DUE CoastColour

Product User Guide

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Contents

1 SCOPE OF THIS DOCUMENT

This document is the Product User Guide for the ESA DUE CoastColour processing. It is the reference product description, which specifies the products, its content and briefly summarizes the algorithms used to generate it.

This is the final version of the document. It reflects the final version of the CoastColour processor and matches the products available through the Calvalus-based CoastColour on-demand processing service at BC.

2 INTRODUCTION

To collect synoptic data about the ocean's ecosystem, we need to apply Earth Observation, or remote sensing. There is only one option: visible spectral radiometry, commonly known as ocean colour. No alternative exists for synoptic study of the marine ecosystem, whether we are concerned with the open ocean or, more particularly with coastal ecosystems, where processes tend to operate with higher frequency and shorter spatial scale than offshore.

There are many reasons why one would want to monitor the coastal ecosystem using ocean colour, bearing in mind that the principal deliverable of the method is the bulk seawater concentration of chlorophyll as contained in phytoplankton. The basic anabolic metabolism of phytoplankton is photosynthesis: they are autotrophs and therefore consumers of carbon dioxide. At the global scale, the flux of carbon through marine phytoplankton is about 50 Gig tons per annum. Coastal zones are amongst the most productive regions, biologically speaking, in the ocean. Hence, the role of the coastal zone in the planetary carbon cycle is of fundamental importance, and it can be quantified using remotely-sensed data on ocean colour. In other words one can infer from the chlorophyll fields the rate of photosynthesis, amongst the most important of the derived products of ocean colour.

Another characteristic of coastal waters is that, optically, they are complex (compared with the open ocean) and large optical gradients can be found. Such strong optical gradients are favourable for the development and refinement of radiative transfer models of ocean colour: instances can be found where each one of the major optically-active substances (chlorophyll, yellow substance, inorganic suspension, organic detritus) dominates. In turn, the bio-optical models so refined can be useful in open-ocean applications, where the optical gradients are often much more subtle.

In coastal regions, the input of sediments from river drainage can have an adverse effect on ecosystem habitat, as can coastal erosion. Ocean colour remote sensing provides an ideal method to monitor sediment movements, providing invaluable information for the aquaculture and fisheries sector. Similarly, the influx into the coastal zone of coloured material in solution through river drainage can be monitored using ocean colour. Coastal zones are under habitat stress because of the large population concentrations over much of the world's coastlines. The delivery of pollutants to coastal waters can be seen directly (if they have a colour signature), or indirectly through their effect on the phytoplankton (if they do not). A good example of the latter is input of inorganic fertilizers from agriculture leading to development of algal blooms, including harmful ones. This is a topic on which the aquaculture industries crave information. More generally, ocean-colour is particularly useful for monitoring water quality at high temporal and spatial resolution, and over extensive areas. This is relevant to the Water Framework Directive of the European Union.

Harvest fisheries can also benefit greatly from the application of ocean-colour data. For at least one hundred years, it has been recognised that we might account for the observed fluctuations between years in exploited fish stocks by studying the fish, in their larval stage. Because the larval stage is usually planktonic, studying this stage means studying a mostly passive component of the pelagic ecosystem and its variable forcing.

Planktonic stages of fish inhabit an ecosystem in which the communities are, for the most part, microbial. The implication is that the intrinsic turnover times are rapid. The pelagic (micro)flora is on the average about thirty times more active, metabolically, than the terrestrial flora, a consequence of the relative sizes of the organisms concerned. To make sense of the ecological impact of the inter-annual variability in forcing of the pelagic ecosystem, we must study it on the appropriate scales of time and space. Generally speaking, this is difficult to achieve using ships as the operational platform.

So, with notable exceptions (Cushing), the long-standing hypothesis that the key to variability of fish populations lies in variable forcing of the pelagic ecosystem when the fish are in their larval stage, has proved difficult to test at the relevant time and space scales. However, the advent of remotely-sensed data on visible spectral radiometry of the ocean has radically changed this situation. It is now possible to collect data on the pelagic ecosystem, highly resolved in space (nominally 1 km or better), with rapid repeat coverage (nominally one day), averaged over any area chosen by the investigator. For the first time, we are suitably equipped to test hypotheses about the fisheries implications of ecosystem variability.

We are therefore more adequately equipped than ever before to manage exploited fish stocks (invertebrate as well as vertebrate) on a rational basis. That is, rather than treating the stocks as theoretical entities subject only to the equations of population dynamics, we are now able to consider, on the correct scales, the influence of environmental and ecosystem variability (in particular fluctuations in the availability of food in the critical period of larval stages).

It is clear that the information we now have at our disposal to elucidate fluctuations in the abundance of fish stocks in enormously enhanced over what was available only recently. We could say that, as a consequence, fisheries science stands on the threshold of a renaissance. One of the tasks of ocean-colour scientists is to deliver the relevant information in such a way that it can be exploited to the maximum in the fisheries sector.

More generally, ocean-colour remote sensing proves to be an ideal vehicle for retrieving a broad range of objective indices of ecosystem status and ecosystem health. These are difficult to quantify, but could be characterized using a series of metrics measurable by remote sensing. These so-called ecological indicators provide a compact description of the pelagic ecosystem at a given time and place. The comprehensive information they embody affords an invaluable background to biological oceanographic research, constitutes important ecological intelligence for fisheries management, and for ecosystem-based management of marine resources in the broadest sense. Rational management requires information. Because the ocean is highly dynamic (especially the coastal zone), the information needs to be updated frequently. We cannot hope to accomplish this using ships as the observing platform. Our only hope is through remote sensing. For the ecosystem, our only avenue is via ocean-colour remote sensing.

The European Space Agency has launched the CoastColour project to work towards these objectives by developing, demonstrating, validating and inter-comparing different Case 2 algorithms over a global range of coastal water types, identifying best practices, and promoting discussion of the results in an open, public form. CoastColour fully exploits the potential of the MERIS instrument for remote sensing of coastal zone water. The product requirements have been derived from a user consultation process. These have been translated into algorithm requirements and subsequently in algorithm specification and implementation. In the progression of the CoastColour project, there were actually two major product versions:

- The Version 1 set of CoastColour products. The complete MERIS archive from 2002 up to 2012 had been processed for 27 different, globally distributed sites. It included a revised Level 1 product and atmospherically corrected coastal products. These are described in the predecessor of this document, the Product User Guide Version 1.
- The CoastColour Version 2 products which are reflected in this Product User Guide Version 2. They are available through the Calvalus-based on-demand processing system at BC.

3 COASTCOLOUR APPROACH

The task of retrieving water optical properties and concentrations from reflections spectra in coastal waters is a complex matter. In contrast to case 1 water, where by definition, only 1 component determines the variability of the water leaving radiance reflectance, in all other types of waters, defined as case 2, a large number of factors determines the reflectance, which surmounts the number of independent pieces of information which can be retrieved from the spectra. These factors are various dissolved and suspended water constituents including a variety of phytoplankton species with varying cell size and compositions of absorbing pigments, then bottom effects, stratification and floating material on or close to the surfaces, including Red Tides, Cyanobacteria carpets and foam produced by *Phaecystics globosa*. Also the atmosphere is more complex in contrast to the deep ocean, with soot containing particles from industry, heating and traffic biomass burning, contrails from aircrafts and desert dust. Considering all of these factors, one can easily come to the conclusion that remote sensing of such areas is not possible. As a consequence as system of procedures is necessary, which reduces the manifold of variables to a number of components, which can be retrieved from reflectance spectra and, at the same time, detects cases, which require special treatments and cases which lead to errors and which have to be flagged. Furthermore, the retrieval uncertainty has to be computed on a pixel to pixel basis.

The general outline of the CoastColour system of procedures is given in Figure 1.

