Atmospheric correction and in-water retrieval of WQ parameters

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EUMETSAT series of short courses: Applying Case 2 Regional Coast Colour (C2RCC) Algorithms to EUMETSAT OLCI Products

Overview

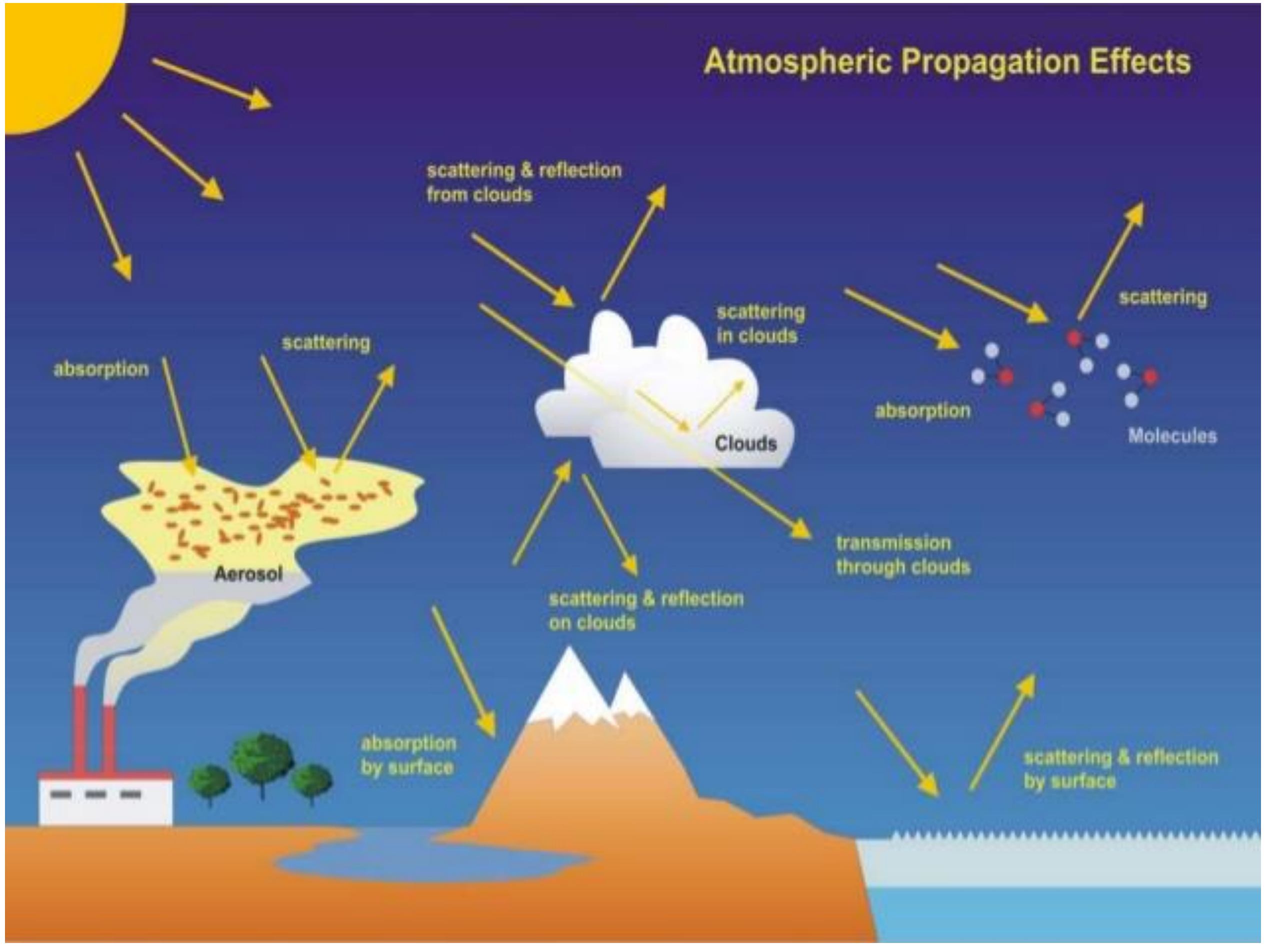
- The atmospheric correction (AC) problem on water
- The inverse problem in the in-water (IW) retrieval
- Demo 2: SNAP for OLCI-L1 and L2 analysis

Nature of light and interactions with matter

Radiation used for remote sensing travels through the atmosphere before reaching the surface. The water incoming light and the radiation leaving it back to the sensor can be affected by particles and gases in the atmosphere.

Three types of interaction:

- Scattering
- Absorption
- Refraction

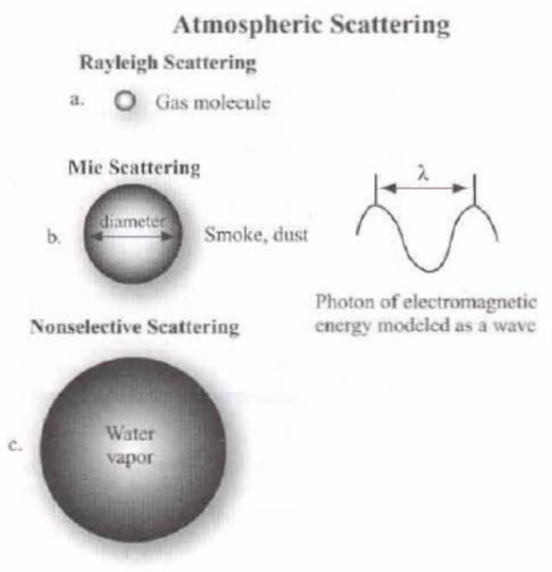


Electro-magnetic radiation interactions with the atmosphere

Scattering happens through interaction with particles or large gas molecules causing redirection of the radiation

- Rayleigh scattering:
    - Due to small size particles < wavelength of the radiation
    - Air molecules scatter short wavelengths (blue sky and ocean)
    - Impact "understood" for most Remote Sensing applications

- Mie scattering:
    - Particles about the same size as the wavelength
    - Water vapour, dust, pollen and smoke
    - More strongly affects longer wavelengths (red sky e.g.)



- Scattering due to larger particles: e.g. caused by water droplets and ice (clouds, fog: white colour)

Electro-magnetic radiation interactions with the atmosphere

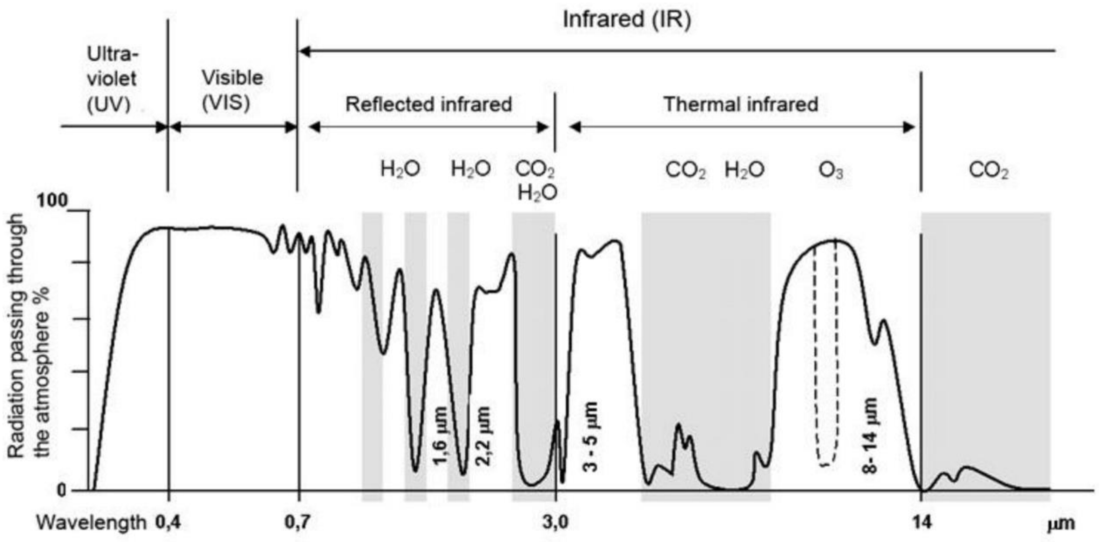
Molecules in the atmosphere **absorb** energy at various wavelengths, like:

- Ozon molecules: UV range
- Carbon dioxide: Thermal Infrared
- Water vapor: long wave infrared, microwaves

Radiation becomes weaker or cannot reach the surface or satellite.

The atmospheric gasses re-emit energy at other wavelengths.

In optical RS the radiation arrives to the surface through **atmospheric windows**.



Electro-magnetic radiation interactions with the atmosphere

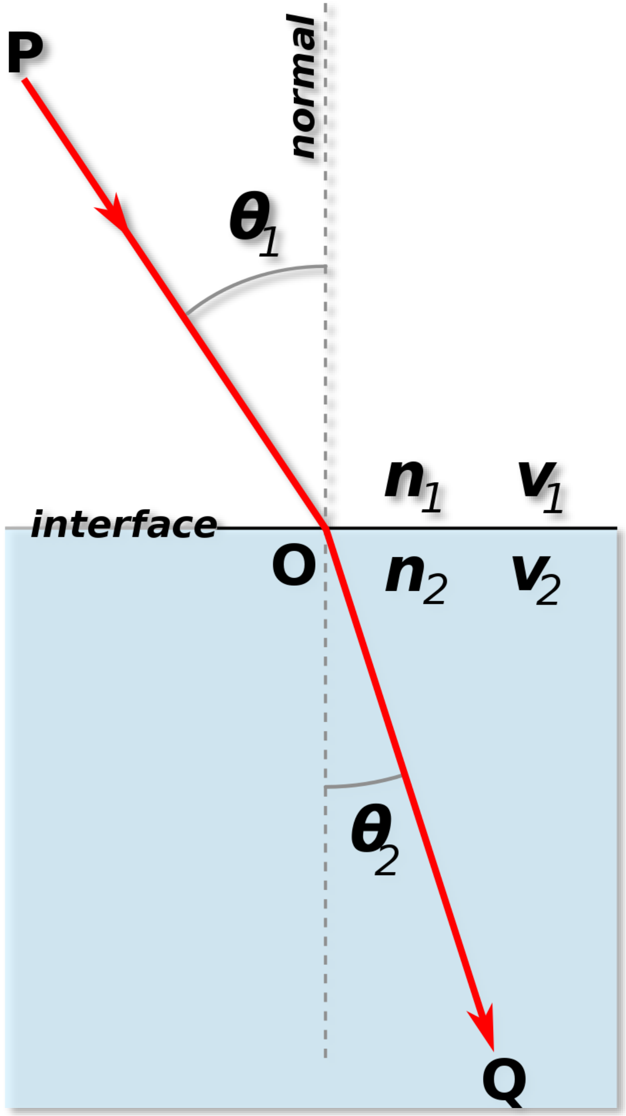
- Refraction refers to the bending (and slowing down) of light when it passes from one medium to another, due to the different densities of the media that changes the speed of the electromagnetic radiation.

