Phytoplankton diversity and its optical properties along different Longhurst provinces in the Atlantic (not Indian) Ocean

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Introduction

Different types of phytoplankton dominate the ocean biomes and by that drive differently the marine food web , biogeochemical cycing in the ocean and exchange mechanisms with the atmosphere. During the Polarstern cruise PS113 (May-June 2018) we transected the Atlantic Ocean from Patagonian Shelf to the English Channel. and measured the optical properties and phytoplankton composition within these different Longhurst provinces (Longhurst 2010). Here we present first results on biooptical properties (phytoplankton absorption and remote sensing reflectance spectra) and phytoplankton composition clearly reflecting these different provinces. We also show the validation to matchups of OLCI on Sentinel-3A which will be further used in future together with our in-line particulate absorption data to upscale the phytoplankton diversity information over the entire ocean.

Material and Methods

All measurements were obtained during the RV Polarstern cruise PS121 in the Atlantic Ocean between 10 May to 9 June 2018. In the following we state the methods we used to obtain quantity and composition of phytoplankton and other particulates, IOP and AOP along the cruise transect. Fig. 1 gives an overview of the position of the discrete water samples at surface and of the CTD and radiometric stations.

a) Discrete measurements of IOPs (absorption) at water samples were performed 1) for samples from the underway surface sampling (obtained at 11 m depth sampled from the ship's sea water supply via the membrane pump through the Teflon tubing) at an interval of 3 hours, and 2) for samples from the CTD rosette at 6 depths within the surface ocean (mostly top 100 m, if a very deep chlorophyll maximum was encountered then even down to 200 m) at 24 CTD stations. The particulate and phytoplankton absorption coefficients were determined with the quantitative filter techniques using sample filtered onto glass-fiber filters and measuring them in a portable QFT integrating cavity setup QFT-ICAM following Röttgers et al. (2016). QFT data have been directly analysed on board following the method by Röttgers et al. (2016) applied to field data described in Liu et al. (2018) to derive the corresponding chlorophyll-a concentrations via the absorption line height method.
b) Samples for determination of phytoplankton pigment concentrations and composition were taken from the same water samples as measured under b). These water samples were filtered on board immediately after sampling and the filters were thermally shocked in liquid nitrogen and then stored in the -80°C freezer.

The samples were brought to AWI after arrival in Bremerhaven within a dry-ice filled box. Then samples were analyzed within six weeks by High Performance Liquid Chromatography Technique (HPLC) at AWI following Taylor et al. (2011).

c) Radiometric measurements to obtain apparent optical properties: At 19 daylight stations (except for station 3) we measured continuously hyperspectral upwelling radiance and downwelling irradiance with the Trios RAMSES sensors ASC-VIS and ACC-VIS, respectively, down to maximum of 130 m, adapted to the incoming sunlight. Except for the station PS113_18-1, the light frame was operated with the ship turned into the sun, avoiding shading by the ship. We stopped 30 sec to 1-min. at depths which were every 5 m up to 30 m and then every 10m up to the maximum depth which depended on the incoming solar radiation to allow a better collection of radiometric data. Light stations took place around local noon time or +/-4 hrs before or after but still with sufficient incoming sunlight (global radiation higher than 250 $Wm^{-2}s^{-1}$ (11:00-13:00). TRIOS RAMSES radiance and irradiance sensors were mounted on the same steel frame (in addition to the AC-s in situ spectrophotometer) in downward and upward 90° direction, respectively. Another RAMSES irradiance sensor was mounted looking upwards at the TOPAWI Triaxus system and operated at all deployments. The data were corrected by changes in solar irradiance, which measured continuously during the light stations with another RAMSES ACC irradiance sensor on the same side of the ship cruise. This sensor was operated always without shading by the ship. The RAMSES data were processed following NASA Ocean Optics protocols as adapted to our deployment in Taylor et al. (2011). We followed the procedures stated in Taylor et al. (2011) following Ocean Optics Protocols (Mueller et al. 2003) to calculate the remote sensing reflectance (RRS) from these data. This is used as input for testing ocean color algorithms (QAA, OC4) to retrieve chl-a conc. and to validate OLCI and MODIS RRS data.

d) Satellite ocean colour products and algorithm validation: We have extracted the matchups of OLCI on Sentinel-3A and MODIS on AQUA within the 3x3 and 1x1 pixel box around each in-situ (chl-a and RRS) data point. We calculated R^2, RMSE and bias according to Liu et al. (2018) in order to evaluate the performance of the respective algorithms and satellite products.