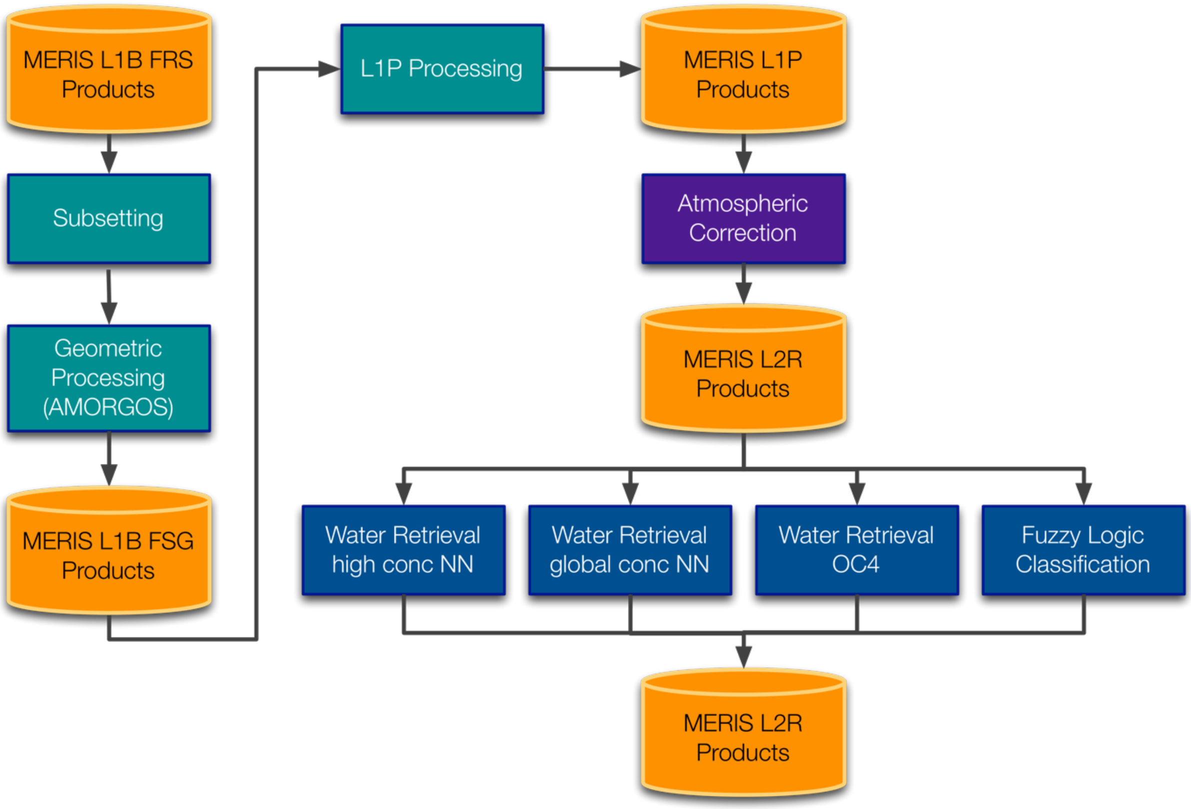

Figure 1: ***General outline of CoastColour processing*.**

Starting point are the MERIS FRS Level 1 products, which include auxiliary data such as surface pressure, ozone, geographical location of pixel, solar and viewing angles, solar flux. A geographical selection is performed in order to detect product which have an overlap with one of the CoastColour sites. Child products are generated and processed with AMORGOS. The AMORGOS tool generates accurate geo-location information - longitude, latitude, altitude - for each MERIS pixel. The output of AMORGOS after processing a MERIS FRS product is called MERIS FSG (G for geolocated). The FSG products are further processed by L1P processing, which performs a radiometric correction, smile correction, equalisation and pixel classification (cloud screening). The results are CoastColour L1P products.

These are input for the atmospheric correction, which performs quality checks and generates directional and normalised water leaving reflectances.

The next step classifies a water pixel by using its TOA spectral signature together with available geographical information (5) and applies currently a certain number of different, partially regionally tuned processing that all provide IOPs. In the final processing a selection will be made which processing will finally applied. Higher level products are derived from the IOPs.

4 Level1P Processing

4.1 General Product Description

The Level 1P product is a refined top of atmosphere radiance product compared with the standard Level 1b product. It provides:

- Improved geolocation
- Improved calibration
- Equalization to reduce coherent noise
- Smile correction
- Pixel characterization information (cloud, snow, …)
- Precise coastline
- Reformatting into NetCDF following Climate Forecast (CF) conventions

The product consists of basically the same type of information as the standard L1b product, namely spectral radiances in 15 bands at top of atmosphere level but with improved radiometry plus additional information including geolocation and geometry, pixel characterisation (flags) and ancillary information such as ECMWF data. The differences with the standard product are

- Changed radiometry in order to improve calibration and remove instrument errors
- Additional pixel characterization flags
- Improved accuracy geolocation at per-pixel level
- Improved land-water mask and coastline
- NetCDF-CF format

The Level 1P product with its bands is described in detail in section 0.

4.2 Methodology and Algorithms

4.2.1 Improved calibration

MERIS standard processing algorithms are revised, and as part of this, the degradation model of the calibration diffusor has been improved, which results in updated gain values per detector. This is applied in L0 to L1 processing. The Reduced Resolution products are currently undergoing a reprocessing (3rd reprocessing) at ESA; however, this applies only to archived RR products, and the Level 1b FRS products available for CoastColour are at 2nd reprocessing quality. The Improved Calibration of CoastColour is reverting the second reprocessing gains and applying the 3rd reprocessing gains, so that that TOA radiances are comparable with the 3rd data.

The radiometric calibration as described below is a non-linear process including several steps. The radiometric gains are the second last step before the L1b are written. However, the last step is the straylight correction which is a non-linear process and not revertible from L1b product. The Improved Calibration of CoastColour is therefore only an approximation. The algorithm is fully defined and implemented. The quality of the Improved Calibration is currently assessed; it is therefore not applied in the CoastColour Preliminary Processing.

The valid MERIS samples are digital counts resulting from the detection and acquisition by MERIS of a bi-dimensional field of spectral radiance in front of the instrument. The objective of the radiometric processing, together with the stray light correction, is to estimate that spectral radiance. An inverse model of the MERIS processing is used for that purpose, using parameters stored in the Characterisation and Radiometric Calibration databases and the MERIS samples themselves. The MERIS acquisition model may be described as:

$$X_{b,k,m,f} = NonLin_{b,m}\left[g\left(T_f^{VEU}\right) * \left[A_{b,k,m} * \left(L_{b,k,m,f} + G_{b,k,m}\left(L_{*,*,*,f}\right)\right) + Sm_{b,k,m,f}\left(L_{b,k,m,*}\right)\right] + g_c\left(T_f^{CCD}\right) * C^0_{b,k,m}\right] + \varepsilon$$

Where

- M is the camera (or module); b is the spectral band; k is the pixel column; f is a frame (processing unit of number of image lines)
- $X_{b,k,m,f}$ is the MERIS raw sample
- $NonLin_{b,m}$ is a non-linear function, representing the non-linear transformations which take place in the CCD, amplifier and A/D converter; NonLin depends on band and gain settings
- T_f^{VEU} is the temperature of the MERIS amplifiers (VEUs) at the time of frame f
- T_f^{CCD} is the temperature of the MERIS detectors (CCDs) at the time of frame f
- g and g_c are (dimensionless) temperature correction functions
- $AL_{b,k,m}$ the "absolute radiometric gain" in counts/radiance unit; AL depends on band & gain settings
- $L_{b,k,m,f}$ the spectral radiance distribution in front of MERIS
- $Sm_{b,k,m,f}$ the smear signal, due to continuous sensing of light by MERIS
- $C^0_{b,k,m}$ the calibrated dark signal (possibly including an on-board compensation), dependent on band and gain settings
- $G_{b,k,m}$ a linear operator (weighted sum) representing the stray light contribution to the signal. For a given sample, some stray light is expected from all the other samples in the module, spread into the sample by specular (ghost image) or scattering processes
- ε is a random process representative of the noise and measurement errors

This model is inverted during processing: The inverse of the absolute instrument gain $AL_{b,k,m}$ is applied to the valid samples of all bands after dark and smear signal subtraction, with a compensation for the estimated temperature which is expressed as a function of time:

$$R_{b,k,m,f} = \left(AL_{b,k,m}\right)^{-1} * \left\{\left(X'_{b,k,m,f} - S_{b,k,m,f}\right) * \left[g_0 + g_1\left(t_f - t_{ref}\right) + g_2\left(t_f - t_{ref}\right)^2\right] - C_{b,k,m,f}\right\}$$

Where $R_{b,k,m,f}$ are the spectral radiances before the straylight correction. The CoastColour Improved calibration is assuming the final straylight corrected radiances as equal to this $R_{b,k,m,f}$. The 2nd reprocessing radiometric gains (AL) are multiplied to R, and then the inverse of the 3rd reprocessing gains are multiplied to give an estimate of the 3rd reprocessing radiances.

4.2.2 Coherent noise equalisation

The MERIS equalization module performs a radiometric equalisation of the MERIS L1b products. It reduces detector-to-detector and camera-to-camera systematic radiometric differences and results into a diminution of the vertical stripping observed on MERIS L1b products. The MERIS swath is imaged by a CCD. The radiance at each pixel of a MERIS L1b products results from the measurements of 5 cameras spread across the swath, each one imaging a part of the swath with 740 so-called detectors in FR (corresponding to 185 mean detectors in RR). This results into 3700 detectors imaging the swath of MERIS FRS product (925 in RR). The response of each one of these detectors is calibrated during the routine operation of the instrument. Residual uncertainties in the calibration process result into detector-to-detector and camera-to-camera systematic radiometric differences. The equalisation corrects for these radiometric differences via a set of detector dependant coefficients correcting for the residual uncertainties in the calibration process. These coefficients are retrieved via a methodology described in Bouvet and Ramino, 2010, based on observations of the Antarctica plateau spread out throughout several years and ideally the MERIS mission lifetime. The coefficients are different for MERIS Reduced and Full Resolution products.

Reference: Bouvet M., Ramino F. (2010): Equalization of MERIS L1b products from the 2nd reprocessing, ESA TN TEC-EEP/2009.521/MB (available on demand at mbouvet@esa.int)

4.2.3 Smile correction

MERIS is measuring the reflected sun light using CCD technique. A CCD is measuring in one of its dimensions one image line, and in the other dimension the spectrally dispersed radiance for each pixel along the image line. I.e., the spectral measurements of each pixel along an image line is made by it's own set of sensors of the CCD. This causes small variations of the spectral wavelength of each pixel along the image. This is called the "smile effect".

The MERIS instrument is composed of 5 cameras, each equipped with it's own CCD sensor. The variations of the wavelength per pixel are in order of 1nm from one camera to another, while they are in the order of 0.1nm within one camera.