- The index of refraction is the ratio of the speed of light in a vacuum, to the speed of light in a substance ($n=c/c_n$). For the atmosphere is 1.0002926 and for water is 1.33. Light travels more slowly through water.

- **Snell's law** describes refraction and makes possible to remove it.

  The angles of incidence and refraction are related by:

$$n1 * \text{sen}\theta 1 = n2 * \text{sen}\theta 2$$



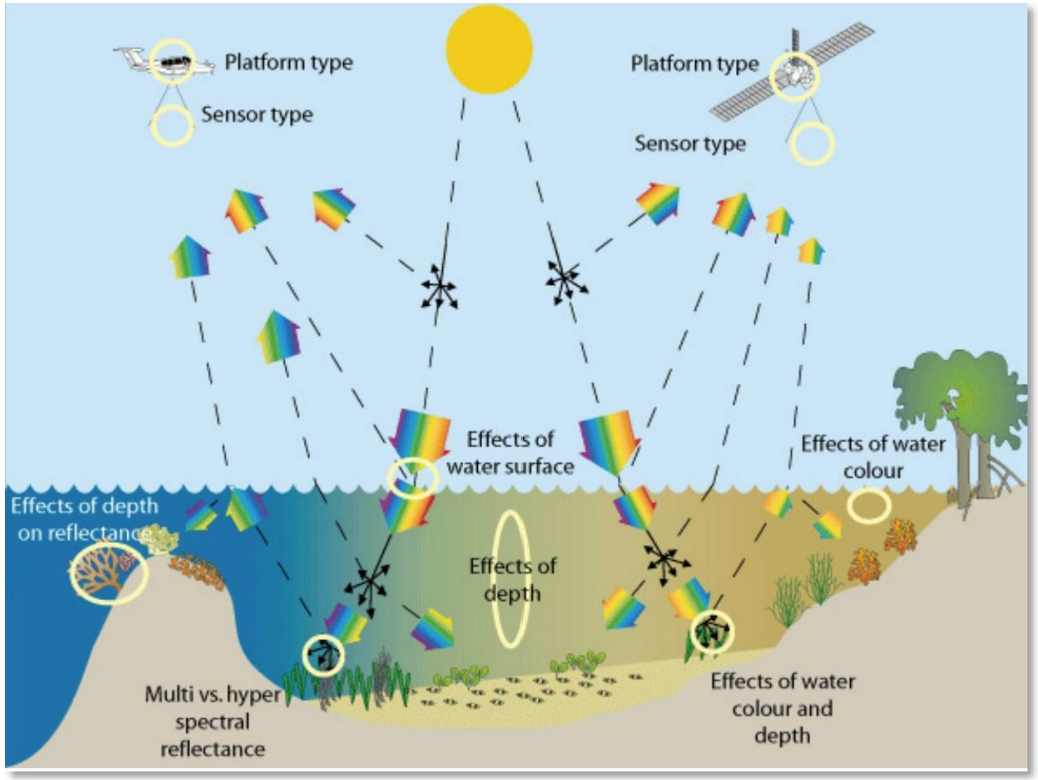
https://en.wikipedia.org/wiki/Snell's_law

Electro-magnetic radiation interactions with the surface

- **Reflection** – Re-direction of light hitting a non-transparent surface
  - Reflection strength depends on the type of surface:
    - ➢ Diffuse – rough
    - ➢ Specular (Lambertian) – smooth

- **Absorption** – Energy of the photon is taken up by the target and converted to other forms of energy (e.g. used for photosynthesis)

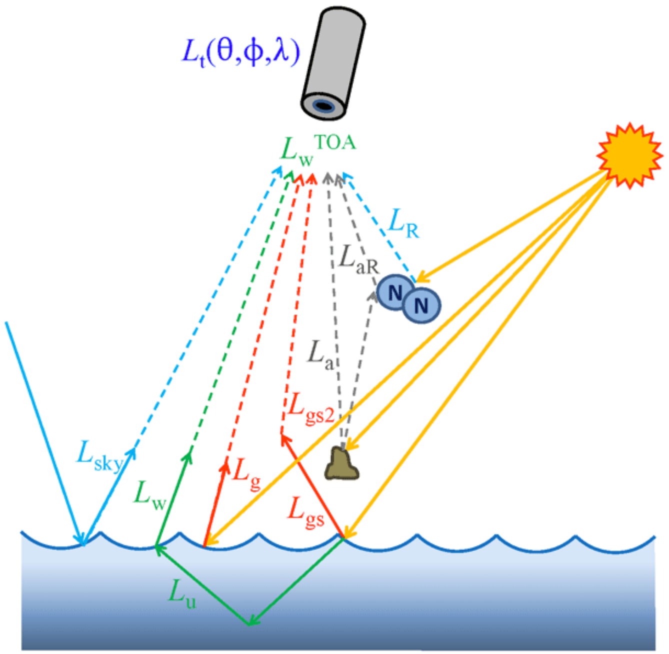
- **Transmission** – Light passing through material without much attenuation
  - Water most affected by transmission of light
  - Plant leaves
  - Ice or ground penetration (with Radar).



(Credits Roelfsema/Phinn)

The Atmospheric Correction

input	process	result
affected by atmosphere: scattering (aerosols), absorption	atmospheric correction models	**Level2**



Qualitative illustration of the various processes contributing to the total TOA radiance. The blue N-N represents a nitrogen molecule, or any other atmospheric gas molecule; the brown blob represents an aerosol particle.

Source: https://www.oceanopticsbook.info/view/atmospheric-correction/the-atmospheric-correction-problem

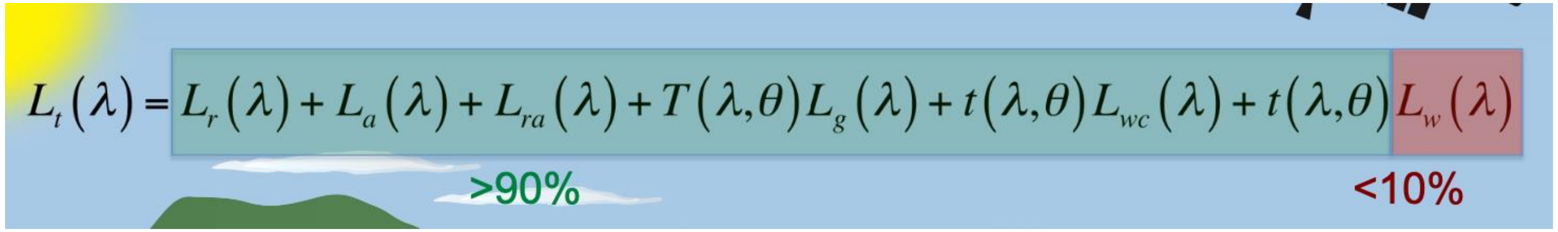
Models need accurate input: **Aerosol Optical Thickness** (AOT)

= measure of aerosols in air column from BOA to TOA

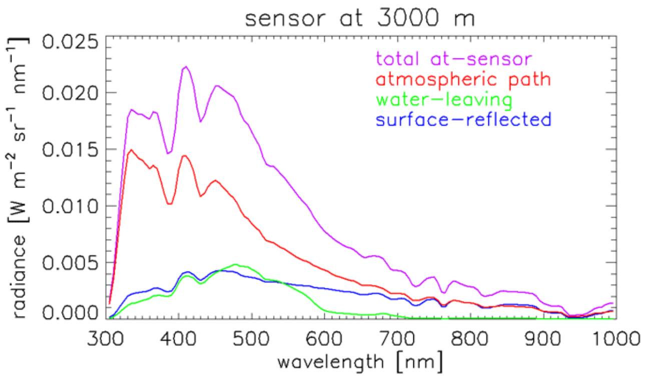
aerosols: e.g., urban haze, smoke particles, desert dust, sea salt, …

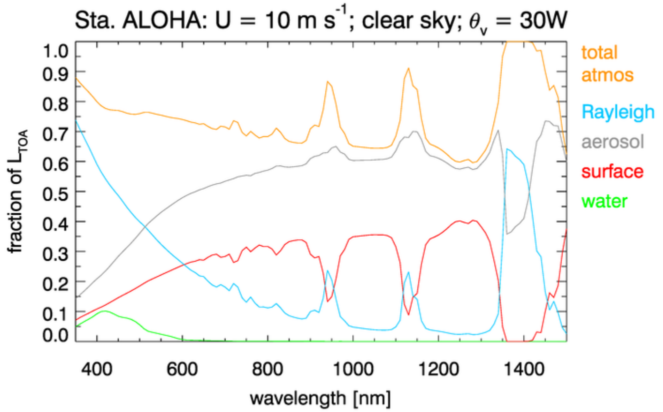
Most critical for water applications (low radiances)

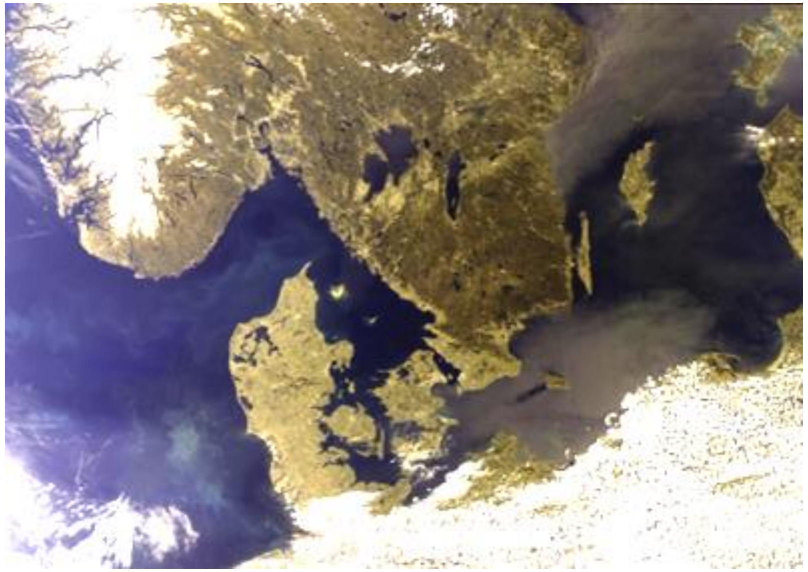
Copernicus Atmosphere Monitoring Service: AOT predictions: more accurate products!