Results

We sampled continuously the surface water at 11m depth from 10 May 2018 12:00 UTC to 3 June 2018 2:10 UTC and from 3 June 2018 16:30 UTC to 9 June 14:00 UTC following the cruise track every 3 hours (we sampled at 2:00, 5:00, 8.00, 11:00, 14:00, 17:00, 20:00, 23:00 UTC) the same surface water and collected 202 underway samples in total (see map in Fig. 1). In addition, we took 143 water samples at the 24 CTD stations (see Table1). For the same water samples as for the pigment samples we measured the particulate, phytoplankton and CDOM absorption directly on board. We took continuous profiles of AOPs (with the RAMSES sensors) at 19 (all CTD stations, except night three night stations and two stations were the sea state was too high, see Table 3).

From the measurements of the QFT-ICAM particulate and phytoplankton absorption we derived a proxy for the chlorophyll concentrations (see Fig. 1) which was generally correlated with the ship's underway system (Ferrybox) and CTD fluorescence sensor data and also corresponded to the chlorophyll-a satellite data maps extracted from OLCI Sentinel-3A data.

It is also very well related with the total chl-a concentration obtained from the samples analysed by HPLC.

We also compared the station QFT particulate, non-algal and phytoplankton absorption and chlorophyll data to the 1% light depth and remote sensing reflectance data, both calculated from the RAMSES sensors' measurements. The measurements clearly showed the characteristic of different biogeochemical provinces, e.g. as defined by Longhurst (2010). Within the Southwest Atlantic shelves (south of 44°S) the highest phytoplankton biomass (indicated by chl-a concentration) with diatoms dominating the community was measured. Here the phytoplankton was at maximum in the upper 30 m and decreased tremendously beneath which also corresponded to the shallow 1% light level (~40 m). Opposed to that within the South Atlantic Gyre (from ~30°S to ~8°N) very low biomass overall was measured, especially in the upper 80 to 100m and the chlorophyll maximum was always deep, with a maximum at Stations between 15°S-12°S. Here the chlorophyll maxima reached 140 m which corresponded also to the very deep 1% light levels over 150 m. Absorption spectra indicated that very small cyanobacteria (*Prochlorococcus*) dominated the community. Figure 2 shows the 1% light depth and the chlorophyll concentration of stations we sampled, details on the measured phytoplankton absorption spectra, phytoplankton composition and related RRS spectra are shown only on the poster because of limited space here.

Outlook

We have further measured with two Wetlabs AC-s continuously the total and particulate absorption at the surface water (operated as inline flowthrough device) and in the water profile (here only total absorption) at the radiometric stations. For the AC-s data the adequate Milli-Q calibration measurements, temperature and salinity and scattering corrections have to be applied and spikes due to air bubbles or very large objects have to be removed. The flow-through data can be further corrected for the CDOM and water absorption and attenuation measurements to obtain particulate absorption and attenuation data. So finally we will obtain continuous surface water IOPs information on phytoplankton and other particulates, but also to some respect in the profiles from the AOPs determined from the radiometric data. In addition to using AOPs of reflectance and diffuse attenuation coefficient for validating ocean color remote sensing data (from the Sentinel-3A and B OLCI, MODIS-Aqua, MODIS-Terra, VIIRS-NPP and VIIRS-NPOESS), also the ACS-particulate absorption data will be further processed to obtain chl-a concentration (following Liu et al. 2018) and phytoplankton pigments and composition (following Liu et al. this issue). Those validated data set will help to identify changes in phytoplankton community and its degradation products and elucidate its link to biogeochemical fluxes. The satellite information, detailed underway surface water samples, CTD, and light station profiles obtained in this task are also used to evaluate and validate global coupled biogeochemical-physical ocean models, such as the DARWIN-MITgcm (see Losa et al. this issue).

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Table 1: Summary of the oceanographic stations sampled for discrete depths by the PHYTOOPTICS group during PS113. The time when the 11m sample was taken is given. Water samples were further processed for analysis of phytoplankton pigments by HPLC, colored dissolved organic matter absorption by LWCC and total particulate, non-algal and phytoplankton absorption by QFT-ICAM instruments. * indicates CTD station were no radiometric data could be collected.

