3.4 JMP EUNOSAT (Joint Monitoring Programme of the EUtrophication of the NOrth-Sea with SATellite data) user case

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Optically complex coastal waters pose many challenges for satellite remote sensing to accurately retrieve biogeochemical parameters such as chlorophyll a concentration due to non-covarying concentrations of suspended particulate matter (SPM) and colored dissolved organic matter (CDOM). Here we evaluate publicly accessible satellite-based chlorophyll products available from Copernicus Marine Environment Monitoring Services (CMEMS), European Space Agency (i.e. ODESA) and other data providers (i.e. IFREMER) generated using 1) blue green ratio algorithms, 2) red-edge algorithms and 3) artificial network approaches and determine their validity for different water types, e.g. clear, turbid or CDOM-rich waters. In the next phase, a blending process is developed to join chlorophyll-a datasets based on best suited algorithm/water type combination, with special attention to the transition zones between different water types to ensure a gradual merge. This step enabled the progression from point-by-point and country-by-country analyses, to basin-wide analysis with data that cover gradients in the ecosystem system. The suitability of the blended chlorophyll product for eutrophication assessment is evaluated by a comparison analysis with *in situ* datasets for all assessment areas in the Greater North Sea.

Ref. No.	Product name & type	Documentation
3.4.1	OCEANCOLOUR_ATL_CHL_L3_REP_OBSERVATIONS_009_067	http://marine.copernicus.eu/documents/PUM/CMEMS-OC-PUM-009-ALL.pdf
3.4.2	OCEANCOLOUR_ATL_CHL_L3_REP_OBSERVATIONS_009_098	http://marine.copernicus.eu/documents/PUM/CMEMS-OC-PUM-009-ALL.pdf

3.4.3	OCEANCOLOUR_ATL_OPTICS_L3_REP_OBSERVATIONS_009_066	http://marine.copernicus.eu/documents/PUM/CMEMS-OC-PUM-009-ALL.pdf
3.4.4	OCEANCOLOUR_ATL_OPTICS_L3_NRT_OBSERVATIONS_009_034	http://marine.copernicus.eu/documents/PUM/CMEMS-OC-PUM-009-ALL.pdf
3.4.5	OCEANCOLOUR_BAL_CHL_L3_REP_OBSERVATIONS_009_080	http://marine.copernicus.eu/documents/PUM/CMEMS-OC-PUM-009-ALL.pdf
3.4.6	OCEANCOLOUR_BAL_CHL_L3_NRT_OBSERVATIONS_009_049	http://marine.copernicus.eu/documents/PUM/CMEMS-OC-PUM-009-ALL.pdf
3.4.7	OCEANCOLOUR_BAL_OPTICS_L3_NRT_OBSERVATIONS_009_048	http://marine.copernicus.eu/documents/PUM/CMEMS-OC-PUM-009-ALL.pdf
3.4.8	OCEANCOLOUR_BAL_OPTICS_L3_REP_OBSERVATIONS_009_097	http://marine.copernicus.eu/documents/PUM/CMEMS-OC-PUM-009-ALL.pdf

Background: monitoring the eutrophication state of the North Sea

The Marine Strategy Framework Directive (MSFD) is currently one of the most important drivers for monitoring the coastal and offshore waters in Europe with the objective of reaching a ‘good environmental status’ (GES) by 2020 (Gohin et al., 2008). It is a crucial legal instrument of the European Commission to protect the marine environment including its ecosystems and biodiversity. Human-induced eutrophication is one of the criteria for assessing the extent to which good environmental status is being achieved. Eutrophication can be defined as the enrichment of water by nutrients causing an accelerated growth of algae and higher forms of plant life to produce an undesirable disturbance to the balance of organisms present in the water and to the quality of the water concerned, and therefore refers to the undesirable effects resulting from anthropogenic enrichment by nutrients (OSPAR, 20171998).

