Continuous Hourly Observations of Chlorophyll Fluorescence, Turbidity, and Irradiance in Massachusetts Bay (2005 – 2023) Reveal the Emergence of Summer Phytoplankton Blooms.

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Continuous hourly observations of chlorophyll fluorescence, turbidity, and irradiance in Massachusetts Bay (2005 – 2023) reveal the emergence of summer phytoplankton blooms.

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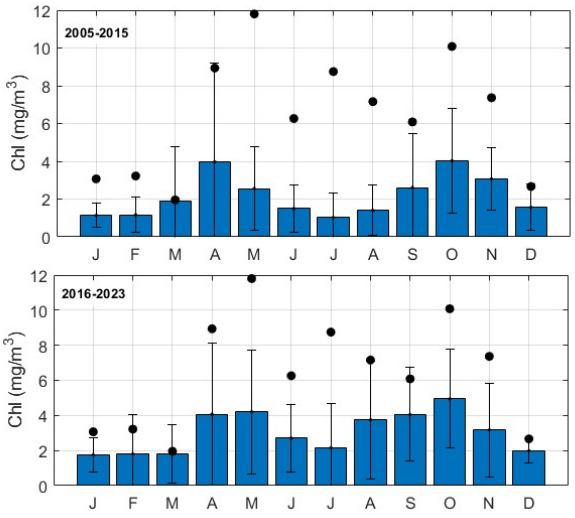
Period of Performance:	1 July 2023 - 30 June 2024

HIGHLIGHTS

The setting: For nearly 25 years, the Massachusetts Water Resources Authority (MWRA) has discharged treated wastewater from its Deer Island Treatment Plant in Boston through a 15 km (9 mi) tunnel into Massachusetts Bay. Since that time MWRA supports a monitoring program to determine whether the nutrient discharge contributes to excess growth of phytoplankton (single-cell marine algae).

Moored observations: Starting in July 2001, a realtime-reporting buoy was deployed in northeastern Massachusetts Bay off Cape Ann by the University of Maine (www.gyre.umeoce.maine.edu), supported by the Northeast Regional Association of Coastal Ocean Observing Systems (www.neracoos.org) and MWRA. In 2005 Bowdoin College researchers added bio-optical sensors on the mooring to provide estimates of chlorophyll (a proxy for phytoplankton concentration) and turbidity (a proxy for suspended particle concentration) with support from MWRA.



Monthly median values of chlorophyll fluorescence for 2005-2015 and 2016-2023 (blue bars; error bars represent one standard deviation) and median of 2021-23 deployments (A0145 and A0146; black circles). Monthly median values increased March through October in the second decade of observations. The 2021-23 monthly median values exceeded the decadal median values for nearly every month April through November but most significantly in the summer months June through August.

Results from the 2022-23 deployment: As seen in prior years, the phytoplankton community at the Cape Ann mooring is characterized by spring and fall blooms; the timing, intensity and duration of which does vary year-to-year. What is notable is a continued shift in the timing of the spring bloom from April to May, a lengthened duration of the spring bloom, and an intensified fall bloom. More recently, a significant summer bloom is emerging. It was weakly present in summer 2021, was anomalously strong in early August 2022, and peaked in mid-July 2023. The pattern of changing phenology and appearance of summer phytoplankton blooms appears to be consistent with changing patterns in stratification and mixing observed in the temperature and salinity characteristics at the mooring site. The past two years have also experienced a slight increase in turbidity that might be indicative of mixing processes bringing more sediment-laded deepwater to the surface.

INTRODUCTION

This report describes work and results from the July 2023 through June 2024 contract period, which covers all deployments recovered within the contract period, in this case deployment 46, for MWRA's continuous biological monitoring in Massachusetts Bay performed by Bowdoin College researchers. While the focus of the report is on the observations from the current reporting year, the overall program goal is to establish benchmark values for seasonal variations in the concentrations of phytoplankton and suspended particles to contextualize the current year observations. This provides MWRA with the ability to identify and respond to critical changes in phytoplankton concentration. The permit to discharge treated effluent from the Deer Island Wastewater Treatment Plant into Massachusetts Bay requires the specific monitoring elements that are outlined in MWRA's Ambient Monitoring Plan. The moored bio-optical program is an important element in the Plan. The details of the moored bio-optical observations are provided in prior annual reports (e.g., Roesler 2016, 2020, 2021). Here we summarize important elements of the bio-optical monitoring.

The bio-optical data set consists of three types of measurements: chlorophyll fluorescence, turbidity, and solar irradiance. The underwater bio-optical sensor package at 3 m below the surface consists of two sensors, an FLNTU that is a combination chlorophyll fluorometer and turbidity sensor, and a F3WB that is a chlorophyll fluorometer with three excitation LEDs that stimulate chlorophyll fluorescence at different wavelengths. The light sensor (OCA507) is deployed at the top of the buoy infrastructure about 3 m above the surface. All 3 sensors are controlled by a data and power handler (DH4) that bring power ultimately from the buoy solar panels and relays hourly values back to the buoy data controller (Campbell data logger) for near-realtime telemetry.

Chlorophyll is a pigment unique to phytoplankton that provides a robust estimate of concentration and is largely responsible for the "greening" of ocean during phytoplankton blooms. A unique character of the chlorophyll molecule is that it fluoresces red light when stimulated with blue light. This is the basis for deploying chlorophyll fluorometers which emit a blue light flash (with a light emitting diode, LED) and measure the intensity of the red light fluoresced by chlorophyll in phytoplankton cells within a known seawater volume. These sensors are calibrated in the laboratory to provide chlorophyll concentrations that are robust within each deployment and across deployments with different sensors. In 2016 Bowdoin researchers added a second chlorophyll fluorometer that has (1) an automated wiper that reduces biofouling and (2) additional colors of stimulating light flashes to identify different types of phytoplankton. Maintaining the two fluorometers provides required overlap for time series integrity and data redundancy to reduce measurement uncertainty and provide insurance against instrument failure.