Even though this variation is small compared to the spectral bandwidth of a band, which is typically 10nm, and can hardly be seen in an image, it can cause disturbances in processing algorithms that require very precise measurements, for example the retrieval of chlorophyll in the ocean. These disturbances can result in visual artefact ("camera borders") or reduced accuracy of the Level 2 products.

Therefore, the MERIS Level 2 processor corrects the smile effect. The Level 1b product is not smile corrected, because this product shall provide the user exactly what the instrument is measuring, and that is in fact the radiance at the given wavelength of each pixel.

The Smile Correction of BEAM is an exact implementation of the Level 2 smile correction, so that the users have a tool to generate smile corrected Level 1b products. While the Level 1b product provides the radiance measurement for individual wavelengths within one spectral band, the smile corrected product has normalised the wavelengths within one spectral band to one reference wavelength. Table 1 provides the reference wavelengths and the reference solar irradiance for this band. Please note that the reference solar irradiance is not corrected for the daily variation.

The smile correction consists of two terms: the irradiance correction and the reflectance correction.

The irradiance correction corrects the variation of the solar irradiance, which is different between the wavelength of the pixel and the reference wavelength:

$$L_{corr,irr}(\lambda_0) = L_{meas,pixel}(\lambda_0) * \frac{F_{0,ref}(\lambda_0)}{F_{0,pixel}(\lambda_0)}$$

The reflectance correction is interpolating along the slope of the reflectances between adjacent wavelengths from the pixel-wavelengths to the reference wavelength:

$$L_{corr,refl}(\lambda_0) = \left[L_{meas,pixel}(\lambda_2) * \frac{F_{0,ref}(\lambda_0)}{F_{0,pixel}(2)} - L_{meas,pixel}(\lambda_1) * \frac{F_{0,ref}(\lambda_0)}{F_{0,pixel}(\lambda_1)}\right] * \frac{(\lambda_{ref} - \lambda_1)}{(\lambda_2 - \lambda_1)}$$

The smile corrected radiance is the sum of the two terms:

$$L_{corr}(\lambda_0) = L_{corr,irr}(\lambda_0) + L_{corr,refl}(\lambda_0)$$

While the irradiance correction can be applied to all 15 bands, it is not possible to define for each band two adjacent bands, which are suitable universally to give a good estimation of the spectral slope within the band. For the bands in absorption lines, i.e. bands 11 and 15, it is totally impossible to find suitable adjacent bands.

4.2.4 Geolocation

The geolocation was realised using the AMORGOS (Accurate MERIS Ortho-Rectified Geo-location Operational Software) tool, available from ESA and developed by ACRI-ST.

AMORGOS is generating accurate geo-location information - longitude, latitude, and altitude - for each MERIS pixel, starting from a MERIS Full Resolution product.

If the input product is a Full Swath one, the current version accepts two modes. The first one preserves the organisation of the input product, namely the Level 1b product grid, it is referred to as the FSG (full swath geo-corrected) mode and generates a MER_FSG_1P product. The second one generate results re-organised in the instrument geometry, it is referred to as the FSO (full swath ortho-geolocated) mode and generates a MER_FSO_1P product.

The FSO mode first restores radiance samples and accompanying flags into Instrument Geometry, un-doing the spatial re-sampling of the Level1 processing, and computes accurate ortho-rectified geo-location using MERIS detectors individual pointing vectors, a High Resolution DEM and accurate spacecraft Orbit and Attitude files.

The FSG mode essentially skips the Instrument Geometry restoration step and computes the same geo-location information for each MERIS detector and each acquisition time but it affects these values to the corresponding MERIS L1B product pixels. It must be noted here that since the MERIS product grid is filled by a nearest neighbour method from the Instrument Acquisition grid with a slight spatial over-sampling, the same instrument sample can be found several times in the same Level 1b product (it is then identified as a DUPLICATE pixel within the Level 1b product flags). Since the additional geo-location information of the MER_FSG_1P product is linked to the source Instrument sample, it will be duplicated the same way than the radiance information.

Ortho-rectified geo-location must be understood as the computation of the intersection of a given sample line of sight with the Earth surface (as represented by the Digital Elevation Model) rather than with the reference ellipsoid as in Level 1b. However, it must be noted that image geometry is either the Instrument one (FSO mode) or the Level 1b one (FSG mode) and thus the output product is not ortho-rectified stricto sensu.

For CoastColour AMORGOS will be run in FSG mode. Further processing of FSO mode products is not possible and not required.

4.2.5 Pixel Characterisation

4.2.5.1. Improved Land-Water Mask and Coastline

If precise latitude and longitude information is available at pixel level (as after processing with AMORGOS), a precise geographical database delineating land and water can be queried to provide the land or water attribute at pixel level. If this database is at higher resolution than the MERIS pixel size it is possible to estimate the land and water fraction per pixel.

The SRTM Water Body Database (SWBD) has been used for this purpose. It is a geographical dataset encoding high-resolution worldwide coastline outlines in a vector format, published by NASA and designed for use in geographic information systems and mapping applications. It was created by the US National Geospatial-Intelligence Agency (NGA) as a complementary product during editing of the digital elevation model database of the Shuttle Radar Topography Mission (SRTM). SWBD data covers the Earth's surface between 56° southern latitude and 60° northern latitude. It is distributed in ESRI shapefile format, divided into 12,229 files, each covering one 1°-by-1° tile of the Earth's surface. SWBD data is in the public domain and has been downloaded from NASA.

The GlobCover land classification product was used to fill up the SWDB for northern latitudes.

The L1P processing adds two flags to the product:

1) A land flag (true = pixel has 0% water fraction)

2) A coastline flag (true = pixel has 0% < water fraction < 100%)

4.2.5.2. Cloud screening

The L1P processing includes a cloud screening procedure. This is a combination of several tests on features such as brightness, height of the scattering surface and high atmospheric turbidity. The tests take high reflection of sun glint into account.

A risk of sun glint is calculated using the wind speed available at the tie-points to get the Fresnel reflection according to Cox and Munk, in the same way as described in MERIS ATBD 2.13 (https://earth.esa.int/instruments/meris/atbd/atbd_2.13.pdf). Additionally a radiometric test is performed to verify the potential of sun glint. The result of this testing is stored in a flag called sun glint risk. This flag cannot differentiate sun glint from clouds and is therefore true for both, clear sky sun glint and clouds over, where from wind-speed & geometry calculation sun glint is possible.

A cloud buffer of 1 pixel has been put around every cloud pixel. It is available as a separate flag in the L1P product, to be used or ignored in further processing.

A cloud shadow is calculated using the cloud top height, derived by a neural network technique, as described in the MERIS ATBD 2.3 Cloud Top Pressure and the sun illumination geometry (https://earth.esa.int/instruments/meris/atbd/atbd_2.3.pdf). The cloud shadow is also available as a separate flag. Currently this algorithm is in an experimental stage and will be improved for further releases.

Cloud shadow is not calculated for cloud buffer pixels.

4.2.5.3. Sea ice/ snow screening

The MERIS Normalised Differential Snow Index MDSI is evaluated to calculate the risk of sea ice (with and without snow cover):

MDSI = (toa_refl_865 - toa_refl_885) / (toa_refl_865 + toa_refl_885)

Ice/Snow is assumed to exist if a pixel is bright and the MDSI exceeds a threshold.

The Ice/Snow test is only applied where an ice climatology has a minimum ice coverage > 0%. The climatology is based on the HadISST data (http://www.hadobs.org/). The result of the test is added to the L1P product as "snow_ice" flag.

4.2.5.4. Land Risk

This flag shall indicate mixed land-water pixels, including floating cyanobacteria blooms. It is currently not derived and always set to false.

5 L2 Processing

As stated in the overview the L2 processing comprises different steps and branches with alternative algorithms and procedures for special user requested tasks.

The first step is the atmospheric correction, which is necessary for almost all further products. Only the fluorescence line height (FLH) and the Maximum Chlorophyll Index (MCI) algorithms can be used with or without atmospheric correction.

After the atmospheric correction we have a network of partly hierarchical organized algorithms available.

5.1 General Product Description

As the result of the user requirements and discussions with the users, a suite of different products has been generated. For some of the products alternative algorithms have been tested and the most appropriate one for a task were used.

In general the following L2 products are generated:

Acro	*Product*	*Algorithm*
Level 2R		
RLw	Directional water leaving radiance reflectance	AC neural network
RLwn	Fully normalized water leaving radiance reflectance	Normalisation neural network
atm_tau	aerosol optical depth at 550nm	Aerosol neural network
ang	Angstrom exponent between 443 and 865nm	Aerosol neural network

Acro	*Product*	*Algorithm*
Level 2W		
a_total_443	Total absorption coefficient of all water constituents	From both neural network water and QAA
a_pig_443	Phytoplankton pigment absorption coefficient	From both neural network water and QAA
a_ys_443	Yellow substance absorption coefficient	From both neural network water and QAA
bb_spm_443	Backscattering coefficient of suspended sediment	From both neural network water and QAA
a_det_443	Pigment absorption at 443 nm	Neural Network Water
a_dg_443	Yellow substance absorption + Pigment absorption at 443 nm	Neural Network Water
b_tsm_443	Backscattering of total suspended particulate matter at 443 nm	Neural Network Water
b_whit_443	Backscattering of suspended particulate matter at 443 nm	Neural Network Water
quality	Quality indicator for IOPs	Neural Network Water
chl_nn	Chlorophyll a concentration	Conversion from a_pig
chl_oc4	Chlorophyll a concentration	OC4
chl_merged	Chlorophyll a concentration	NN and OC4
chl_weight	Chlorophyll a concentration	Dependent from conc_tsm
tsm	Total suspended matter	Conversion from b_total
kd_λ	Downwelling irradiance attenuation coefficient @ [413, 443, 490, 510, 560, 620, 664, 680, 709, 754] nm	Postprocessing of nnWater
kd_min	Minimal downwelling irradiance attenuation coefficient	Postprocessing of nnWater
owt	Optical Water Type, class [1, 2, 3, 4, 5, 6, 7, 8, 9, sum], and dominant class	Fuzzy classification
Z90_max	Maximal signal depth	Postprocessing of nnWater
turbidity	Turbidity in Formazine Units	TFU algorithm, postprocessing of nnWater

5.2 Methodology and Algorithms

5.2.1 Atmospheric correction

The correction of the influence of the atmosphere (shortly *atmospheric correction, AC*) is the most critical step in ocean colour remote sensing of case 2 water coastal waters.

