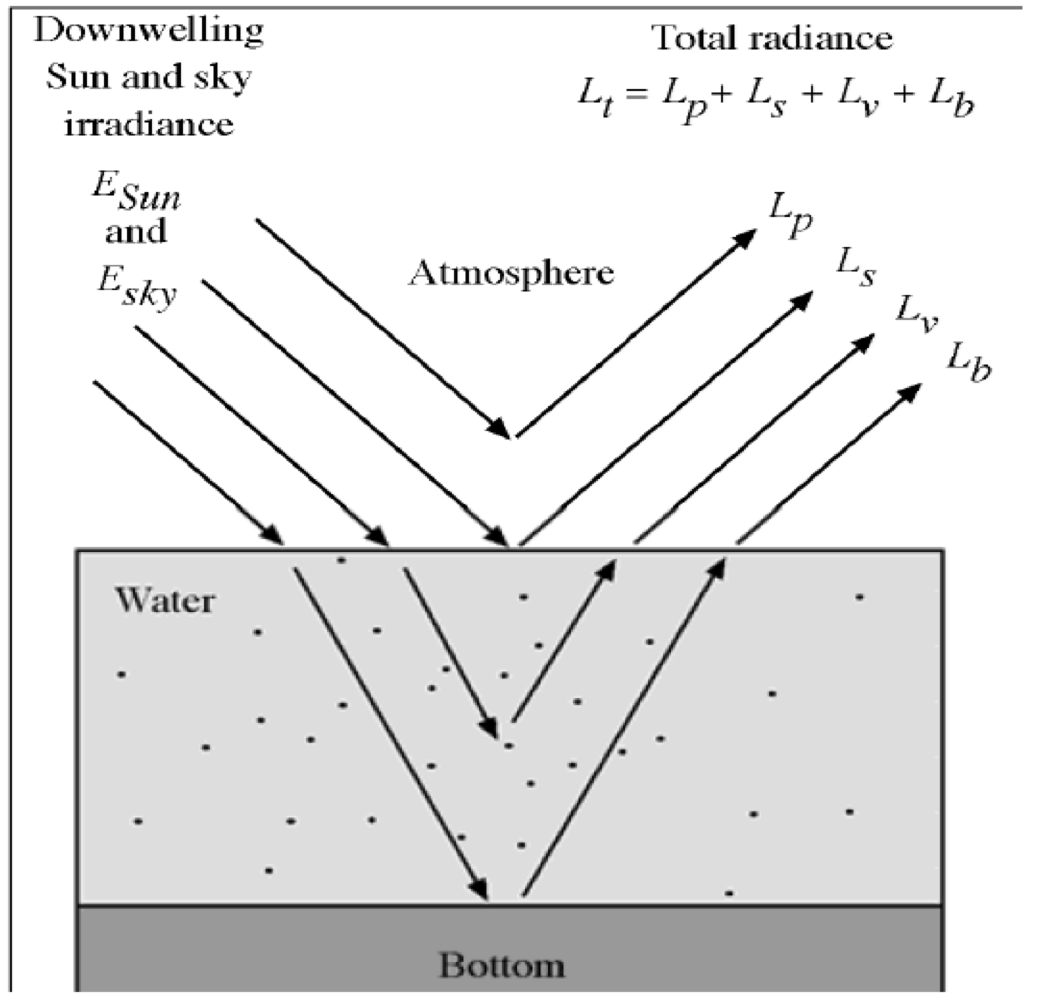
Water Surface, Subsurface Volumetric, and Bottom Radiance

The total radiance, (Lt) recorded by a remote sensing system over a water body is a function of the electromagnetic energy from four sources:

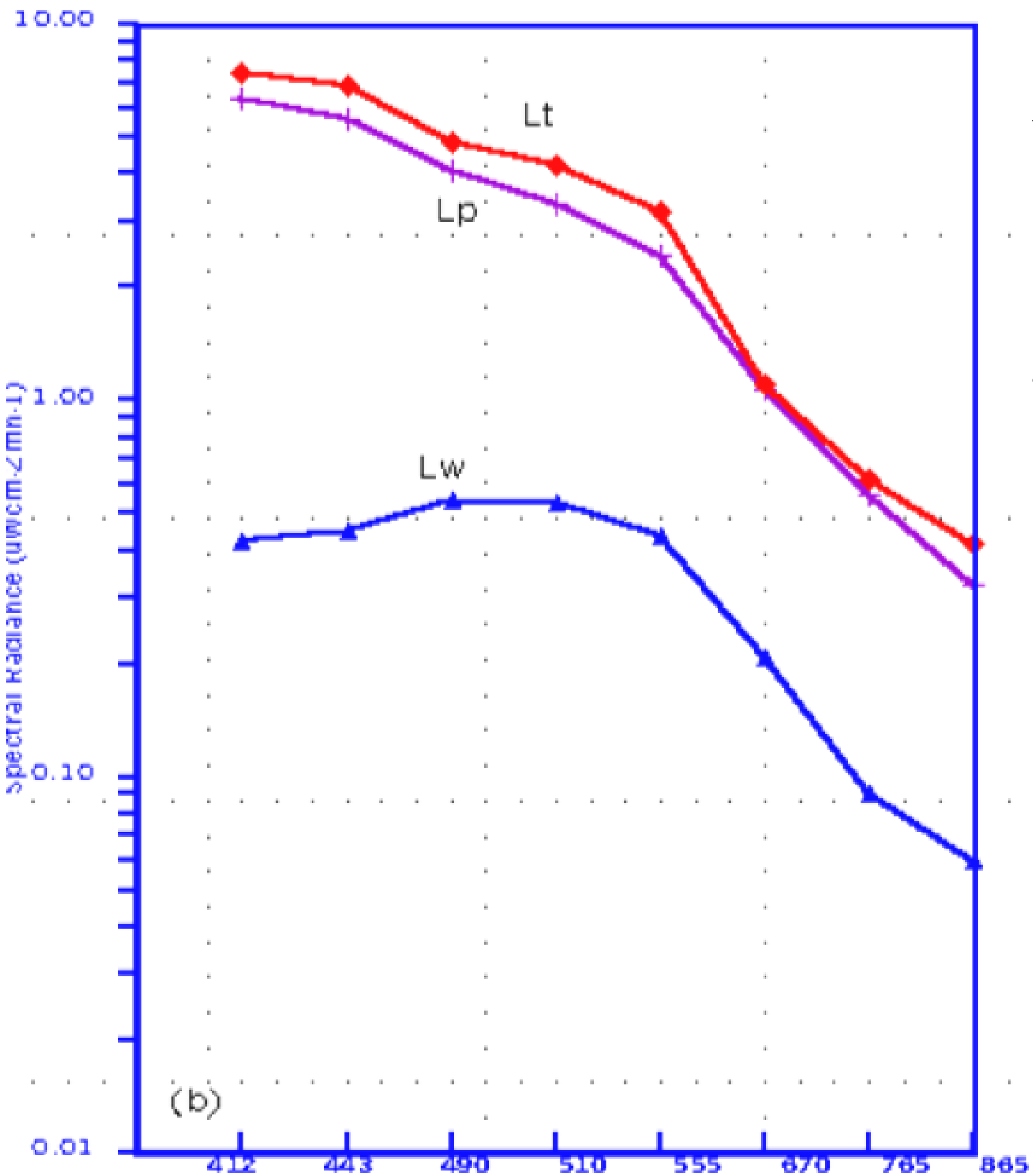
$$L_t = \boxed{L_p + L_s} + \boxed{L_v + L_b}$$

$$Lw = Lv + Lb$$

•Lv – is called subsurface volumetric radiance, provides information about organic & inorganic constituents.
•Lb – is called bottom radiance, carries bathymetry information.

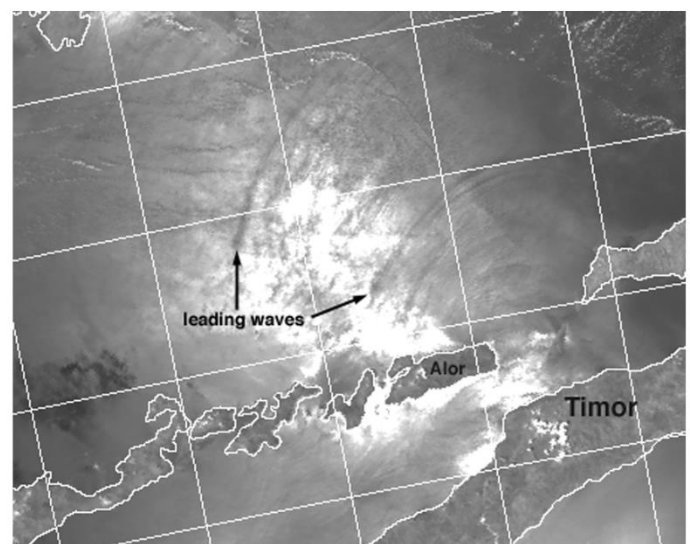


Ocean color Sensor measured spectral radiance



Lp – Path radiance; is the radiance recorded by a sensor resulting from the atmosphere (scattering mechanism)

Ls – secular reflection from sea surface (sun glint), contains near-surface (millimeter)



Rayleigh scattering

In R.S it's other name of *molecular scattering*.

The magnitude and direction of Rayleigh scattering are well known.

The scattering coefficient due to Rayleigh scattering is given by

Rayleigh scattering coefficient = $0.008735 \times \lambda^{-4.08}$

the degree of scattering is inversely proportional to the 4^{th} power of '**λ**'

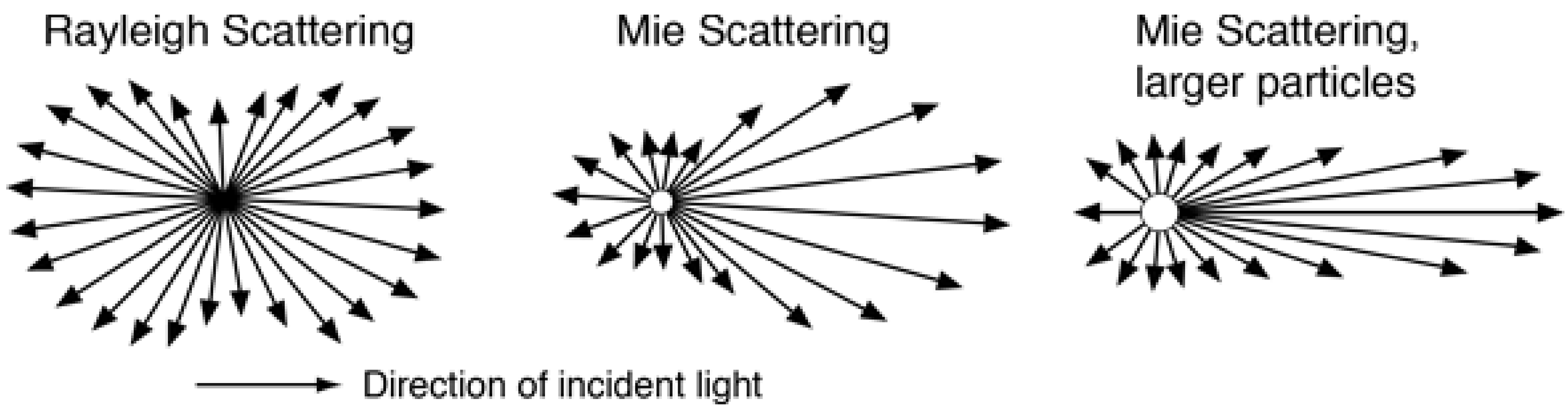
Mie scattering

Molecular size equal to '**λ**', molecules are dust, pollutants, smoke, ocean spray, salt particles and water vapour molecules. All are called *AEROSOLS*.