Turbidity is a measure of water cloudiness due to suspended microscopic particles such as sediments, phytoplankton, and bacteria. Suspended particles scatter light; the intensity of scattering is determined primarily by the concentration of particles. Turbidity sensors emit a flash of red light (with an LED) and measure the intensity of that red light scattered backward out of a known seawater volume. These sensors are likewise calibrated to provide quantitative

and robust estimates of suspended particles within each deployment and across deployments with different sensors.

Solar irradiance is a measure of the intensity of sunlight in the visible waveband. This is the portion of the electromagnetic spectrum that stimulates photosynthesis and also contributes to warming the surface layer of the ocean through light penetration (called shortwave warming). It is measured with an irradiance sensor that sits on top of the mooring. It is used to improve the estimate of chlorophyll concentrations derived from fluorescence measurements as intense sunlight can reduce (quench) the capacity for phytoplankton to fluoresce.

The focus of this report is presentation of the data from deployment A0146, the 46th deployment of the mooring A01, covering the dates 9 September 2022 to 20 September 2023. It is the only A01 deployment recovered within the 2022-23 contract year. The data have been added to the dataset and this report includes brief descriptions of the quality assurance and analysis methods, and bio-optical interpretations of all years of data.

SENSORS AND DATA RECOVERY

Details on the bio-optical sensors and their calibration protocols have been outlined in previous reports (e.g., Roesler 2016) and papers (Roesler et al. 2017). A brief summary is provided in this section. Two sensors of each type (Table 1) are dedicated to this monitoring program. This allows for two complete sensor packages at all times; one deployed on the mooring, while the second is prepared for the next deployment, with sufficient time for sensor maintenance and calibration. The WETLabs facility (a subsidiary of SeaBird Electronics) services and calibrates the sensors when they are on shore in between most deployments in the field. Recently, the company has had substantial backlogs of instruments and so Bowdoin researchers routinely perform maintenance and calibration between every deployment in the event the company is unable to turn sensors around in a timely fashion between deployments.

Table 1. Components of the optical sensing package on the buoy. Text in parentheses indicate how instrument is referred to in this report.

INSTRUMENT	PURPOSE
WETLabs ECO FLNTU ("FLNTU")	Optical sensor, measures chlorophyll fluorescence (470 nm excitation) and turbidity, at 3 m depth.
WETLabs ECO FL3-WB ("F3WB")	Optical sensor, measures chlorophyll fluorescence (3 excitation wavelengths), at 3 m depth, equipped with an automated anti-biofouling shutter.
Satlantic OC507-ICSA ("OCA507")	Optical sensor, measures solar irradiance; mounted on the buoy tower.
WETLabs DH4 ("DH4")	Data logger, collects and stores data from optical sensors; computes mean FLNTU data; transmits means to Campbell Scientific Data Logger, which transmits it in real time to the University of Maine where it is relayed to NERACOOS and posted online.

The sequence of bio-optical observations from data collection to analysis is as follows. Each hour, the Campbell Scientific data logger sends power to the DH4 data handler which starts the bio-optical sensor sampling. All three sensors collect a "burst" of approximately 60 samples for a minute. The FLNTU and F3WB both store these burst samples internally. They can each store approximately 3 months' worth of observations before overwriting. The OCA507 does not store its samples internally. The DH4 stores the complete set of samples for the entire deployment. DH4 firmware computes hourly average values in real time for each sensor and sends those values to the Campbell data logger for telemetry. The data stream from the FLNTU is parsed, calibrations are applied, and the data are made available at the online data portal http://gyre.umeoce.maine.edu/data/gomoos/buoy/html/A01.html and sent to NERACOOS, which also presents the data online in real time at their website www.neracoos.org. Data limitations of the Campbell are such that one of the three F3WB channels (532 nm excitation) is not transmitted. Only the FLNTU data is available on the data portal.

Once the deployment is recovered, the raw data streams are downloaded from the DH4. Synchronization of the internal clocks on the sensors, the DH4, and the Campbell is verified, and any corrections applied. The individual measurements within each burst sampling are analyzed to ensure the mean values reported in real time are robust estimates of the bursts, by comparison to their median and standard deviation, and to process the 532 nm chlorophyll fluorescence data stream that is not reported in realtime. The result is a time series of robust hourly values of each optical data stream. Description of the sensor data streams, and the information derived from them is detailed in Roesler (2021).

The 7-step post-processing protocol for the real-time data for quality control

As explained in detail in prior reports (e.g., Roesler 2020, 2021, 2022), a series of processing steps are necessary to maintain the high quality of the dataset.

Step 1. Quality assurance on times recorded by the sensors, DH4 and the Cambell data logger.

Step 2. Calibration comparison and correction between sensors within the deployment.

Step 3. Correction for sensor drift from preceding and subsequent deployments.

Step 4. Identification, flagging, and removal of biofouled data.

Step 5. Identification, flagging, and correction of chlorophyll fluorescence observations impacted by non-photochemical quenching (NPQ; Carberry et al. 2019).

Step 6. Removal of single value outliers (SVOs).

Step 7. Identification of values below minimum detection levels (MDLs) and within MDL of zero.

Details and examples for all steps other than #2 can be found in Roesler (2020); details and examples for step #2 can be found in Roesler (2021). A graphical representation of data flagging is displayed in Figure 1.