It is defined here as the determination of the water leaving radiance reflectance spectrum (RLw(λ)) from the top-of-atmosphere radiance reflectance spectrum (RL_toa(λ)). This requires the determination of the radiance backscattered from all targets above the water surface including air molecules, aerosols, thin clouds, foam on the water as well as all radiance which is specularly reflected at the water surface, in particular the sun glint. Furthermore, the transmission of the solar radiance through the atmosphere to the water surface and of the radiance from the water surface to the sensor has to be computed.

In the case of high concentrations of humic matter in the water (gelbstoff) the reflection of the water body can become extremely small so that algorithms fail, which are based on an extrapolation of the path radiance from the red and near infrared bands to the blue-green spectral range. They produce incorrect water leaving reflectance spectra, partly with negative reflectances in the first 1-3 bands. In clear water cases the reflectance in the red bands are very low and unreliable and cause a problem when submitted to the water neural network algorithm. To avoid these problems an atmospheric correction procedure has been developed as an alternative to the standard MERIS correction, which reconstructs the water leaving radiance reflectance from TOA reflectance by using an artificial neural network. It uses 12 MERIS bands, and has been trained with simulated spectra to correct also sun glint contaminated pixels. The procedure is based on 2 ESA contracts, the Case 2 Regional Processor and the Glint correction processor, and is implemented in BEAM. It will be described in detail below.

For both algorithms an adjacency effect correction will be performed for areas close to the coast. A new element is an auto-associative NN, which is used to determine out of scope spectra.

The atmospheric correction procedure is based on radiative transfer simulations. The simulated radiance reflectances are used to train a neural network, which, in turn, is used for the parametrisation of the relationship between the top of atmosphere radiance reflectances, RL_toa and the water leaving radiance reflectances (RLw). Furthermore it computes (1) the atmospheric path radiances (RL_path), (2) the downwelling irradiance at water level (Ed), (3) the aerosol optical thickness at 550 nm and three other wavelengths and (4) the angstrom exponents of the aerosol optical thickness. The water leaving radiance reflectances (RLw) is then be used as input to another procedure for retrieving the IOPs and concentrations of the water constituents.

The model atmosphere comprises three parts: (1) a standard atmosphere, which includes layers with variable concentrations of different aerosols, cirrus cloud particles and a rough, wind dependent sea surface with specular reflectance, but with a constant air pressure- and ozone profile, (2) a layer on top of the standard atmosphere, which contains only the difference between the standard and real atmosphere concerning air molecules and ozone, and (3) a module to compute the water leaving radiance reflectance.

Of importance is the correction of the sun glint, which is included in the atmospheric correction. It allows using the full swath of a MERIS scene, even for high glint conditions.

Three interfaces are defined: top of the actual atmosphere (TOA), top of standard atmosphere (TOSA) and bottom of atmosphere (BOA).

The atmospheric correction comprises three steps:

1) Calculation of the path radiances and transmittances of the variable "Rayleigh - ozone-layer" by using actual values of sea surface pressure and total ozone content from the ancillary data of MERIS and subtracting them from the standard values. Thus, the path radiance might become negative or the transmittance might become > 1 in cases where the air pressure and ozone con-tent differences are negative. The path radiance and transmittances of this 'correction layer' are used to calculate the downwelling solar irradiance and the upward directed radiance at the top of standard atmosphere (TOSA). The actual pressure regards also the altitude of a lake by including the altitude-pressure formula into the procedure. Furthermore, the correction of a band shift along the cameras is performed in this module. This band shift is due to small misalignments of the 5 cameras. This has in particular an effect on the actual solar irradiance and the Rayleigh scattering. Both effects are corrected within this module.

Output of this procedure is the radiance reflectance at top of standard atmosphere, RL_tosa.

2) Calculation of the water leaving radiance reflectance, Rlw, by using a forward artificial neural network fwNN. The training of this network is based on the same training data set - computed with Hydrolight radiative transfer model -, which is used to train the backward NN for retrieving the inherent optical properties of water.

3) Calculation of the water leaving radiance reflectance, path radiances reflectance at TOSA, and the downwelling irradiance at bottom of atmosphere (BOA). This calculation is done with the neural network, which is trained with simulated radiances. It includes effects of different aerosols, cirrus clouds, specularly reflected sun and sky radiance and the coupling between all these components and the air molecules.

Input to the neural network are the TOSA radiance reflectances of 12 MERIS bands (412, 443, 490, 520, 560, 620, 665, 681, 708, 756, 778, 865 nm) s. in Figure 5 (1,2) as well as the solar zenith angle, the viewing zenith angles and the difference between viewing and sun azimuth angle (3). Output of the NN are the water leaving radiance reflectances (11), the path radiance reflectance (9) and the transmittance / downwelling irradiance (10), all of the12 MERIS bands, and the aerosol optical thickness at 443, 550, 778, 865 nm (12) from which the angstrom coefficient is computed (13). Further outputs for test purposes, which are not used to generate products, are the total scattering and absorption coefficients of water and the sun glint ratio. The core of the algorithm is a multiple non-linear regression method ("Neural Network"). Its coefficients are determined from a large set of simulated atmospheric and water conditions for the input variables and corresponding output variables. The coefficients of the NN are computed by using a feed forward backpropagation optimisation ("training") technique. The data set for training and testing is produced by radiative transfer simulations using an ocean-atmosphere Monte Carlo photon tracing model, which has been developed at GKSS. This model allows us to label the events, which are photons has encountered. By this it is possible to count photons separately as sun glint photons, which were specularly reflected at the surface and not scattered in the atmosphere. Another model, which has been used recently for computing the training data set, is a modified 6SV code, which is based on the successive order of scattering technique (SOS) and which also includes polarisation.

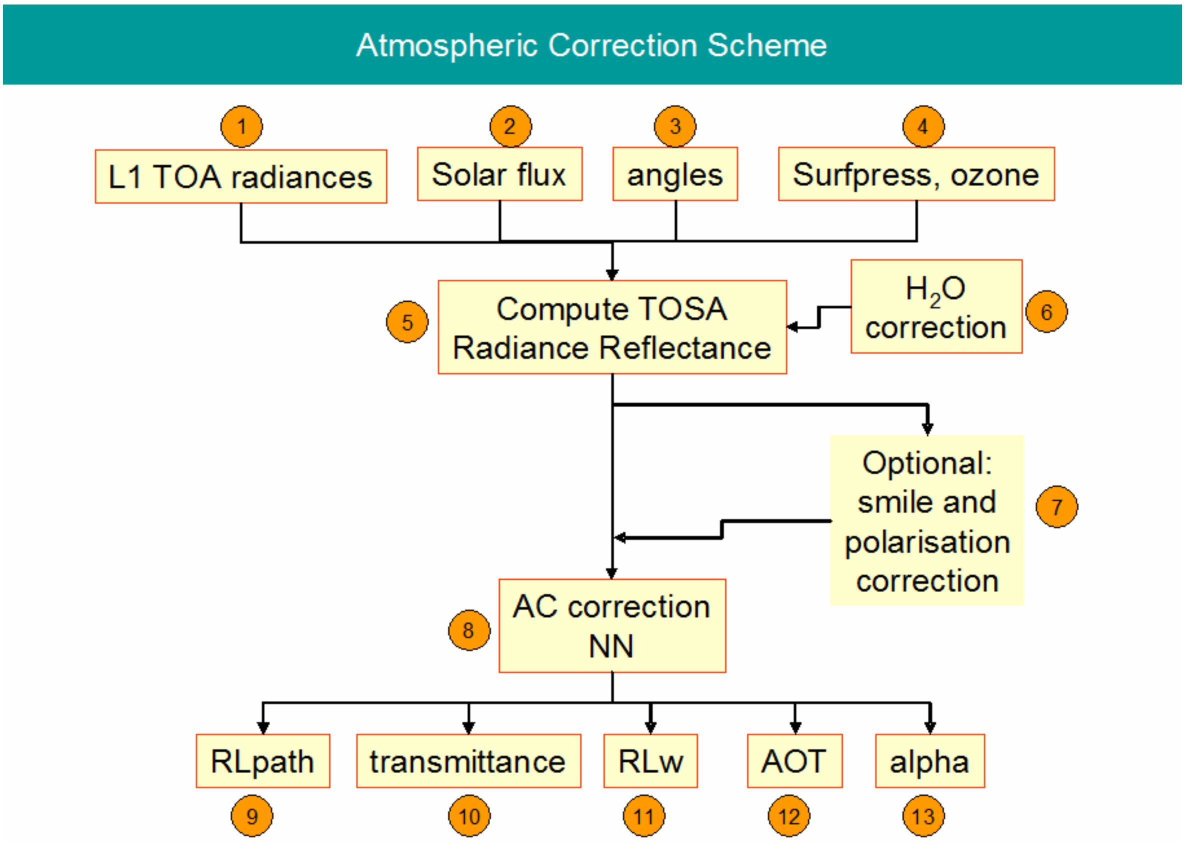

Figure 2: Atmospheric correction scheme

The neural network has the input/output neurons as given in Figure 3.