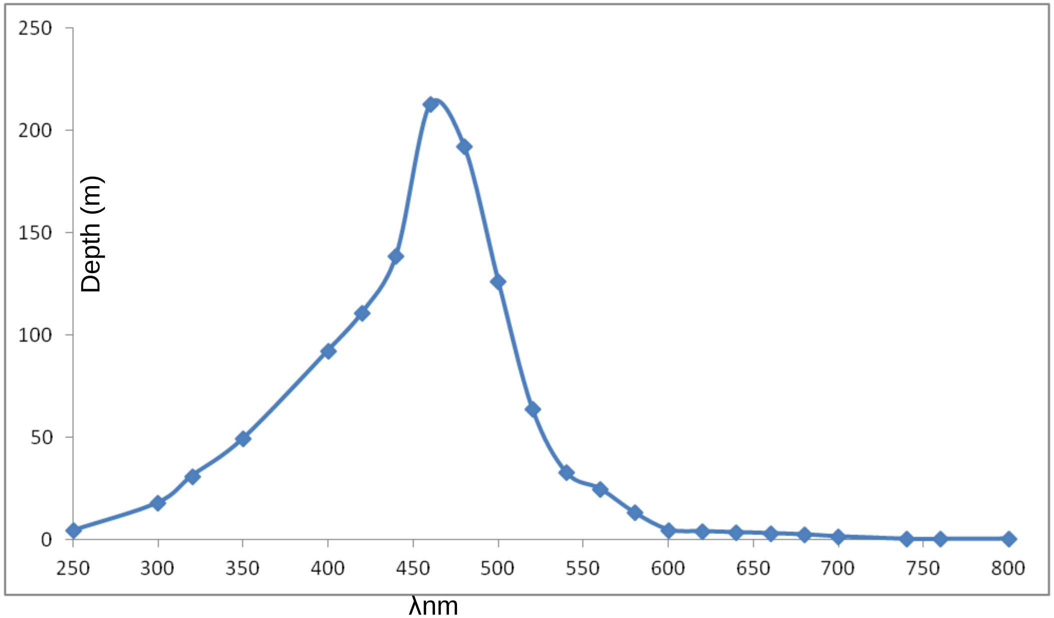
This scattering is called Aerosol scattering

Mie scattering coefficient = $0.008735 \times \lambda^{-1.3}$

Mie scattering is less dependent on '**λ**'



Spectral characteristics and the optical properties of pure water



Rrs= Lu/Ed

$$R = 0.33 \frac{b_b}{a + b_b}$$

Apparent optical properties (AOP's)
& Inherent optical properties (IOP's)

IOP - radiation field within the body of water

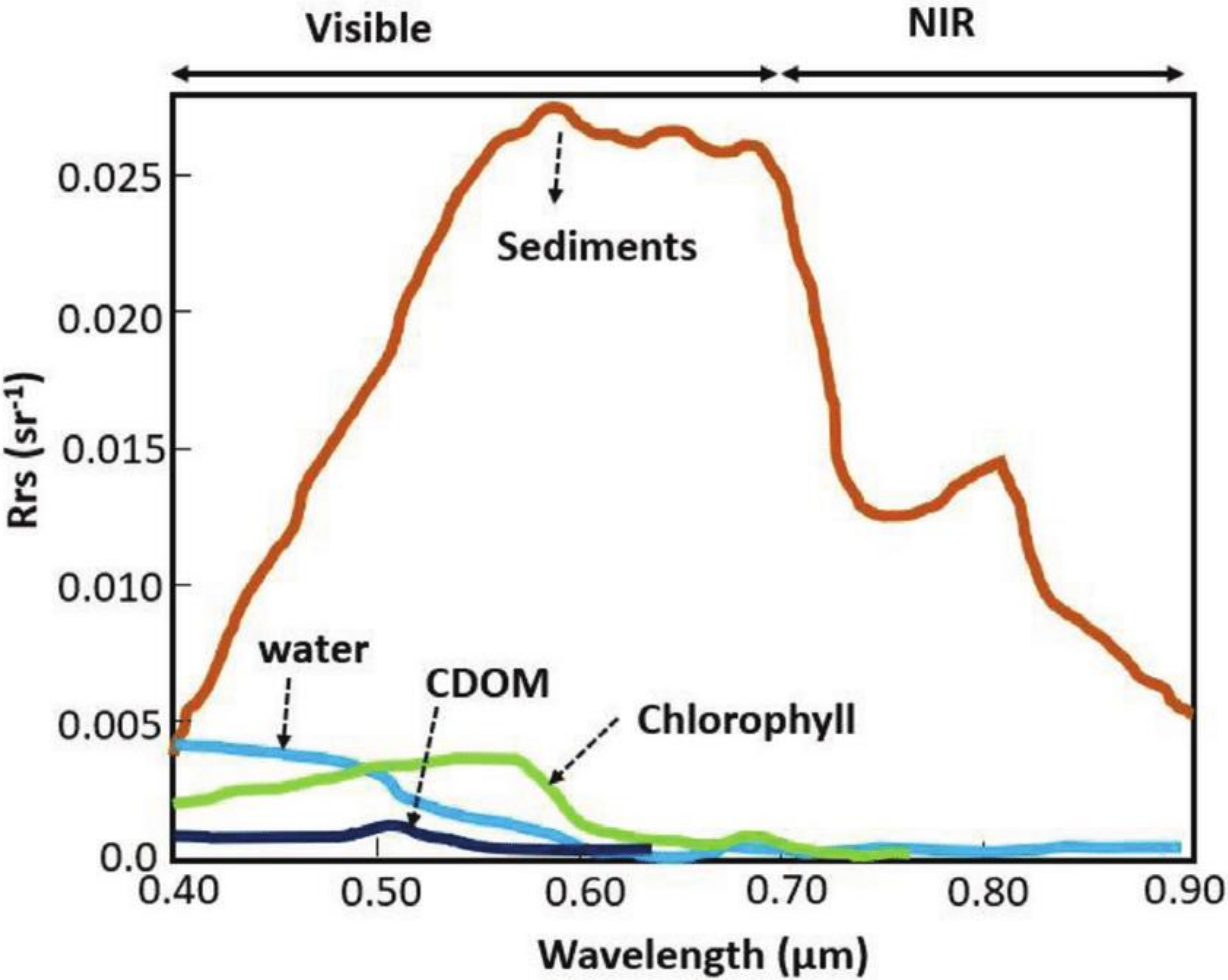
Wavelength (nm)	Absorption $\alpha(\lambda)$ (m^{-1})	Scattering $b(\lambda)$ (m^{-1})	Total Attenuation $c(\lambda)$ (m^{-1})
250 – ultraviolet	0.190	0.032	0.2200
300 – ultraviolet	0.040	0.015	0.0550
320 – ultraviolet	0.020	0.012	0.0320
350 – ultraviolet	0.012	0.0082	0.0202
400 – violet	0.006	0.0048	0.0108
420 – violet	0.005	0.0040	0.0090
440 – violet	0.004	0.0032	0.0072
460 – dark blue	0.002	0.0027	0.0047
480 – dark blue	0.003	0.0022	0.0052
500 – light blue	0.006	0.0019	0.0079
520 – green	0.014	0.0016	0.0156
540 – green	0.029	0.0014	0.0304
560 – green	0.039	0.0012	0.0402
580 – yellow	0.074	0.0011	0.0751
600 – orange	0.20	0.00093	0.2009
620 – orange	0.24	0.0082	0.2408
640 – red	0.27	0.00072	0.2707
660 – red	0.310	0.00064	0.3106
680 – red	0.38	0.00056	0.3806
700 – red	0.60	0.0005	0.6005
740 – near-infrared	2.25	0.0004	2.2504
760 – near-infrared	2.56	0.00035	2.5604
800 – near-infrared	2.02	0.00029	2.0203

AOP's & IOP's

IOPs	Notation	Units	AOPs	Notation	Units
Total absorption coefficient	$a\ (\lambda)$	m^{-1}	Remote-sensing reflectance	$Rrs\ (\lambda)$	sr^{-1}
Particles absorption coefficient	$a_p(\lambda)$	m^{-1}	Water-leaving reflectance	$RLw\ (\lambda)$	–
NAP absorption coefficient	$a_{NAP}(\lambda)$	m^{-1}	Water-leaving radiance (or	$Lw\ (\lambda)$	$mW\ cm^{-2}$
Absorption by phytoplankton	$a_{ph}(\lambda)$	m^{-1}	above-water upwelling		$\mu m^{-1}\ sr^{-1}$
Absorption by detritus	$a_d(\lambda)$	m^{-1}	radiance)		
CDOM absorption coefficient	$a_g(\lambda)$	m^{-1}	Above-water downwelling	$Es\ (\lambda)$	$mW\ cm^{-2}$
Total (back)scattering coefficient	$b_{(b)}\ (\lambda)$	m^{-1}	irradiance (or incident		μm^{-1}
NAP scattering coefficient	$b_{NAP}(\lambda)$	m^{-1}	irradiance)		
NAP backscattering coefficient	$b_{bNAP}(\lambda)$	m^{-1}	Downwelling irradiance	$Ed\ (\lambda)$	$mW\ cm^{-2}$
Backscattering ratio	$b_{bp}(\lambda)/b_p(\lambda)$	–			μm^{-1}
Total beam attenuation coefficient	$c(\lambda)$	m^{-1}	Diffuse attenuation of Ed	$Kd\ (\lambda)$	m^{-1}
Particles beam attenuation coefficient	$c_p(\lambda)$	m^{-1}	Diffuse attenuation of PAR	K_{par}	m^{-1}
Turbidity		FNU, FTU			

Case-I waters are those waters whose inherent optical properties (IOPs) are dominated by phytoplankton (e.g., most open ocean waters).

Case-2 waters are all other waters (e.g., some coastal and inland waters contain colored dissolved organic matter (CDOM) and inorganic mineral particles in addition to phytoplankton).