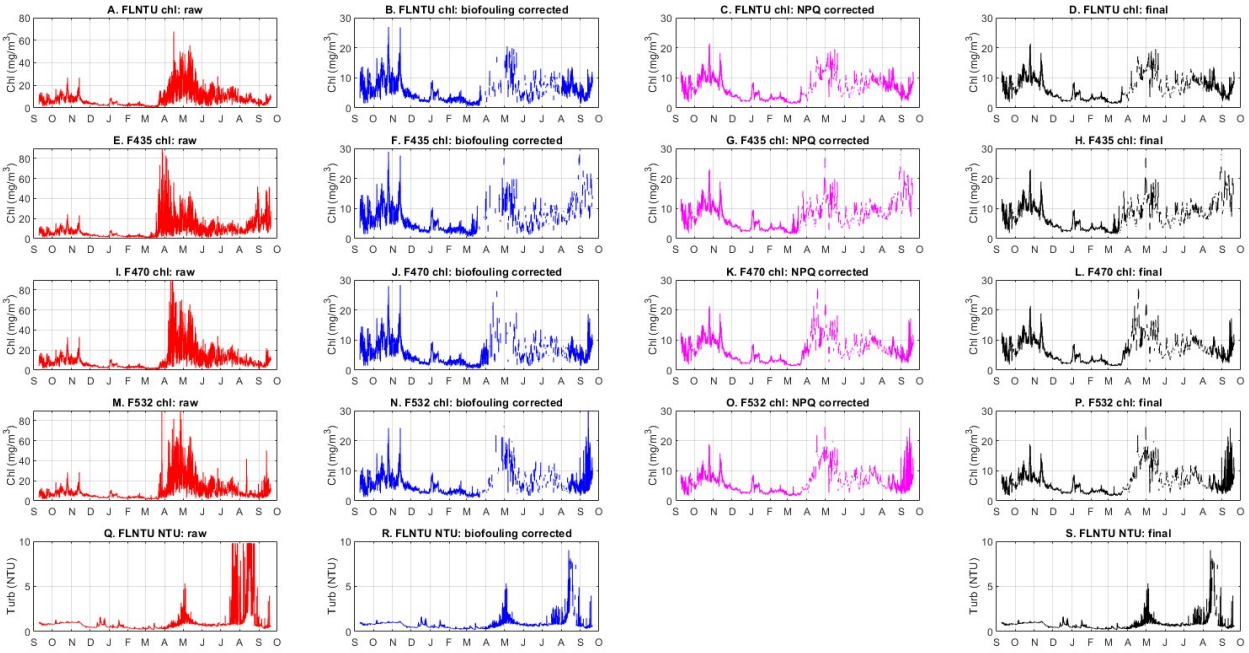


Figure 1. Time series of deployment 46 in-water observations and flagged data processing steps for (A-D) FLNTU chlorophyll, (E-H) 435 nm excitation F3WB chlorophyll, (I-L) 470 nm excitation F3WB chlorophyll, (M-P) 532 nm excitation F3WB chlorophyll, and (Q-S) FLNTU turbidity. Raw data (left panel), biofouling-corrected data (left center panel), non-photochemical quenching corrected data (right center panel), and final processed data (right panel) demonstrate major flagging and correction steps.

Data products provided. In order to give a clear sequence of observations, flagging and correction steps, we provide hourly data arrays including each stage of the post-processing. These are also helpful for optimization of correction schemes for biofouling and NPQ.

Separate data files are submitted for:

- the chlorophyll (Chl) and turbidity (NTU) sensors of the FLNTU,
- each channel of the calibrated ECO F3WB chlorophyll fluorometer (F1 through F3),
- the 7-channel irradiance (ED7).

The Appendix provides data string formats:

Table A1 provides the data string for hourly chlorophyll fluorescence data obtained from the FLNTU and F3WB sensors.

Table A2 provides the data string format for the hourly turbidity.

Table A3 provides the data string format for the hourly downwelling irradiance and upwelling radiance data files.

Table A4 provides a list of the data file names, descriptions, units and array sizes.

The data arrays provided have the Matlab binary storage “mat” file format.

RESULTS AND DISCUSSION

Time series bio-optical observations. The time series bio-optical observations from the FLNTU span October 2005 through September 2023 (deployments A0115-A0146), while the observations from the F3WB and irradiance sensors span from July 2016 to September 2023 (deployments A0137-A0146). *Measurements from the most recent deployment exhibits higher variability in both chlorophyll and turbidity, compared to most previous years, and while all individual observations are within the range observed over the entire time series (Figure 2 A, C), the magnitude and duration of phytoplankton blooms is larger since 2021 (Figure 2 B, D, F).*

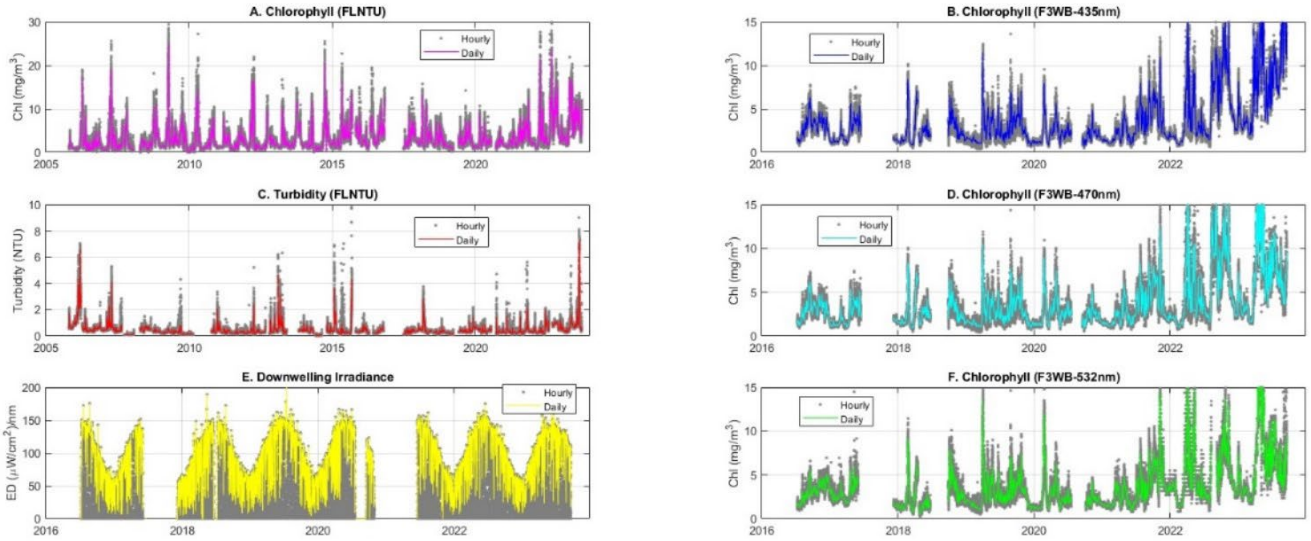


Figure 2. Time series of hourly values (gray symbols) and daily median values (colored lines) from observations of chlorophyll fluorescence (A: FLNTU, 2005-2023; B, D, and F: F3WB, 2016-2023), turbidity (C: FLNTU, 2005-2023), and solar irradiance (E: 2016-2023). Daily values are medians for all but irradiance, which is the daily maximum.