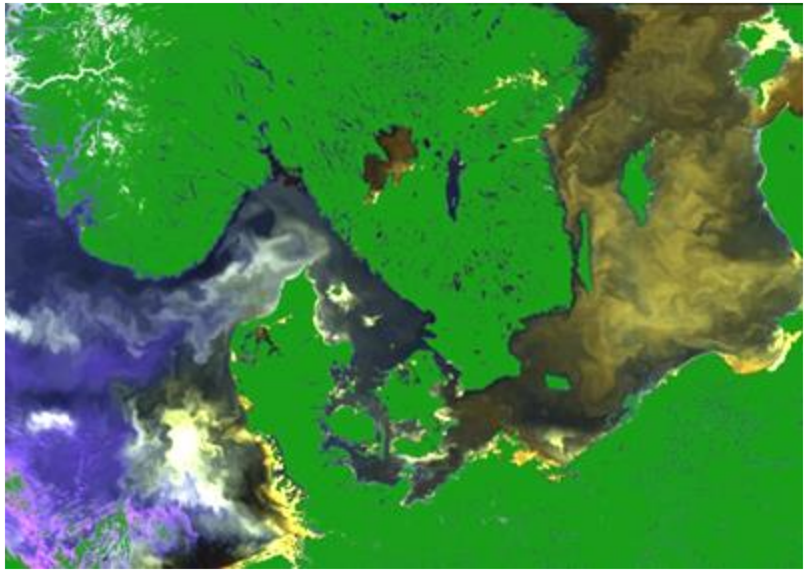


The atmospheric correction problem on water









- The total radiance curve at 3000 m sensor altitude partitioned into the contributions by water-leaving radiance, surface reflectance, and atmospheric path radiance.

- Atmospheric path radiance: 70-90% of Lt
- Below 500 nm and over 1350 nm Rayleigh scattering is the largest contributor. In between aerosols are the greatest contributors.

Source: https://www.oceanopticsbook.info/view/atmospheric-correction/the-atmospheric-correction-problem

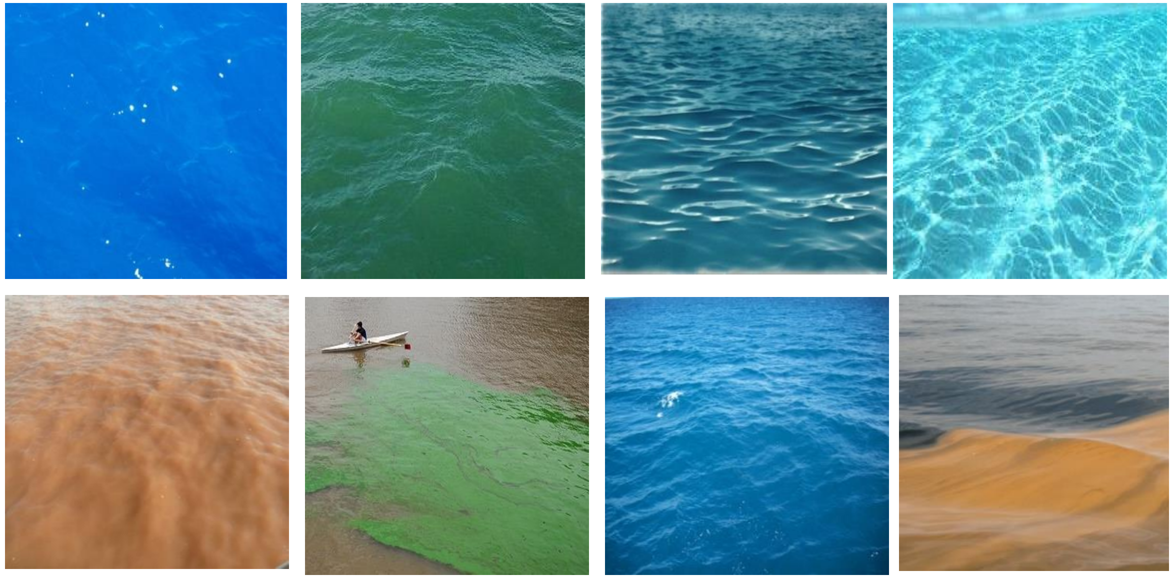
Observations

- The atmosphere contributes more than 90% of the top of atmosphere radiance → the atmospheric correction over the ocean is a critical processing step.

- Optical data often need atmospheric corrections if the target of study is the land, ocean or ice surface.
  - Remove/reduce the effect of the atmosphere by supporting observations or models

- A good indicator of the quality of the atmospheric correction is the decoupling of the atmospheric signal (e.g. aerosol optical thickness) from the surface reflectance.

- **What is the colour of the water?**



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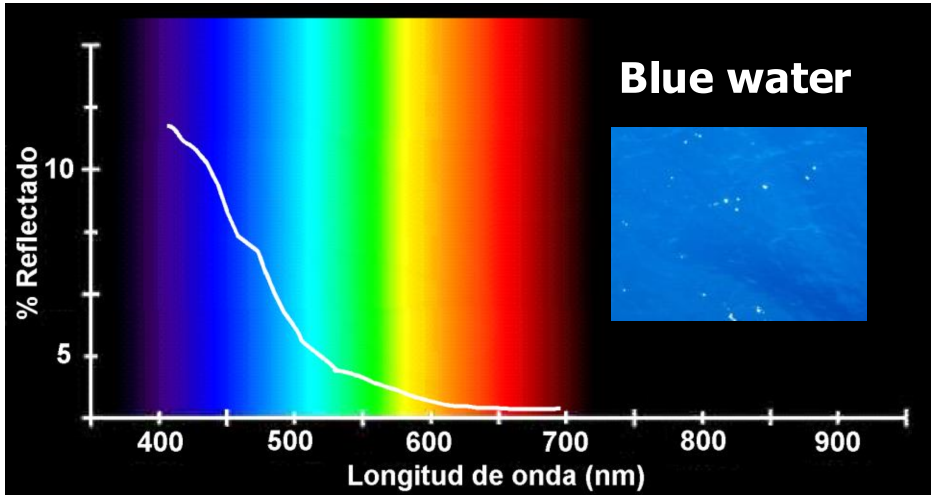
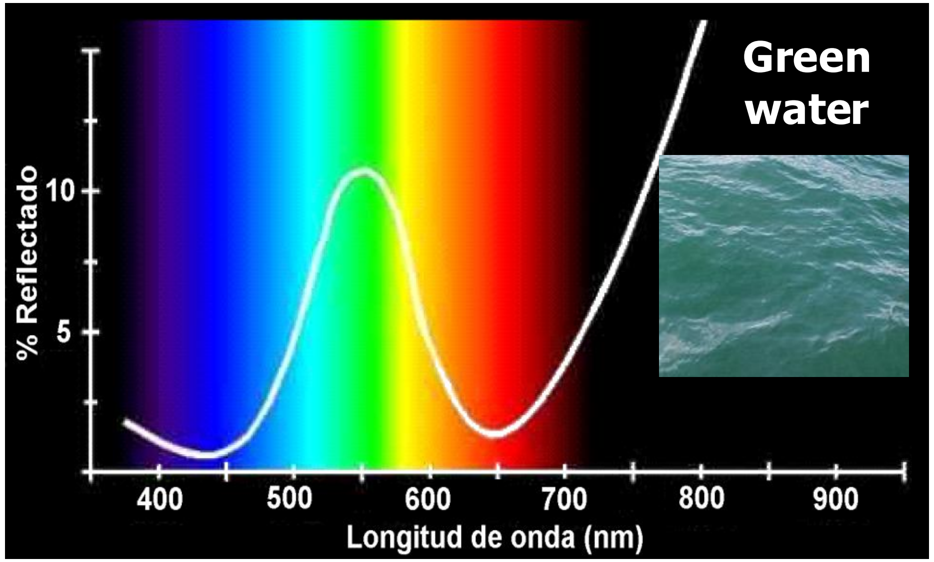
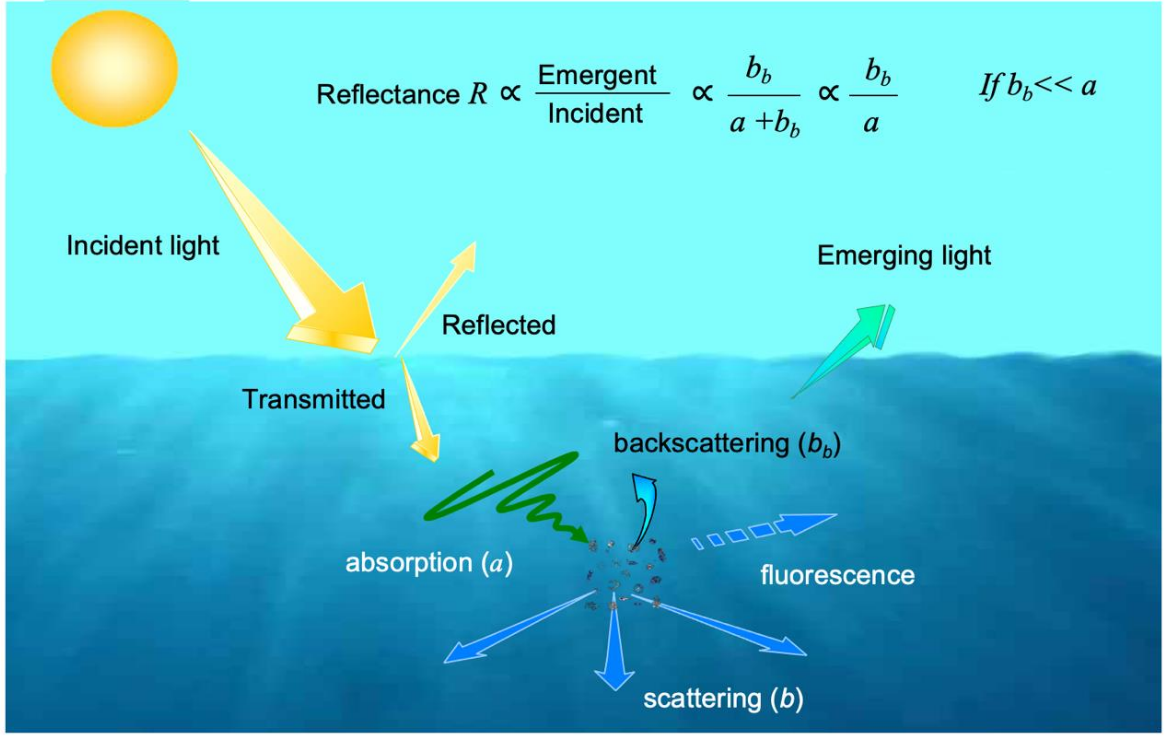
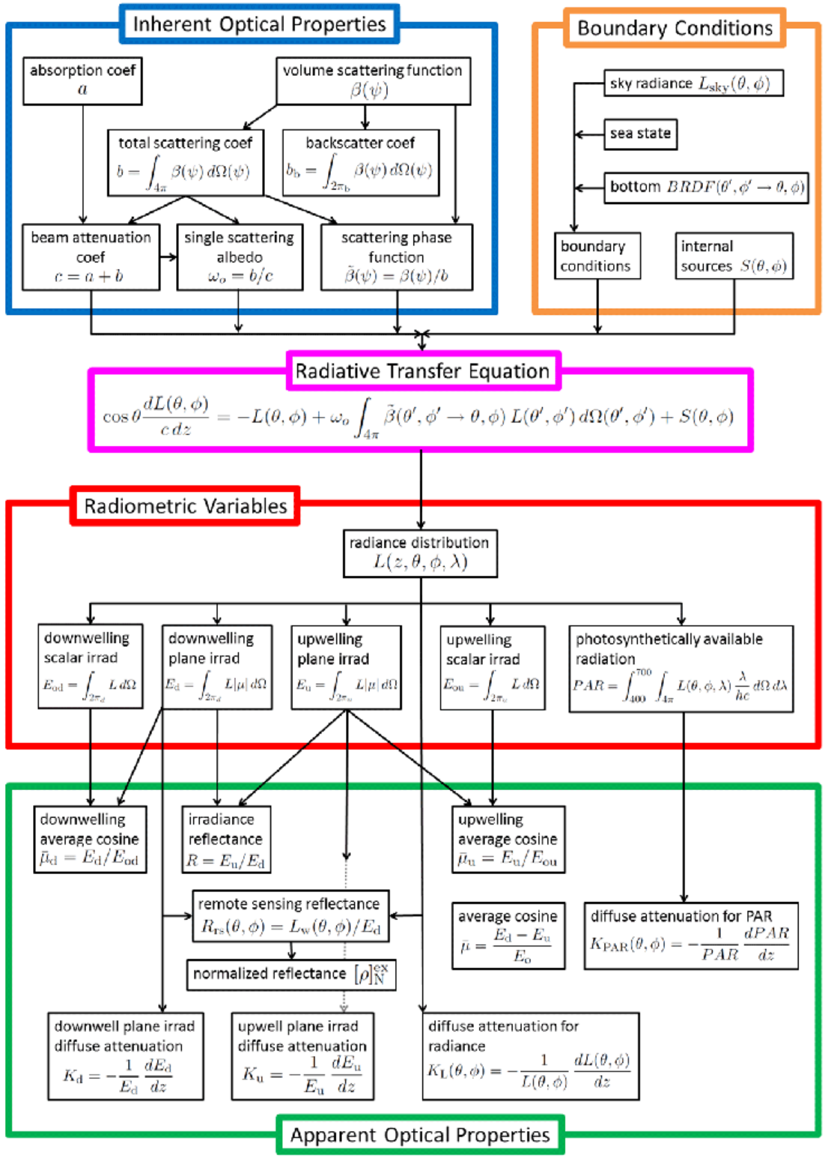