The eutrophication status is established by monitoring of nutrients, and chlorophyll-a (CHL) concentration as a proxy of phytoplankton biomass. More specifically, the indicator of choice is the 90-percentile of the CHL (CHL-P90) concentrations over the phytoplankton growing season (i.e. March – September incl.) for a period of six years expressed in µg/l or mg/m. CHL-P90 represents the chlorophyll-a level such that 90% of the observations are equal to or less than this value. While *in situ* data acquisition is still considered as the main monitoring tool, the European Commission highlighted "the need for greater coherence with related EU legislation (Water Framework Directive and Habitats and Birds Directive) and for more coherent and coordinated approaches within and between marine regions and sub-regions". While preparing for the second cycle of MSFD assessment, various OSPAR groups (Intersessional Correspondence Group on Eutrophication (ICG-EUT) and the Hazardous Substances and Eutrophication Committee (HASEC)) have identified incomparability of monitoring methods for chlorophyll as a main issue hampering a coherent assessment of the common indicator chlorophyll-a in the greater North Sea. Moreover, the assessment levels for chlorophyll, based on background concentrations, have been determined with different methods between member states. This results in different GES determinations across national borders that cannot be explained by differences in water quality (Figure 3.4.1). Additionally, the budgets for marine monitoring are decreasing in many European countries forcing them to efficiently use monitoring resources.

During the last years there is a growing tendency to use optical remote sensing as a supporting tool to achieve the monitoring requirements because of severe resource constraints of available ship time and personnel and the need for a coherent assessment of chlorophyll between all OSPAR member states bordering the North Sea. Satellite data of chlorophyll combine cheaper data collection with a much improved geographical and temporal coverage compared to traditional *in situ* data.

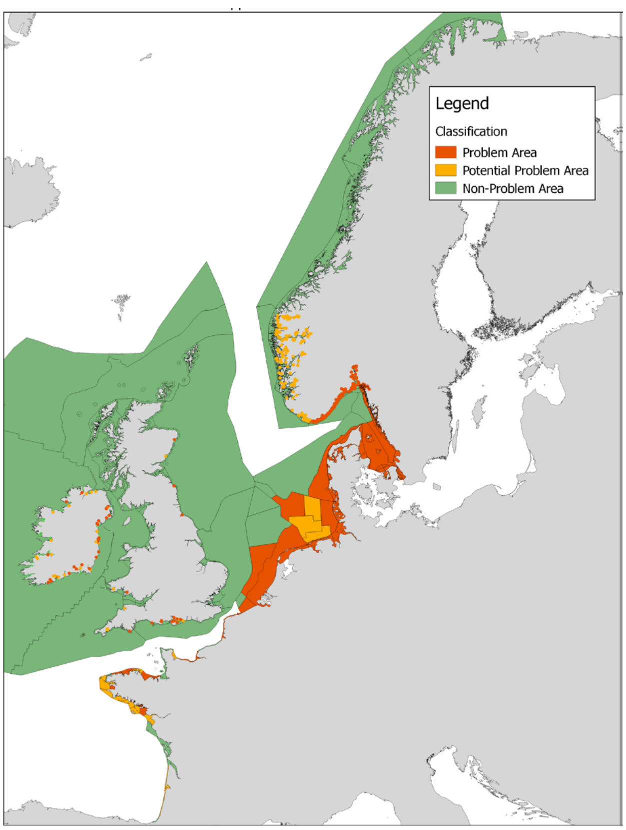

Figure 3.4.1: *Map of problem areas for eutrophication in the OSPAR region (OSPAR Quality Status Report 2017)*

Scientific context

The two-year EU JMP-EUNOSAT project, which started in February 2017, aims at the development of a coherent set of assessment levels and a cost effective Good Environmental Status (GES) assessment for eutrophication in the greater North Sea. The consortium consists of 14 partners from all countries bordering the North Sea.

Satellite data from ocean colour sensors (i.e. SeaWiFS, MODIS, MERIS, VIIRS, Sentinel-3) can provide spatially coherent data on chlorophyll concentrations using chlorophyll retrieval algorithms. There has been considerable success with blue/green-ratio algorithms in case 1 waters where the variation of optical properties (absorption and scattering) is dominated by phytoplankton and associated material. (O'Reilly et al., 1998; Gohin et al., 2002). In contrast, the optical complexity in coastal waters often poses many challenges to the accurate retrieval of biogeochemical parameters using satellite remote sensing (SathyendranathIOCCG, 2000;, Lee 2006). Chlorophyll retrieval by blue green ratio algorithms tends to fail when applied to coastal waters whose optical properties are strongly influenced by non-covarying concentrations of suspended particulate matter (SPM) and coloured dissolved organic matter

(CDOM). Such waters are defined as case 2 waters. Several constituent retrieval algorithms for use in case 2 waters have been developed: 1) red-edge algorithms (Gons et al., 2002) taking advantage of the chlorophyll absorption peak near 670 nm and 2) artificial network approaches trained to varying parameter concentrations and optical property ranges specifically developed for use with MERIS data, such as the MERIS Ground Segment Processor (MEGS, Doerffer and& Schiller, 2007) and the FUB/WeW (Schroeder et al., Schaale & Fisher, 2007).