Visible
NIR
Sediments
water
CDOM
Chlorophyll
Rrs (sr⁻¹)
0.025
0.020
0.015
0.010
0.005
0.0
0.40
0.50
0.60
0.70
0.80
0.90
Wavelength (μm)

Atmospheric correction for Ocean colour Remote sensing

Thankful to Dr.M.Mohan and Dr.Prakash Chauhan

1.2. METHODOLOGY FOR ATMOSPHERIC CORRECTION

The radiance detected by a space borne sensor at the top of the atmosphere (TOA) in the wave length λ can be split into (Doerffer, 1992):

$$L_t(\lambda) = L_a(\lambda) + L_r(\lambda) + t_d(\lambda) \cdot L_w(\lambda) \quad (1)$$

where,

L_t = sensor detected radiance

$L_a = F_0 \cdot \omega_{0a} \cdot \tau_a \cdot p_a / (4\pi \cos\theta_v)$ = aerosol path radiance

$L_r = F_0 \cdot \omega_{0r} \cdot \tau_r \cdot p_r / (4\pi \cos\theta_v)$ = Rayleigh path radiance

ω_{0r} = Rayleigh single scattering albedo (~1.0)

ω_{0a} = aerosol single scattering albedo

$\tau_{r,a}$ = Rayleigh/aerosoi opt. depth

$p_{r,a}$ = a function related to Rayleigh/aerosol scattering phase function

L_w = water leaving radiance

$t_d \approx \exp[-(1/\cos\theta_v + 1/\cos\theta_s)(\tau_r/2 + \tau_{oz})]$ = atmos. diffuse transmittance

θ_v = sensor viewing zenith angle

θ_s = solar zenith angle

τ_{oz} = ozone absorption optical depth

1.2.1. THE METHOD OF ANGSTROM EXPONENT

Since $L_w \sim 0$ for $\lambda > 700$ nm, one can write

$$L_t = L_a + L_r \quad (7)$$

or

$$L_a = L_t - L_r$$

Global observations on of aerosols indicate that the spectral variation of the aerosol optical depth can be modeled, to a good degree of approximation, by a power law

$$\tau_a \propto (\lambda)^{-\alpha} \quad (8)$$

which is called the Angstrom relation where α is known as the Angstrom exponent. Applying (8) on the expression for aerosol path radiance [refer Eq. (1)] and assuming the phase function to be constant over the wave length range considered,

$$L_a/F_0 = \text{const.} \, (\lambda)^{-\alpha}. \quad (9)$$

Taking logarithm on both sides,

$$\log(L_a/F_0) = \text{const.} - \alpha \cdot \log(\lambda) \quad (10)$$

By plotting $\log(L_a/F_0)$ against $\log(\lambda)$ for two or more wavelengths greater than 700 nm, α can be determined as the negative of the slope of the best fit straight line. [In the case of OCM the wave lengths are 765 nm (band-7) and 865nm (band-8) and in the case of MOS-B, the wave lengths are 750 nm (band-9) and 870 nm (band-11)]. Using these two bands, one can determine the Angstrom exponent for each pixel of the image as

$$\frac{\log(L_{a1}/F_{01}) - \log(L_{a2}/F_{02})}{\log(\lambda_2) - \log(\lambda_1)} = \alpha \quad (11)$$

where the suffixes 1 and 2 correspond to the two atmospheric correction bands. With the α determined thus, the aerosol path radiances in the ocean colour wavelengths (corresponding to OCM bands 1 - 5 are computed as

$$L_a(\lambda<700\text{nm}) = L_{a1} \cdot (F_0/F_{01}) \cdot (\lambda/\lambda_1)^{-\alpha} \quad (12)$$

And further used to determine the water leaving radiance as

$$L_w = t_d^{-1} \cdot [L_t - L_r - L_a] \quad (13)$$

Assumptions :

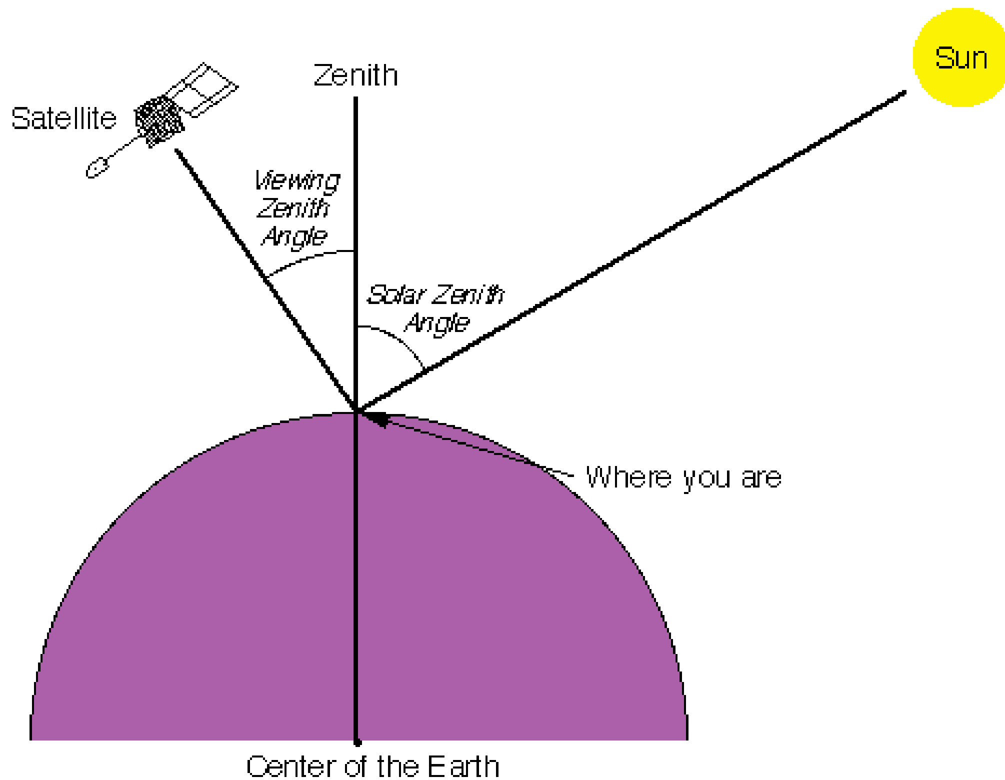
- Light undergoes single scattering
- **λ** >700nm, Lw=0

Oceansat-2 OCM specifications

Parameters	Specifications
1. IGFOV at nominal altitude (m)	360 x 250
2. Swath (km)	1420
3. No. of spectral bands	8
4. Spectral range (nm)	402- 885
5. Spectral bands	B1 : 404-424 nm B2: 431-451 nm B3: 476-496 nm B4: 500-520 nm B5: 546-566 nm B6: 610-630 nm (B1–B6: For retrieval of Ocean constituents) B7: 725-755 nm B8: 845-885 nm (B7–B8: For Computing atmospheric noise)
6. Quantization Bits	12
7. Along track steering	$\pm 20^0$
8. Data acquisition modes	Local Area Coverage (LAC) & Global Area Coverage (GAC)

Normalized water- leaving radiance:

The normalized water-leaving radiance is approximately the radiance that would exit the ocean in the absence of the atmosphere, with the sun at the zenith.

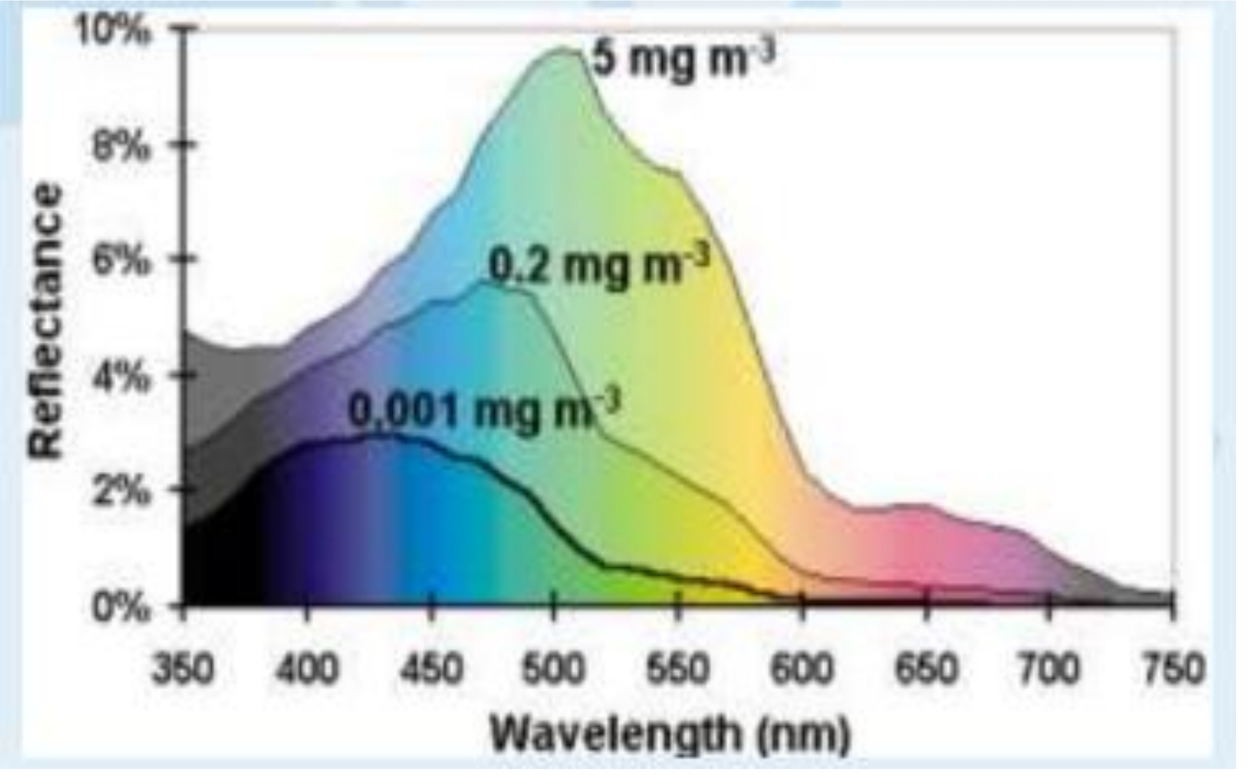


$$R_{rs}(\lambda) = L_{wn}(\lambda) / F_0(\lambda)$$

Phytoplankton Spectral signatures

Ocean biomass = Microscopic algae containing chlorophyll and other pigments

•Estimate biomass by measuring the color of light reflected from within water bodies