What does the colour of water depend on?

www.eumetsat.int





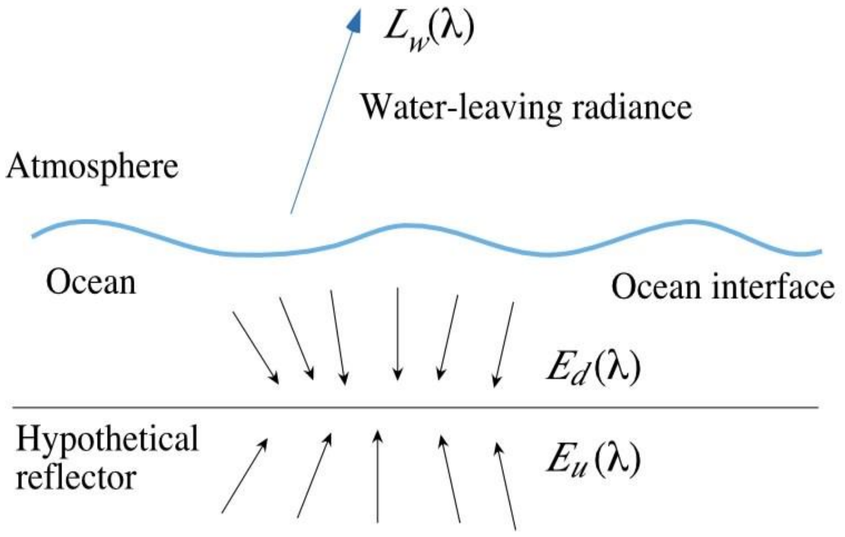
https://www.oceanopticsbook.info/view/inherent-and-apparent-optical-properties/introduction

Optical properties: AOPs

AOP (Apparent Optical Properties)

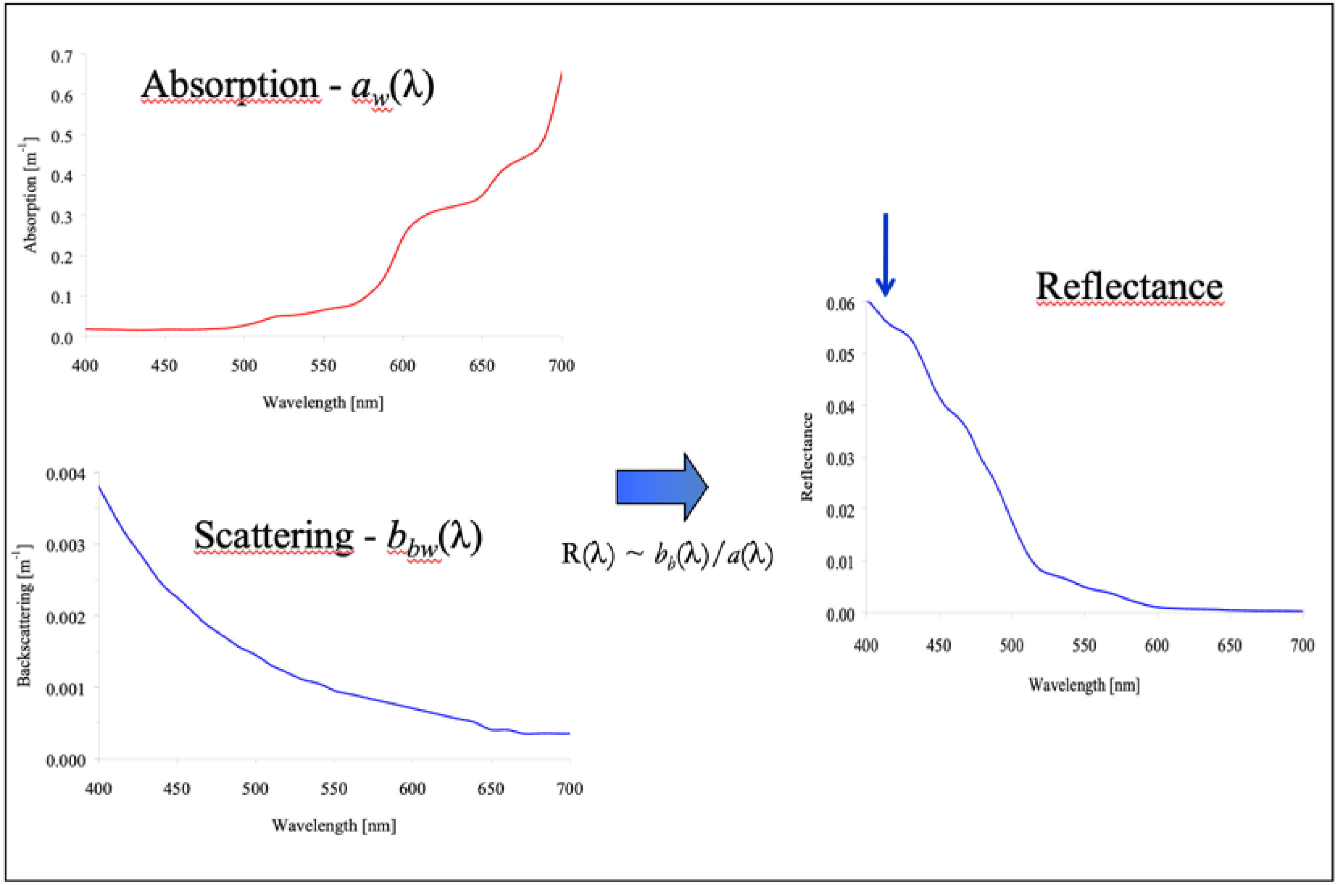
- Characteristics of the medium dependent on geometric distribution of the light field and on the medium IOPs. They change with varying illumination conditions, such as solar zenith and azimuth angles.

- Examples are irradiance (E), radiance (L), reflectance (R), diffuse attenuation coefficient (K), which depend on the surface boundary conditions.