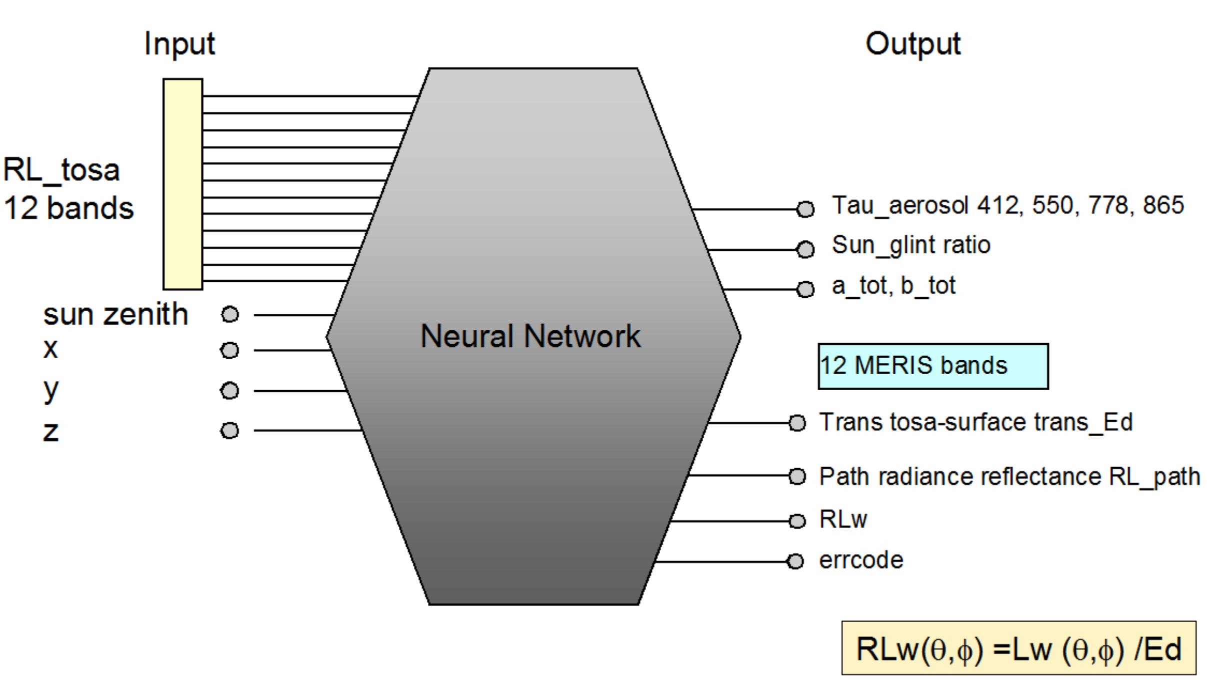

Figure 3: Outline of the neural network to determine the water leaving radiance reflectance RLw.

5.2.2 Water Algorithm

Level 2W is the result of the in-water processing. The L2W product contains inherent optical properties (IOPs), concentrations of water constituents and other optical water parameters such as the spectral vertical attenuation coefficient. The IOPs are available from 2 different algorithms: a neural network based fully spectrum inversion, specifically trained for a specific bio-optical models, developed for coastal waters based on the insitu data provided by the users, and a large value range of concentration in order to cover a widest range of coastal conditions. The second IOP retrieval algorithm is the inversion with the Quasi Analytical Algorithm (QAA). An optical water type (OWT) is added to the product in order to support the user in deciding on the selection the products (algorithms, NN or QAA, and in version 2 different chlorophyll products resulting from the neural network inversion, the clear water OC4 algorithm and a weighted merging of the two). Quality flags are set in order to characterise the success of the different processing steps.

One issue that was found on the CoastColour Version 1 products was the degraded quality in Case 1 waters at moderate or low chlorophyll concentrations. Although this water type was not the main objective of CoastColour, Case 1 waters are often present in a large portion of each MERIS product covering a coastal site, for example because spatially the products extends into the clear water part of the ocean, or because some sites are only temporarily Case 2 waters. As a consequence, many products show less performing, noisy parts where Case 1 water conditions occur.

In parallel to the second Phase of CoastColour, the ESA Ocean Colour CCI project (OC-CCI) started which has its focus on Case 1 waters. OC-CCI products are derived from MERIS RR data and include also the coastal zone and cover all CoastColour sites. Quality flagging is performed to flag out turbid Case 2 waters where the Case 1 water algorithm don't work properly. It was found that the OC4 algorithm, which is used in OC-CCI processing, performs very well for clear and moderate turbid water types. E.g. many parts of the North Sea can be processed with a small error. It should be noted that the OC4 algorithm provides only the chlorophyll concentration and no further products.

5.2.2.1. OC4 algorithm

The OC4 algorithm is defined for MERIS (OC4ME)[1]:

RS_1 = blue wavelength, for MERIS:
$RS_1 = \max\{RS(443), RS(490), RS(510)\}$

RS_2 = green wavelength, for MERIS:
$RS_2 = RS(560)$

$X = \log_{10} \frac{RS_1}{RS_{21}}$

$Chl_a = 10^{(a_0 + a_1 * X + a_2 * X^2 + a_3 * X^3 + a_4 * X^4)}$;

$a_0 = 0.3255, \quad a_1 = -2.7677, \quad a_2 = 2.4409, \quad a_3 = -1.1288, \quad a_4 = -0.4990$

In CoastColour a study was performed to improve the chlorophyll product by using OC4 for clear and moderate turbid waters, and the extreme neural net chlorophyll product for water bodies with higher turbidity. A result of the study was that the OC4 chl should be used where the TSM concentration (from the CoastColour v1 neural network) is below 5 mg/l, and the chl from the v1 NN where the TSM concentration is above 10mg/l. For TSM between 5 and 10 mg/l an average chl is calculated, which the mean of the two chl concentrations weighted with the TSM concentration. This ensures a smooth transition between the two algorithms.

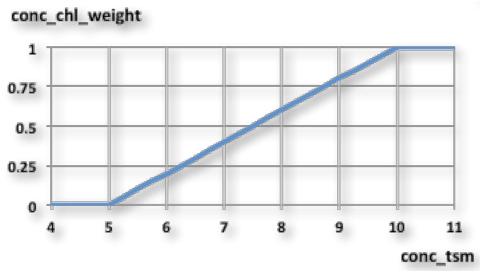

Figure 4: Chlorophyll weighting factor

The merged chlorophyll band value is then computed as follows:

$$chl_{merged} = w * chl_{NN} + (1 - w) * chl_{OC4}$$

with w being the weighting factor value from the `conc_chl_weight` band.

[1] http://oceancolor.gsfc.nasa.gov/REPROCESSING/R2009/ocv6/

5.2.2.2. Optical Water Types

A fuzzy classification method has been applied to remote sensing reflectance at water level. It allows for pixels to be assigned partial or graded class memberships to different water types with which they share spectral characteristics. This is accomplished by using a fuzzy membership function that expresses the likelihood that a pixel, with its observed radiance vector, belongs to a class with a known reflectance distribution. For CoastColour, the clustering method yielded eight water type classes; spectra are pictured in Figure 5. The eight water type classes cover the most water spectra except for water characterized by coccolithophore plankton bloom. For this water type, the 9th OWT has been created. Figure 6 shows how the 8 classes (green) collectively form the 9th OWT. These were derived from satellite data (SeaWiFS) using the coccolithophore mask. Coccolithophore Rrs peaks at 490nm, compared to 555nm for sediment classes.

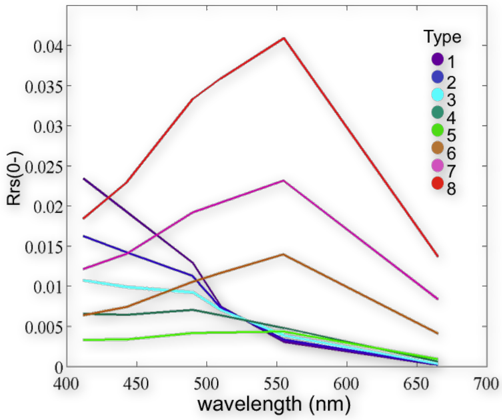

Figure 5: CC optical water type classes 1-8

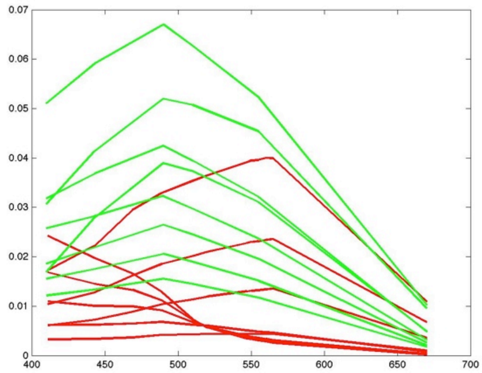

Figure 6: CC optical water type class 9 (coccolithophore class)

The fuzzy code of the CC water processor classifies ocean color radiometric level 2 (based on remote sensing reflectance) into 9 different optical water types and computes their fuzzy membership values (each has a value range of 0…1), the sum of the membership values, and the dominant class.