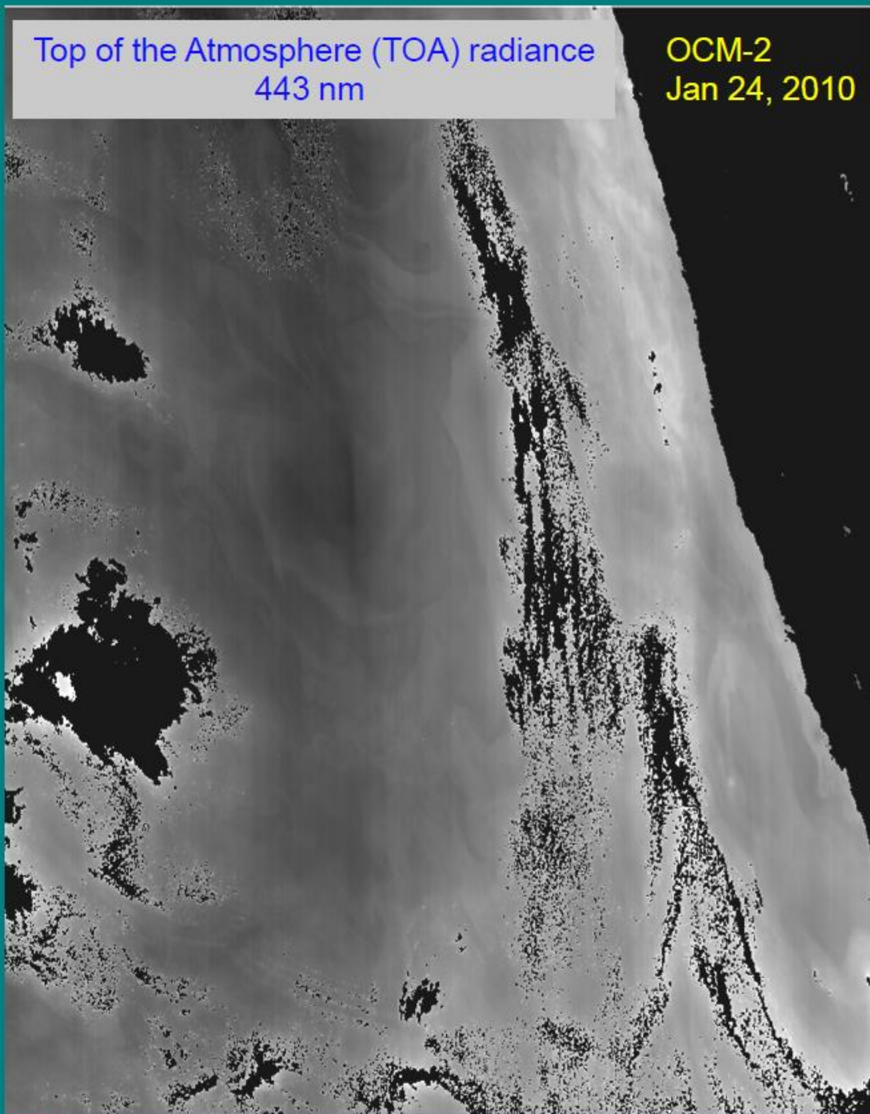


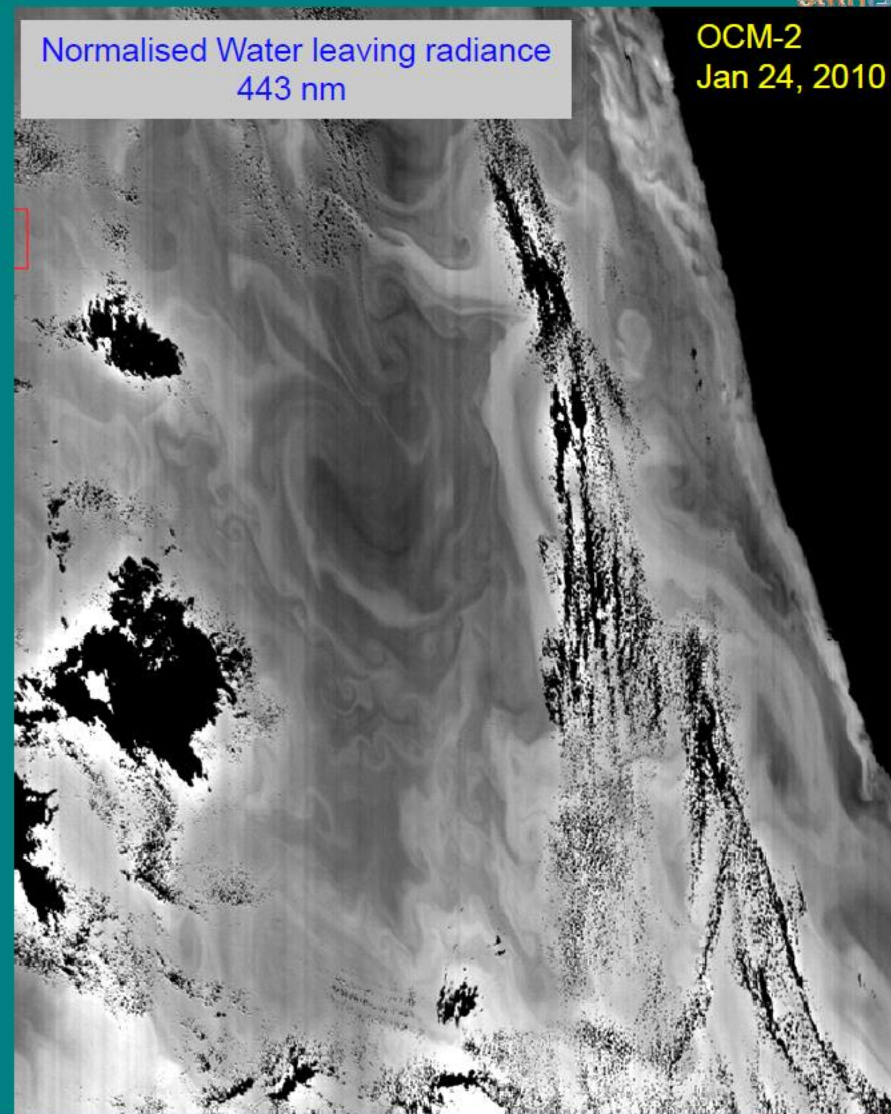
Low chlorophyll concentration: clear water = large signal in blue

High chlorophyll concentration: green water = large signal in green/yellow

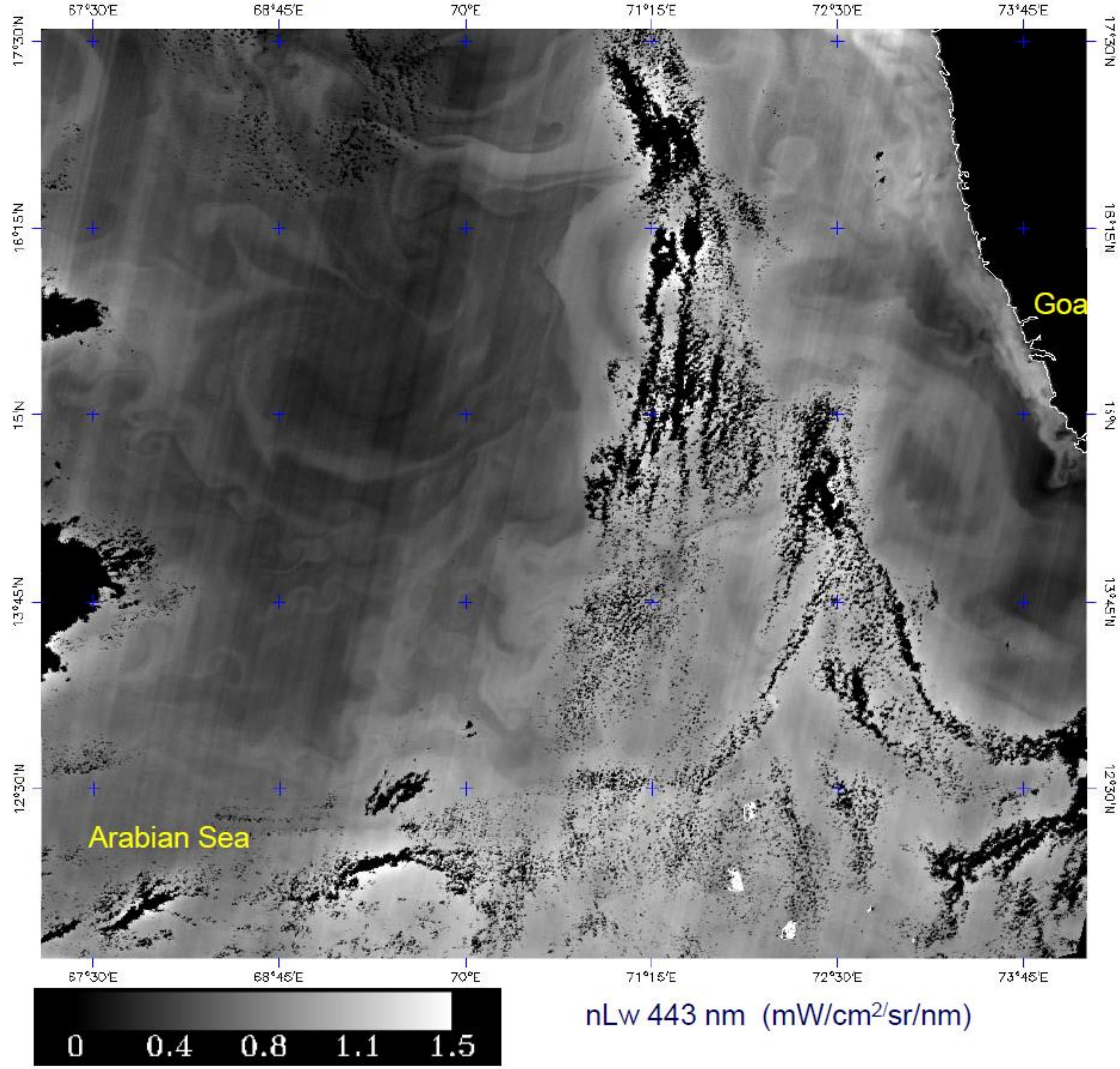
Clouds/ haze/fog are major obstruction to acquire the data.
No alternative to acquire the data.