IOP (Inherent Optical Properties)

- Medium properties that depend only on the composition of this medium, regardless of light conditions.
- Examples are scattering (b), absorption (a), and fluorescence.
- In a multi-component medium, the total inherent optical properties can be obtained by a simple addition of the individual contribution.



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IOPs and the colour of the water

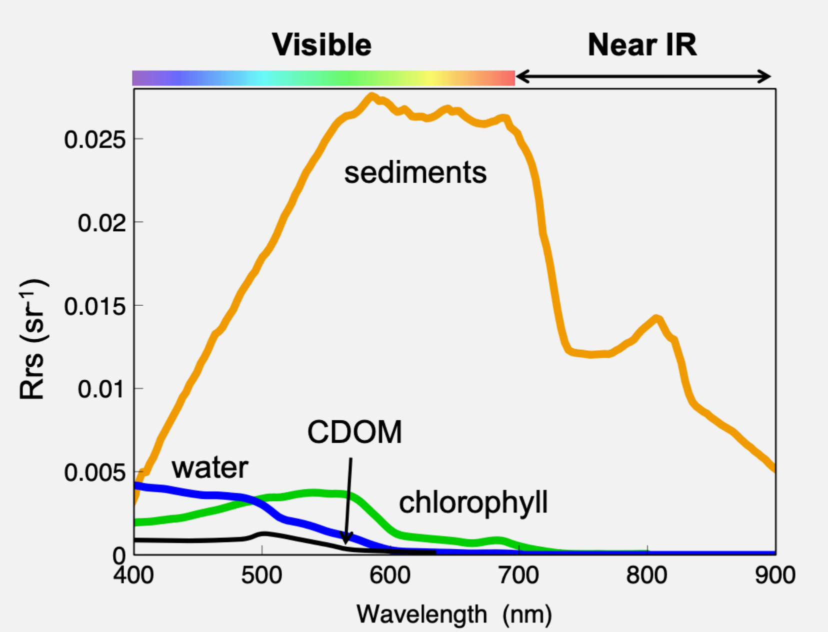
- Light absorption (a) by phytoplankton (ph), non-algal particles (nap) and CDOM + water (w)

a = aph + anap + aCDOM + aw

- Light scattering (b) by particles in forward (bf) and backward directions (bb)

b = bf + bb

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



From substances to IOPs to AOPs

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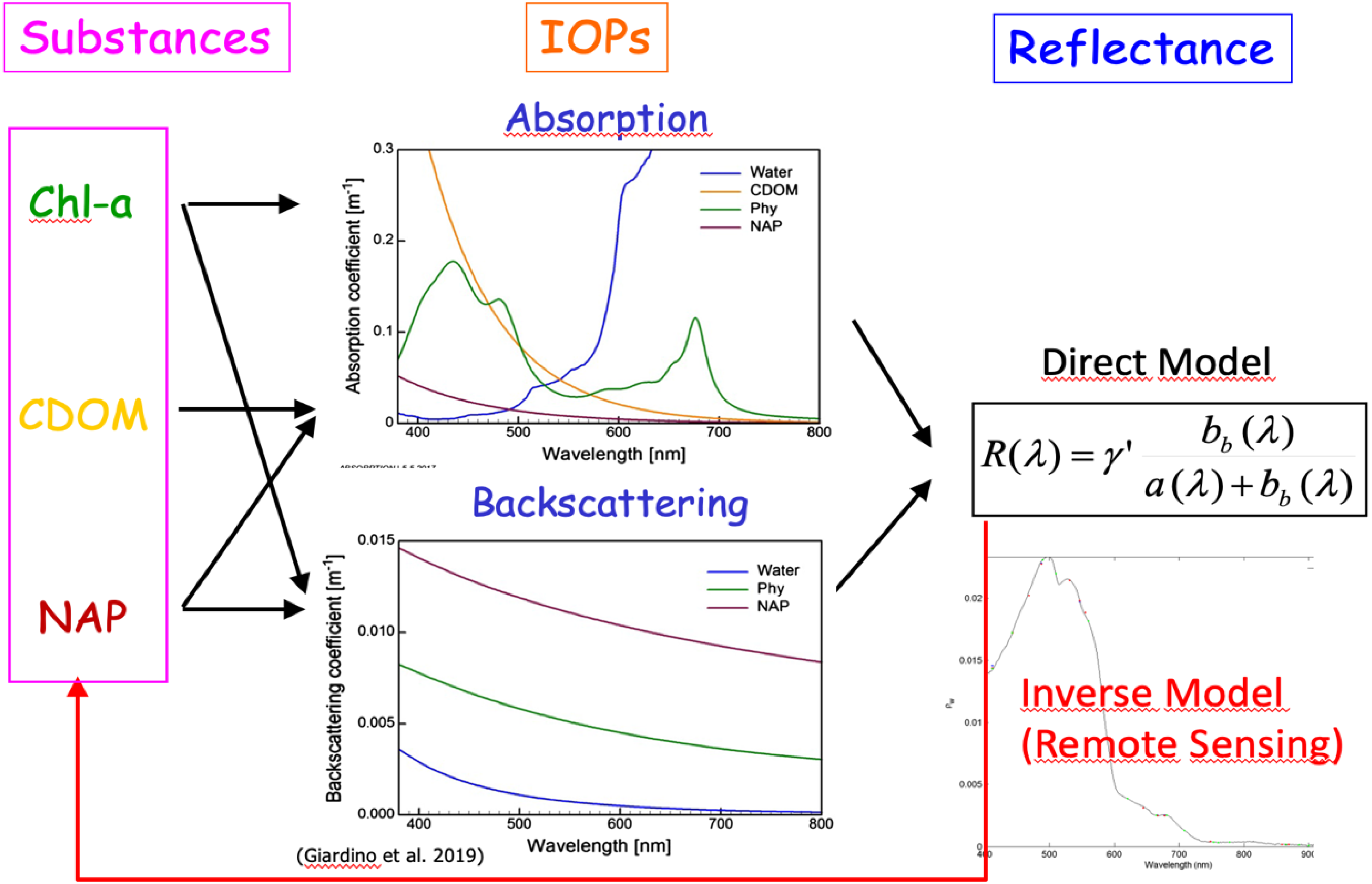

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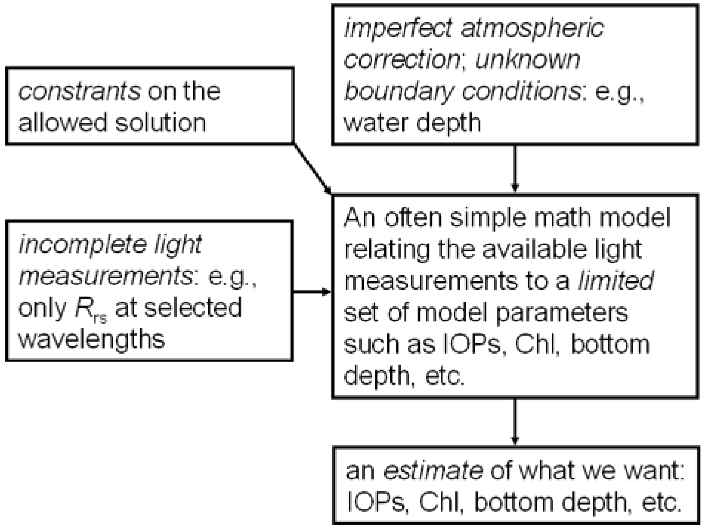
From AOPs to IOPs to substances: inverse modelling

The conceptual process involved in solving a remote-sensing inverse radiative transfer problem



Most popular techniques:
"*Inversions are always based on an assumed model that relates what is known to what is desired.*"

https://www.oceanopticsbook.info/view/remote-sensing/inverse-problems

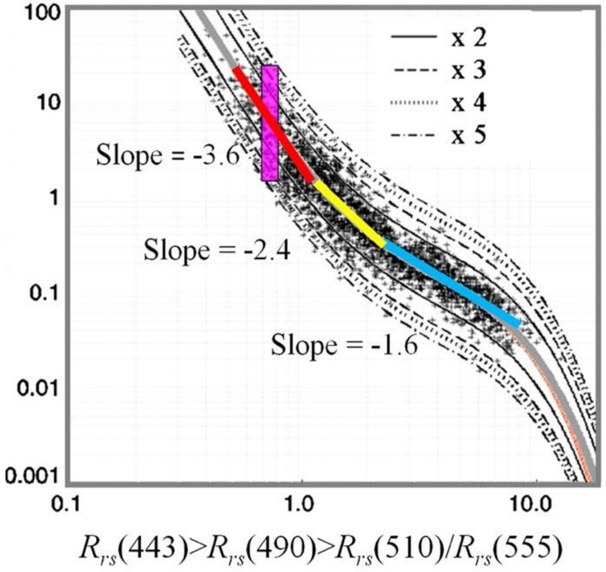
Some techniques that give possible accurate solutions

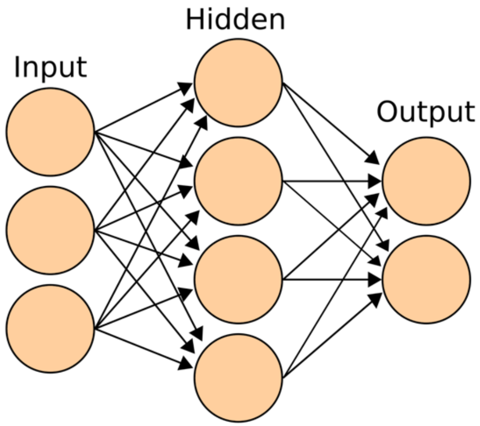
1. Numerical modelling: by solving the radiative transfer equation→ HydroLight, 6S, MODTRAN, Monte Carlo simulations, Mie theory.

2. Semi-analytical models: Quasi-Analytical Algorithm (QAA), Garver-Siegel-Maritorena (GSM) model, HOPE, GIOP…

3. Empirically: build relationships with in-situ data (regression). E.g. Chlorophyll-a determination with polynomial algorithms (OC4ME).