Station	UTC Date	Time	Sampled Depth (m)	Lat	Lon
PS113_1-2	2018-05-10	18:37:49	11,20,30,40,65,100	47.65	-60.71
PS113_3-2	2018-05-11	15:45:09	11,20,30,40,50,100	44.90	-56.76
PS113_5-2*	2018-05-12	15:37:38	11,20,35,50,70,100	42.17	-52.86
PS113_6-2*	2018-05-13	15:39:42	11,20,40,60,80,100	38.88	-48.65

PS113_7-2	2018-05-14	16:06:55	11,30,60,75,90,100	35.79	-44.78
PS113_9-2	2018-05-15	15:05:58	11,30,50,70,100,120	33.12	-41.59
PS113_11-2	2018-05-16	15:06:03	11,30,60,90,105,130	30.69	-39.04
PS113_13-2	2018-05-17	14:41:11	11,30,50,70,100,130	27.06	-37.26
PS113_14-2	2018-05-18	15:06:17	11,50,75,110,130,160	22.99	-35.34
PS113_15-1	2018-05-19	11:41:52	11,40,70,100,130,180	19.60	-33.62
PS113_17-2	2018-05-20	14:57:41	11,40,80,110,135,185	15.94	-31.56
PS113_18-2	2018-05-21	13:46:28	11,70,110,140,180,200	12.53	-29.64
PS113_20-1*	2018-05-22	09:51:15	11,70,85,120,180,200	-9.77	-28.12
PS113_21-1*	2018-05-22	19:19:42	11,50,80,110,140	-9.18	-27.80
PS113_22-2	2018-05-23	13:11:20	11,60,85,100,130,180	-6.28	-26.59
PS113_23-2	2018-05-24	13:35:38	11,30,50,65,90,150	-2.23	-25.04
PS113_25-1*	2018-05-25	23:28:11	11,30,50,70,100,130	2.14	-24.98
PS113_26-2	2018-05-26	12:25:03	11,30,50,70,90,130	4.17	-24.63
PS113_27-1	2018-05-27	10:28:53	11,35,45,60,80,110	8.30	-23.52
PS113_28-1	2018-05-28	09:27:36	11,30,45,60,80,100	11.19	-22.69
PS113_29-2	2018-05-30	17:19:20	11,20,40,60,80,100	19.80	-21.15
PS113_30-2	2018-05-31	18:04:22	11,35,50,80,100,135	22.61	-20.55
PS113_31-1	2018-06-01	08:34:14	11,40,60,80,100,120	24.16	-19.81
PS113_33-1	2018-06-05	08:34:14	11,40,60,80,100,120	35.96	-13.01

Table 2: Summary of the oceanographic LIGHT stations (date and time in UTC; lat = latitude, lon= longitude) sampled where an AC-s (Wetlabs) and RAMSES upwelling radiance and downwelling irradiance sensors were measuring and lowered to the indicated maximum depth (Max). At stations PS113_5-1 and PS113_6-1 only the AC-s instrument was operated.

Station	Date	Time	Lat	Lon	Max (m)
PS113_1-1	2018-05-10	17:26	-47.66	-60.72	70
PS113_3-1	2018-05-11	14:40	-44.90	-56.75	70
PS113_5-1	2018-05-12	14:37	-42.11	-52.87	100
PS113_6-1	2018-05-13	14:32	-38.87	-48.65	100
PS113_7-1	2018-05-14	14:37	-35.79	-44.79	100
PS113_9-1	2018-05-15	13:29	-33.12	-41.58	120
PS113_11-1	2018-05-16	13:31	-30.66	-39.05	120
PS113_13-1	2018-05-17	13:28	-27.05	-37.27	70
PS113_14-1	2018-05-18	13:30	-22.98	-35.33	120
PS113_15-2	2018-05-19	11:56	-19.60	-33.62	80
PS113_17-1	2018-05-20	13:32	-15.94	-31.54	100
PS113_18-1	2018-05-21	12:31	-12.53	-29.64	80
PS113_22-1	2018-05-23	11:31	-6.29	-26.57	70
PS113_23-1	2018-05-24	12:19	-2.24	-25.01	82
PS113_26-1	2018-05-26	11:05	4.16	-24.64	90
PS113_27-2	2018-05-27	10:41	8.30	-23.52	100
PS113_28-2	2018-05-28	9:40	11.19	-22.70	100
PS113_29-1	2018-05-30	15:58	19.82	-21.15	90
PS113_30-1	2018-05-31	16:40	22.61	-20.54	90
PS113_31-2	2018-06-01	8:38	24.16	-19.81	110
PS113_33-2	2018-06-05	11:00	35.96	-13.12	130