Result of Atmospheric correction



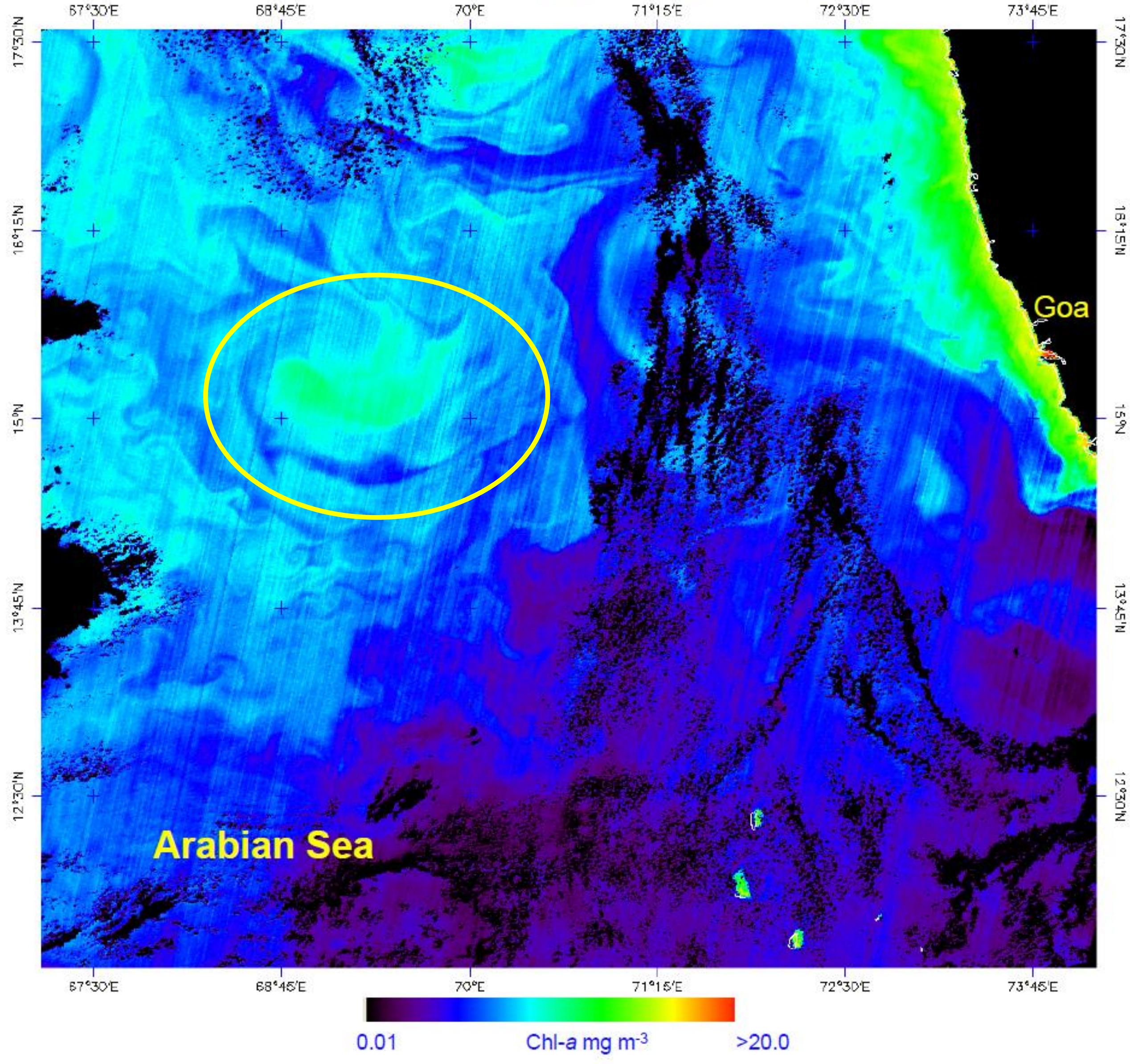


Results of atmospheric correction of Oceansat-2 OCM data

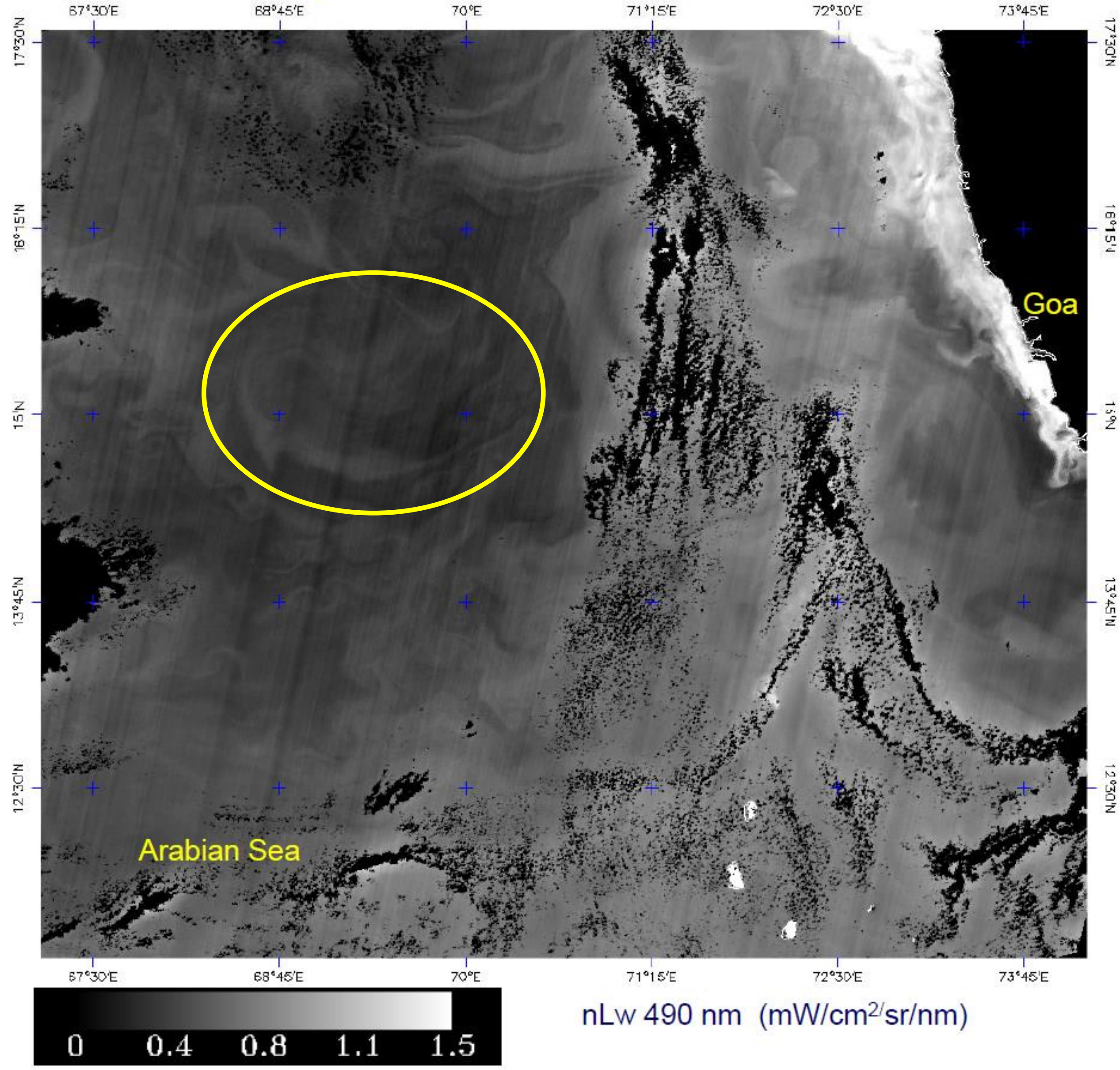


nLw 443 nm (mW/cm^2/sr/nm)

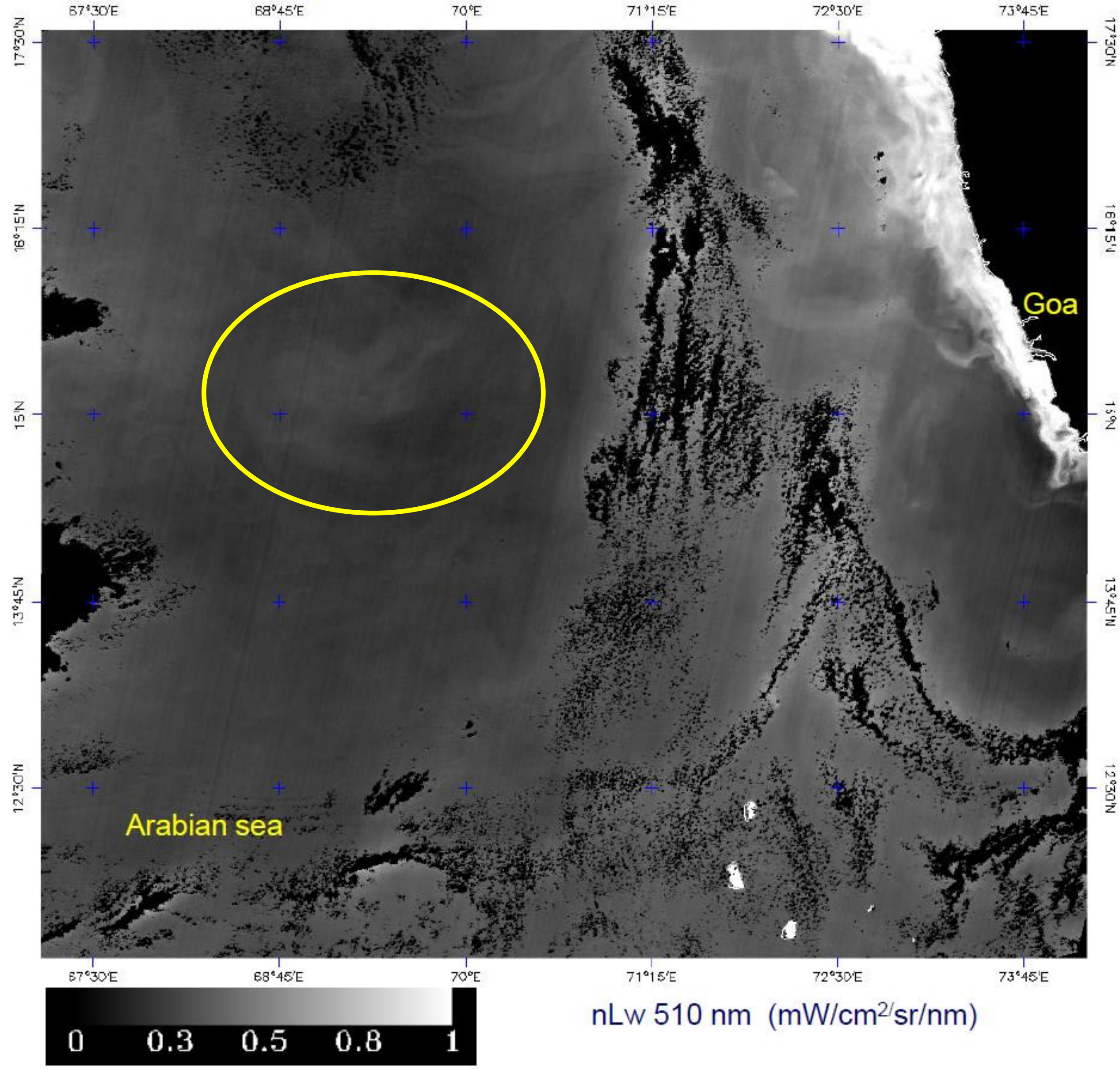
OCM-2 Chlorophyll-*a* image Jan 24, 2010