4. Machine learning/deep learning: Case 2 Regional Coast Colour (C2RCC) based on neural net technologies.



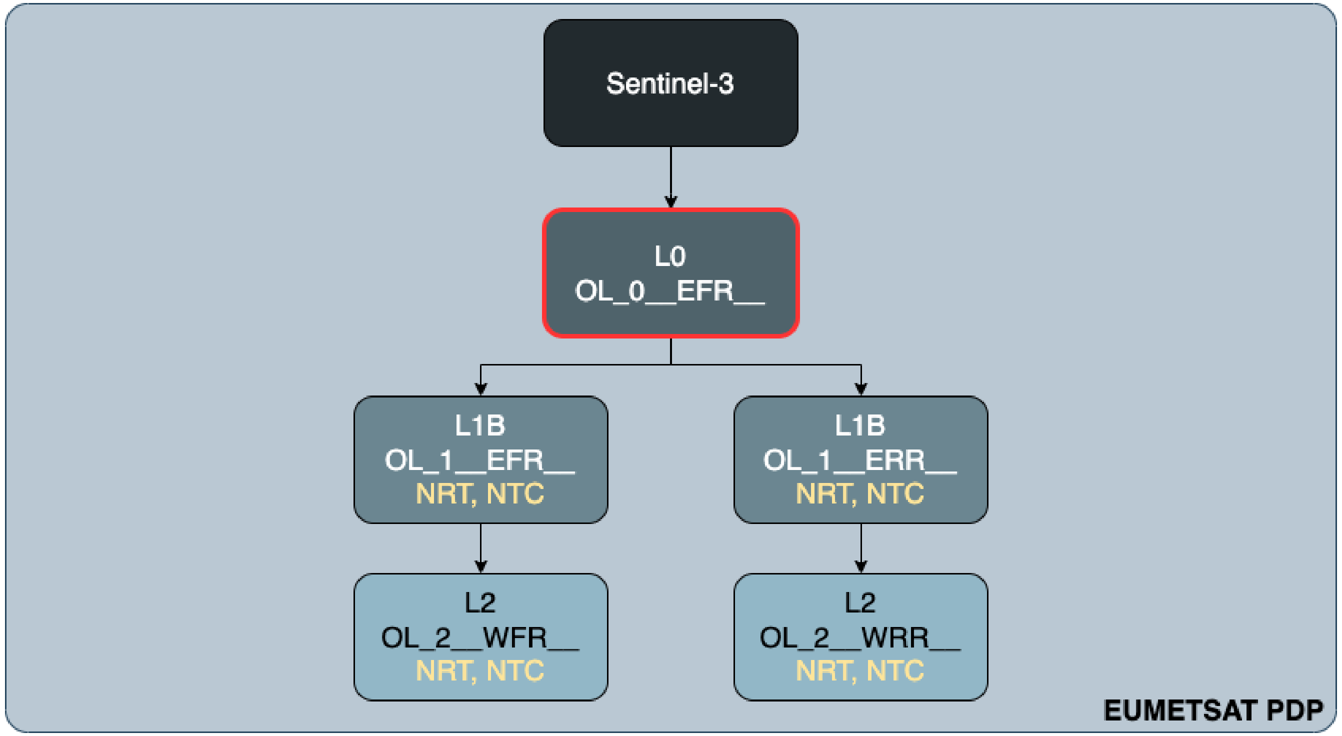


OLCI product levels

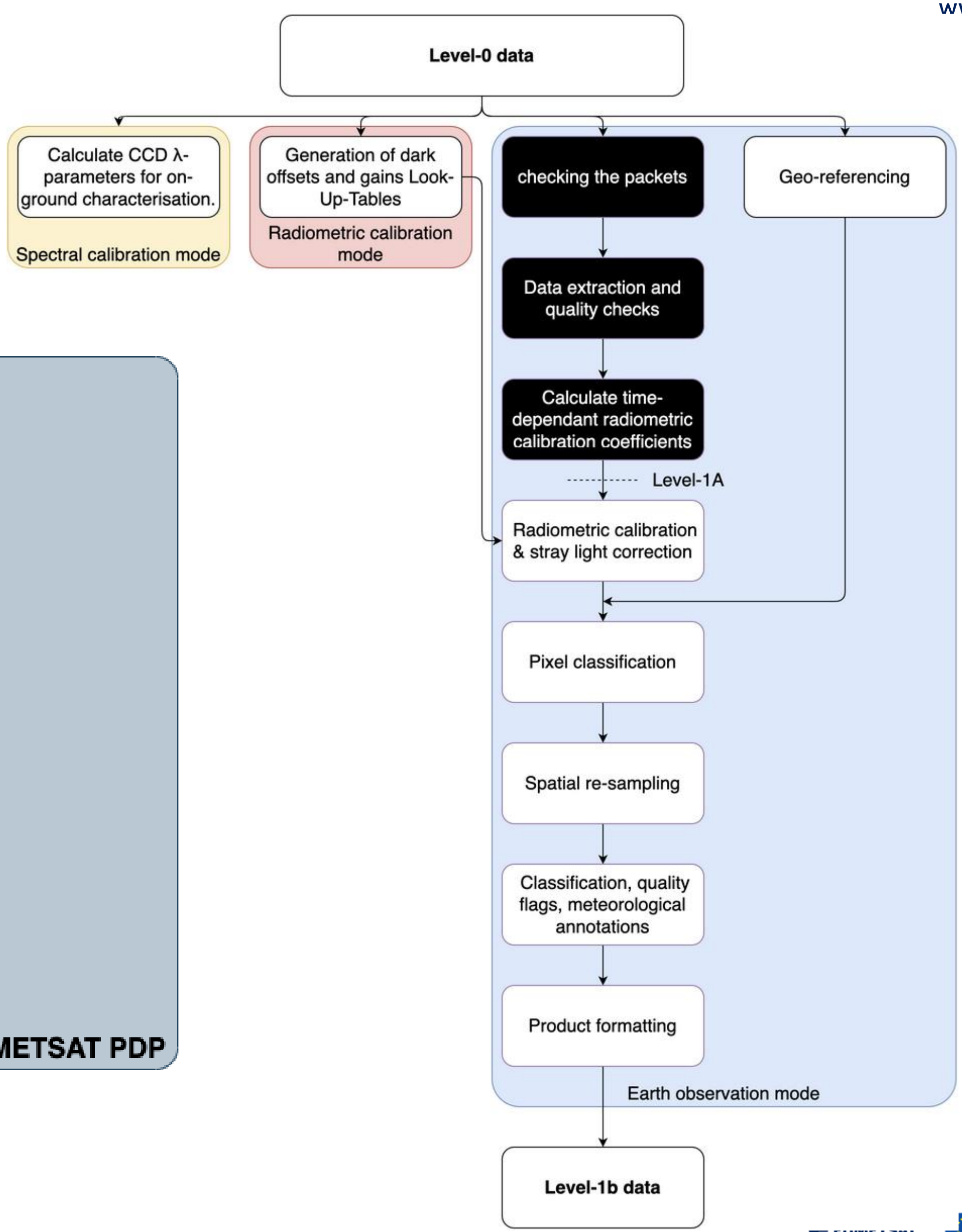
Level 0: This step processes raw data contained in instrument source packets. Level 0 products are internal products and are not disseminated to users.

Level 1: This step processes the level 0 data to geo-located and calibrated top of atmosphere radiances for each OLCI band.

Level 2: This step processes the level 1 data to water leaving reflectance and bio-optical variables (e.g. chlorophyll-a concentration).



https://vuser.eumetsat.int/resources/user-guides/sentinel-3-olci-level-1-data-guide



OLCI Level1B

Two level 1B OLCI products are distributed:

- 'OL_1_ERR___' /' OL_1_EFR__': two resolutions, full (FR) and reduced (RR).
- For the nominal orbit, at sub-satellite point, OLCI full resolution is approximately 300m on ground.
- For the nominal orbit, at sub-satellite point, OLCI reduced resolution is approximately 1.2km on ground.
- The OLCI level 1B measurement products are TOA (upwelling) radiances [$mWm^{-2}sr^{-1}nm^{-1}$], calibrated to geophysical units and ortho-geolocated onto the Earth's surface.
- Products are available at both near-real time (NRT) and non-time critical (NTC) timeliness
- The data is delivered in netcdf format to users

OLCI Level1b Quality flags

Flag	Description
land	land as the underlying surface, whatever the atmosphere conditions, ie, whether cloudy or not
coastline	coastline pixels
fresh_inland_water	pixels within inland water bodies, and so are also flagged as land
tidal_region	pixels enclosed in areas of high tidal activity
bright	any pixel with a TOA reflectance greater than a defined threshold is assumed to be cloud contaminated, thick aerosols or haze, bright land surfaces (such as sand, snow and ice), or bright water surfaces (such as sea ice or sun glint). For more information see the **OLCI L0 and L1 ATBD**)
straylight_risk	identifies pixels for which an insufficient number of neighbours were available for a good correction of the Ground Imager straylight. For more information see **The Global Monitoring for Environment and Security (GMES) Sentinel-3 mission, Donlon et al., 2012**)
invalid	missing data due to a transmission error, resulting in missing packets, or due to out of swath or defects in the CCD cells (as discussed in the **OLCI L0 and L1 ATBD**).
cosmetic	if missing data have been cosmetically filled, eg, because the transmission error gap was between valid frames, ie, lines (as discussed in the **OLCI L0 and L1 ATBD**).
duplicated	duplicated pixel during cross-track ground pixel resampling
sun_glint_risk	sunglint risk flag, estimated from the wind speed and Solar Zenith and Viewing Angles (SZA, VZA) (as discussed in the **OLCI L0 and L1 ATBD**).
dubious	pixels within potential contamination by neighbouring saturated pixels
saturated_Oa01 to saturated_Oa21	saturation at the ADC and sensor level