Approximate decadal changes in annual climatology. Previous reports have demonstrated changing patterns in the annual cycle of observed phytoplankton biomass. As the MWRA moored observation program has accumulated nearly 20 years of data, it is possible to examine nearly decadal changes in the cycle. The separation of the observations into pre- and post-2016, the year of added bio-optical sensors, provides a clean division based upon data

availability and redundancy for the post 2016 data sets. The daily observations of chlorophyll and turbidity measured with the FLNTU sensor indicate that the range of values are not significantly different between the two decades (Figure 3), maximal chlorophyll values within 5% (25.0 and 23.5 mg/m^3) and maximal turbidity values within 10% (6.6 and 7.3 ntu). However, the median value in the second decade is nearly 40% higher than in the first decade (2.68 versus 1.81 mg/m^3) with nearly the same spread. There was no significant difference in the turbidity statistics.

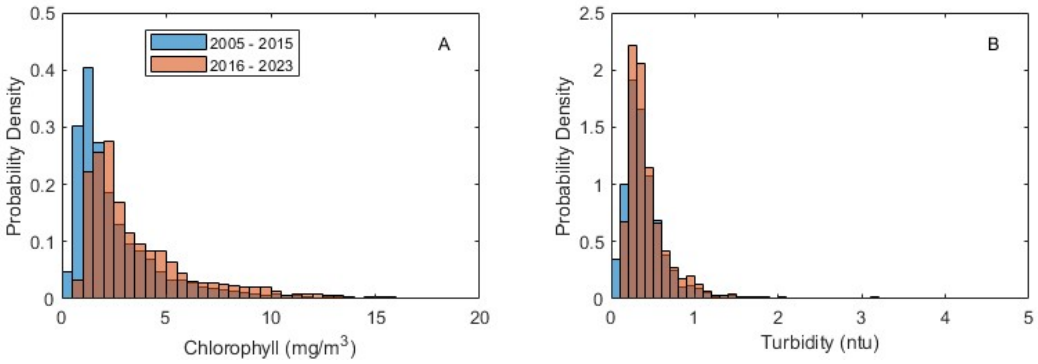


Figure 3. Histogram of daily observations of A. chlorophyll (mg/m^3) and B. turbidity (ntu) measured with the FLNTU sensors for the two time intervals (2005 – 2015 and 2016 – 2023, blue and orange, respectively, with transparent coloration to show overlapping distributions.).

The seasonal cycle of chlorophyll also differed between the two time intervals (Figure 4 A and B). Wintertime values were comparable but there was a greater likelihood of a small winter bloom in February in the most recent interval preceding the peak spring bloom observed in early April in both time intervals. A second bloom in early May was observed in both time intervals although since 2016 the April peak was smaller (approximately 6.5 versus 8 mg/m^3) and the May peak was larger (5 versus 3.5 mg/m^3), thus leading to a generally lower value and longer duration of high chlorophyll, as if the bloom is spread out. This is followed by consistently higher summertime minimum values in July (2.1 versus 1.0 mg/m^3) and a striking appearance of a late summer increase in chlorophyll in August – September, which has been observed since 2001. The early October and early November fall blooms remain consistent between the two time intervals, albeit it now merges with the decline of the late summer bloom. The time-integrated seasonal chlorophyll climatology for the two time intervals is over the year is 881 versus 1,127 mg/m^3/year, with the difference accounted for by the late summer bloom.

There is little seasonal pattern in the turbidity (Figure 4 C and D) and it is not correlated with chlorophyll, confirming that the turbidity signal is driven by other suspended particles, typically small lithogenic sediments and bacteria, with the large pulses in turbidity from year to year determined by storm events, deep mixing and bottom resuspension.