Results of atmospheric correction of Oceansat-2 OCM data



Results of atmospheric correction of Oceansat-2 OCM data



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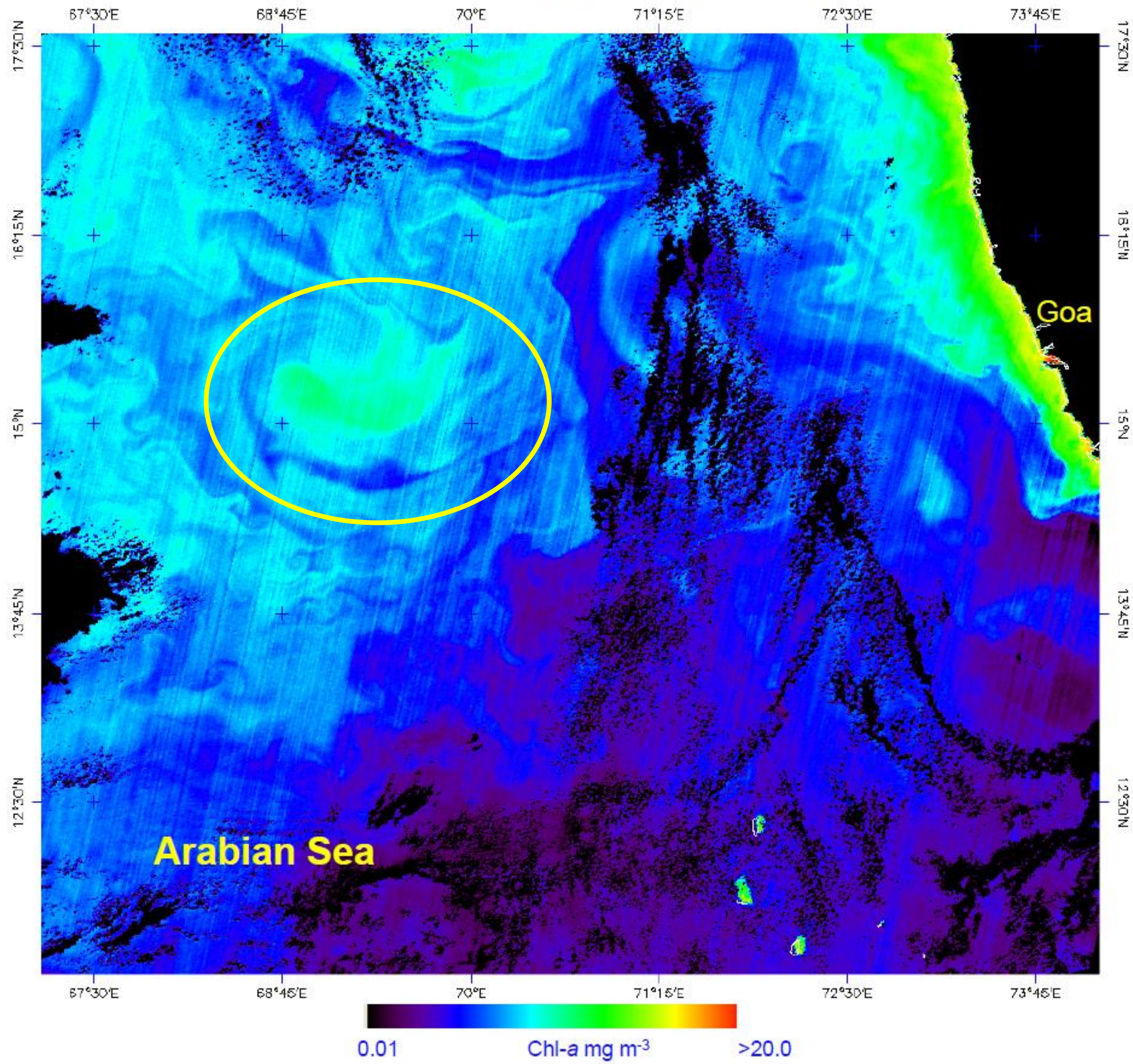
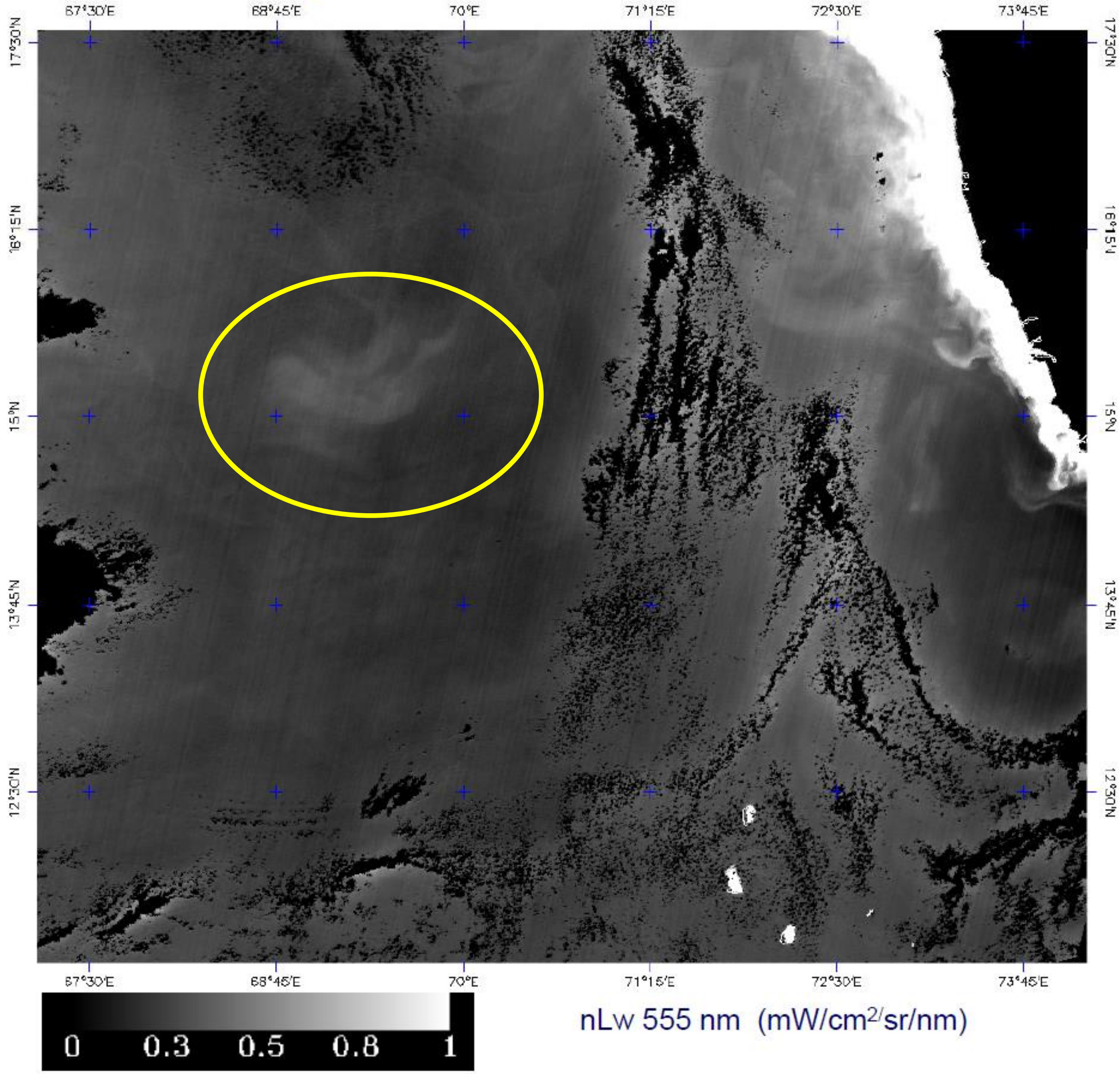
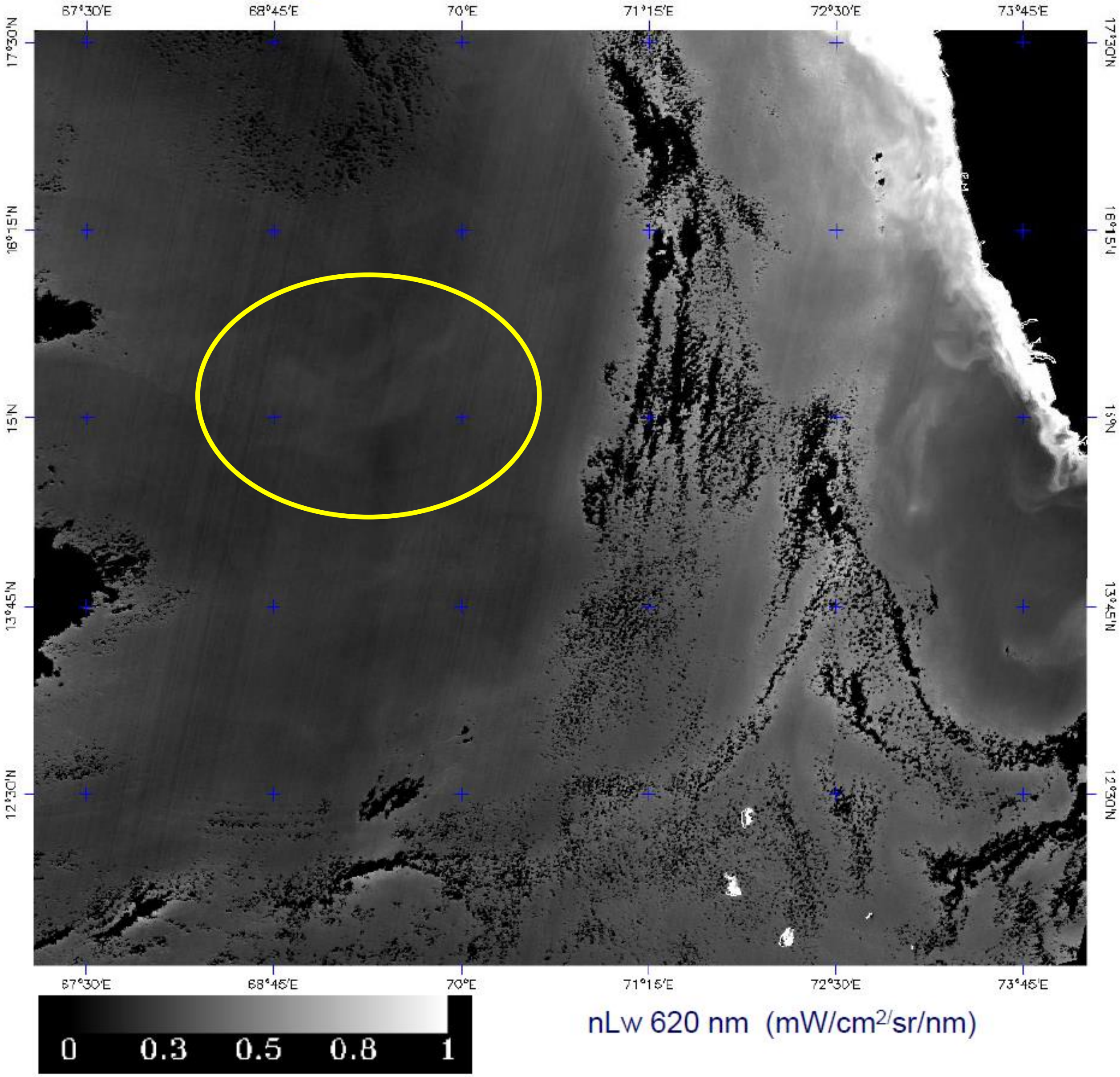