5.2.3 Validation

The L2W products were validated against the CoastColour in-situ database which was compiled from data provided by the champion users, and the MERMAID database. The products were also assessed in Case Studies in the North Sea and the Baltic Sea. The CC-in-situ and MERMAID investigation provide the global overview, with an overall satisfactory result. Knowing the large variety of optical properties among global coastal sites is already a big progress. The comparison of the CC chlorophyll with the in-situ chlorophyll reveals also the (known) differences in determination of chlorophyll by different in-situ methods. Please refer also to the DEL-27 CoastColour Validation Report, which is available online at: http://www.coastcolour.org/publication.html.

6 CoastColour Product File Format

The file format for the L1P, the L2R and L2W products shall ideally be the same in order to reduce specification redundancies and ease data access and software development. Most importantly, the file format shall be

1. self-describing and self-contained,
2. supported by a number of imaging applications and software libraries,
3. well-known and accepted within the EO user community.

Both the HDF and NetCDF data formats meet these requirements; in fact they have been developed to support scientists, researchers and engineers and are in use in a number of ESA projects such as GlobCover (HDF), GlobColour, Medspiration, GlobAerosol and the Sentinel 3 L1/L2 Product Definition and Proto studies (all NetCDF).

The growing number of ESA projects utilizing the NetCDF format is actually reason enough to go for it. Another major impact is described in the following. Applications reading and writing HDF- and NetCDF-formatted files typically use a dedicated library to do that. HDF and NetCDF libraries are available for a number of programming environments and languages, e.g. C, Java, IDL, MATLAB. In contrast to HDF, a pure Java implementation of the NetCDF 3 and 4 formats is available (which even can read HDF 4 and 5). The HDF Java library actually is a wrapper of the HDF C library and as such uses a shared library binding, which makes it highly dependent on specific hardware architecture (32/64 bit). A pure Java implementation of the file-formatting library is highly desirable as all the processing chains developed in this project will be implemented in Java and compiled against the BEAM Java APIs. Platform and architecture independence is an important issue since it shall be easy to deploy the processing code on different computers in order to parallelize the data processing and address the NRT requirements in this project.

6.1 NetCDF Data Model

In order to specify the product structure, we will use the NetCDF terminology comprising the terms *dataset*, *variable*, *attribute* and *dimension*. A NetCDF file is referred to as *dataset*. A dataset is composed of zero or more named *variables* that store the actual data. The data can be one- or multi-dimensional arrays of primitive data types (integers or floating point numbers). A dataset and also a data variable may be associated with a number of named *attributes*. An attribute has a value, which can either be scalar or a 1-dimensional array of a primitive type (including characters). An n-dimensional data variable is also associated with n named *dimensions*. Dimensions establish the index space of data variables by describing the meaning, size and value range of each dimension. Figure 7 illustrates this simple but yet effective data model of NetCDF version 4.

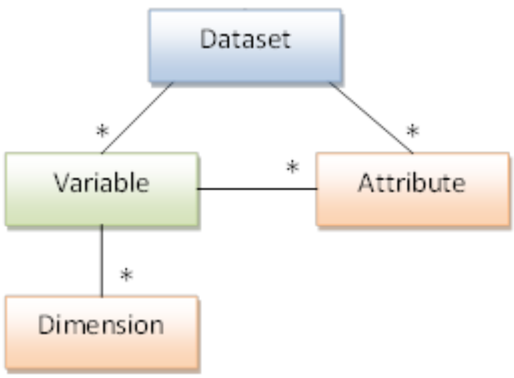

Figure 7: The NetCDF 4 Data Model

6.2 Product Specification

This chapter is applicable to the L1P and L2 products. A dataset is physically represented by one single NetCDF product file. The CoastColour data products are provided as compressed gz files. Most NetCDF reader can directly read this file. Each dataset contains multiple variables. In the following table similar or related variables are grouped in order to give an overview of the product and to describe the contents. In section 6.4.

Table 6-1: Product List

Dataset	Group of Variables	Contents
L1P	TOA	Pre-processed MERIS TOA radiances.
	GEO	Ortho-corrected geo-coding.
	FLAGS	Flags characterising pixels
L2R	RSURF	Contains water leaving reflectances, normalised water leaving reflectances, aerosol optical depth and angstrom exponent. Using the BEAM CoastColour Processor the user can add other variables (currently not publicly available)
	GEO	Ortho-corrected geo-coding.
	FLAGS	Flags characterising pixels
L2W	IOP	IOPs and optical water properties (a_total, a_pig, a_ys, bb_spm)
	CONC	Concentration retrieval products (CHL, TSM).
	OWT	Optical Water Type Class Membership
	OTH	Other water properties
	GEO	Ortho-corrected geo-coding.
	FLAGS	Flags characterising pixels

6.2.1 Grid

The original MERIS FRS/FSG L1b grids are retained for the L1P and L2 products, specifically the

1. FR grid at pixel resolution and the
2. Tie-point grid located at each 64^{th} pixel in along- and across-track direction.

The grids are kept because remapping of the L1P to another grid incorporates several issues which can be avoided by sustaining the original MERIS FR grids. Typical issues are

- Interpolating (non-nearest-neighbour) resampling methods distort the original measurement of spectra.
- Introduction of many no-data pixels due to re-projection will increase product size.
- Duplication of pixels due to oversampling, especially true for Plate Carrée at high and low latitudes, will increase amount of data to be processed and therefore processing time.

6.3 Metadata

Attributes and dimensions are used to realize the self-describing nature of NetCDF files. In order to utilize these attributes in software, associate datasets and variables with meta-data. The NetCDF group defines a number of standard attributes for annotating datasets. These are for example the attributes `units`, `long_name`, `value_range`, `_FillValue`, `title` and `history`. Whenever applicable, these standard attributes are used.

The NetCDF standard attributes provide basic metadata for the interpretation of data variables but they don't tell much about the spatial and temporal properties of the data. The *NetCDF Climate and Forecast (CF) Metadata Convention* (brief CF Convention) defines metadata that provide a definitive description of what the data in each variable represents.

The file format for **L1P** product and the final **L2** products are **NetCDF**. The metadata associated with the NetCDF datasets and its variables are fully compliant with the **CF Conventions**.

6.4 Variable Definition

6.4.1 Annotation Data

Annotation data is provided within the tie-point grid for all L1P and L2 datasets. The annotation data comprises the original tie-point grids from the MERIS L1B product. These tie-point grids contain geographic coordinates and ECMWF derived geophysical data.

Table 6-2: Common Annotation Data

Variable name	Description	Unit	Type	Size (W×H)
latitude	Latitude of intersection of line of sight with WGS84 ellipsoid.	deg	fl	4/1024
longitude	Latitude of intersection of line of sight with WGS84 ellipsoid.	deg	fl	4/1024
dem_alt	Altitude at intersection of line of sight with WGS84 ellipsoid taken from DEM.	M	fl	4/1024
dem_rough	Roughness at intersection of line of sight with WGS84 ellipsoid taken from DEM.	-	fl	4/1024
sun_zenith	Sun zenith angle	deg	fl	4/1024
sun_azimuth	Sun azimuth angle	deg	fl	4/1024
view_zenith	View zenith angle	deg	fl	4/1024
view_azimuth	View azimuth angle	deg	fl	4/1024
zonal_wind	ECMWF zonal wind	m/s	fl	4/1024
merid_wind	ECMWF meridional wind	m/s	fl	4/1024
atm_press	ECMWF atmospheric pressure at sea level	hPa	fl	4/1024
ozone	ECMWF ozone concentration	DU	fl	4/1024
rel_hum	ECMWF relative humidity	g/cm^2	fl	4/1024

6.4.2 GEO Variables

This group of variables comprises the ortho-geolocation information generated by the AMORGOS tool and is common to all L1P and L2 products.

Table 6-3 Common Geolocation Data

Variable name	Description	Unit	T	Size (W×H)
lon	Ortho-corrected longitude. (The normally existing stripes of invalids at the left and right border are filled with values from the longitude tie-point grid)	deg	fl	4
lat	Ortho-corrected latitude. (The normally existing stripes of invalids at the left and right border are filled with values from the latitude tie-point grid)	deg	fl	4
altitude	DEM altitude (from GETASSE30)	m	ss	2

6.4.3 L1P TOA Variables

The L1P TOA variables comprise the 15 MERIS radiance bands, the MERIS detector index and flags.

Table 6-4 L1P TOA Data

Variable name	Description	Unit	T	Size (W×H)
radiance_<i>	TOA radiances in the 15 MERIS bands		us	15×2
detector_index	Index of the MERIS pixel		ss	2

6.4.4 L1P FLAGS Variables

The L1P FLAGS variables comprise the flags of the MERIS L1B product and also the flags of the CoastColour L1P pre-processing.