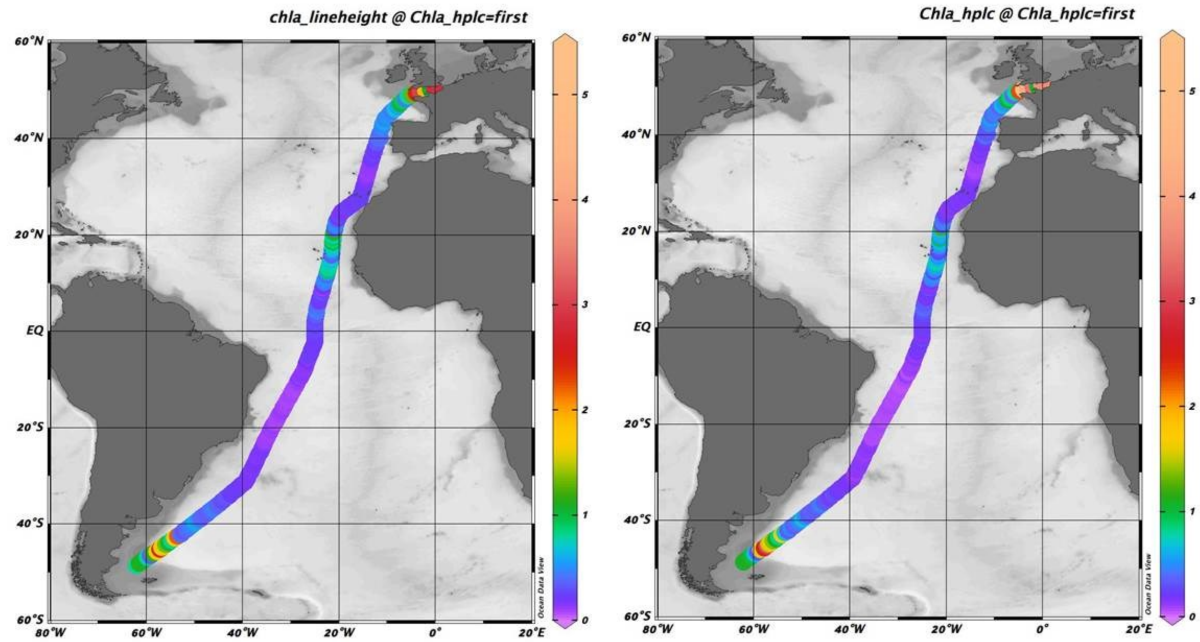

Fig. 1: Map showing surface water chlorophyll-a concentration at PS113 (May-June 2018) obtained from (left) HPLC analysed water samples and (right) QFT-ICAM measurements of phytoplankton absorption on water samples samples collected from 11 m depth during PS113 using the method by Roesler and Barnard (2013) and further modified by Liu et al. (2018).