Method

The technical objective of JMP EUNOSAT is to evaluate publicly accessible satellite-based chlorophyll products available from Copernicus Marine Environment Monitoring Services (CMEMS), European Space Agency (i.e. ODESA) and other data providers (i.e. IFREMER) and determine their validity for different water types, e.g. clear, turbid or CDOM-rich waters, so that the choice of satellite product is determined by environmental conditions per (cross-border) assessment area, rather than national boundaries of the member states.

We started from a collection of well-validated operational satellite-based chlorophyll products for the Greater North Sea: 1) CMEMS OC-CCI (CMEMS nr. 67), 2) CMEMS GSM (CMEMS nr. 98), 3) CMEMS OC4 adapted to Baltic waters (CMEMS nr. 80), 4) OC4 applied to OC-CCI remote sensing reflectance product (CMEMS nr. 66) and 5) MEGS 7.5 applied to the MERIS archive. For each of these products it was determined for which water types, described in terms remote sensing reflectance (Rrs) spectra, they provided the most accurate chlorophyll estimations (i.e. relative error < 50%) based on a variety of reference datasets from the CCRR project (Nechad et al., 2015). These reference data sets were specifically designed to test algorithms and assess their accuracy for retrieving water quality parameters and comprise 5000 matchups of chlorophyll-a concentrations and hyperspectral Rrs-spectra covering a wide range of water types in terms of CHL, SPM and CDOM concentrations. The Rrs-spectra were used as input to the considered chlorophyll algorithms and their resulting chlorophyll estimates were compared to the reference values allowing the development of a pixel-based quality assessment.

Figure 3.4.2 (A & B) shows the application of this approach on satellite observations for the 8th of April 2010 for the OC4 and OC5 products showing an algal bloom in the Belgian and Dutch coastal waters. Figure 2 C&D shows a classification map indicating the water types where the OC4 and OC5 algorithms are applicable indicating that the OC5 algorithm can be applied in more situations than the OC4 algorithm. The OC4 algorithm is inaccurate in the English Channel and South-East UK due to high concentrations of suspended matter (SPM).