Table 6-5 L1P Flag Data

Variable name	Description	Unit	T	Size (W×H)
l1_flags	MERIS L1b flags (copy from M1b product)		ub	2
l1p_flags	Flags set by pre-processing (e.g. cloud screening, land/water classification …)		ss	2

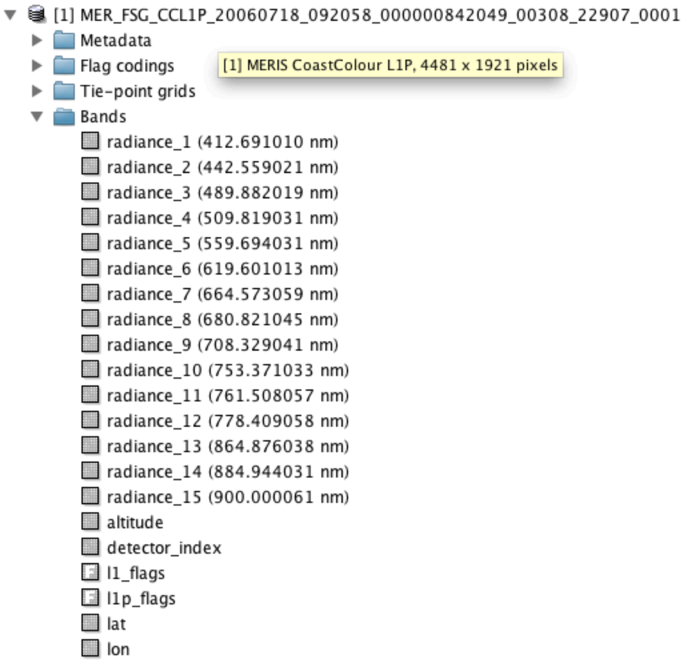

Figure 8: CoastColour L1P product opened in BEAM VISAT

6.4.5 L2R RSURF Variables

The L2R RSURF variables comprise data related to the atmospheric correction. This includes normalised and bidirectional water leaving radiance reflectances, aerosol optical thickness, and the angstrom exponent.

Table 6-6 L2R RSURF Data

Variable name	Description	Unit	T	Size (W×H)
norm_reflec_<i>	Normalised water leaving radiance reflectances.	-	fl	12×4
reflec_<i>	Bidirectional water leaving radiance reflectances.	-	fl	12×4
atm_tau_550	Aerosol optical thickness at 550 nm	-	fl	4
ang_443_865	Aerosol angstrom exponent between 443 and 865nm	-	fl	4
quality_indicator	Input spectrum out of range check	-	fl	4
detector_index	Index of the MERIS pixel	-	ss	2

6.4.6 L2R FLAGS Variables

The L2R FLAGS variables comprise the flags of the MERIS L1B product, the flags of the CoastColour L1P and the flags of the L2R processing.

Table 6-7 L2R Flag Data

Variable name	Description	Unit	T	Size (W×H)
l1_flags	MERIS L1b flags (copy from M1b product)	-	ub	2
l1p_flags	Flags set by pre-processing (e.g. cloud screening, land/water classification …)	-	ss	2
l2r_flags	Flags specific to atmospheric correction	-	us	2

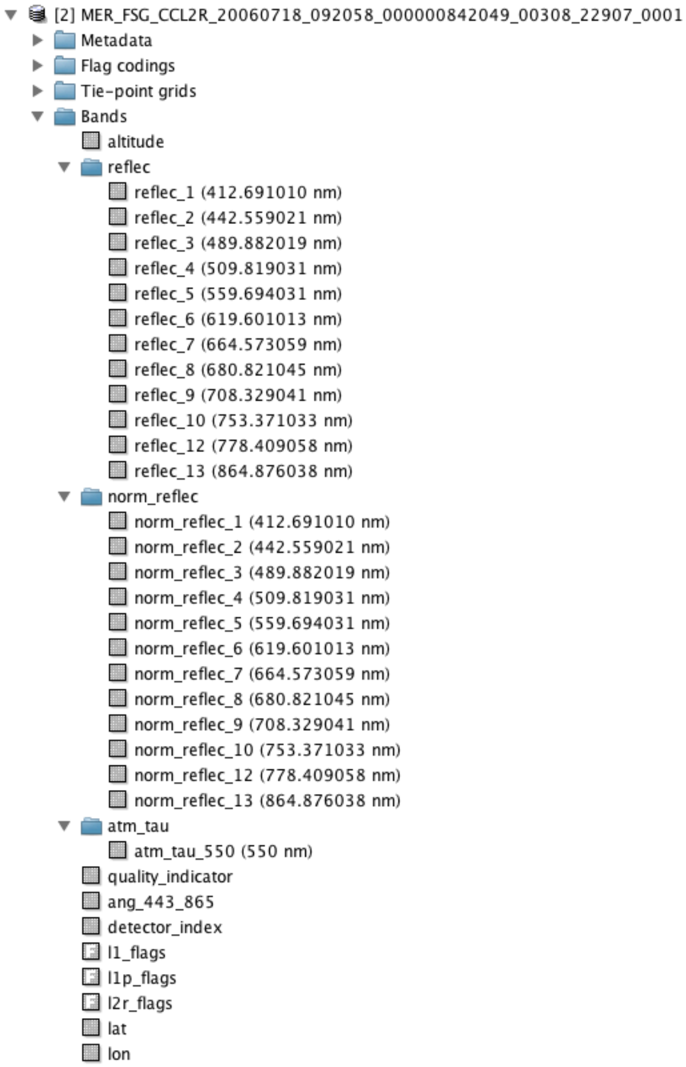

Figure 9: CoastColour L2R product opened in BEAM VISAT

6.4.7 L2W IOP Variables

The L2W IOP variables comprises the inherent optical properties of the water.

Table 6-8 L2W IOP Data

Variable name	Description	Unit	T	Size (W×H)
iop_a_total_443	Total absorption coefficient of all water constituents, NN	m^{-1}	fl	4
iop_bb_spm_443	Total scattering or backscattering coefficient, NN	m^{-1}	fl	4
iop_a_pig_443	Phytoplankton pigment absorption coefficient, NN	m^{-1}	fl	4
iop_a_ys_443	Yellow substance absorption coefficient, NN	m^{-1}	fl	4
iop_a_det_443	Pigment absorption at 443 nm, NN	m^{-1}	fl	4
iop_a_dg_443	Yellow substance absorption + Pigment absorption at 443 nm, NN	m^{-1}	fl	4
iop_b_tsm_443	Backscattering of total suspended particulate matter at 443 nm, NN	m^{-1}	fl	4
iop_b_whit_443	Backscattering of suspended particulate matter at 443 nm, NN	m^{-1}	fl	4
qaa_iop_a_total_443	Total absorption coefficient of all water constituents, QAA	m^{-1}	fl	4
qaa_iop_a_ys_443	Yellow substance absorption coefficient, QAA	m^{-1}	fl	4
qaa_iop_a_pig_443	Phytoplankton pigment absorption coefficient, QAA	m^{-1}	fl	4
iop_bb_spm_443	Total scattering or backscattering coefficient, QAA	m^{-1}	fl	4

6.4.8 L2W CONC Variables

The L2W CONC variables comprise the data of chlorophyll and total suspended matter concentrations. The computation of the merged chlorophyll band value is described in §5.2.2.

Table 6-9 L2W Concentrations Data

Variable name	Description	Unit	T	Size (W×H)
conc_tsm	Concentration of total suspended matter	mg/l	fl	4
conc_chl_nn	Chlorophyll-a concentration, derived from NN	g/m^3	fl	4
conc_chl_oc4	Chlorophyll-a concentration, from OC4 algorithm	g/m^3	fl	4
conc_chl_merged	Chlorophyll-a concentration, merged from NN and OC4	g/m^3	fl	4

Variable name	Description	Unit	T	Size (W×H)
conc_chl_weight	Weighting factor for chl_nn in merged band	1	fl	4

6.4.9 L2W OWT Variables

Variable name	Description	Unit	T	Size (W×H)
owt_class_<*i*>	Fuzzy membership value of optical water type class <i> for pixel; i=1…9	1	fl	4
owt_class_sum	Sum of membership values	1	fl	4
owt_dominant_class	Number of dominant class	1	ub	1

6.4.10 L2W OTH Variables

The L2W OTH variables comprise other water properties and the quality indicator for the IOP retrieval.

Table 6-10 L2W Other Data

Variable name	Description	Unit	T	Size (W×H)
iop_quality	Quality indicator of the IOP retrieval	1	fl	4
Kd_<i>	Spectral downwelling irradiance attenuation coefficient	m^{-1}	fl	8 x 4
Kd_min	Minimum downwelling irradiance attenuation coefficient.	m^{-1}	fl	4
Z90_max	Maximal signal depth	m	fl	4
Turbidity_index	Turbidity in formazine units	FNU	fl	4

6.4.11 L2W FLAGS Variables

The L2W FLAGS variables comprise the flags specific to the retrieval of water properties and the flags of the lower levels.