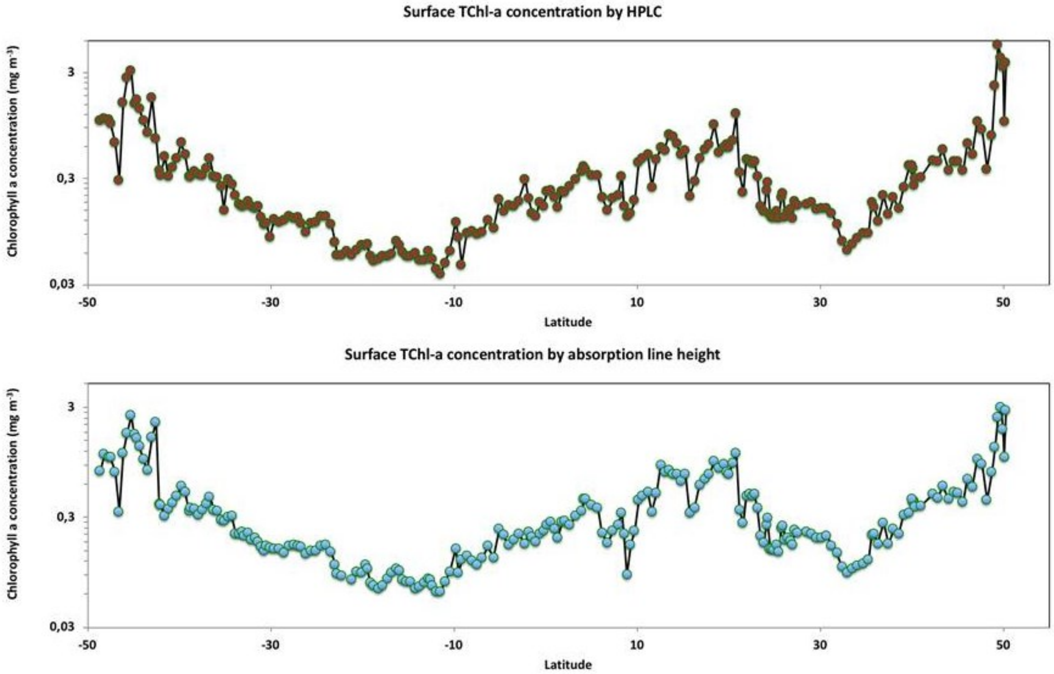

Fig. 2: Surface water chlorophyll-a concentration at PS113 (May-June 2018) versus latitude obtained from (upper panel) HPLC analysed water samples and (lower panel) QFT-ICAM measurements of phytoplankton absorption analysed as pointed out in Figure 1.

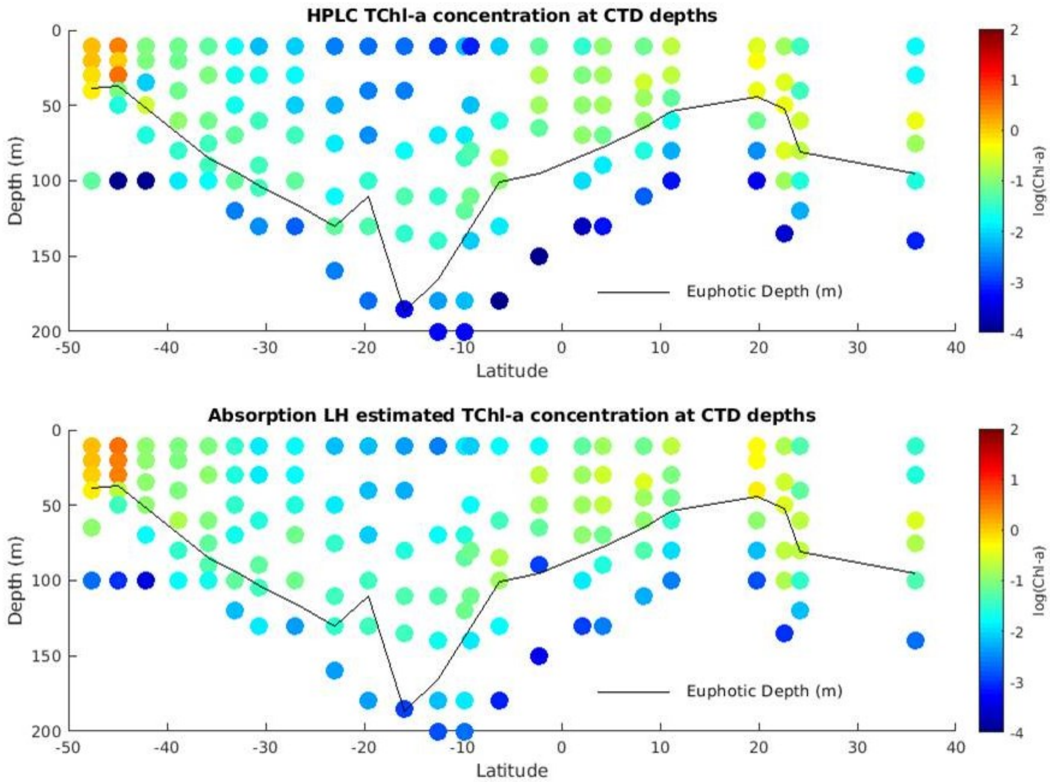

Fig. 3: Chlorophyll-a concentration obtained from HPLC and QFT-ICAM measurements of phytoplankton absorption as described in Fig.1 at the CTD stations listed in Table 1 during PS113. In a black line the 1% light depth derived from the RAMSES downwelling irradiance data at each station is given.