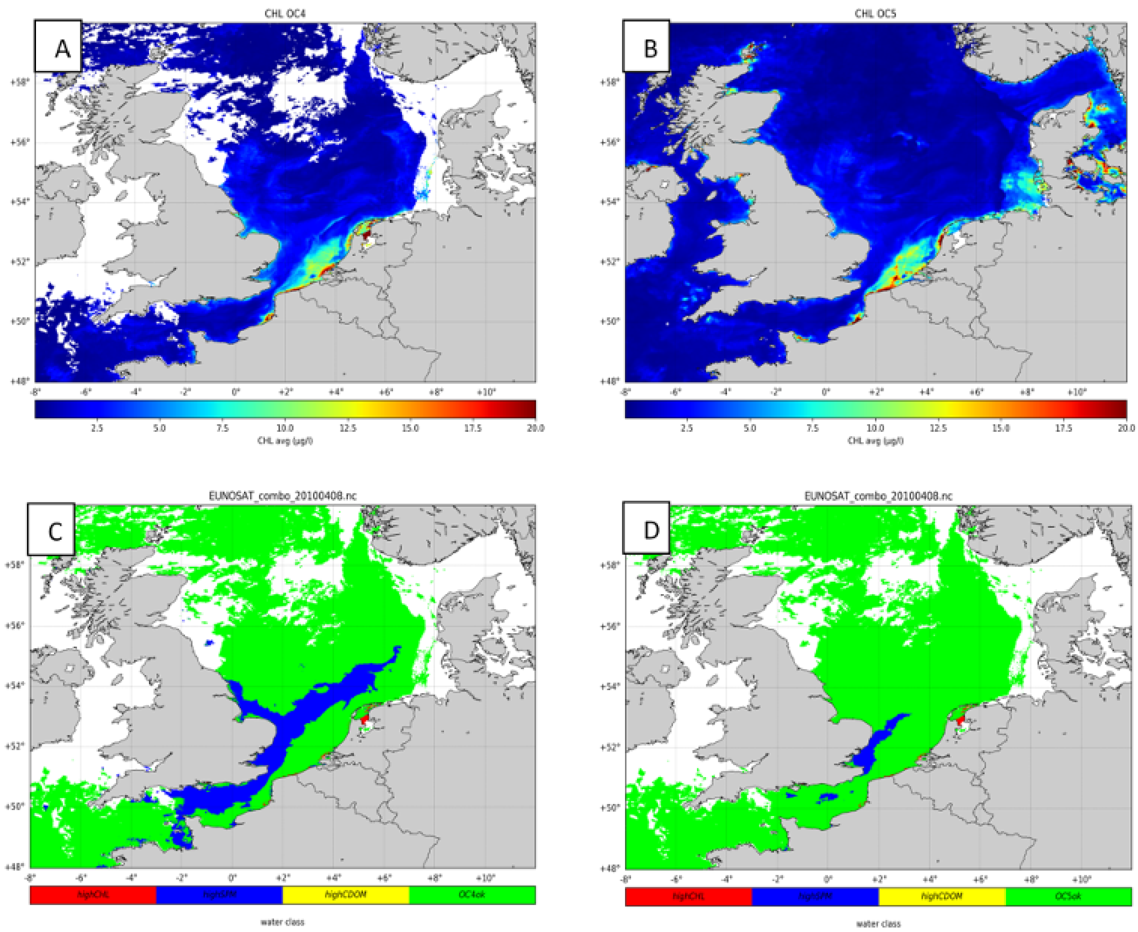

Figure 3.4.2: *(A & B) Chlorophyll-a products generated using the OC4 and OC5 algorithms for the 8th of April 2010 showing an algal bloom in the Belgian and Dutch coastal waters. (C & D) Water type classification map indicating the water types where the OC4 (C) and OC5 (D) algorithms are applicable indicating that OC5 can be applied in more situations than OC4 . OC4 is inaccurate in the English Channel and South-East UK due to high concentrations of suspended matter (SPM).*

In the next phase of the JMP EUNOSAT project, a blending process is developed to join chlorophyll-a datasets based on best suited algorithm/water type combination, with special attention to the transition zones between different water types to ensure a gradual merge. This step will enable progress from point-by-point and country-by-country analyses, to basin-wide analysis with data that cover gradients in the ecosystem system. This will enable a definition of cross-border assessment areas based on ecosystem characteristics. The blended JMP-EUNOSAT chlorophyll-a product will be compared to available *in situ* datasets for all assessment areas. This regional intercomparison will quantify the suitability of used standard products and blending approach for eutrophication assessment. Figure 3.4.3 shows different quality controlled CHL products (i.e. OC4, OC5, MEGS_7.5) for the 8th of April 2010. These products are merged on a pixel by pixel basis with a priority rule given to OC4, then OC5 and finally MEGS_7.5 filling up the map with the most appropriate algorithms available.