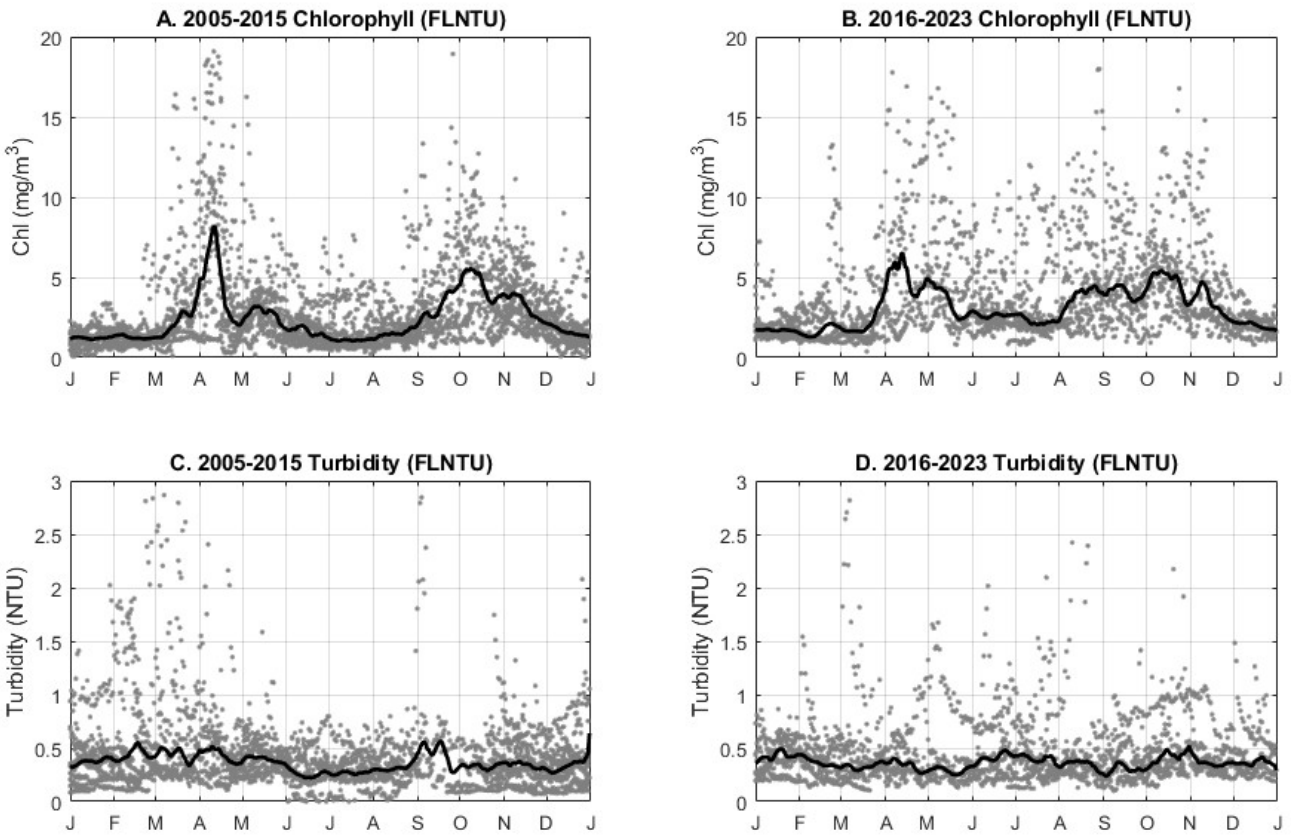


Figure 4. Daily observations of chlorophyll (top panels) and turbidity (bottom panels) measured with the FLNTU sensor for the two time intervals (2005 – 2015, left panels, and 2016 – 2023, right panels) shown by grey dots. Climatological daily median values given by black lines.

Monthly climatological means for the bio-optical time series for the two time intervals are shown in Figure 5 for the FLNTU and F2 sensors (the F2 sensor has the same chlorophyll excitation wavelength of 470 nm and thus is the best for intercomparison). The extended duration of spring blooms in the second time interval is found in both chlorophyll sensors (Figure 5 A-C), as well as the higher summer values and extended fall blooms. Notably, the monthly mean values for deployments 45 and 46 are only within one standard deviation of the monthly climatology for winter (Dec – Mar) and late summer (Aug – Sept) and are more than one standard deviation larger for the remaining months.

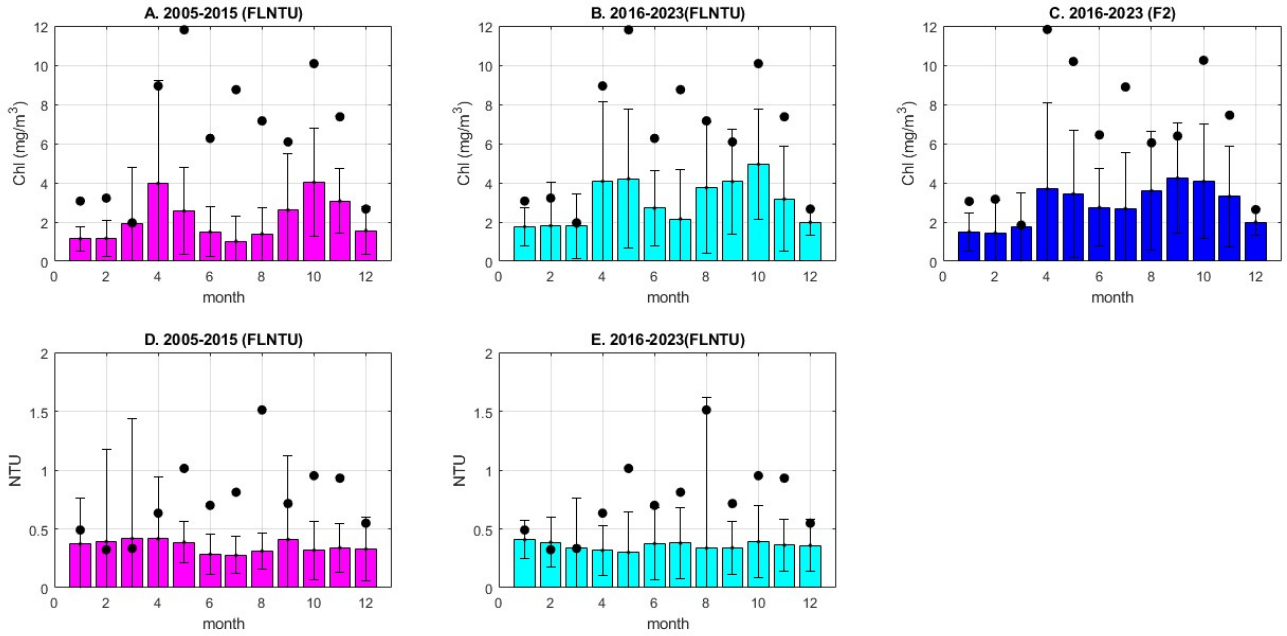


Figure 5. Monthly median values of chlorophyll fluorescence and turbidity for the two time intervals (2005 – 2015 and 2016 – 2023): A and B. FLNTU chlorophyll fluorescence (bars), C. F3WB F2 chlorophyll fluorescence (bars, 2016 – 2023), D and E. FLNTU turbidity (bars). Error bars indicate standard deviation. Observed monthly median values for the 2021-23 data (A0145 and A0146) are shown as black symbols.