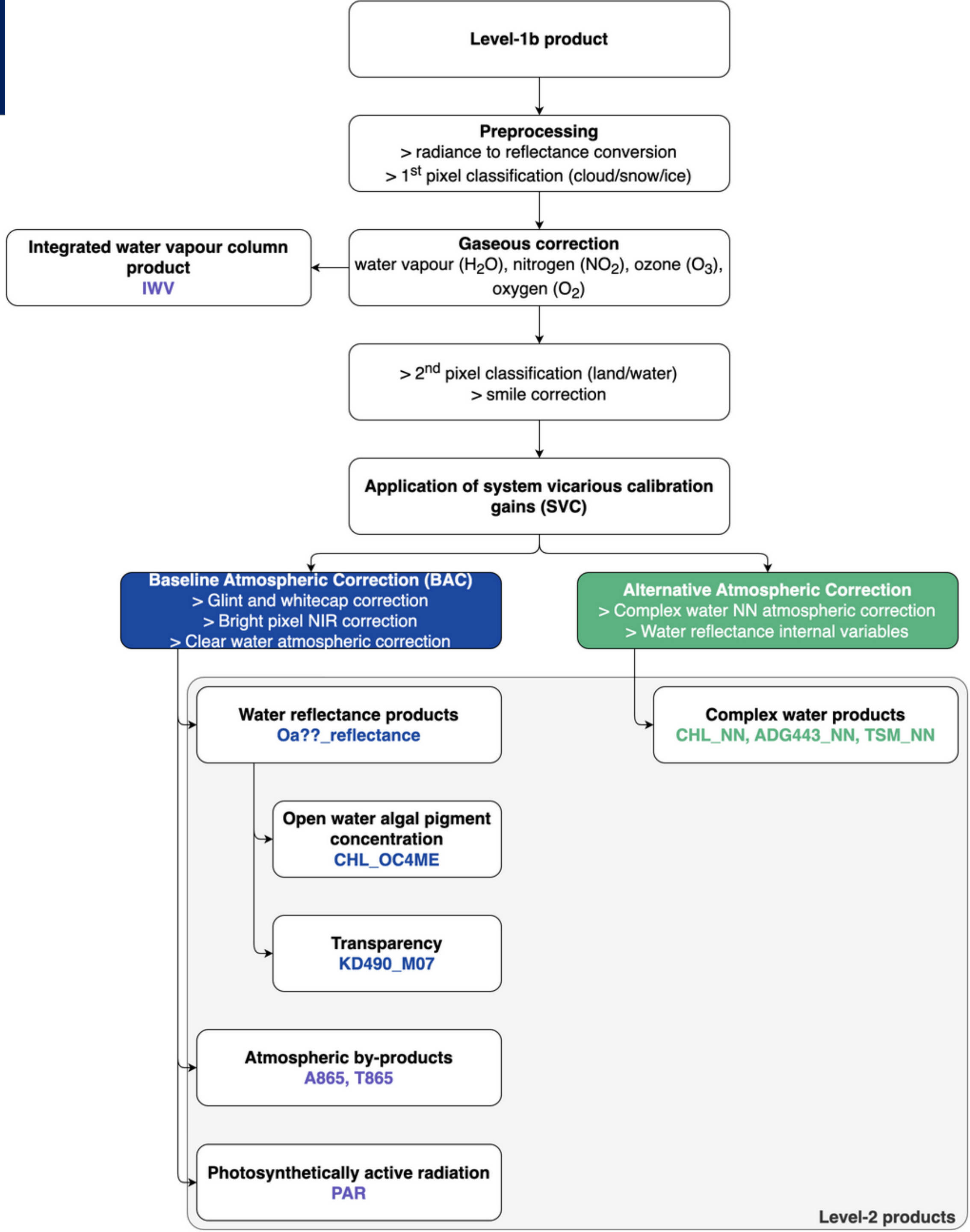
OLCI Level 2

Level 2 pre-processing includes pixel classification, gaseous correction, computation of the Integrated Water Vapour product (IWV), alongside the smile correction, adjustments for white caps and sun glint, and application of System Vicarious Calibration gains.

Then, the default operation is that two atmospheric correction (AC) approaches are run in parallel:

- Baseline Atmospheric Correction (BAC), which feeds most ocean colour steps and products, denoted here as Open Water products.
- Alternative Atmospheric Correction (AAC), which feeds the NN Case 2 Regional/Coast Colour (C2RCC) processing and outputs three Complex Water products.

https://vuser.eumetsat.int/resources/user-guides/sentinel-3-ocean-colour-level-2-data-guide

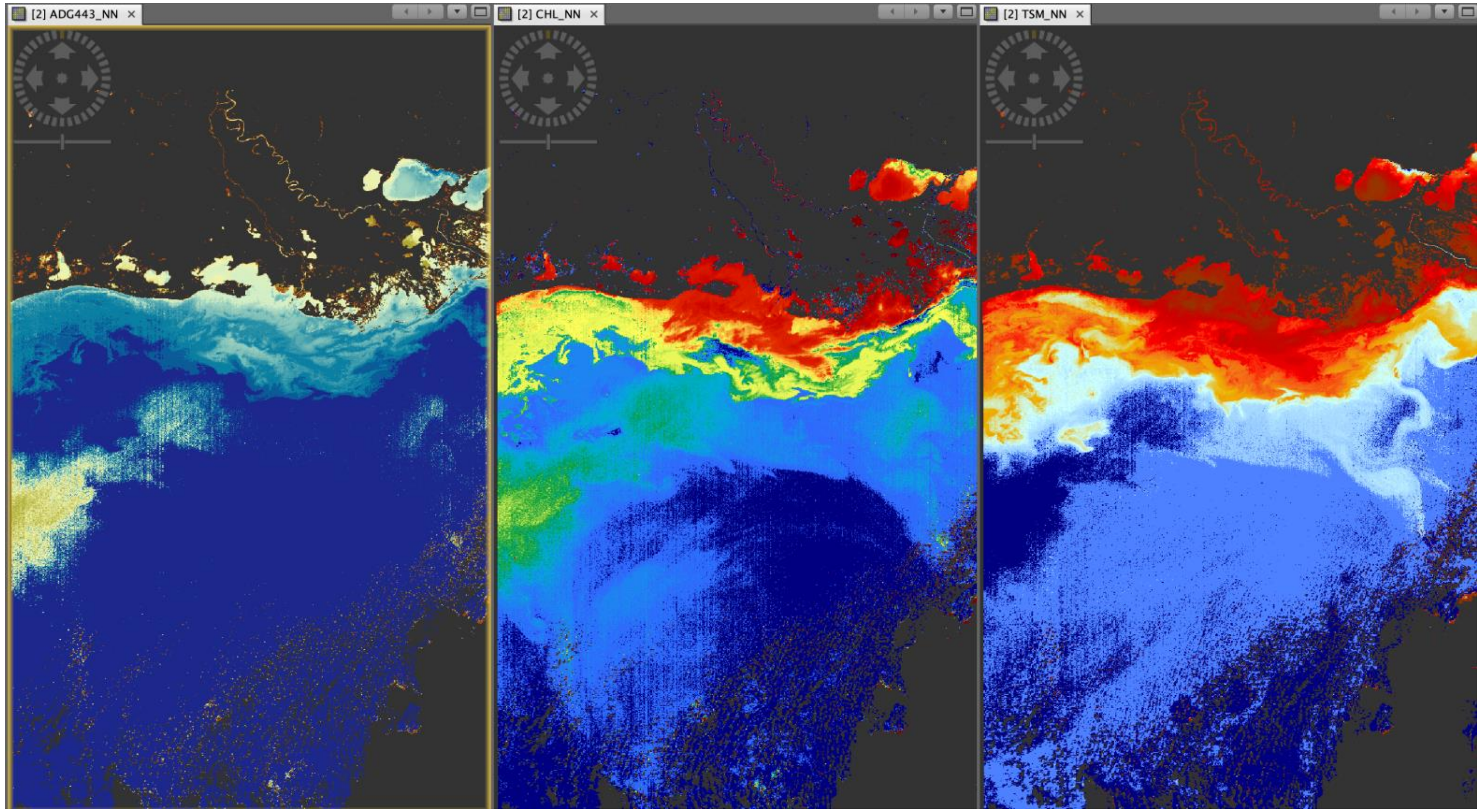


OLCI Level 2 BAC

- The version implemented in the OLCI processing chain is an update of the Moore et. al. 1999 paper, with improvements to the OLCI ATBD (Moore et al., 2017) resulting from the fourth reprocessing of the MERIS data.
- The OLCI algorithm uses a coupled atmosphere-hydrological model where the water contribution is implemented in terms of Inherent Optical Properties (IOPs). The model is solved using spectral optimisation inversion at six NIR bands.
- The BAC processing outputs:
  - the water reflectance (not corrected for the BRDF effect).
  - Aerosol optical depth (T865).
  - Ångström exponent (A865).
  - Photosynthetically Active Radiation (PAR) product.
  - Algal pigment concentration based on the Ocean Colour for MERIS (OC4Me) algorithm developed by Morel et al. (2007), following the approach of O'Reilly et al. (1998), with the product called CHL_OC4ME.
  - A chlorophyll index (CI) approach was developed for Collection OL_L2M.003 for application specifically in low-chlorophyll oligotrophic waters
  - Diffuse Attenuation coefficient at 490nm (KD490_M07), as outlined in Morel et al. (2007).
  - Inherent optical properties (absorption of anw, aphy, acdom, bbpm and bbp slope implemented with a three-step semi-analytical algorithm).
  - Kd490 nm and Optical Water classes based on Mélin and Vantrepotte (2015).

OLCI Level 2 AAC (Doeffer & Schiller. 2007)

- The output of AAC processing is water reflectance (400–753nm, 778, 865 and 1020nm), which is an internal processor product (not delivered).
- Inherent Optical Properties from the internal water reflectance, including total backscattering coefficient (bbp), phytoplankton absorption coefficient (apig), and coloured Detrital and Dissolved Material absorption coefficient (adetritus + ag), all at 442.5nm.
- The three OLCI NN operational products (such as CHL_NN, ADG443_NN, and TSM_NN) are derived from IOPs outputted by the second IOP NN.