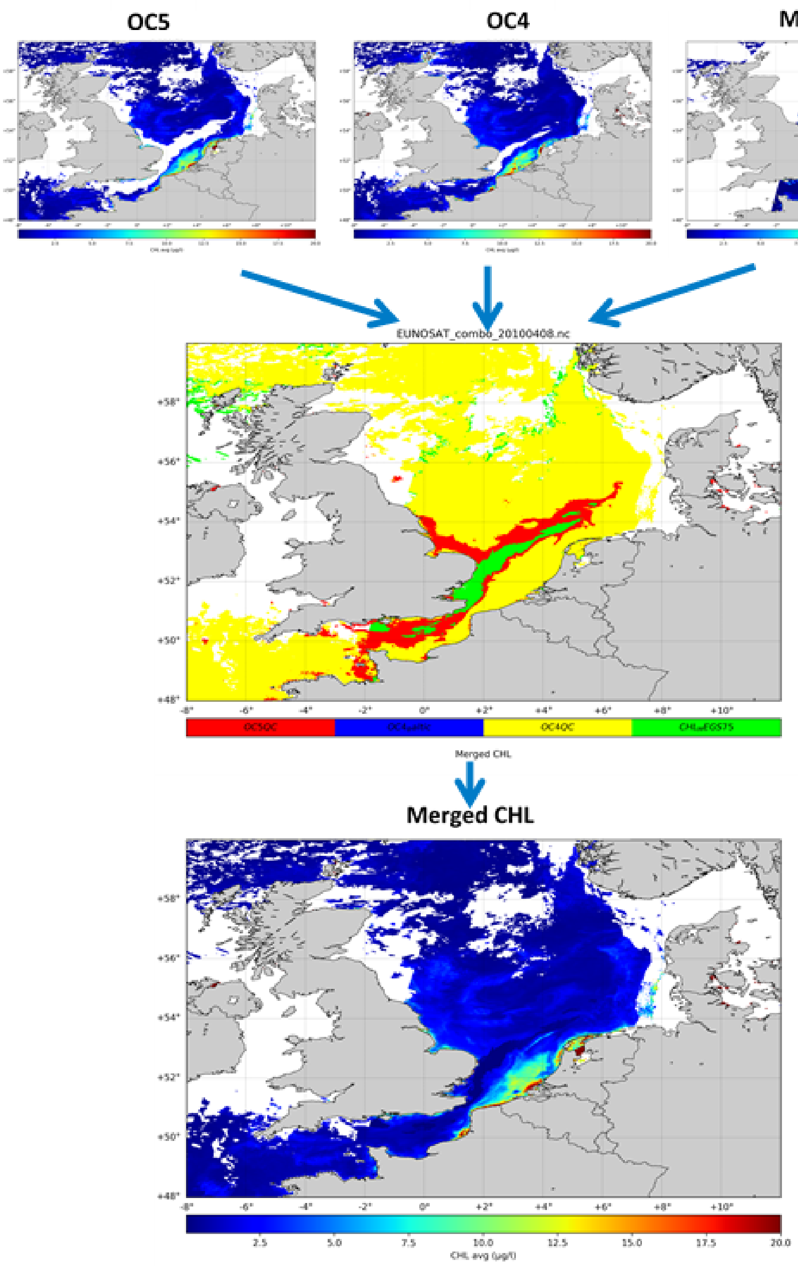

Figure 3.4.3: *Blending process of different quality controlled CHL products on a pixel per pixel basis. The different quality controlled CHL products (i.e. OC4, OC5 and MEGS_7.5) for the 8th of April 2010 are presented in the top row. These CHL products are merged together on a pixel-per-pixel basis with a priority rule given to OC4, then OC5 and finally MEGS_7.5 filling up the map with the most appropriate algorithms available.*

Intercomparison of satellite products with ship based observations

The quality controlled and merged satellite-based chlorophyll-a observations are compared to *in situ* observations that have been collected in national monitoring programs. Figure 4 shows 90-percentile map of chlorophyll a for the growing season (March-Oct incl.) of 2003 providing a spatial interpretation of the intensity of the algal blooms in the North Sea. Additionally, chlorophyll-a time series are provided for the national monitoring stations Stonehaven (Schotland), Rottumerplaat 50 (the Netherlands), 330 (Belgium) and Boulonge (France) for the year 2003 showing the ability of the satellite data to capture the temporal chlorophyll dynamics. The *in situ* measured CHL was analyzed using the HPLC-method. For the time series of satellite data, we extracted a 3 x 3 macro-pixel and the 1 x 1 km center pixel containing the monitoring station location. The resulting time series are presented in monthly bins as *in situ* data is mostly collected on a monthly basis in these stations. The satellite data is presented as boxplots to demonstrate the increased availability of satellite data compared to *in situ* sampling, i.e. 20-50 observations per growing season depending on the location, cloud cover and water conditions.