Results of atmospheric correction of Oceansat-2 OCM data

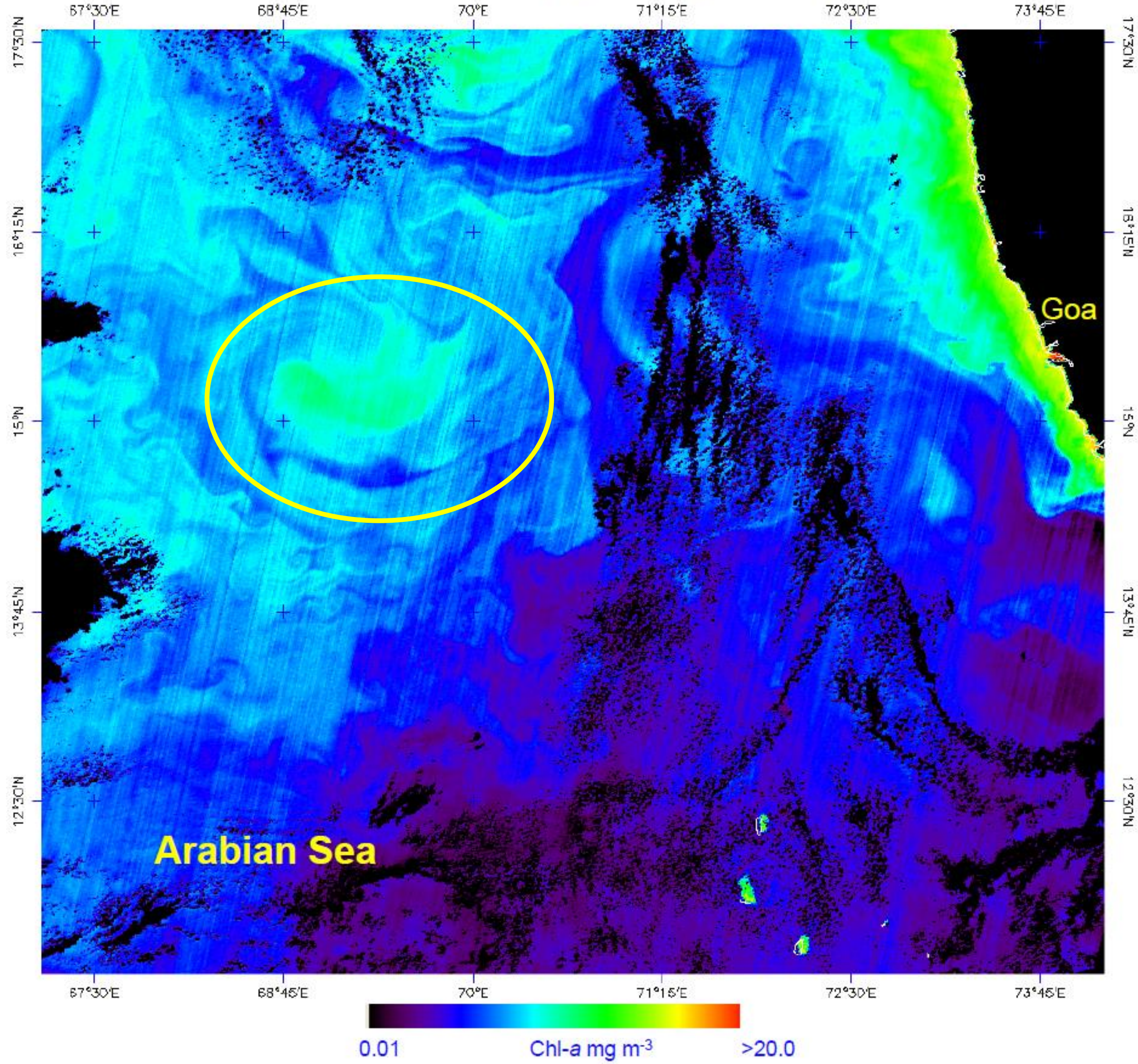


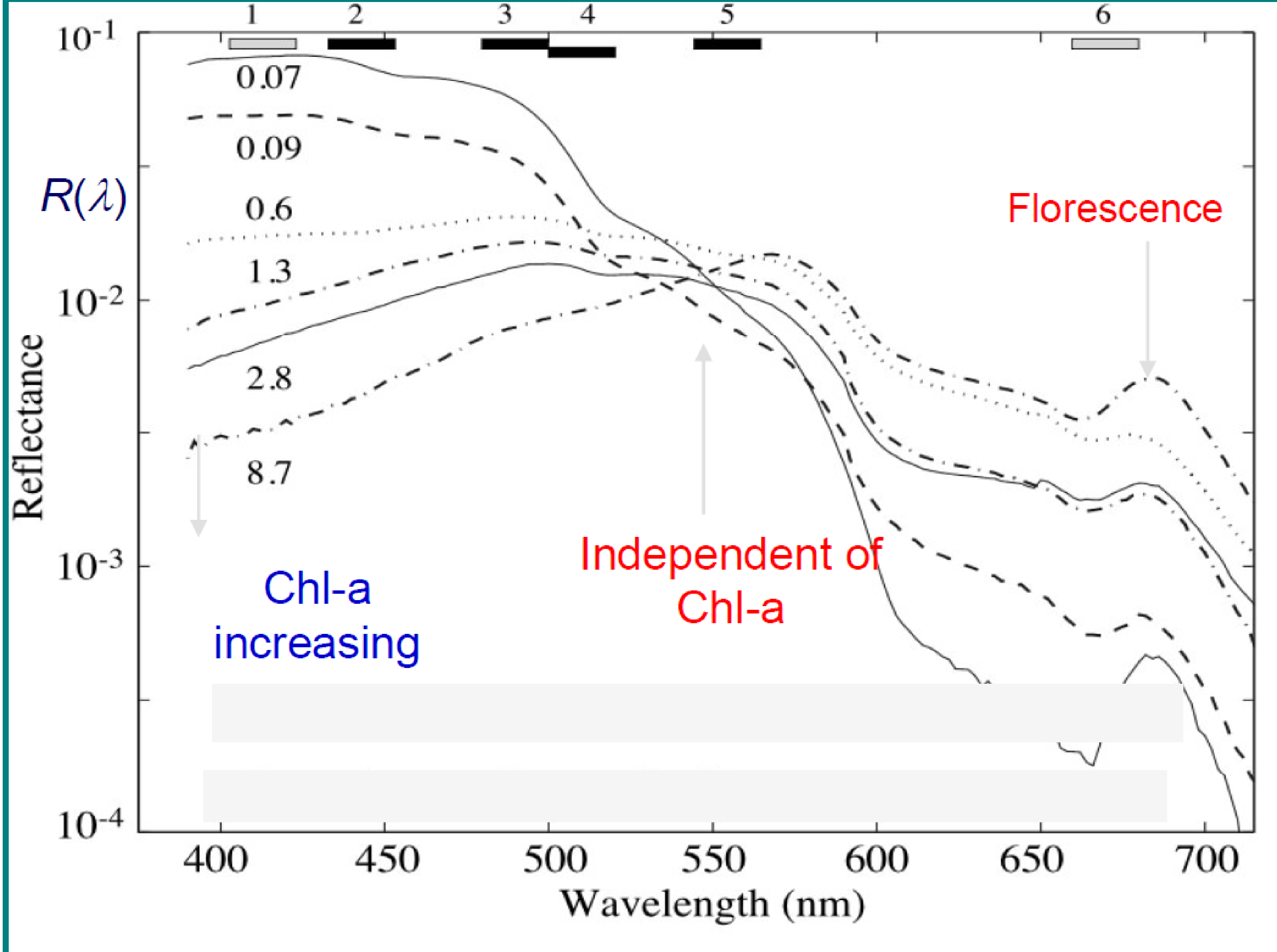
Results of atmospheric correction of Oceansat-2 OCM data



nLw 620 nm (mW/cm^{2}/sr/nm)

OCM-2 Chlorophyll-*a* image Jan 24, 2010





1
2
3
4
5
6
0.07
0.09
0.6
1.3
2.8
8.7
$R(\lambda)$
Reflectance
Florescence
Independent of Chl-a
Chl-a increasing
10^{-1}
10^{-2}
10^{-3}
10^{-4}
400
450
500
550
600
650
700
Wavelength (nm)

Chlorophyll-a (mg/m3), Oc4 Algorithm

The equation has following form

$$C = 10^{(a+bR+cR^2+dR^3)} + e$$

where, C= chlorophyll;

R = log10[max(*Rrs*443>490>510/*Rrs*555)]

a = 0.48; b = -3.03; c = 2.24; d = -1.25; and e = -0.03

Diffuse Attenuation coefficient, Kd490

$$\log_{10}(K_d 490) = (a+b^*K+c^*K^2+d^*K^3)+ e$$

Where, $K = \log_{10}[Lwn(490)/Lwn(555)]$

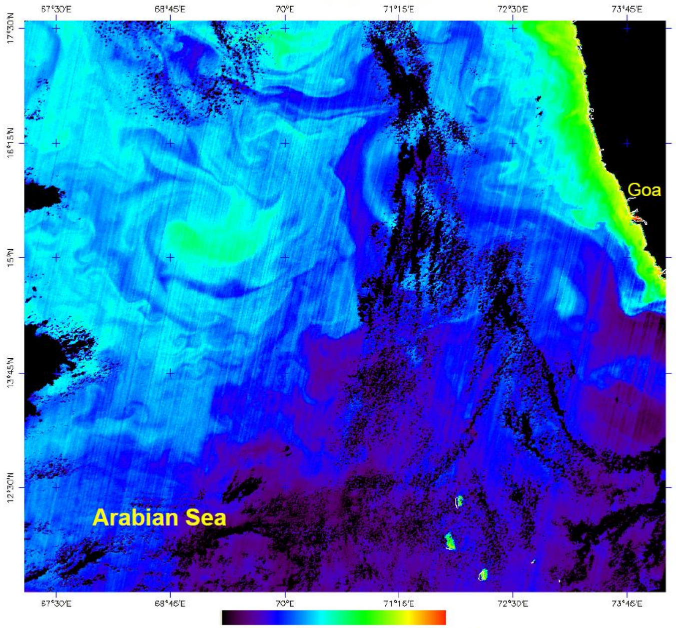
a = -0.28; b = -1.58; c = 1.19; d = -0.53 and e = -0.49

Total Suspended mater (TSM) mg/L

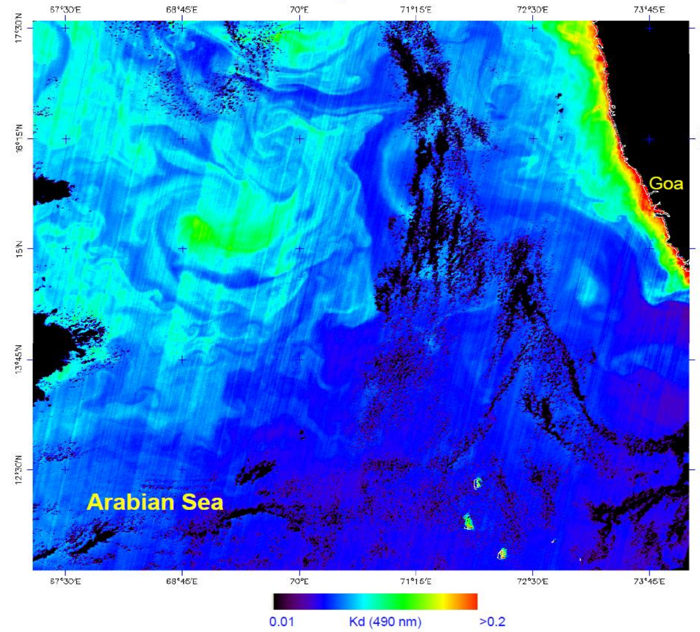
$\text{Log}(S) = 62.80^*Xs + 0.70$ for $1.0 < S(\text{mgL}^{-1}) < 250.0$

$$Xs = [R_{rs}(\lambda_{555})+R_{rs}(\lambda_{620})]^*[R_{rs}(\lambda_{555})]/[R_{rs}(\lambda_{490})$$

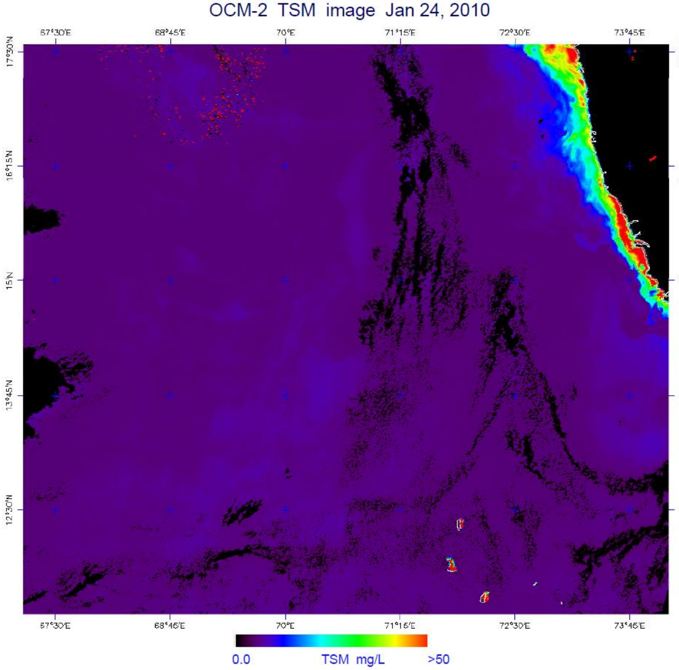
OCM-2 Chlorophyll-*a* image Jan 24, 2010