Variations in Annual Median Values

Annual median values of chlorophyll have varied over time between 1.5 and nearly 4 mg/m^3 from 2005 to 2022. The interannual pattern observed with the FLNTU chlorophyll fluorometer (Figure 6A) sensor is one of increase over 4 years (2005 – 2009), return to low value (2010) and increase over 4 years (2011 – 2015), decrease over 4 year (2016 - 2019), then increase over 3 years (2021 – 2023). What is imbedded in this pattern is that the high value every 4 or 5 years, has increased from about 2.5 mg/m^3 in 2009 to 3.5 mg/m^3 in 2015, to 6 mg/m^3 in 2023. This is a consistent pattern across the two different sensors since 2016 (Figure 6 B, D, F). Turbidity has demonstrated a very different pattern with highest annual values in 2005 (likely biased by the late winter deployment), 2013 and 2023 with lower values for years in between (Figure 6C). Annual median irradiance values have not varied with statistical significance since 2016 (Figure 6E).

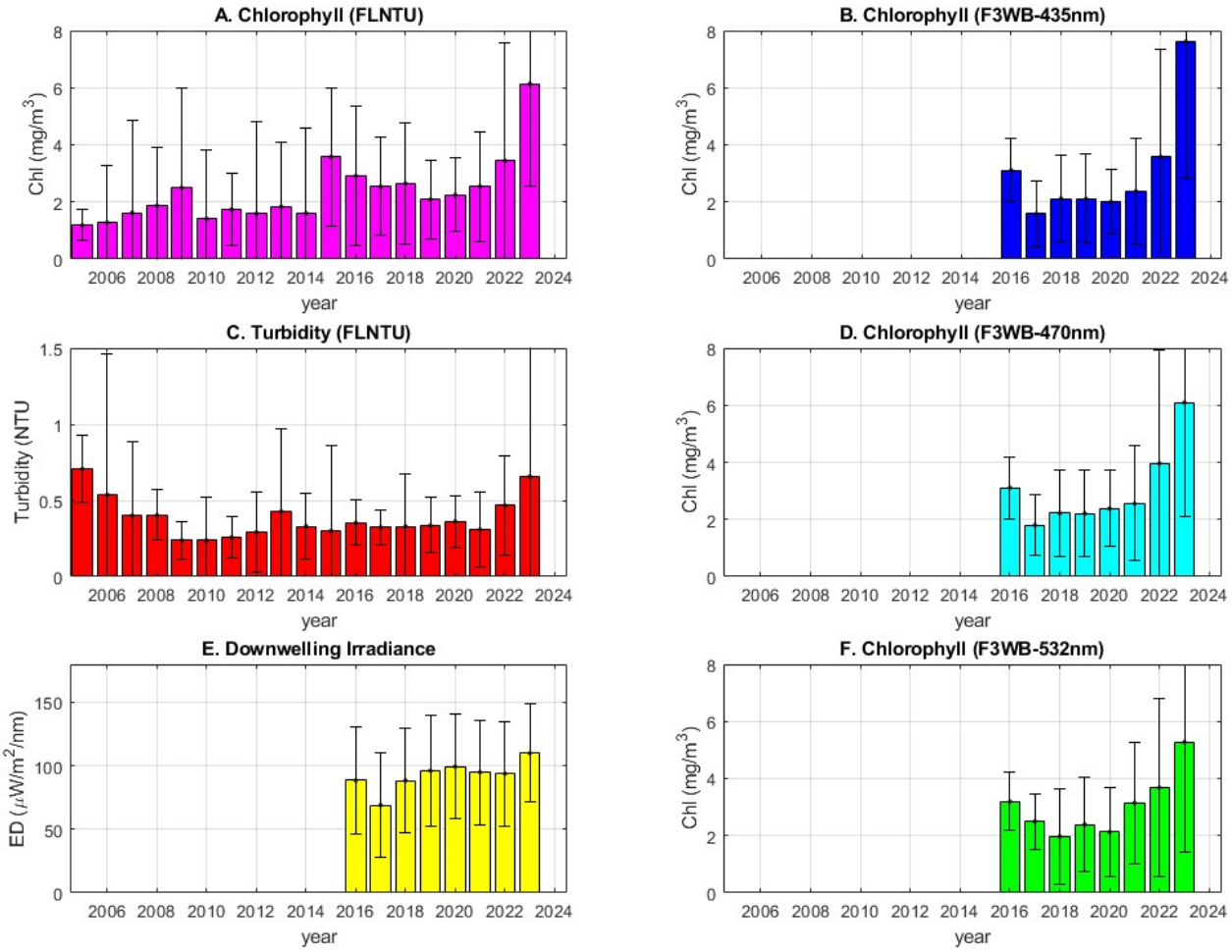


Figure 6 . Annual median values for A. FLNTU chlorophyll, B. F3WB F1 chlorophyll, C. FLNTU turbidity, D. F3WB F2 chlorophyll, E. OCR507A downwelling irradiance, and F. F3WB F3 chlorophyll. Error bars indicate one standard deviation about the annual median value. 2005 data represents and 2023 data represents January – September.

A single analysis of variance (ANOVA) of the daily chlorophyll observations provides some statistical assessment of the year-to-year changes in concentration. A whisker-plot representation of the daily chlorophyll values from the FLNTU chlorophyll fluorometer observations (Figure 7A) demonstrated the consistency of the median annual chlorophyll observations from 2005 through 2021. The 25th and 75th percentiles are also generally consistent with the narrowest range observed in 2006 and 2020 and the largest range observed in 2016 until 2022. The last two years suggest an increase in both the median and the range. Interestingly, when outliers are identified as 3 standard deviations from the median (red + symbols), there are more in the early years of the time series but fewer in recent years suggesting, consistent with the observations that the higher values the last two years are associated with blooms that last weeks, rather than episodic values.