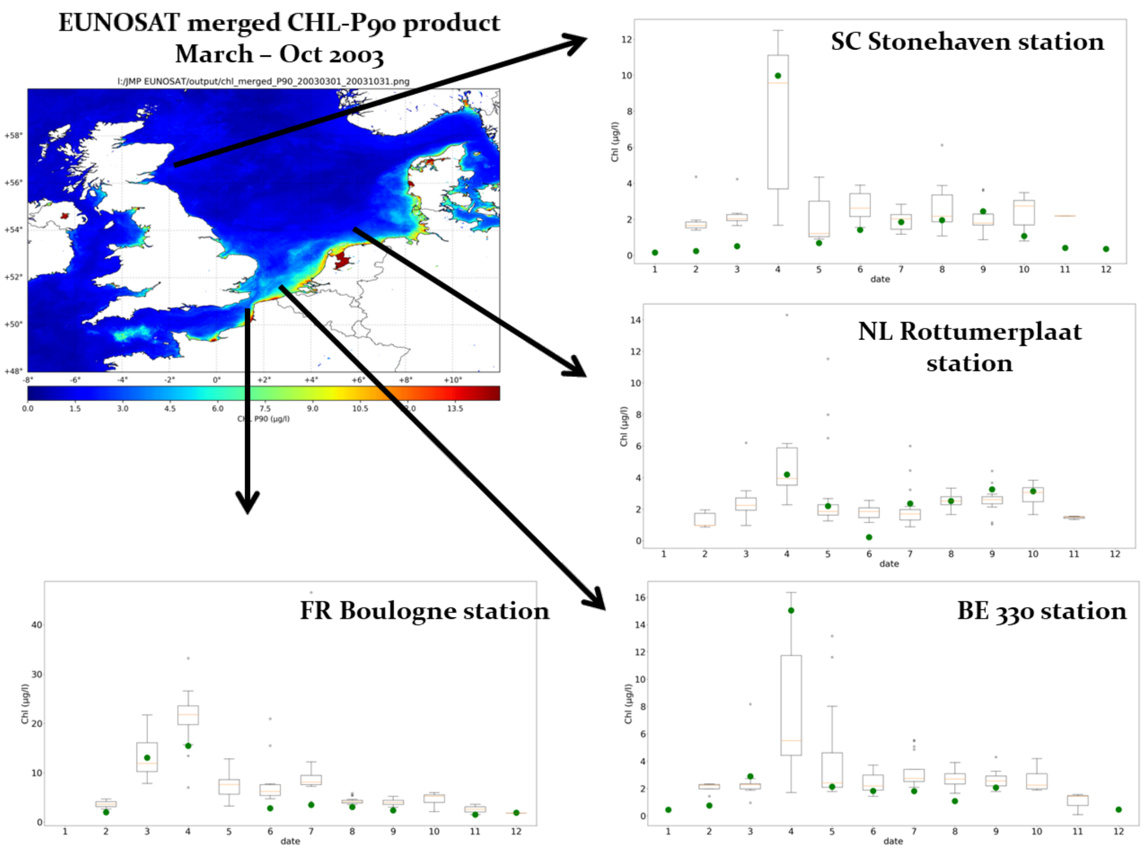

Figure 3.4.4: *90-percentile map the blended and quality controlled chlorophyll a product for the growing season (March-Oct incl.) of 2003 providing a spatial interpretation of the intensity of the algal blooms in the North Sea. Additionally, a direct comparison of chlorophyll-a time series is*

provided for the national monitoring stations Stonehaven (Schotland), Rottumerplaat (the Netherlands), 330 (Belgium) and Boulonge (France) for the year 2003 showing the ability of the satellite data to capture the temporal chlorophyll-a dynamics.

Towards operational collaboration between North Sea Countries

For efficient monitoring of eutrophication, it is advised to combine all available monitoring platforms, *i.e*. dedicated monitoring surveys taking water samples, Ferryboxes mounted on ‘ships of opportunity’ and satellite observations. In this way the strengths and weaknesses of one platform can be compensated by another in terms of spatial and temporal resolution, sampling depth, ability to measure different variables, analytical precision and costs. To enable such a combined use of different data sources, there is a need for a scientifically sound procedure to feed data collected with different methods into one common indicator for the assessment (e.g. chlorophyll) describing both the state and the development of the pelagic environment. Data distributions centers such as CMEMS play a key role in this endeavor as they provide validated ocean colour products as input for the JMP-EUNOSAT processing chain. With the Copernicus program guaranteeing a reliable source of data to at least 2036, special efforts are made to ensure future integration of Sentinel-3/OLCI data into the processing chain.

Product used to cover the period 1993-2017:

· OCEANCOLOUR_ATL_CHL_L3_REP_OBSERVATIONS_009_067
OCEANCOLOUR_ATL_CHL_L3_REP_OBSERVATIONS_009_098
OCEANCOLOUR_ATL_OPTICS_L3_REP_OBSERVATIONS_009_066
OCEANCOLOUR_ATL_OPTICS_L3_NRT_OBSERVATIONS_009_034
OCEANCOLOUR_BAL_CHL_L3_REP_OBSERVATIONS_009_080
OCEANCOLOUR_BAL_CHL_L3_NRT_OBSERVATIONS_009_049
OCEANCOLOUR_BAL_OPTICS_L3_NRT_OBSERVATIONS_009_048
OCEANCOLOUR_BAL_OPTICS_L3_REP_OBSERVATIONS_009_097