Table 6-11 L2W Flags data

Variable name	Description	Unit	T	Size (W×H)
l1_flags	MERIS L1b flags (copy from M1b product)	-	ub	1
l1p_flags	Flags set by pre-processing (e.g. cloud screening, land/water classification …)	-	us	2
l2r_flags	Flags specific to atmospheric correction	-	us	2
l2w_flags	Flags specific to retrieval of water IOPs	-	ub	1

- [3] MER_FSG_CCL2W_20060718_092058_000000842049_00308_22907_0001
  - Metadata
  - Flag codings
  - Index codings
  - Tie-point grids
  - Bands
    - iop
      - iop_a_total_443 (443 nm)
      - iop_a_ys_443 (443 nm)
      - iop_a_pig_443 (443 nm)
      - iop_bb_spm_443 (443 nm)
      - iop_a_det_443 (443 nm)
      - iop_b_tsm_443 (443 nm)
      - iop_b_whit_443 (443 nm)
      - iop_quality
      - iop_a_dg_443
    - Kd
      - Kd_min
      - Kd_412 (412 nm)
      - Kd_443 (443 nm)
      - Kd_490 (490 nm)
      - Kd_510 (510 nm)
      - Kd_560 (560 nm)
      - Kd_620 (620 nm)
      - Kd_664 (664 nm)
      - Kd_680 (680 nm)
      - Kd_709 (709 nm)
      - Kd_754 (754 nm)
    - Z90_max
    - turbidity
    - altitude
    - l1_flags
    - l1p_flags
    - l2r_flags
    - l2w_flags
    - conc
      - conc_tsm
      - conc_chl_nn
      - conc_chl_oc4
      - conc_chl_merged
      - conc_chl_weight
    - owt
      - owt_class_1
      - owt_class_2
      - owt_class_3
      - owt_class_4
      - owt_class_5
      - owt_class_6
      - owt_class_7
      - owt_class_8
      - owt_class_9
      - owt_class_sum
      - owt_dominant_class
    - qaa
      - qaa_iop_a_total_443 (443 nm)
      - qaa_iop_a_ys_443 (443 nm)
      - qaa_iop_a_pig_443 (443 nm)
      - qaa_iop_bb_spm_443 (443 nm)
    - lat
    - lon

Figure 10: CoastColour L2W product opened in BEAM VISAT

6.5 CoastColour NetCDF Format Specification

The provided CoastColour products are in line with the NetCDF CF-convention. Beside the used attributes defined by CF-convention we have defined some extra attributes. These attributes were introduced on the one hand to reduce the size of the resulting NetCDF files and on the other hand to provide more information about the product to the user.

In the following table the CoastColour specific attributes are list and their purpose is described.

6-12 CoastColour Specific Attributes

NetCDF Element	Description
`tp_x`	Width of the tie-point grids (Annotation Data).
`tp_y`	Height of the tie-point grids (Annotation Data).
`offset_x`	The x-coordinate of the first (upper-left) tie-point in pixel coordinates (Annotation Data).
`offset_y`	The y-coordinate of the first (upper-left) tie-point in pixel coordinates (Annotation Data).
`subsampling_x`	The sub-sampling of the tie-point grid in x-direction given in pixel coordinates (Annotation Data).
`subsampling_y`	The sub-sampling of the tie-point grid in y-direction given in pixel coordinates (Annotation Data).
`metadata`	Contains metadata information (MPH, SPH, ...) from the MERIS product and information about the processing chain
`valid_pixel_expression`	Attribute used for a variable to store an expression identifying valid pixels (optional).
`bandwidth`	The bandwidth of a spectral band (optional).
`wavelength`	The wavelength of a spectral band (optional).
`product_type`	The type (identifier) of the product. One of MER_FSG_CCL1P, MER_FSG_CCL2R, or MER_FSG_CCL2W (contained in the global attributes).
`metadata_profile`	The value is 'beam'. Identifying the NetCDF file as one with special BEAM extensions (contained in the global attributes).
`metadata_version`	The version of the content contained in the metadata variable (contained in the global attributes).
`auto_grouping`	Value used within BEAM to group bands by the given pattern (contained in the global attributes).

7 Tools

CoastColour NetCDF formatted products can be opened with all NetCDF compatible software packages. We recommend specifically using the BEAM toolbox, which is specifically developed by ESA for the exploitation of MERIS and other Earth Observation data products.

The tie-point grid and the product grid have different resolutions. With BEAM these are automatically mapped. MERIS product specific data, such as flags, are interpreted with BEAM and offered as bitmasks. BEAM is open source and free available from earth.esa.int/beam.

NASA provides the free of the charge the Panoply data viewer: www.giss.nasa.gov/tools/panoply

ACRONYMS AND ABBREVIATIONS

AATSR	Advance Along Track Scanning Radiometer
AC	Atmospheric Correction
AMORGOS	Accurate MERIS ortho-rectified geolocation operational software
ANN	Artificial neural network
AOI	Area of interest
AOP	Apparent optical properties
API	Application Programming Interface
ATBD	Algorithm theoretical basis document
BC	Brockmann Consult
BEAM	Basic Envisat AATSR and MERIS toolbox
BOA	Bottom of Atmosphere
BRDF	Bi-directional Reflectance Distribution Function
BRF	Bidirectional Reflectance Factor
CC	CoastColour
CDOM	Coloured dissolved organic matter
CEOS	Committee on Earth Observation Satellites
Chl	Chlorophyll
ChloroGIN	Chlorophyll Global Integrated Network
CO	Centre of Oceanography of the University Lisbon
CSIR	Council for Scientific and Industrial Research
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CZCS	Coastal Zone Colour Scanner
DDS	ESA's satellite data distribution system
DEL	Delivery
DEM	Digital Elevation Model
DJF	Design justification file
DORIS	Doppler Orbitography and Radio-positioning Integrated by Satellite
DPM	Detailed Processing Model
DPQR	Demonstration products and qualification report
DQWG	Data quality working group
DUE	Data User Element of the ESA Earth Observation Envelope Programme
ECMWF	European Centre for Medium range Weather Forecast
ECSS	European Co-operation for Space Standardisation
EE	Earth Explorer (Mission)
ENVISAT	Environmental Satellite (http://envisat.esa.int)
EO	Earth observation
EOLI	ESA Earth Observation Link
ERS	European Remote Sensing satellite
ESA	European Space Agency
ESRIN	European Space Research Institute (http://www.esa.it/export/esaCP/index.html)
FFH	Flora Fauna Habitat Directive
FR	Full Resolution (300m resolution MERIS products)
FRS	Full Resolution full Swath
FSG	Full resolution full Swath, Geo-corrected
FTP	File transfer protocol
FLH	Fluorescence Line Height
fwNN	forward artificial neural network
GEO	Group on Earth Observations
GEOSS	Global Earth Observation System of Systems

GIOP	Generic IOP algorithm
GMES	Global Monitoring for Environment and Security
GOCI	Geostationary Ocean Colour Imager
HAB	Harmful Algal Bloom
ICOL	Improved Contrast over Ocean and Land
IDE	Integrated Development Environment
IGBP	Geosphere Biosphere Program
INPE	National Institute for Space Research
IOCCG	International Ocean Colour Coordinating Group
IOP	Inherent optical properties
IPF	Instrument Processing Facility
ITT	Invitation to tender
IVM	Institute of Environmental Studies
JAI	Java advanced imaging
JIIO	Java image input/output
JRC	Joint Research Centre
Kd(490)	Diffuse absorption coefficient at 490 nm
KO	Project kick-off
KORDI	Korea Ocean Satellite Center
L1, L2	Level 1, Level 2
L1P	A pre-processed version of the standard Level-1 data products.
L2R	Advanced atmospherically corrected L1P data
LISE	University of the Littoral Opal Coast
LOICZ	Land Ocean Interaction in the Coastal Zone
LTO	Linear tape open
LUT	Look Up Table
MEGS	MERIS Ground Segment Data Processing Prototype
MERCI	MERIS Catalogue and Inventory
MERIS	Medium Resolution Imaging Spectrometer (ESA instrument)
MODIS	Moderate Resolution Imaging Spectrometer (NASA instrument)
MUMM	Management Unit of the North Sea Mathematical Models
NASA	National Aeronautics and Space Administration
NetCDF-CF	Network Common Data Format following Climate Forecast conventions
NN	Neural Network
NIR	Near InfraRed
NRT	Near-real time
OCM	Ocean Colour Monitor
OLCI	Ocean and Land Colour Instrument
OSSD	Open Source Software Development
PAR	Photosynthetically active radiation
PCD	Product Confidence Data
PM	Progress meeting
PML	Plymouth Marine Laboratory
POGO	Partnership for Observation of the Global Oceans
PUG	Product User Guide
Q4	4th quarter of the year (October-December)
QA4EO	Quality Assurance Framework for Earth Observation data
QAA	quasi-analytical algorithm
RB	Requirements baseline
RD	Reference document

REVAMP	Regional Validation of MERIS chlorophyll Product
RID	Review item discrepancy
RH	relative humidity
ROI IOCCG	Regional bio-Optical algorithms Initiative
RLw	water leaving radiance reflectances
RR	Reduced resolution (1km resolution MERIS products)
RRob	Round Robin
SAFARI	Societal Applications in fisheries and Aquaculture using Remotely-sensed Imagery
SAG	Science advisory group
SDD	Secchi disk depth
SeaWiFS	Sea-viewing Wide Field-of-view Sensor (GeoEye/NASA instrument)
SoW	Statement of work
SPH	Specific Product Header
SPM	Suspended particulate material
SUM	System User Manual
SW	Software
TOA	Top Of Atmosphere
TOSA	Top Of Standard Atmosphere
TS	Technical specification
TSM	Total Suspended Matter
UCM	User Consultation Meeting
UML	Universal Modelling Language
UT	Universal Time
VISAT	Visualisation and analysis tool
WFD	Water Framework Directive
WGS84	World Geodetic Standard 1984
WP	Work package
WPD	Work package description
XP	Extreme programming
YS	Yellow Substance