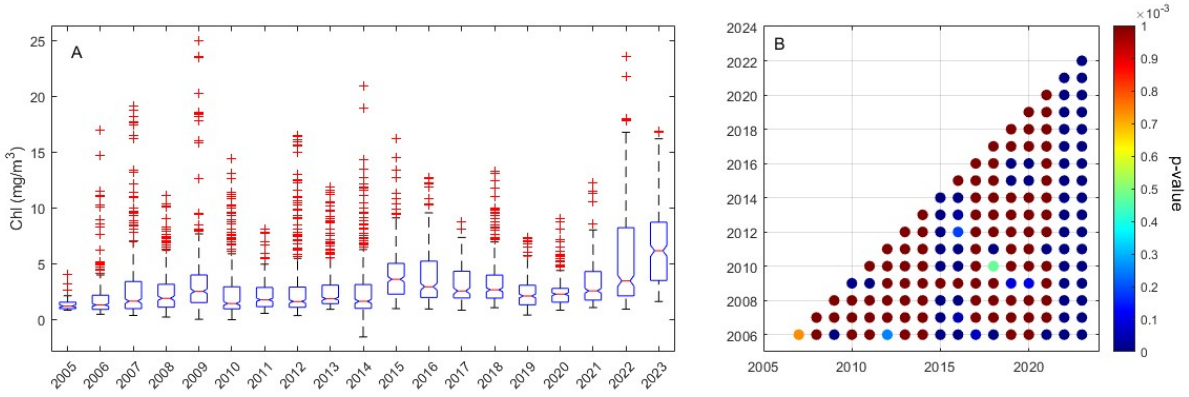


Figure 7. Results of the analysis of variance (ANOVA) of daily chlorophyll values from FLNTU chlorophyll observations over the 2005 to 2023 time series. A. Whisker plot where red bar is the annual median value, the blue box limits show the 25th and 75th percentile range, the error bars indicate the range of all values not identified as outliers and the red + symbols are the outlier values that are 3 standard deviations from the median. B. Multiple comparison tests between years based upon p-values. Red symbols indicate p-values exceeding 0.001, blue symbols are less than 0.0001

Annual median chlorophyll values in 2022 and 2023 are significantly different from all other years ($p<0.0001$; Figure 7B). The years 2015 and 2016 also exhibited higher median annual values and were statistically different from all other years but 2009. This recent changes can be attributed to the late summer and autumn blooms observed both years in both fluorometers.

Possible Mechanisms for a changing phenology. The Gulf of Maine has been undergoing substantial changes (Balch et al. 2022). Continuous observations at A01 clearly demonstrate changes in timing, or phenology, of the phytoplankton blooms. The first nine years of observations suggested the timing of the spring and fall blooms, their intensity and duration were robust (Figure 8A). Starting in 2015, the timing, intensity and duration of blooms became more variable. In 2021 an extended late summer late autumn (July through November) bloom of relatively low concentration was observed. In 2022 that same time interval was characterized by two intense and distinct blooms in August and October. In 2023 there was little evidence of the summertime interval of low chlorophyll concentration observed in every other year (except perhaps 2015).

An analysis of the annual pattern of stratification and mixing was conducted to test whether there are (1) changes in the timing of springtime onset of stratification that initiates the spring bloom by limiting the mixing of phytoplankton cells to depths at which light is limiting, (2) changes in the timing of autumn onset of destratification that results in deep water injection of nutrients into the surface lit zone thereby stimulating the fall bloom. The stratification between the surface and 20 m depth sensor packages (that measure temperature and salinity from which density is derived) shows that the onset of stratification generally in occurs in April and

destratification generally occurs in October, consistent with the April and October spring and fall phytoplankton blooms (Figure 8B). However, this pattern has demonstrated much more variability since 2021 with weaker spring stratification and later autumn destratification and with midsummer weakened stratification intervals. Stratification can be parsed into contributions by temperature (Figure 8C) and salinity (Figure 8D) using the coefficients of thermal expansion and haline contractions. These coefficients describe the changes in ocean density resulting from change in temperature and salinity, respectively. Thermal stratification is generally driven by the seasonal cycle of solar energy as the shortwave energy from the sun penetrates the surface layer of the ocean and warms it. This appears as a relatively invariant pattern until 2021 in which there is a clear signal of intense warming in late winter and early spring that cannot be explained by seasonal solar patterns. Salinity stratification is generally highest in the spring due to the increased river runoff caused by seasonal precipitation patterns and the spring freshet (snow melt and drainage to rivers). Salinity-induced stratification accounts for much of the variations in the timing of the spring bloom. In the last few years, stratification appears weaker overall, which will make the system more sensitive to any energy inputs by wind. In a typical year, windy episodes would not supply sufficient energy to mix the water column and inject nutrients from deep water into the surface layer. However, if stratification is weak, that same windy episode would be sufficient to mix the water column and inject nutrients, stimulating phytoplankton growth. Verification would require sampling of the region after wind events to document enhanced nutrient concentrations.

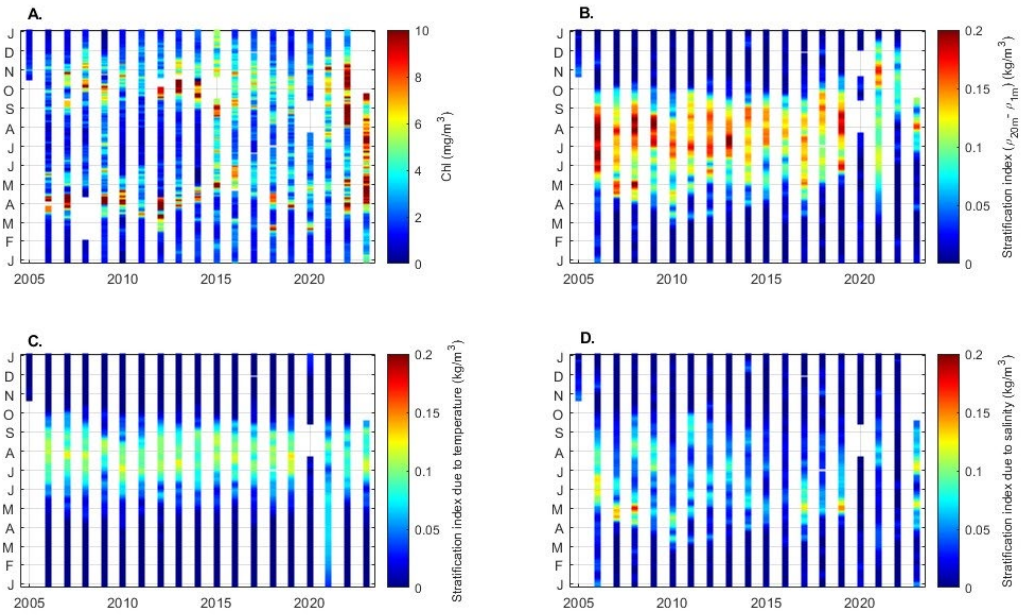


Figure 8. Hovmöller diagrams of A. chlorophyll concentration, B. stratification index (upper 20 m), C. thermal contribution to stratification, D. salinity contribution to stratification, over the entire bio-optical times series at Buoy A01.