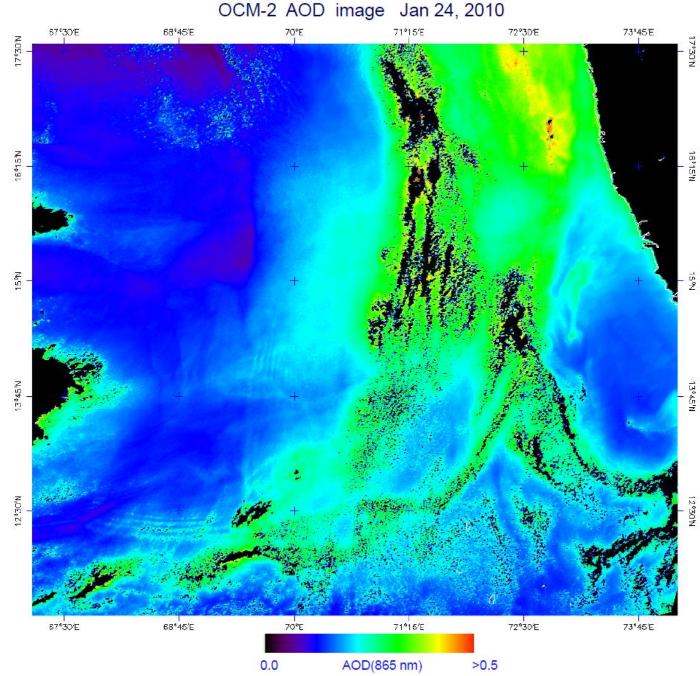
OCM-2 K_d image Jan 24, 2010

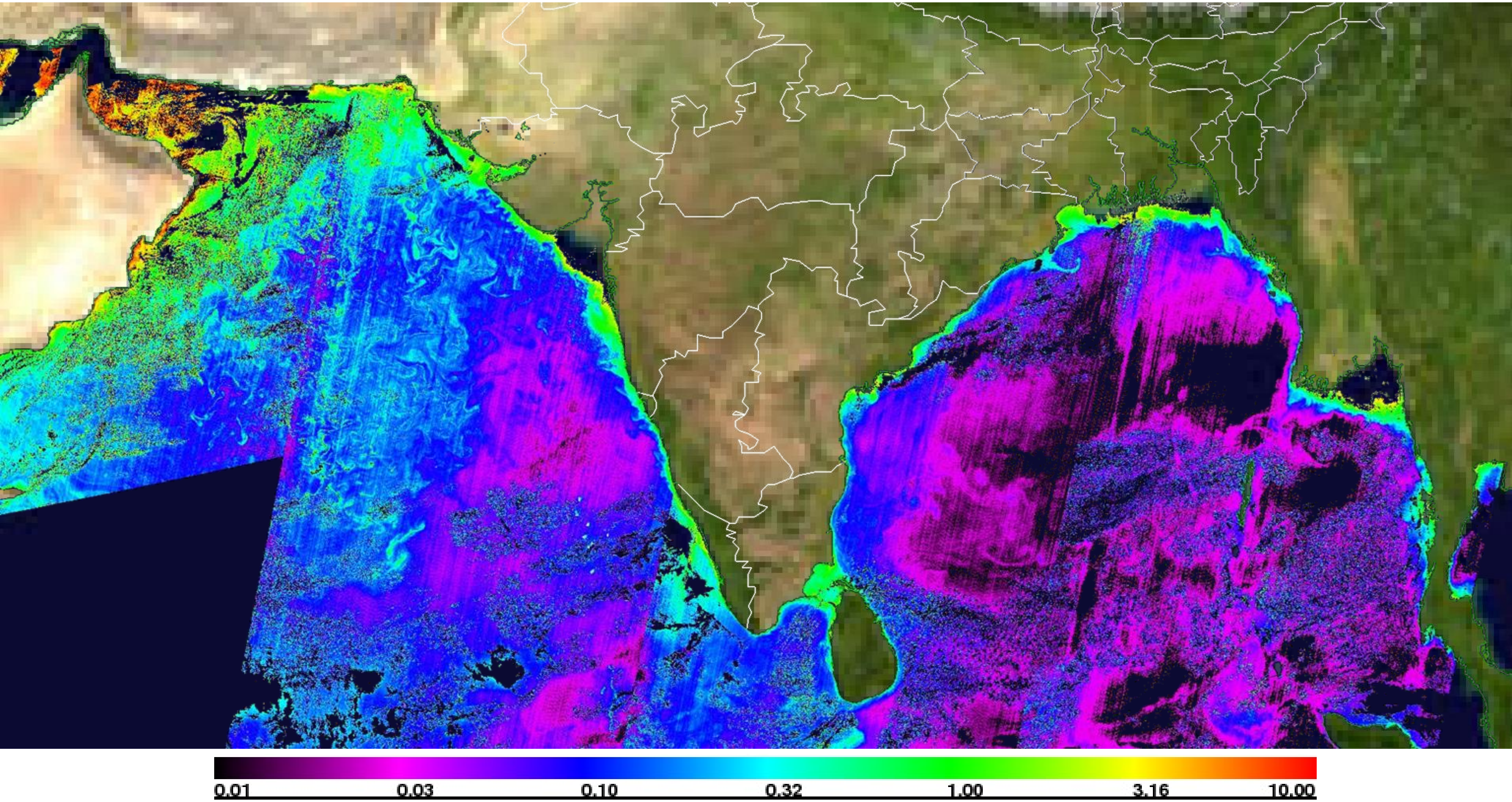


OCM-2 TSM image Jan 24, 2010

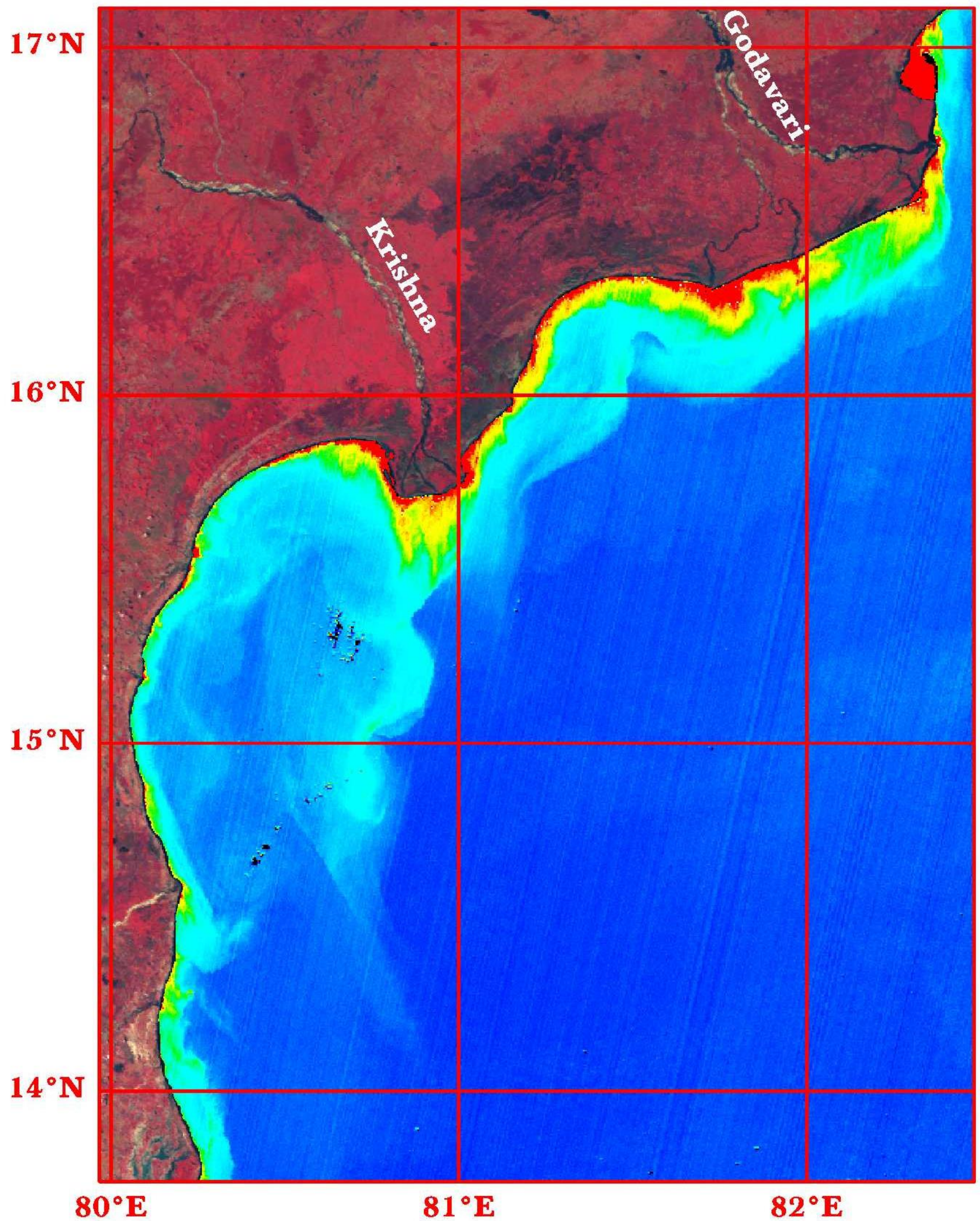


OCM-2 AOD image Jan 24, 2010




0.01
0.03
0.10
0.32
1.00
3.16
10.00

Suspended sediment map derived using Ocean Colour Monitor data



Suspended particulate matter:

The inorganic particulates consist of sand and dust created by erosion of land-based rocks and soils. These enter the ocean through:

- *River runoff.*
- *Deposition of wind-blown dust.*
- *Wave or current suspension of bottom sediments.*

Current Ocean-Colour Sensors

SENSOR / DATA LINK	AGENCY	SATELLITE	LAUNCH DATE	SWATH (KM)	SPATIAL RESOLUTION (M)	BANDS	SPECTRAL COVERAGE (NM)	EQUATORIAL CROSSING TIME
GOCI Geostationary	KARI/KIOST (South Korea)	COMS	26 June 2010	2500	500	8	400 - 865	8 times/day
MODIS-Aqua	NASA (USA)	Aqua (EOS-PM1)	4 May 2002	2330	250/500/1000	36	405-14,385	13:30
MODIS-Terra	NASA (USA)	Terra (EOS-AM1)	18 Dec 1999	2330	250/500/1000	36	405-14,385	10:30
OCM-2	ISRO (India)	Oceansat-2 (India)	23 Sept 2009	1420	360/4000	8	400 - 900	12:00
OLCI	ESA/ EUMETSAT	Sentinel 3A	16 Feb 2016	1270	300/1200	21	400 - 1020	10:00
OLCI	ESA/ EUMETSAT	Sentinel 3B	25 April 2018	1270	300/1200	21	400 - 1020	10:00
SGLI	JAXA (Japan)	GCOM-C	23 Dec 2017	1150 - 1400	250/1000	19	375 - 12,500	10:30
SGLI	JAXA (Japan)	GCOM-C	23 Dec 2017	1150 - 1400	250/1000	19	375 - 12,500	10:30
VIIRS	NOAA (USA)	Suomi NPP	28 Oct 2011	3000	375 / 750	22	402 - 11,800	13:30
VIIRS	NOAA/NASA (USA)	JPSS-1/NOAA-20	18 Nov 2017	3000	370 / 740	22	402 - 11,800	13:30

Source: http://ioccg.org/resources/missions-instruments/current-ocean-colour-sensors/

Thank you…

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