OLCI Level2 Water quality flags

Flag	Description
INVALID	Invalid flag: instrument data missing or invalid
WATER	Water (marine) with clear sky conditions, ie no clouds
CLOUD	Cloudy pixel
CLOUD_AMBIGUOUS	Possibly a cloudy pixel, the flag removes semi-transparent clouds and other ambiguous cloud signatures
CLOUD_MARGIN	Cloud edge pixel, the flag provides an a-priori margin on the 'CLOUD or CLOUD_AMBIGUOUS' flag of two pixels at RR and four pixels at FR
COASTLINE	Direct copy of the L1B coastline flag
SNOW_ICE	Possible sea-ice or snow contamination
INLAND_WATER	Fresh inland waters flag (from L1B); these pixels will also be flagged as LAND rather than WATER
TIDAL	Pixel is in a tidal zone (from L1B)
COSMETIC	Cosmetic flag (from L1B)
SUSPECT	Suspect flag (from L1B)
HISOLZEN	High solar zenith: SZA > 70°
SATURATED	Saturation flag: saturated within any band from 400 to 754nm or in bands 779, 865, 885 and 1020nm
MEGLINT	Flag for pixels corrected for sun glint
HIGHGLINT	Flag for when the sun glint correction is not reliable
WHITECAPS	Flag for when the sea surface is rough and the whitecap correction is no more reliable at the wind speed above 12m/s, see section 3.2.3 of **Sentinel-3 OLCI L2 report for baseline collection OL_L2M_003**
ADJAC	Flag for adjacency effect indicating bright coastal pixels, see details in section 3.4.4.1 of **Sentinel-3 OLCI L2 report for baseline collection OL_L2M_003**
TURBID_ATMOSPHERE	Pixel's diffuse path transmittance in band 865nm (obtained from the NN AAC) is lower than a threshold (0.955), or pixel is saturated or excessively bright at 442.5nm **Sentinel-3 OLCI L2 report for baseline collection OL_L2M_003**
WV_FAIL	IWV retrieval algorithm failed
AC_FAIL	BAC atmospheric correction is suspect
OC4ME_FAIL	OC4Me algorithm failed
OCNN_FAIL	NN algorithm failed
KDM_ FAIL	KD490 algorithm failed

WQSF_ prefix

Quality flags (WQ) are an indicator of the algorithm team's assessment of the quality of the data

https://sentinels.copernicus.eu/en/web/sentinel/technical-guides/sentinel-3-olci/level-2/ocean-products

OLCI Level2 Science flags

Flag	Description
BPAC_ON	Spectral optimisation inversion in the BAC's Bright Pixel Correction was activated, converged, and a NIR signal of water was determined.
WHITE_SCATT	'White' scatterer within the water eg coccoliths
LOWRW	Water reflectance at 560nm is less than a defined threshold or HIINLD_F raised (flag for low pressure water, ie high altitude inland waters)
HIGHRW	High water reflectance at 560nm or the TSM retrieved as part of the BPAC is above a threshold
ANNOT	Annotation flags for the quality of the atmospheric correction, including: • ANGSTROM (Ångström exponent cannot be computed) • AERO_B (blue aerosols) • ABSO_D (desert dust absorbing aerosols) • ACLIM (aerosol model does not match aerosol climatology) • ABSOA (absorbing aerosols) • MIXR1 (aerosol mixing ratio is equal to 0 or 1) • DROUT (value of residual surface reflectance for the selected aerosol model candidate pairs is above a certain threshold compared to climatology) • TAU06 (aerosol optical thickness is greater than a defined threshold)
RWNEG_O01 to RWNEG_O21	Provides a 'negative water reflectance' flag for each band's water reflectance: the value below which pixels are flagged varies according to the band, with the threshold stored in OL_2_ACP_AX ADF (for more information, see **Auxiliary Data Format Specification for OLCI Level 2**).

Which flags should I apply?

Product names	Products	Common flags	Processing chain flags	Product flags
Water reflectance –BAC Open Waters	Oa**_reflectance → Oa**_reflectance	**Ocean Colour products** (WATER *or* INLAND_WATER) *and not* (CLOUD CLOUD_AMBIGUOUS CLOUD_MARGIN INVALID COSMETIC SATURATED SUSPECT HISOLZEN HIGHGLINT SNOW_ICE)	**Baseline Atmospheric Correction** **Open Water** **products** *not* (AC_FAIL WHITECAPS ADJAC RWNEG_O2 RWNEG_O3 RWNEG_O4 RWNEG_O5 RWNEG_O6 RWNEG_O7 RWNEG_O8)	*none*
Algal pigment concentration –BAC Open Waters	chl_oc4me → CHL_OC4ME			*not* OC4ME_ FAIL
Diffuse attenuation coefficient –BAC Open Waters	trsp → KD490_M07			*not* KDM_FAIL
Photosynthetically Active Radiation –BAC Open Waters	par → PAR			*not* PAR_ FAIL
Aerosol Optical Thickness and Ångström exponent –BAC Open Waters	w_aer → T865, A865			*none*
Algal pigment concentration –AAC Complex Waters	chl_nn → CHL_NN		**Alternative Atmospheric Correction** **Complex Water** **products** *no specific flags to be applied*	*not* OCNN_FAIL
Total suspended matter concentration –AAC Complex Waters	tsm_nn → TSM_NN			*not* OCNN_FAIL
Coloured Detrital and Dissolved Material absorption –AAC Complex Waters	iop_nn → ADG443_NN			*not* OCNN_FAIL
Integrated Water Vapour Column	iwv → IWV	**Atmospheric products**	**Water Vapour** *not* MEGLINT	*not* WV_FAIL

For more information on which quality flags to apply in specific circumstances, see the FAQs below, and the following Jupyter Notebook example for how to apply them.

Exploring and visualising OLCI chlorophyll products
V1.0, 1 Jul 2023
This Jupyter Notebook shows how to explore and visualise the level 2 Sentinel-3 Ocean and Land Colour Instrument (OLCI) chlorophyll marine products.
Software and code

Recommended Water Flags

The following recommend flags are defined for the Water products:

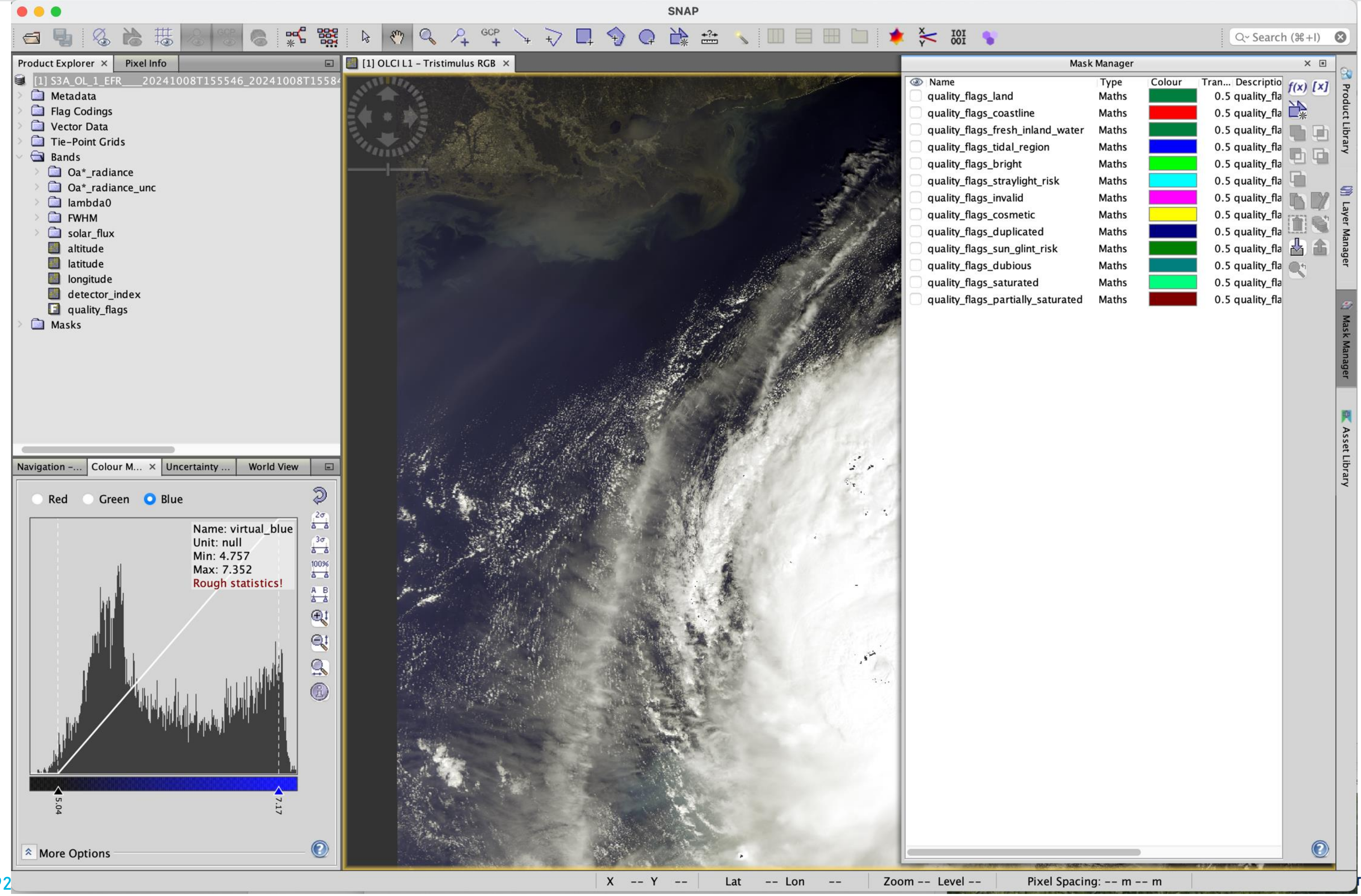
- **WQSF_REFLECTANCE_RECOM**
- **WQSF_CHL_OC4ME_RECOM**
- **WQSF_KD490_M07_RECOM**
- **WQSF_PAR_RECOM**
- **WQSF_W_AER_RECOM**
- **WQSF_CHL_NN_RECOM**
- **WQSF_TSM_NN_RECOM**
- **WQSF_ADG443_NN_RECOM**
- **WQSF_IWV_NN_RECOM**

Detailed information can be obtained from the product notice published on the Eumetsat website:

https://user.eumetsat.int/s3/eup-strapi-media/S3_PN_OLCI_L2_M_003_05_Sentinel_3_Product_Notice_OLCI_Level_2_Ocean_Colour_21e0333d3d.pdf

https://gitlab.eumetsat.int/eumetlab/oceans/ocean-training/sensors/learn-olci/-/blob/main/1_OLCI_introductory/1_6_OLCI_CHL_comparison.ipynb

Demo 2. SNAP OLCI L1 and L2 visualisation and analysis



Thank you!

Questions are welcome.

Contacts and further information

For information on our training programme

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