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Appendix. Data file formats.

Table A1. Format of the hourly observational data file for chlorophyll fluorescence data arrays, including those derived from FLNTU and FL3-WB sensors.

Column	ID	Value/Range	Comment
1	Year	2005-2023	
2	Month	1-12	
3	Day	0-31	
4	Hour	0-25	
5	Minute	0-60	
6	Second	0-60	
7	Date.Time	732607 – 738773	MATLAB® format, decimal local standard time (EST)
8	Raw Fchl	-3.42 – 230.91	Raw hourly mean
9	Flag_Offset	0, 1	Between deployments
10	Fchl_corr_offset		Corrected for offsets
11	Flag_Biofouling1	0, 1	Biofilm
12	Flag_Biofouling2	0, 1	Structural
13	Fchl_corr_biofouling	NaN	Values removed
14	Flag_NPQ	0, 1	NPQ
15	Fchl_corr_NPQ	-1.58 - 45.19	Values corrected (Carberry et al. 2019)
16	Flag_SVO	0, 1	Single value outlier
17	Fchl_corr_SVO	NaN	Values removed
18	Flag_MDL1	0, 1	< - Method detection level (MDL)
19	Flag_MDL2	0, 1	-MDL to 0
20	Flag_MDL3	0, 1	0 to +MDL
21	Fchl_corr	-0.04 to 29.47 /NaN	Cumulative removal/correction
22	Deployment	15 – 46	Deployment number
23	ECO-FLNTU S/N	001-9999	Sensor serial number, FLNTU

Table A2. Format of the hourly observational data file for Turbidity.

Column	ID	Value/Range	Comment
1	Year	2005-2023	
2	Month	1-12	
3	Day	0-31	
4	Hour	0-25	
5	Minute	0-60	
6	Second	0-60	
7	Date.Time	732607 - 738773	MATLAB® format, decimal local standard time (EST)
8	Raw Turbidity	-0.59 to 25.95	
9	Flag_Offset	0, 1	
10	Turb_corr_offset		Corrected for offsets
11	Flag_Biofouling1	0, 1	Biofilm
12	Flag_Biofouling2	0, 1	Structural
13	Turb_corr_biofouling	NaN	Values removed
14	Flag_SVO	0, 1	Single value outlier
15	Turb_corr_SVO	NaN	Values removed
16	Flag_MDL1	0, 1	< - Method detection level (MDL)
17	Flag_MDL2	0, 1	-MDL to 0
18	Flag_MDL3	0, 1	0 to +MDL
19	Turb_corr	-0.05 to 9.81 /NaN	Cumulative removal/correction
20	Deployment	15 - 46	Deployment number
21	ECO-FLNTU S/N	001-9999	Sensor serial number, FLNTU

Table A3. Format of the hourly observational data file for downwelling irradiance (ED) and upwelling radiance (LU).

Column	ID	Value/Range	Comment
1	Year	2005-2023	
2	Month	1-12	
3	Day	0-31	
4	Hour	0-25	
5	Minute	0-60	
6	Second	0-60	
7	Date.Time	732607 - 738773	MATLAB® format, decimal local standard time (EST)
8-14	Raw Ed(7)	-33.32 - 240.31	
15	Flag_Offset	0, 1	
16-22	Ed(7)_corr_offset		Corrected for spectral and intersensor offsets
23	Flag_Biofouling	0, 1	Biofouling
24-30	Ed(7)_corr_biofouling	NaN	Values removed
31	Flag_SVO	0, 1	Single value outlier
32	Flag_MDL1	0, 1	< - Method detection level (MDL)
33	Flag_MDL2	0, 1	-MDL to 0
34	Flag_MDL3	0, 1	0 to +MDL
35	Flag Cal	0, 1	Indicates multiplicative scaling
36-42	Ed(7)_final	-0.05 – 229.45/NaN	Cumulative removal/correction
43	Deployment	15 – 46	Deployment number
44	OCI_507_SN	001-9999	OCI 507 sensor serial number

Table A4. List of submitted data arrays (.mat files) for chlorophyll fluorescence (from FLNTU sensor and each of the three channels of the F3WB sensor), turbidity, spectral irradiance, and central wavelengths of irradiance sensor.

Array Name	**Description**	**Units**	**Array size (row x columns)**	**Format**
H_Chl_46	hourly chlorophyll fluorescence, FLNTU for full time series and each deployment	mg/m3	7454x23	Table A1
H_NTU_46	hourly turbidity from FLNTU for full time series and each deployment	NTU	7454x21	Table A2
H_F1_46	Hourly chlorophyll fluorescence response from 435 nm excitation (F3WB) for full time series and each deployment	mg/m3	7454x23	Table A1
H_F2_46	Hourly chlorophyll fluorescence response from 470 nm excitation (F3WB) for full time series and each deployment	mg/m3	7454x23	Table A1
H_F3_46	Hourly chlorophyll fluorescence response from 532 nm excitation (F3WB) for full time series and each deployment	mg/m3	7454x23	Table A1
H_ED_46	Hourly spectral irradiance, 7 channels for full time series and each deployment	μW/cm2/nm	7454x44	Table A3
H_ED_46_wave	Irradiance central wavelength	nm	7x1	n/a

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